CHAPTER 4 THERMAL EVALUATION

4.0 INTRODUCTION

The HI-STAR 100 System is designed for the long-term storage of spent nuclear fuel (SNF) in a vertical position. An array of HI-STAR 100 Systems regularly spaced on a square pitch will be stored on a concrete ISFSI pad in an open environment. In this section, compliance of the HI-STAR 100 thermal performance to 10CFR72 requirements for storage under normal conditions is established. The analysis considers passive rejection of decay heat from the stored SNF assemblies to the environment under the most severe design basis ambient conditions. Effects due to incident solar radiation as well as partial radiation blockage due to the presence of neighboring casks at an ISFSI site are included in the analyses.

The guidelines presented in NUREG-1536 [4.1.3] include eight specific acceptance criteria that should be fulfilled by the cask thermal design. These eight criteria are summarized here as follows:

1. The fuel cladding temperature at the beginning of dry cask storage should generally be below the anticipated damage-threshold temperatures for normal conditions and a minimum of 20 years of cask storage.

2. The fuel cladding temperature should generally be maintained below 570°C (1058°F) for short-term accident, short-term off-normal, and fuel transfer conditions.

3. The maximum internal pressure of the cask should remain within its design pressures for normal (1% rod rupture), off-normal (10% rod rupture), and accident (100% rod rupture) conditions.

4. The cask and fuel materials should be maintained within their minimum and maximum temperature criteria for normal, off-normal, and accident conditions.

5. For fuel assemblies proposed for storage, the cask system should ensure a very low probability of cladding breach during long-term storage.

6. Fuel cladding damage resulting from creep cavitation should be limited to 15% of the original cladding cross sectional area.

7. The cask system should be passively cooled.

8. The thermal performance of the cask should be within the allowable design criteria specified in FSAR Chapters 2 and 3 for normal, off-normal, and accident conditions.

As demonstrated in this chapter (see Section 4.5), the HI-STAR 100 System is designed to comply with all eight criteria listed above. All thermal analyses to evaluate the normal condition performance of a HI-STAR 100 System are described in Section 4.4. All analyses for off-normal conditions are described in Section 11.1. All analyses for accident conditions are described in Section 11.2. Section 4.2 lists the material properties data required to perform the thermal analyses and Section 4.3 provides the applicable temperature limits criteria required to demonstrate the adequacy of the HI-STAR 100 System design under all conditions. This FSAR chapter is in full compliance with NUREG-1536 requirements, subject to the exceptions and clarifications discussed in Chapter 1, Table 1.0.3.

4.1 DISCUSSION

A sectional view of the HI-STAR 100 dry storage system has been presented earlier (see Figure 1.2.1). The system consists of an MPC loaded into an overpack with a bolted closure plate. The fuel assemblies reside inside the MPC which is sealed with a welded lid to form the confinement boundary. The MPC contains a stainless steel honeycomb basket structure which provides square-shaped fuel compartments (called boxes) of appropriate dimensions to facilitate insertion of fuel assemblies prior to welding of the lid. Each box panel (except the periphery panels of the MPC-68) is provided with Boral thermal neutron absorber sandwiched between a sheathing plate and the box panel along the entire length of the active fuel region. Prior to sealing the lid, the MPC is backfilled with helium up to the design basis initial loading (Table 1.2.2). This provides a stable and inert environment for long-term storage of the SNF. Additionally, the annular gap formed between the MPC and the overpack is backfilled with helium of the same quality before the overpack vent and drain port plugs are installed. Heat is transferred from the SNF in a HI-STAR 100 System to the environment by passive heat transport mechanisms only.

The helium backfill gas is an integral part of the MPC and overpack thermal designs. The helium fills all the spaces between solid components and provides an improved conduction medium (compared to air) for dissipating decay heat in the MPC. Additionally, helium in the spaces between the fuel basket and the MPC shell is heated differentially and, therefore, subject to the "Rayleigh" effect which is discussed in detail later. To ensure that the helium gas is retained and is not diluted by lower conductivity air, the MPC confinement boundary is designed to comply with the provisions of the ASME B&PV Code Section III, Subsection NB, as an all-seal-welded pressure vessel with redundant closures. Similarly, the overpack helium retention boundary is designed as an ASME B&PV Code Section III, Subsection NB pressure vessel. Both the MPC confinement boundary and the overpack helium retention boundary are required to meet maximum leakage rate Technical Specifications included in Chapter 12 of this FSAR. These leakage rate criteria are selected to ensure the presence of helium during the entire storage life. It is additionally demonstrated in Section 11.1.3 that the failure of one confinement boundary seal, a severe off-normal event, will not result in a breach of the confinement boundary. The helium gas is therefore retained and undiluted, and may be credited in the thermal analyses.

An important thermal design criterion imposed on the HI-STAR 100 System is to limit the maximum fuel cladding temperature to within design basis limits (Table 2.2.3) for long-term storage of design basis fuel assemblies. An equally important design criterion is to reduce temperature gradients within the MPC to minimize thermal stresses. In order to meet these design objectives, the HI-STAR 100 MPC basket is designed to possess certain distinctive characteristics, which are summarized in the following.

The MPC design minimizes resistance to heat transfer within the basket and basket periphery regions. This is ensured by an uninterrupted panel-to-panel connectivity realized in the all-welded honeycomb basket structure. Furthermore, the MPC design incorporates top and bottom plena with interconnected downcomer paths. The top plenum is formed by the gap between the bottom of the MPC lid and the top of the honeycomb fuel basket, and by elongated semicircular holes in each basket cell wall. The bottom plenum is formed by large elongated semicircular holes at the base of all cell walls. The MPC basket is designed to eliminate structural

discontinuities (i.e., gaps) which introduce large thermal resistances to heat flow. Consequently, temperature gradients are minimized in the design, which results in lower thermal stresses within the basket. Low thermal stresses are also ensured by an MPC design which permits unrestrained axial and radial growth of the basket to eliminate the possibility of thermally induced stresses due to restraint of free-end expansion.

Finally, it is heuristically apparent from the geometry of the MPC that the basket metal, the fuel assemblies, and the contained helium mass will be at their peak temperatures at or near the longitudinal axis of the MPC. The temperatures will attenuate with increasing radial distance from this axis, reaching their lowest values at the outer surface of the MPC shell. Conduction along the metal walls and radiant heat exchange from the fuel assemblies to the MPC metal mass would therefore result in substantial differences in the bulk temperatures of helium columns in different fuel storage cells. Since two fluid columns at different temperatures in communicative contact cannot remain in static equilibrium, the non-isotropic temperature field in the MPC internal space due to conduction and radiation heat transfer mechanisms guarantee the incipience of the third mode of heat transfer: natural convection.

The helium columns traverse the vertical storage cavity spaces, redistributing heat within the MPC. Elongated holes in the bottom of the cell walls, liberal flow space and elongated holes at the top, and wide open downcomers along the outer periphery of the basket ensure a smooth helium flow regime. The most conspicuous beneficial effect of the helium thermosiphon circulation, as discussed above, is the mitigation of internal thermal stresses in the MPC. Another beneficial effect is reduction of the peak fuel cladding temperatures of the fuel assemblies located in the interior of the basket. However, in the interest of conservatism, *no credit* for the thermosiphon action is taken in the thermal analysis reported in this chapter. To partially compensate for the reduction in the *computed* heat rejection capability due to the complete neglect of the global thermosiphon action within the MPC, flexible heat conduction elements made of aluminum are interposed in the large peripheral spaces between the MPC shell and the fuel basket. These heat conduction elements, shown in the MPC Drawings in Section 1.5, are engineered to possess lateral flexibility such that they can be installed in the peripheral spaces to create a nonstructural thermal connection between the basket and the MPC shell. In their installed condition, the heat conduction elements will conform to and contact the MPC shell and the basket walls. MPC manufacturing procedures have been established to ensure that the thermal design objectives for the conduction elements set forth in this document are realized in the actual hardware.

Two distinct MPC basket geometries are included in the HI-STAR 100 System for storage of PWR and BWR SNF assemblies. For intact PWR fuel storage, a 24-assembly design is depicted in Figure 1.2.4. A 68-assembly design for storage of intact or damaged BWR fuel is shown in Figure 1.2.2. Damaged BWR fuel and fuel debris must comply with design basis characteristics listed in Table 2.1.7 to allow storage in the MPC-68 and MPC-68F, respectively. Each basket design must comply with the applicable temperature limits for normal, off-normal and accident conditions under the imposed heat generation loads from stored fuel assemblies.

The design basis intact PWR and BWR decay heat per assembly and the MPC total decay heat load for the two basket configurations (i.e., MPC-24, and MPC-68) are stated in Tables 2.1.6 and

1.2.2, respectively. Table 2.1.7 lists the design basis thermal requirements for damaged fuel assemblies. Table 2.1.11 lists the design basis thermal requirements for stainless steel clad fuel assemblies for storage in the MPC-24 or MPC-68. The HI-STAR 100 System consisting of the overpack and MPCs under normal storage conditions at an ISFSI pad is conservatively analyzed for the limiting design basis heat loads.

Thermal analysis of the HI-STAR 100 System is based on including all three fundamental modes of heat transfer: conduction, natural convection and radiation. Different combinations of these modes are active in different regions of the system. These modes are properly identified and conservatively analyzed within each region of the MPC and overpack to enable bounding calculations of the temperature distribution within the HI-STAR 100 System.

On the outside surface of the overpack, heat is dissipated to the environment by buoyancy induced convective air flow (natural convection) and thermal radiation. In the overpack internal metal structure, only conductive heat transport is possible. Between metal surfaces (e.g., between neighboring fuel rod surfaces) heat transport is due to a combination of conduction through a gaseous medium (helium) and thermal radiation. The heat transfer between the fuel basket external surface and the MPC shell's inner surface is further influenced by the so-called "Rayleigh" effect. However, in the interest of conservatism, the most potent heat transport mechanism, the buoyancy induced thermosiphon which occurs within the MPC basket (aided by the MPC design which provides low pressure drop helium flow recirculation loops formed by the fuel cells, top plenum, downcomers and bottom plenum) is neglected.

The total heat generation in each assembly is non-uniformly distributed over the active fuel length to account for the design basis fuel burnup distribution listed in Chapter 2 (Table 2.1.8). As discussed later in this chapter (Subsection 4.4.6), an array of conservative assumptions bias the results of the thermal analysis towards much reduced computed margins than would be obtained by a rigorous analysis of the problem.

The complete thermal analysis is performed using the industry standard ANSYS finite element modeling package [4.1.1] and the finite volume Computational Fluid Dynamics (CFD) code FLUENT [4.1.2]. ANSYS has been previously used and accepted by the NRC on numerous dockets [4.1.3,4.V.5.a]. The FLUENT CFD program is independently benchmarked and validated with a wide class of theoretical and experimental studies reported in the technical journals. Additionally, Holtec has confirmed the code's capability to reliably predict temperature fields in dry storage applications using independent full-scale test data from a loaded cask [4.1.4]. This study concluded that FLUENT can be used to model all modes of heat transfer, namely, conduction, convection, and radiation in dry cask systems.

4.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

Materials used in the HI-STAR 100 System include stainless steels (Alloy X), carbon steels, Holtite-A neutron shield, Boral neutron absorber, aluminum alloy 1100 heat conduction elements, and helium. In Table 4.2.1, a summary of references used to obtain cask material properties for performing all thermal analyses is presented.

Thermal conductivities of the constituent Alloy X steels and the bounding Alloy X thermal conductivity are reported in Appendix 1.A of this report. Tables 4.2.2, 4.2.3 and 4.2.9 provide numerical thermal conductivity data of materials at several representative temperatures. Table 4.2.8 lists the thermal properties of Boral components (i.e., B_4C core and aluminum cladding materials). Surface emissivity data for key materials of construction is provided in Table 4.2.4.

The emissivity properties of painted external cask surfaces are generally excellent. Kern [4.2.5] reports an emissivity range of 0.8 to 0.98 for a wide variety of paints. In the HI-STAR 100 thermal analysis, an emissivity of 0.85† is applied to external painted surfaces. A conservative solar absorptivity coefficient of 1.0 is applied to all exposed cask surfaces.

In Table 4.2.5, the heat capacity and density of different cask materials are presented. These properties are used in performing transient (i.e., hypothetical fire accident condition) analyses. Table 4.2.6 provides viscosity data on the helium gas.

The overpack outside surface heat transfer coefficient is calculated by accounting for both natural convection heat transfer and radiation. The natural convection coefficient depends upon the product of Grashof (Gr) and Prandtl (Pr) numbers. Following the approach developed by Jakob and Hawkins [4.2.9], the product $Gr \times Pr$ is expressed as $L^3 \Delta T Z$, where L is the height of the cask, ΔT is the overpack surface-to-ambient temperature differential and Z is a parameter which depends upon air properties (which are known functions of temperature) evaluated at the average film temperature. The temperature dependence of Z for air is provided in Table 4.2.7.

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† This is conservative with respect to prior cask industry practice, which has historically accepted higher emissivities. For example, a higher emissivity for painted surfaces (ε = 0.95) is used in the TN-32 cask TSAR (Docket 72-1021).

Table 4.2.1

SUMMARY OF HI-STAR 100 SYSTEM MATERIALS THERMAL PROPERTY REFERENCES

Material	Emissivity	Conductivity	Density	Heat Capacity
Helium	N/A	Handbook [4.2.2]	Ideal Gas Law	Handbook [4.2.2]
Air	N/A	Handbook [4.2.2]	Ideal Gas Law	Handbook [4.2.2]
Zircaloy	EPRI [4.2.3]	NUREG [4.2.6], [4.2.7]	Rust [4.2.4]	Rust [4.2.4]
UO_2	Not Used	NUREG [4.2.6], [4.2.7]	Rust [4.2.4]	Rust [4.2.4]
Stainless steel	Kern [4.2.5]	ASME [4.2.8]	Marks [4.2.1]	Marks [4.2.1]
Carbon steel	Kern [4.2.5]	ASME [4.2.8]	Marks [4.2.1]	Marks [4.2.1]
Aluminum Alloy 1100 (Heat Conduction Elements)	Handbook [4.2.2]	ASME [4.2.8]	ASME [4.2.8]	ASME [4.2.8]
Boral†	Not Used	Test Data	Test Data	Test Data
Holtite-A††	Not Used	Conservative Bounding Values	See Footnote	See Footnote

† AAR Structures Boral thermophysical test data.

†† The Holtite-A thermophysical properties (density, ρ, and heat capacity, c_p) were selected to conservatively understate the neutron shield thermal inertia (product of ρ and c_p) in the fire accident evaluation (see Table 4.2.5).

Table 4.2.2

SUMMARY OF HI-STAR 100 SYSTEM MATERIALS THERMAL CONDUCTIVITY DATA

Material	@ 200°F (Btu/ft-hr-°F)	@ 450°F (Btu/ft-hr-°F)	@ 700°F (Btu/ft-hr-°F)
Helium	0.0976	0.1289	0.1575
Air	0.0173	0.0225	0.0272
Alloy X	8.4	9.8	11.0
Carbon Steel Radial Connectors	29.2	27.1	24.6
Carbon Steel Gamma Shield Layers	24.4	23.9	22.4
Holtite-A†	See Footnote	See Footnote	See Footnote
Cryogenic Steel	23.8	23.7	22.3

† No credit taken for conduction through Holtite-A for the steady-state analysis. Before and after fire conditions for fire accident analysis (i.e., the conductivity is conservatively set equal to zero). A conductivity of 1.0 Btu/ft-hr-°F is conservatively applied during fire condition.

Table 4.2.3

SUMMARY OF FUEL ELEMENT COMPONENTS THERMAL CONDUCTIVITY DATA

Zircaloy Cladding		**Fuel (UO_2)**	
Temperature (°F)	**Conductivity (Btu/ft-hr-°F)**	**Temperature (°F)**	**Conductivity (Btu/ft-hr-°F)**
392	8.28†	100	3.48
572	8.76	448	3.48
752	9.60	570	3.24
932	10.44	793	2.28†

† Lowest value of conductivity is used in the thermal analysis for conservatism.

Table 4.2.4

SUMMARY OF MATERIALS SURFACE EMISSIVITY DATA

Material	Emissivity
Zircaloy cladding	0.80
Painted surfaces	0.85
Rolled carbon steel	0.66
Stainless steel	0.36
Sandblasted aluminum	0.40

Table 4.2.5

MATERIALS DENSITY AND HEAT CAPACITY PROPERTIES SUMMARY

Material	Density (lbm/ft^3)	Heat Capacity ($Btu/lbm-^{o}F$)
Helium	(Ideal Gas Law)	1.24
Zircaloy cladding	409	0.0728
Fuel (UO_2)	684	0.056
Carbon steel	489	0.1
Stainless steel	501	0.12
Boral	154.7	0.13
Aluminum Alloy 1100	169.9	0.23
Holtite-A	105.0	0.39

Table 4.2.6

HELIUM GAS VISCOSITY[†] VARIATION WITH TEMPERATURE

Temperature (°F)	Viscosity (Micropoise)
167.4	220.5
200.3	228.2
297.4	250.6
346.9	261.8
463.0	288.7
537.8	299.8
737.6	338.8

† Obtained from Rohsenow and Hartnett [4.2.2].

Table 4.2.7

VARIATION OF NATURAL CONVECTION PROPERTIES PARAMETER "Z" FOR AIR WITH TEMPERATURE†

Temperature, (°F)	**Z ($ft^{-3}{}^{\circ}F^{-1}$)**
40	$2.1x10^6$
140	$9.0x10^5$
240	$4.6x10^5$
340	$2.6x10^5$
440	$1.5x10^5$

† Obtained from Jakob and Hawkins [4.2.9]

Table 4.2.8

BORAL COMPONENT MATERIALS†
THERMAL CONDUCTIVITY DATA

Temperature (°F)	B_4C Core Conductivity (Btu/ft-hr-°F)	Aluminum Cladding Conductivity (Btu/ft-hr-°F)
212	48.09	100.00
392	48.03	104.51
572	47.28	108.04
752	46.35	109.43

† Both B_4C and aluminum cladding thermal conductivity values are obtained from AAR Structures Boral thermophysical test data.

Table 4.2.9

HEAT CONDUCTION ELEMENTS (ALUMINUM ALLOY 1100)
THERMAL CONDUCTIVITY DATA

Temperature (°F)	Conductivity (Btu/ft-hr-°F)
100	131.8
200	128.5
300	126.2
400	124.5

4.3 SPECIFICATIONS FOR COMPONENTS

HI-STAR 100 System materials and components designated as "Important to Safety" (i.e., required to be maintained within their safe operating temperature ranges to ensure their intended function) which warrant special attention are summarized in Table 4.3.1. Long-term stability and continued neutron shielding ability of Holtite-A neutron shield material under normal storage conditions are ensured when material exposure temperatures are maintained below the maximum allowable limit. The integrity of the overpack helium retention boundary is assured by maintaining the temperature of the mechanical seals within the manufacturer's recommended operating temperature limits. Long-term integrity of SNF is ensured by the HI-STAR 100 System thermal performance, which demonstrates that fuel cladding temperatures are maintained below design basis limits. Boral used in MPC baskets for criticality control (a composite material composed of B_4C and aluminum) is stable up to 1000°F for short-term and 850°F for long-term dry storage†. However, for conservatism, a significantly lower maximum temperature limit is imposed.

Compliance to 10CFR72 requires, in part, identification and evaluation of short-term off-normal and severe hypothetical accident conditions. The inherent mechanical stability characteristics of cask materials and components ensure that no significant functional degradation is possible due to exposure to short-term temperature excursions outside the normal long-term temperature limits. For evaluation of HI-STAR 100 System thermal performance under off-normal or hypothetical accident conditions, material temperature limits for short-duration events are provided in Table 4.3.1.

Demonstration of fuel cladding integrity against the potential for degradation and gross rupture throughout the entire dry cask storage period is mandated by the Code of Federal Regulations (Part 72, Section 72.72(h)). The specific criteria required to demonstrate fuel cladding integrity is set forth in the NUREG-1536 document as listed below.

A. The dry cask storage system shall ensure a less than 0.5 percent probability of cladding failure during long-term storage.

B. Fuel cladding damage shall be limited to 15% of the original cladding cross section.

Several potential damage mechanisms for Zircaloy clad fuel have been discussed by Schwartz and Witte [4.3.6] and Levy et al. [4.3.1]. These mechanisms are listed below:

i. stress corrosion cracking
ii. hydriding
iii. creep induced stress rupture
iv. Diffusion Controlled Cavity Growth (DCCG)

Out of the four potential damage mechanisms listed above, two mechanisms, namely creep-

† AAR Structures Boral thermophysical test data.

induced stress rupture [4.3.1] and DCCG [4.3.6], are the controlling mechanisms established for Zircaloy cladding life prediction during dry storage of spent nuclear fuel. Pacific Northwest Laboratory (PNL) has established a Commercial Spent Fuel Management (CSFM) model based on creep rupture data for Zircaloy [4.3.1]. The CSFM model enables a cask designer to determine fuel-specific maximum initial peak cladding temperature limits. The Zircaloy cladding temperature limit established using the generic CSFM Inerted Dry Storage (IDS) temperature limit curves [4.3.1] meets the NUREG-1536 Criterion (A) discussed earlier in this section. This requires a less than 0.5% probability of rods rupture during the entire storage life (assumed to equal 40 years) against creep rupture mode of local cladding damage, which may result in pinhole or through-cladding cracks during dry storage.

The DCCG mode of cladding damage is concluded in the above-mentioned Schwarz et al., report to be the only mechanism which may result in gross cladding damage [4.3.6]. This mode of cladding damage manifests itself as a sudden non-ductile type of fracture. NUREG-1536 (Criterion (B), discussed earlier in this section), requires that the total damage from the DCCG mode of degradation be limited to 15% of the original cladding cross sectional area during the entire dry storage period.

In accordance with the NUREG-1536 criteria, the HI-STAR 100 storage system is designed to preclude both local and gross fuel cladding failures during the entire duration of storage. Initial maximum peak cladding temperature limits are determined using the CSFM IDS temperature limit curves to preclude local cladding failure [4.3.1] and the LLNL methodology to preclude gross cladding failure [4.3.6]. A discussion on the application of the PNL and LLNL methodologies in establishing the HI-STAR system specific fuel types cladding temperature limits criteria is provided in the balance of this section.

The generic CSFM IDS temperature limit curves [4.3.1] define the maximum allowable initial storage temperature at initial cladding stresses as a function of fuel age. Therefore, for SNF of a given age (decay time), the permissible peak cladding temperature is a direct function of the cladding hoop stress, which in turn depends on the radius-to-thickness ratio of the fuel rod and its internal pressure. The rod internal pressure P_i is calculated based upon the maximum initial fill pressures (Tables 4.3.2 and 4.3.5) with fission gas release at a conservatively bounding maximum burnup under HI-STAR 100 System storage conditions (40,000 MWD/MTU for BWR fuel and 42,500 MWD/MTU for PWR fuel). The free rod volumes in the third column of Tables 4.3.2 and 4.3.5 are defined as free rod volumes, in each fuel rod, available for pressurization with fill gas. The free rod volume is the cumulative sum of the open top plenum space, the pellet-to-cladding annular space and the inter-pellet junction space. As a lower bound value of the free rod volume will lead to a conservative estimate of the cladding stress at operating temperatures, the nominal gas plenum space is included in the free rod volume. The plenum length for miscellaneous BWR fuel assemblies is set to 12 inches. The fission gas release fraction data is based on Regulatory Guide 1.25 (Table 4.3.4). The radius-to-thickness ratio r^* is determined based on rod nominal dimension values (Tables 4.3.3 and 4.3.6) including the maximum cladding thickness loss due to in-reactor oxidation, as reported in the PNL study [4.3.4].

By utilizing P_i and r^*, the cladding stress for various PWR fuel types is calculated from Lame's formula and summarized in Table 4.3.3. It can be seen from Figure 4.4.21 that the average temperature of the gas in the fuel rods, a great bulk of which is located in the top region of the SNF, is well below 300°C for the PWR fuel array types. Therefore, to compute the cladding hoop stress in a conservative manner, the ideal gas law is used to obtain the value of the in-rod gas pressure at 300°C. An inspection of cladding stress data summarized in Table 4.3.3 indicates 96.7 MPa is the bounding value of cladding stress (σ_{max}) for the PWR SNF. Corresponding fill gas data and calculations of cladding stress for the various BWR SNF types are summarized in Tables 4.3.5 and 4.3.6, respectively. It can be seen from Figure 4.4.22 that the average temperature of gas in the fuel rods, a great bulk of which is located in the top region of the SNF, is well below 300°C for all BWR fuel array types considered in this topical report. Therefore, to compute the cladding hoop stress in a conservative manner, the ideal gas law is used to obtain the value of the in-rod gas pressure at 300°C. An inspection of the cladding stress data in Table 4.3.6 indicates that the bounding value of the cladding hoop stress for all SNF types is 53.3 MPa (except for 8x8 GE Dresden-1 and 6x6 GE Humboldt Bay fuel types). A conservative cladding stress of 54.7 MPa is used in determining BWR fuel peak cladding temperature limits.

The bounding values of σ_{max} for the array of PWR and BWR SNF types are thus 96.7 MPa and 54.7 MPa, respectively (except for 8x8 GE Dresden-1 and 6x6 GE Humboldt Bay fuel assembly types for which the bounding value of σ_{max} is 59.1 MPa).

Several implicit assumptions in the calculation of σ_{max}, such as neglect of the rod cavity growth due to thermal expansion, internal fill pressure, and in-core irradiation, ensure that the hoop stress value (which is the sole determinant in the establishment of permissible cladding temperature for a given cooling time) is indeed a bounding number.

The generic CSFM IDS temperature limit curves developed in the PNL study [4.3.1] are used to determine Zircaloy cladding temperature limits at the conservative 300°C average rod temperature. The fuel cladding temperature limits obtained from these PNL curves ensure a low failure probability for rods (less than 0.5% over the 40-year dry storage life).

The value of σ_{max} is also required to establish the peak cladding temperature limit using the DCCG method, which we discuss in the following. The DCCG model-based Zircaloy cladding temperature limit computation, in accordance with the LLNL procedure [4.3.6], requires a solution to the following equation expressed in terms of the area fraction of de-cohesion (A):

$$\int_{A_i}^{A_f} \frac{dA}{f(A)} = \int_{t_o}^{t_o + t_s} G(t)\, dt$$

where:

A_i = initial area fraction of de-cohesion

A_f = end of storage life area fraction of de-cohesion (limited to 0.15)

$t_o =$ age of fuel prior to dry cask storage

$t_s =$ dry cask storage period (40 years)

$f(A) =$ area fraction of de-cohesion function

$$= \frac{[1-(\frac{A_i}{A})^{1/2}](1-A)}{A^{1/2}[\frac{1}{2}\ell n\frac{1}{A}-\frac{3}{4}+A(1-\frac{A}{4})]}$$

$$G(t) = \frac{32}{3\pi^{1/2}} \frac{F_b^{3/2}(\alpha)}{F_v(\alpha)} \frac{\Omega\delta\ \sigma_\infty(t)}{K\lambda^3} \frac{D_{GB}[T(t)]}{T(t)}$$

$$F_b(\alpha) = \pi \sin^2(\alpha)$$

$$F_v(\alpha) = \frac{2\pi}{3}(2-3\cos\alpha + \cos^3\alpha)$$

$T =$ time-dependent peak cladding temperature

$K =$ Boltzmann constant (1.38053×10^{-23} J/K)

A discussion on the balance of parameters in the G(t) damage function is provided below.

Cladding Hoop Stress ($\sigma_\infty(t)$)

The cladding hoop stress is principally dependent upon the specific fuel rod dimensions, initial fill rod pressure, time-dependent storage temperature, and fuel burnup dependent fission gas release from the fuel pellets into the rod plenum space. The peak fuel rod pressure for various PWR and BWR fuel types at the start of the dry storage period are summarized in Tables 4.3.3 and 4.3.6. The highest peak rod stress among the various PWR fuel types and a bounding peak rod stress for BWR fuel are applied as constant (time-independent) cladding hoop stresses in the DCCG model-based damage function.

Grain Boundary Cavity Dihedral Angle (α)

The LLNL report [4.3.6] has determined the dihedral angle (α) for pure metals to be 75°. To account for possible non-ideal conditions, a conservatively lower α equal to 60° is applied to the DCCG model.

Zirconium Atomic Volume (Ω)

The zirconium atomic volume estimated from several literature sources as documented in the LLNL report [4.3.6] is in the range of 2.31×10^{-29} m^3 to 3.37×10^{-29} m^3. In the interest of conservatism, the maximum estimated atomic volume equal to 3.37×10^{-29} m^3 is used for the analysis.

Grain Boundary Thickness (δ)

The LLNL report [4.3.6] has recommended a grain boundary thickness of three Burgers vectors to be adequate for the analysis. Thus, $\delta = 3\ (3.23\times10^{-10}) = 9.69\times10^{-10}$ m is used in the analysis.

Average Cavity Spacing (λ)

Cavity spacing is controlled by the type of nucleation mechanism and the density of nucleation sites. The LLNL report [4.3.6] references an experimental study which found that the cavity spacing is in the range of 10×10^{-6} to 20×10^{-6} m. In the interest of conservatism, the minimum reported cavity spacing equal to 10×10^{-6} m is used in the analysis.

Grain Boundary Diffusion Rate (D_{GB})

Two grain boundary diffusion rate correlations for zirconium are reported in the LLNL report [4.3.6]. The two correlations provide diffusion rate estimates which are approximately two orders of magnitude apart from each other. Consequently, the more conservative correlation (i.e., $D_{gb} = 5.9\times10^{-6}\ \exp\ [-131{,}000/RT]\ m^2/s$) which provides a higher estimate of the grain boundary diffusion rate is used in the analysis.

Time-Dependent Peak Cladding Temperature (T)

The steady state peak cladding temperature during long-term storage is principally dependent upon the thermal heat load from the stored fuel assemblies which is imposed on the cask. It is well established that the rate of radioactive decay in a fuel assembly exponentially attenuates with the age of fuel. Consequently, the peak cladding temperature during long-term storage will also attenuate rapidly as a direct consequence of the heat load reduction with time. In recognition of this anticipated decaying cask temperature response, the PNL report [4.3.1] recommends a uni-modal power law type decaying temperature model of the form $T = T_o\ t^{\gamma}$. In the DCCG analysis, an improved multi-modal exponentially attenuating decay heat model based on the Branch Technical Position Paper ASB 9-2 is used. Thus, the form of the decaying temperature model is expressed as:

$$T = \frac{\sum_{K=0}^{10} A_K \exp(-a_k\, t)}{\sum_{K=0}^{10} A_K \exp(-a_k\, t_o)} [(T_o - T_a)] + T_a$$

where:

$A_0 =$	0.5980	$a_0 =$	1.772
$A_1 =$	1.65	$a_1 =$	5.774×10^{-1}
$A_2 =$	3.1	$a_2 =$	6.743×10^{-2}
$A_3 =$	3.87	$a_3 =$	6.214×10^{-3}
$A_4 =$	2.33	$a_4 =$	4.739×10^{-4}
$A_5 =$	1.29	$a_5 =$	4.810×10^{-5}
$A_6 =$	0.462	$a_6 =$	5.344×10^{-6}
$A_7 =$	0.328	$a_7 =$	5.716×10^{-7}
$A_8 =$	0.17	$a_8 =$	1.036×10^{-7}
$A_9 =$	0.0865	$a_9 =$	2.959×10^{-8}
$A_{10} =$	0.1140	$a_{10} =$	7.585×10^{-10}

$t =$ time after reactor discharge (s)

$t_o =$ initial age of fuel at start of storage (s)

$T_o =$ initial peak cladding temperature limit (°K)

$T_a =$ ambient temperature (°K)

It should be noted that the area fraction of de-cohesion function f(A) approaches zero in the limit as $A \rightarrow A_i$. Consequently, the mathematical singularity in the integral $\int_{A_i}^{A} \frac{dA}{f(A)}$ is numerically accommodated by using an alternate form given below:

$$\int_{A_i}^{A} \frac{dA}{f(A)} = \text{Limit}\ \varepsilon \rightarrow 0 \int_{A_i \rightarrow \varepsilon}^{A_f} \frac{A^{1/2}[\frac{1}{2}\ell n \frac{1}{A} - \frac{3}{4} + A(1-\frac{A}{4})]\, dA}{[1-(\frac{A_i}{A})]^{1/2}(1-A)}$$

The allowable area fraction of de-cohesion using $A_i = 0.05$, $\varepsilon = 0.0001$, and $A_f = 0.15$ is determined to be equal to 0.15211. This is consistent with an alternate form of the DCCG model reported in the PNL study [4.3.1, Appendix D] as reproduced below:

$$A_f = \int_0^{t_f} G(t)\, dt \leq 0.15$$

All parameters in the G(t) function (except for the initial peak cladding temperature limit T_o), have been defined as discussed previously in this section. The cumulative cladding damage experienced during the proposed 40-year dry cask storage period is determined by integrating the G(t) function. The initial peak cladding temperature limit parameter T_o is iteratively adjusted to limit the cumulative damage to 15% as required by the NUREG-1536 Criterion (B) discussed earlier in this section. The initial peak cladding temperature limit for 5-year old fuel is determined to be 388.5°C (731°F) and 405.4°C (762°F) for the bounding PWR and BWR fuel

assemblies (except for 8×8 GE Dresden-1, 6x6 Dresden 1, 6×6 Humboldt Bay, and Quad+ fuel types), respectively. The temperature limits are slightly higher than the respective temperature limits determined from the generic CSFM IDS temperature limit curves [4.3.1]. Consequently, the more conservative peak cladding temperature limits obtained from the generic CSFM IDS temperature limit curves are applied to the HI-STAR 100 System thermal analysis for long-term storage.

4.3.1 Evaluation of Stainless Steel Clad Fuel

Approximately 2,200 PWR and BWR fuel assemblies stored in the United States employ stainless steel cladding. All stainless steel cladding materials are of the austenitic genre with the ASTM alloy compositions being principally type 304 and 348H. The long-term storage condition peak allowable temperature applicable to stainless steel fuel is significantly higher than that applicable to Zircaloy clad fuel. A recent EPRI/PNL study [4.3.5] recommends a 430°C (806°F) peak stainless steel cladding temperature limit versus a typical 380°C (716°F) [4.3.1] peak Zircaloy cladding temperature limit. Since the peak cladding temperature limits applied to the thermal analysis herein for both Zircaloy clad and stainless steel clad fuel are based on the Zircaloy clad limit, it is readily apparent that the PNL criteria [4.3.1] is overly restrictive for stainless steel clad fuel. The peak cladding temperature limits applied to both Zircaloy and stainless steel clad fuel assemblies are provided in Table 4.3.1.

It is recognized that the peak cladding temperature of stainless fuel will differ from Zircaloy clad fuel principally due to the following differences:

i. Differences in decay heat levels
ii. Differences in cladding emissivity
iii. Differences in cladding conductivity
iv. Differences in fuel rod array dimensions

The net planar thermal resistance of the equivalent homogenized axisymmetric MPC basket containing stainless steel clad fuel is greater than that with Zircaloy clad fuel. The higher resistance arises principally from the significantly lower emissivity of the stainless steel cladding. This factor is, however, offset by significantly lower design basis heat loads prescribed for a HI-STAR 100 System containing stainless steel clad fuel. A 20% reduction in the design basis heat duty for stainless steel fuel (20% lower than Zircaloy clad fuel) bounds the nominal percentage decrease in MPC basket effective thermal conductivity† (stainless steel fueled baskets are between 9% (MPC-68) to 13% (MPC-24) less conducting, as shown in Table 4.4.7). As can be seen by comparing the design basis maximum allowable decay heat loads for Zircaloy clad (Tables 4.4.18 and 4.4.19) and stainless steel clad (Table 2.1.11) fuel assemblies, the allowable assembly decay heat load for stainless steel clad fuel is approximately 73% of the PWR Zircaloy clad fuel heat load and 35% of the BWR Zircaloy clad fuel heat load. Therefore, it is concluded that the peak cladding temperature for stainless steel clad fuel will be bounded by Zircaloy clad fuel results. Consequently, in view of significantly higher peak stainless steel cladding

† The term "effective conductivity" of the fuel basket is defined in Section 4.4.1.

temperature limits recommended by the EPRI study [4.3.5] and the conservative heat loads prescribed for stainless steel clad fuel, a separate thermal analysis to demonstrate the adequacy of stainless steel clad integrity for storage in the HI-STAR 100 System is not necessary.

4.3.2 Short-Term Cladding Temperature Limit

For short-term durations, relatively high fuel cladding temperature limits have been historically accepted by the USNRC. For example, the Safety Analysis Report of the STC transport cask (Docket No. 71-9235), recently certified by the USNRC, permits 1200°F (approximately 649°C) as the maximum value of the peak cladding temperature (T_{max}) for transport of SNF with up to 45,000 MWD/MTU burnup. NUREG-1536 and PNL test data [4.3.4], limiting themselves to medium burnup levels (28,800 MWD/MTU), endorse a somewhat lower T_{max} value (T_{max} = 570°C or 1058°F). Based on the published industry test data, guidance in the literature, and analytical reasoning, we herein prescribe 570°C as the admissible value of T_{max} for the SNF for the relatively lower burnup levels in the HI-STAR 100 System for storage[††].

A Brookhaven report written for EPRI [4.3.7] asserts that fuel cladding rupture becomes "virtually absent at stresses below about 200 MPa". It can be readily deduced that the peak cladding stress for the limiting condition of 570°C cladding temperature will be below 200 MPa for the SNF burnup levels considered in this FSAR. Recalling σ_{max} at 96.7 MPa (Table 4.3.3) at 300°C gas temperature, the cladding circumferential stress (σ_{peak}) at 570°C is obtained by direct proportionality in absolute gas temperature:

$$\sigma_{peak} = \sigma_{max}\,(570 + 273)/(300 + 273) = 142.3 \text{ MPa (approximately 20,600 psi)}$$

Therefore, short-term temperature values (T_{max}) of 570°C are considered safe to preclude fuel cladding failure.

The EPRI report cites experiments on fourteen irradiated Turkey Point Unit 3 rods carried out by Einziger et al.[†] in 1982 which showed no breach in cladding even after as much as 7% strain was accumulated in elevated temperatures lasting for 740-1,000 hours. Einziger's test data corroborates our selection of T_{max} = 570°C as the short duration limiting temperature.

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†† 40,000 MWD/MTU for BWR fuel and 42,500 MWD/MTU for PWR fuel bounds permissible maximum burnups.

† "High Temperature Post Irradiation Materials Performance of Spent Pressurized Water Reactor Fuel Rods under Dry Storage Conditions," by R.E. Einziger, S.D. Atkin, D.E. Stallrecht, and V.S. Pasupathi, Nuclear Technology, 57:65-80 (1982).

Table 4.3.1

HI-STAR 100 SYSTEM MATERIAL TEMPERATURE [°F] LIMITS

Material	Normal Long-Term Temperature Limits	Short-Term Temperature Limits
Fuel cladding (Zircaloy and stainless steel)	See Table 4.3.7	1058
Boral†	800	950
Overpack closure plate mechanical seal, vent and drain port plug seals	See Table 2.2.3	See Table 2.2.3
Holtite-A††	300	300

† Based on AAR Structures Boral thermophysical test data.

†† See Appendix 1.B.

Table 4.3.2

SUMMARY OF PWR ASSEMBLY RODS INITIAL GAS FILL DATA

Assembly Type	Rods Per Assembly	Free Rod Volume (in.^{3})	Fill Pressure (psig) at 70°F	Fill Gas Volume at STP†	
				(Liters) Per Rod	(Liters) Per Assembly
W-14x14 Std.	179	1.72	0-460	0.845	151.2
W-15x15 Std.	204	1.25	0-475	0.633	129.1
W-17x17 Std.	264	1.05-1.25	275-500	0.666	175.8
B&W-15x15 Mark B	208	1.308	415	0.582	121.1
B&W-17x17 Mark C	264	0.819	435	0.381	100.6
CE-14x14 Std.	164	1.693	300-450	0.814	133.5
CE-16x16 Std.	220	1.411	300-450	0.678	149.2
B&W-15x15 Mark B-11	208	1.260	415	0.560	116.5
CE-14x14 (MP2)	176	1.728	300-450	0.831	146.2

† STP stands for standard temperature (°C) and pressure (1 atmosphere).

Table 4.3.3
BOUNDING VALUES OF FUEL CLADDING STRESS FOR PWR SNF

	W-14X14 Std	W-15x15 Std	W-17x17 Std	B&W-15x15 Mark B	B&W-17x17 Mark C	CE-14x14 Std	CE-16x16 Sys 80	B&W-15x15 Mark B-11	CE-14x14 (MP2)
Fresh Fuel Rods O.D. (inch)	0.4220	0.422	0.374	0.430	0.379	0.440	0.382	0.414	0.440
End of Life Oxidation Thickness (inch)†	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
End of Life Rods O.D. (inch)	0.4166	0.4166	0.3686	0.4246	0.3736	0.4346	0.3766	0.4086	0.4346
Rods I.D. (inch)	0.3734	0.373	0.329	0.377	0.331	0.384	0.332	0.370	0.388
Average tube Diameter (inch)	0.3950	0.3948	0.3488	0.4008	0.3523	0.4093	0.3493	0.3893	0.4113
Wall Thickness (inch)	0.0216	0.0218	0.0198	0.0238	0.0213	0.0253	0.0223	0.0193	0.0233
Hot Volume Pressure at 300°C (MPa)††	9.77	10.67	10.08	9.62	10.87	10.01	9.61	9.76	9.67
Cladding Stress (MPa)	89.3	96.7	88.8	81.0	90.0	81.0	75.2	98.4	85.3

† PNL-4835 [4.3.4] reported maximum cladding thickness loss due to in-reactor oxidation.

†† This average rod gas temperature conservatively bounds the plenum gas temperature, which, as can be seen from Figure 4.4.21, is approximately 225°C. The cladding stresses reported in the bottom row of this table will be accordingly reduced by the factor (225+273)/(300+273) = 0.87. However, 96.7 MPa cladding stress for PWR SNF is used as the upper bound value in this FSAR.

Table 4.3.4

SUMMARY OF FISSION GASES RELEASE PER ASSEMBLY†

Component	Release†† Fraction	Release Amount (g-moles/ PWR assembly)	Release Amount (g-moles/ BWR assembly)
Tritium	0.3	0.004	0.003
^{85}Kr	0.3	0.805	0.297
^{129}I	0.12	0.137	0.050
^{131}Xe	0.10	2.664	0.985

† Bounding for 42,500 MWD/MTU burnup PWR assemblies and 40,000 MWD/MTU burnup BWR assemblies.

†† From Regulatory Guide 1.25.

Table 4.3.5
SUMMARY OF BWR ASSEMBLY RODS INITIAL GAS FILL DATA

Assembly Type	Rods/ Assembly	Free Rod Volume (in³)	Fill Pressure (psig) at 70°F	Fill Gas Volume at STP	
				(liters) Per Rod	(liters) Per Assembly
GE-7x7 (1966)	49	2.073	0-44.1[†]	0.126	6.17
GE-7x7 (1968)	49	2.073	0-44.1	0.126	6.17
GE-7x7R	49	1.991	0-44.1	0.121	5.93
GE-8x8	60	1.504	0-44.1	0.0915	5.49
GE-8x8R	62	1.433	0-147[††]	0.240	14.88
EXXON-9x9	79	1.323	58.8-88.2[†††]	0.141	11.1
6x6 GE Dresden-1	36	2.304	58.8-88.2	0.245	8.82
6x6 Dresden-1 MOX	36	2.286	58.8-88.2	0.243	8.75
6x6 GE Humboldt Bay	36	2.346	58.8-88.2	0.250	9.0
7x7 GE Humboldt Bay	49	1.666	58.8-88.2	0.177	8.67
8x8 GE Dresden-1	64	1.235	58.8-88.2	0.131	8.38
8x8 SPC	63	1.615	58.8-88.2	0.172	10.8
9x9 SPC-2 wtr. Rods	79	1.248	58.8-88.2	0.133	10.5
9x9 SPC-1 wtr. Rod	80	1.248	58.8-88.2	0.133	10.6
9x9 GE11/GE13	74	1.389	58.8-88.2	0.150	11.1
9x9 Atrium 9B SPC	72	1.366	58.8-88.2	0.145	10.4
10x10 SVEA-96	96	1.022	58.8-88.2	0.109	10.5
10x10 GE12	92	1.167	58.8-88.2	0.124	11.4
6x6 Dresden Thin Clad	36	2.455	58.8-88.2	0.261	9.4
7x7 Oyster Creek	49	2.346	58.8-88.2	0.250	12.2
8x8 Oyster Creek	64	1.739	58.8-88.2	0.185	11.8
8x8 Quad[+] Westinghouse	64	1.201	58.8-88.2	0.128	8.2
8x8 TVA Browns Ferry	61	1.686	58.8-88.2	0.179	10.9
9x9 SPC-5	76	1.249	58.8-88.2	0.133	10.1

† Conservatively bounding for GE-7x7 (1966), GE-7x7 (1968), GE-7x7R and GE-8x8 (ORNL/TM-9591/V1-R1).

†† Conservatively bounding initial fill pressure. ORNL/TM-9591/V1-R1 reports GE-8x8R prepressurized to 3 atm.

††† BWR fuel rods internal pressurization between 4 to 6 atm (PNL-4835).

Table 4.3.6

BOUNDING VALUES OF FUEL CLADDING STRESS FOR BWR SNF

Fuel Type	Fresh Fuel Rod O.D. (inch)	End of Life Oxidation Thickness (inch)	End of Life Rods O.D. (inch)	Rods I.D. (inch)	Average Tube Diameter (inch)	Wall Thickness (inch)	Hot Volume Pressure at 300°C (MPa)	Cladding Stress (MPa)
GE-7x7 (1966)	0.563	0.0047	0.5536	0.499	0.5263	0.0273	4.61	44.4
GE-7x7 (1968)	0.570	0.0047	0.5606	0.499	0.5298	0.0308	4.61	39.6
GE-7x7R	0.563	0.0047	0.5536	0.489	0.5213	0.0323	4.76	38.4
GE-8x8	0.493	0.0047	0.4836	0.425	0.4543	0.0293	5.08	39.4
GE-8x8R	0.483	0.0047	0.4736	0.419	0.4463	0.0273	6.52	53.3
EXXON-9x9	0.42	0.0047	0.4106	0.36	0.3853	0.0253	5.08	38.7
6x6 GE Dresden-1	0.5645	0.0047	0.5551	0.4945	0.5248	0.0303	6.1	52.8
6x6 Dresden-1 MOX	0.5625	0.0047	0.5531	0.4925	0.5228	0.0303	6.1	52.8
6x6 GE Humboldt Bay	0.563	0.0047	0.5536	0.499	0.5263	0.0273	5.98	57.6†
7x7 GE Humboldt Bay	0.486	0.0047	0.4766	0.4204	0.4485	0.0281	6.13	48.9
8x8 GE Dresden-1	0.412	0.0047	0.4026	0.362	0.3813	0.0203	6.29	59.1†
8x8 SPC	0.484	0.0047	0.4746	0.414	0.4443	0.0303	5.19	38.0
9x9 SPC-2 wtr. Rods	0.424	0.0047	0.4146	0.364	0.3893	0.0253	5.32	40.9
9x9 SPC-1 wtr. Rod	0.423	0.0047	0.4136	0.364	0.3888	0.0248	5.25	41.1
9x9 GE11/GE 13	0.44	0.0047	0.4306	0.384	0.4073	0.0233	5.17	45.2
9x9 Atrium 9B SPC	0.433	0.0047	0.4236	0.3808	0.4022	0.0214	5.32	50.0

† These two fuel types are separately analyzed for peak fuel cladding temperature limits.

Table 4.3.6 (continued)

BOUNDING VALUES OF FUEL CLADDING STRESS FOR BWR SNF

Fuel Type	Fresh Fuel Rod O.D. (inch)	End of Life Oxidation Thickness (inch)	End of Life Rods O.D. (inch)	Rods I.D. (inch)	Average Tube Diameter (inch)	Wall Thickness (inch)	Hot Volume Pressure at 300°C (MPa)	Cladding Stress (MPa)
10x10 SVEA-96	0.379	0.0047	0.3696	0.3294	0.3495	0.0201	4.38	38.1
10x10 GE12	0.404	0.0047	0.3946	0.352	0.3733	0.0213	4.99	43.7
6x6 Dresden Thin Clad	0.5625	0.0047	0.5531	0.5105	0.5318	0.0213	5.77	72.5†
7x7 Oyster Creek	0.5700	0.0047	0.5606	0.499	0.5298	0.0308	4.74	40.7
8x8 Oyster Creek	0.5015	0.0047	0.4921	0.4295	0.4608	0.0313	4.87	35.9
8x8 Quad+ Westinghouse	0.4576	0.0047	0.4482	0.3996	0.4239	0.0243	6.42	56.0†
8x8 TVA Browns Ferry	0.483	0.0047	0.4736	0.423	0.4483	0.0253	5.14	45.5
9x9 SPC-5	0.417	0.0047	0.4076	0.364	0.3858	0.0218	5.46	48.3

† These fuel types are separately analyzed for peak fuel cladding temperature limits.

Table 4.3.7

INITIAL PEAK ZIRCALOY† CLADDING TEMPERATURE LIMITS FOR STORAGE

Fuel Age (years)	**Temperature Limits for PWR SNF (°C) [°F]**	**Temperature Limits for Design Basis BWR SNF (except 8x8 GE Dresden-1, 6x6 Dresden 1, 6x6 GE Humboldt Bay, and Quad+) (°C) [°F]**	**Temperature Limits for 8x8 GE Dresden-1, 6x6 Dresden-1, 6x6 GE Humboldt Bay, and 8x8 Quad+ SNF†† (°C) [°F]**
5	382.3 [720]	398.2 [749]	391.2 [736]
6	370.2 [698]	382.3 [720]	376.2 [709]
7	347.0 [657]	357.9 [676]	352.2 [666]
10	341.6 [647]	351.4 [665]	346.6 [656]
15	334.1 [633]	344.9 [653]	339.5 [643]

† The listed limits are conservatively applied to stainless steel clad fuel assemblies, which actually have substantially higher limits.

†† The 8x8 GE Dresden-1, 6x6 Dresden-1, Quad+ and 6x6 Humboldt Bay fuel types are low heat emitting assemblies. The Technical Specifications limit the heat load for these assemblies to 115 watts per assembly (approximately 58% lower than the design basis maximum heat load for BWR fuel (Table 4.4.19) (183.5 watts/assembly for Quad+). Consequently, these assembly types are not deemed to be limiting.

4.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF STORAGE

4.4.1 Thermal Model

The HI-STAR 100 MPC basket designs consist of two distinct geometries to hold 24 PWR or 68 BWR fuel assemblies. The basket is a matrix of square compartments (called boxes) to hold the fuel assemblies in a vertical position. The basket is a honeycomb structure of Alloy X plates with full-length edge-welded intersections to form an integral basket configuration. Individual cell walls (except outer periphery MPC-68 cell walls) are provided with Boral neutron absorber sandwiched between the box wall and a sheathing plate over the full length of the active fuel region.

The design basis decay heat generation (per PWR or BWR assembly) for long-term normal storage is specified in Table 2.1.6. The decay heat is conservatively considered to be non-uniformly distributed over the active fuel length based on the design basis axial burnup distribution provided in Chapter 2 (Table 2.1.8).

Transport of heat from the interior of the MPC basket to its outer periphery is accomplished by a combination of conduction through the MPC basket metal grid structure, conduction and radiation heat transfer in the relatively small helium gaps between the fuel assemblies and basket cell walls, and radiation and conduction from the fuel basket periphery to the MPC shell. Heat dissipation across the gap between the MPC basket periphery and the MPC shell is by a combination of helium conduction, natural convection (by means of the "Rayleigh" effect), radiation across the gap, and conduction in the aluminum alloy 1100 heat conduction elements. Between the MPC exterior and the overpack interior is a small clearance region which is evacuated and backfilled with helium. Helium, besides being inert, is a better heat conduction medium than air. Thus, heat conduction through the MPC/overpack helium gap will minimize temperature differentials across this region.

The overpack, under normal storage conditions, passively rejects heat to the outside environment. Cooling of the outside overpack vertical and horizontal (top) surfaces is by natural convection and thermal radiation. The bottom surface conducts heat through the ISFSI concrete pad to the ground. Analytical modeling details of the various thermal transport mechanisms are provided in the following.

4.4.1.1 Analytical Model - General Remarks

Transport of heat from the heat generation region (fuel assemblies) to the outside environment (ambient air or ground) is analyzed broadly in terms of three interdependent thermal models. The first model considers transport of heat from the fuel assembly to the basket cell walls. This model recognizes the combined effects of conduction (through helium) and radiation, and is essentially a finite element technology based update of the classical Wooton & Epstein [4.4.1] (which considered radiative heat exchange between fuel rod surfaces) formulation. The second model considers heat transport within an MPC cross section by conduction and radiation. The effective cross sectional thermal conductivity of the basket and basket periphery regions, obtained from a combined fuel assembly/basket heat conduction-radiation model developed on

ANSYS, are applied to an axisymmetric thermal model of the HI-STAR 100 System on the FLUENT [4.1.2] code. The third model deals with the transmission of heat from the MPC exterior surface to the external environment (heat sink). From the MPC shell to the overpack exterior surface, heat is conducted through an array of concentric shells representing the MPC-to-overpack helium gap, overpack inner shell, intermediate shells, Holtite-A and overpack outer shell. Heat rejection from the outside cask surfaces to ambient air is considered by accounting for natural convection and thermal radiation heat transfer mechanisms from the vertical (cylindrical shell) and top cover (flat) surfaces. The bottom overpack face, in contact with the ISFSI pad, rejects a small quantity of heat by conduction through the pad to the ground. The reduction in radiative heat exchange between cask outside vertical surfaces and ambient air because of blockage from the neighboring casks arranged for normal storage in a regular square array on the ISFSI pad is recognized in the analysis. The overpack closure plate is modeled as a heated surface in convective and radiative heat exchange with air and as a recipient of heat input through insolation. Insolation on the cask surfaces is based on 12-hour levels prescribed in 10CFR71, averaged over a 24-hour period, after accounting for partial blockage conditions.

Subsections 4.4.1.1.1 through 4.4.1.1.11 contain a systematic description of the mathematical models devised to articulate the temperature field in the HI-STAR 100 System. Table 4.4.2 shows the relationship between the mathematical models and the corresponding regions (i.e., fuel, MPC, overpack, etc.) of the HI-STAR 100 System. The description begins with the method to characterize the heat transfer behavior of the prismatic (square) opening referred to as the "fuel space" with a heat emitting fuel assembly situated in it. The methodology utilizes a finite element procedure to replace the heterogeneous SNF/fuel space region with an equivalent solid body having a well-defined temperature-dependent conductivity. In the following subsection, the method to replace the "composite" walls of the fuel basket cells with an equivalent "solid" wall is presented. Having created the mathematical equivalents for the SNF/fuel spaces and the fuel basket walls, the method to represent the MPC cylinder containing the fuel basket by an equivalent cylinder whose thermal conductivity is a function of the spatial location and coincident temperature is presented.

Following the approach of presenting descriptions starting from the inside and moving to the outer region of a cask, the next subsections present the mathematical model to simulate the overpack. Subsection 4.4.1.1.11 concludes the presentation with a description of how the different models for the specific regions within the HI-STAR 100 System are assembled into the final FLUENT model. Finally, a subsection to describe the solution for the special case of vacuum in the MPC space (no helium) is presented.

4.4.1.1.1 Overview of the Thermal Model

Thermal analysis of the HI-STAR 100 System is performed by assuming that the system is subject to its maximum heat duty with each storage location occupied and with the heat generation rate in each stored fuel assembly equal to design basis maximum value. While the assumption of equal heat generation imputes a certain symmetry to the cask thermal problem, the

thermal model must incorporate three attributes of the physical problem to perform a rigorous analysis of a fully loaded cask:

i. While the rate of heat conduction through metals is a relatively weak function of temperature, radiation heat exchange is a nonlinear function of surface temperatures.

ii. Heat generation in the MPC is axially non-uniform due to non-uniform axial burnup profile in the fuel assemblies.

iii. Inasmuch as the transfer of heat occurs from inside the basket region to the outside, the temperature field in the MPC is spatially distributed with the maximum values reached in the central core region.

It is clearly impractical to model every fuel rod in every stored fuel assembly explicitly. Instead, the cross section bounded by the inside of the storage cell, which surrounds the assemblage of fuel rods and the interstitial helium gas, is replaced with an "equivalent" square (solid) section characterized by an effective thermal conductivity. Figure 4.4.1 pictorially illustrates the homogenization concept. Further details of this procedure for determining the effective conductivity are presented in Subsection 4.4.1.1.2; it suffices to state here that the effective conductivity of the cell space will be a function of temperature because the radiation heat transfer (a major component of the heat transport between the fuel rods and the surrounding basket cell metal) is a strong function of the temperatures of the participating bodies. Therefore, in effect, every storage cell location will have a different value of effective conductivity (depending on the coincident temperature) in the homogenized model. The temperature-dependent fuel assembly region effective conductivity is determined by a finite volume procedure, as described in Subsection 4.4.1.1.2.

In the next step of homogenization, a planar section of MPC is considered. With each storage cell inside space replaced with an equivalent solid square, the MPC cross section consists of a metallic gridwork (basket cell walls with each square cell space containing a solid fuel cell square of effective thermal conductivity, which is a function of temperature) circumscribed by a circular ring (MPC shell). There are five distinct materials in this section, namely the homogenized fuel cell squares, the Alloy X structural materials in the MPC (including Boral sheathing), Boral, alloy 1100 aluminum heat conduction elements, and helium gas. Each of the five constituent materials in this section has a different conductivity. It is emphasized that the conductivity of the homogenized fuel cells is a strong function of temperature.

In order to replace this thermally heterogeneous MPC section with an equivalent conduction-only region, resort to the finite element procedure is necessary. Because the rate of transport of heat within the MPC is influenced by radiation, which is a temperature-dependent effect, the equivalent conductivity of the MPC region must also be computed as a function of temperature. Finally, it is recognized that the MPC section consists of two discrete regions, namely, the basket region and the peripheral region. The peripheral region is the space between the peripheral storage cells and the MPC shell. This space is essentially full of helium surrounded by Alloy X plates and alloy 1100 aluminum heat conduction elements. Accordingly, as illustrated in Figure 4.4.2 for MPC-68, the MPC cross section is replaced with two homogenized regions with temperature-dependent conductivities. In particular, the effective conductivity of the fuel cells is

subsumed into the equivalent conductivity of the basket cross section. The finite element procedure used to accomplish this is described in Subsection 4.4.1.1.4. The ANSYS finite element code is the vehicle for all modeling efforts described in the foregoing.

In summary, appropriate finite element models are used to replace the MPC cross section with an equivalent two region homogeneous conduction lamina whose local conductivity is a known function of coincident absolute temperature. Thus, the MPC cylinder containing discrete fuel assemblies, helium, Boral and Alloy X, is replaced with a right circular cylinder whose material conductivity will vary with the radial and axial position as a function of the coincident temperature.

The MPC-to-overpack gap is simply an annular space which is readily modeled with an equivalent conductivity which reflects conduction and radiation modes of heat transfer. The overpack is a radially symmetric structure except for the neutron absorber region which is built from radial connectors and Holtite-A (see Figure 4.4.7). Using the classical equivalence procedure described in Subsection 4.4.1.1.9, this region is replaced with an equivalent radially symmetric annular cylinder.

The thermal analysis procedure described above makes frequent use of equivalent thermal properties to ease the geometric modeling of the cask components. These equivalent properties are rigorously calculated values based on detailed evaluations of actual cask system geometries. All these calculations are performed conservatively to ensure a bounding representation of the cask system. This process, commonly referred to as submodeling, yields accurate (not approximate) results. Given the detailed nature of the submodeling process, experimental validation of the individual submodels is not necessary.

In this manner, a HI-STAR 100 System overpack containing a loaded MPC standing upright on the ISFSI pad is replaced with a right circular cylinder with spatially varying temperature-dependent conductivity. Heat is generated within the basket space in this cylinder in the manner of the prescribed axial burnup distribution. In addition, heat is deposited from insolation on the external surface of the overpack. Under steady state conditions the total heat due to internal generation and insolation is dissipated from the outer cask surfaces by natural convection and thermal radiation to the ambient environment. Details of the elements of mathematical modeling are provided in the following.

4.4.1.1.2 Fuel Region Effective Thermal Conductivity Calculation

Thermal properties of a large number of PWR and BWR fuel assembly configurations manufactured by the major fuel suppliers (i.e., Westinghouse, CE, B&W, and GE) have been evaluated for inclusion in the HI-STAR 100 System thermal analysis. It is noted that PWR fuel assemblies are equipped with removable non-fuel hardware, in particular, control rods which are inserted in guide tube locations for in-core usage. In dry cask storage, PWR fuel is optionally stored with the control rods. The control rods, when inserted in the fuel assemblies, displace gas in the guide tubes replacing it with solid materials (neutron absorbers and metals) which conduct heat much more readily. As a result, dissipation of heat in the fuel assemblies is enhanced by the presence of these control rods. For conservatism, credit for presence of control rods in fuel

assemblies is neglected. Bounding PWR and BWR fuel assembly configurations are determined using the simplified procedure described below. This is followed by the determination of temperature-dependent properties of the bounding PWR and BWR fuel assembly configurations to be used for cask thermal analysis using a finite volume (FLUENT) approach.

To determine which of the numerous PWR assembly types listed in Table 4.4.5 should be used in the thermal model for the MPC-24 fuel basket, we must establish which assembly has the maximum thermal resistance. The same determination must be made for the MPC-68, out of the menu of SNF types listed in Table 4.4.6. For this purpose, we utilize a simplified procedure which we describe below.

Each fuel assembly consists of a large array of fuel rods typically arranged on a square layout. Every fuel rod in this array is generating heat due to radioactive decay in the enclosed fuel pellets. There is a finite temperature difference required to transport heat from the innermost fuel rods to the storage cell walls. Heat transport within the fuel assembly is based on principles of conduction heat transfer combined with the highly conservative analytical model proposed by Wooton and Epstein [4.4.1]. The Wooton-Epstein model considers radiative heat exchange between individual fuel rod surfaces as a means to bound the hottest fuel rod cladding temperature.

Transport of heat energy within any cross section of a fuel assembly is due to a combination of radiative energy exchange and conduction through the helium gas which fills the interstices between the fuel rods in the array. With the assumption of uniform heat generation within any given horizontal cross section of a fuel assembly, the combined radiation and conductive heat transport effects result in the following heat flow equation:

$$Q = \sigma\ C_o\ F_\varepsilon\ A\ [T_C^4 - T_B^4] + 13.5740\ L\ K_{cs}\ [T_C - T_B]$$

where:

F_ε = Emissivity Factor

$$= \frac{1}{\left(\frac{1}{\varepsilon_C} + \frac{1}{\varepsilon_B} - 1\right)}$$

$\varepsilon_C, \varepsilon_B$ = emissivities of fuel cladding, fuel basket (see Table 4.2.4)

C_o = Assembly Geometry Factor

$$= \frac{4N}{(N+1)^2} \text{ (when N is odd)}$$

$$= \frac{4}{N+2} \text{ (when N is even)}$$

N	=	Number of rows or columns of rods arranged in a square array
A	=	fuel assembly "box" heat transfer area
	=	4 × width × length
L	=	fuel assembly length
K_{cs}	=	fuel assembly constituent materials volume fraction weighted mixture conductivity
T_C	=	hottest fuel cladding temperature (°R)
T_B	=	box temperature (°R)
Q	=	net radial heat transport from the assembly interior
σ	=	Stefan-Boltzmann Constant (0.1714×10^{-8} Btu/ft²-hr-°R⁴)

In the above heat flow equation, the first term is the Wooten-Epstein radiative heat flow contribution while the second term is the conduction heat transport contribution based on the classical solution to the temperature distribution problem inside a square shaped block with uniform heat generation [4.4.5]. The 13.574 factor in the conduction term of the equation is the shape factor for two-dimensional heat transfer in a square section. Planar fuel assembly heat transport by conduction occurs through a series of resistances formed by the interstitial helium fill gas, fuel cladding and enclosed fuel. An effective planar mixture conductivity is determined by a volume fraction weighted sum of the individual constituent material resistances. For BWR assemblies, this formulation is applied to the region inside the fuel channel. A second conduction and radiation model is applied between the channel and the fuel basket gap. These two models are combined, in series, to yield a total effective conductivity.

The effective conductivity of the fuel for several representative PWR and commonly used BWR assemblies is presented in Tables 4.4.5 and 4.4.6. At higher temperatures (approximately 450°F and above), the zircaloy clad fuel assemblies with the lowest effective thermal conductivities are the W-17×17 OFA (PWR) and the GE11-9×9 (BWR). A discussion of fuel assembly conductivities for some of the newer 10×10 array and plant specific BWR fuel designs is presented near the end of this subsection. As noted in Table 4.4.6, the Dresden 1 (intact and damaged) fuel assemblies are excluded from consideration. The design basis decay heat load for Dresden-1 intact and damaged fuel (Table 2.1.7) is approximately 58% lower than the MPC-68 design basis maximum heat load (Table 4.4.19). Examining Table 4.4.6, the effective conductivity of the damaged Dresden-1 fuel assembly in a damaged fuel container is approximately 40% lower than the bounding (GE-11 9×9) fuel assembly. Consequently, the fuel cladding temperatures in the HI-STAR 100 System with Dresden-1 intact of damaged fuel assemblies will be bounded by design basis fuel cladding temperatures. This is demonstrated in Subsection 4.4.1.1.16. Based on this simplified analysis, the W-17×17 OFA PWR and GE11-9×9 BWR fuel assemblies are determined to be the bounding configurations for analysis of zircaloy

clad fuel at design basis maximum heat loads. As discussed in Section 4.3.1, stainless clad fuel assemblies with significantly lower decay heat emission characteristics are not deemed to be bounding.

Having established the governing (most resistive) PWR and BWR SNF types, we use a finite volume code to determine the effective conductivities in a conservative manner. Detailed conduction-radiation finite volume models of the bounding PWR and BWR fuel assemblies are developed in the FLUENT code as shown in Figures 4.4.8 and 4.4.9, respectively. The PWR model was originally developed on the ANSYS code which enables individual rod-to-rod and rod-to-basket wall view factor calculations to be performed by the AUX12 procedure for the special case of black body radiation (surfaces emissivity = 1). Limitations of radiation modeling techniques implemented in ANSYS do not permit taking advantage of quarter symmetry of the fuel assembly geometry. Unacceptably long CPU time and large workspace requirements necessary for performing gray body radiation calculations for a complete fuel assembly geometry on ANSYS prompted the development of an alternate simplified model on the FLUENT code. The FLUENT model is benchmarked with the ANSYS model results for a Westinghouse 17×17 fuel assembly geometry for the case of black body radiation (emissivities = 1). The FLUENT model is found to yield conservative results in comparison to the ANSYS model for the "black" surface case. The FLUENT model benchmarked in this manner is used to solve the gray body radiation problem to provide the necessary results for determining the effective thermal conductivity of the governing PWR fuel assembly. The same modeling approach using FLUENT is then applied to the governing BWR fuel assembly, and the effective conductivity of GE11-9×9 fuel determined.

The combined fuel rods-helium matrix is replaced by an equivalent homogeneous material which fills the basket opening by the following two-step procedure. In the first step, the FLUENT-based fuel assembly model is solved by applying equal heat generation per unit length to the individual fuel rods and a uniform boundary temperature along the basket cell opening inside periphery. The temperature difference between the peak cladding and boundary temperatures is used to determine an effective conductivity as described in the next step. For this purpose, we consider a two-dimensional cross section of a square shaped block of size equal to 2L and a uniform volumetric heat source (q_g) cooled at the periphery with a uniform boundary temperature. Under the assumption of constant material thermal conductivity (K), the temperature difference (ΔT) from the center of the cross section to the periphery is analytically given by [4.4.5]:

$$\Delta T = 0.29468 \frac{q_g L^2}{K}$$

This analytical formula is applied to determine the effective material conductivity from a known quantity of heat generation applied in the FLUENT model (smeared as a uniform heat source, q_g) basket opening size and ΔT calculated in the first step.

As discussed earlier, the effective fuel space conductivity is a function of the temperature coordinate. The above two step analysis is carried out for a number of reference temperatures. In

this manner, the effective conductivity as a function of temperature is established.

In Table 4.4.23, 10×10 array type BWR fuel assembly conductivity results from a simplified analysis are presented to determine the most resistive fuel assembly in this class. From the data in Table 4.4.23, the Atrium-10 fuel type is determined to be the most resistive in this class of fuel assemblies. A detailed finite element model of this assembly type was developed to rigorously quantify the heat dissipation characteristics. The results of this study are presented in Table 4.4.24 and compared to the BWR bounding fuel assembly conductivity depicted in Figure 4.4.14. The results of this study demonstrate that the bounding fuel assembly conductivity is conservative with respect to the 10x10 class of BWR fuel assemblies.

Table 4.4.25 summarizes plant specific fuel types effective conductivities. From these analytical results, the SPC-5 is determined to be the most resistive fuel assembly in this group of fuel types. A rigorous finite element model of SPC-5 fuel assembly was developed to confirm that its in-plane heat dissipation characteristics are bounded from below by the Design Basis BWR fuel conductivities used in the HI-STAR thermal analysis.

Temperature-dependent effective conductivities of PWR and BWR design basis fuel assemblies (most resistive SNF types) are shown in Figure 4.4.14. The finite volume computational results are also compared to results reported from independent technical sources. From this comparison, it is readily apparent that FLUENT-based fuel assembly conductivities are conservative. The FLUENT computed values (not the published literature data) are used in the MPC thermal analysis presented in this document.

4.4.1.1.3 Effective Thermal Conductivity of Boral/Sheathing/Box Wall Sandwich

Each MPC basket cell wall (except the MPC-68 outer periphery cell walls) is manufactured with a Boral neutron absorbing plate for criticality control. Each Boral plate is sandwiched in a sheathing-to-basket wall pocket. A schematic of the "Box Wall-Boral-Sheathing" sandwich geometry of an MPC basket is illustrated in Figure 4.4.3. During fabrication, a uniformly normal pressure is applied to each "Box Wall-Boral-Sheathing" sandwich in the assembly fixture during stitch-welding of the sheathing periphery on the box wall. This ensures adequate surface-to-surface contact for elimination of any macroscopic air gaps. The mean coefficient of linear expansion of the Boral is higher than the thermal expansion coefficients of the basket and sheathing materials. Consequently, basket heat-up from the stored SNF will further ensure a tight fit of the Boral plate in the sheathing-to-box pocket. The presence of small microscopic gaps due to less than perfect surface finish characteristics requires consideration of an interfacial contact resistance between the Boral and box-sheathing surfaces. A conservative contact resistance resulting from a 2 mil Boral to pocket gap is applied in the analysis. In other words, no credit is taken for the interfacial pressure between Boral and stainless plate/sheet stock produced by the fixturing and welding process.

Heat conduction properties of a composite "Box Wall-Boral-Sheathing" sandwich in the two principal basket cross sectional directions as illustrated in Figure 4.4.3 (i.e., lateral "out-of-plane" and longitudinal "in-plane") are unequal. In the lateral direction, heat is transported across

layers of sheathing, air-gap, Boral (B_4C and cladding layers) and box wall resistances which are essentially in series (except for the small helium filled end regions shown in Figure 4.4.4). Heat conduction in the longitudinal direction, in contrast, is through an array of essentially parallel resistances comprised of these several layers listed above. For the ANSYS based MPC basket thermal model, corresponding non-isotropic effective thermal conductivities in the two orthogonal sandwich directions are determined and applied in the analysis.

These non-isotropic conductivities are determined by constructing two-dimensional finite-element models of the composite "Box Wall-Boral-Sheathing" sandwich in ANSYS. A fixed temperature is applied to one edge of the model and a fixed heat flux is applied to the other edge, and the model is solved to obtain the average temperature of the fixed-flux edge. The equivalent thermal conductivity is obtained using the computed temperature difference across the sandwich as input to a one-dimensional Fourier equation for conduction heat transfer as follows:

$$K_{eff} = \frac{q \times L}{T_h - T_c}$$

where:

Keff = effective thermal conductivity
q = heat flux applied in the ANSYS model
L = ANSYS model heat transfer path length
T_h = ANSYS calculated average edge temperature
T_c = specified edge temperature

The heat transfer path length is the width or thickness of the sandwich, respectively, depending on the direction of transfer (i.e., in-plane or out-of-plane).

4.4.1.1.4 Finite Element Modeling of Basket In-Plane Conductive Heat Transport

The heat rejection capability of each MPC basket design (i.e., MPC-24, and MPC-68) is evaluated by developing a thermal model of the combined fuel assemblies and composite basket walls geometry on the ANSYS finite element code. The ANSYS model includes a geometric layout of the basket structure in which the basket "Box Wall-Boral-Sheathing" sandwich is replaced by a "homogeneous wall" with an equivalent thermal conductivity. Since the thermal conductivity of the Alloy X material is a weakly varying function of temperature, the equivalent "homogeneous wall" must have a temperature-dependent effective conductivity. Similarly, as illustrated in Figure 4.4.4, the conductivities in the "in-plane" and "out-of-plane" directions of the equivalent "homogeneous wall" are different. Finally, as discussed earlier, the fuel assemblies and the surrounding basket cell openings are modeled as homogeneous heat generating regions with effective temperature dependent in-plane conductivity. The methodology used to reduce the
heterogeneous MPC basket - fuel assemblage to an equivalent homogeneous region with effective thermal properties is discussed in the following.

Consider a cylinder of height, L, and radius, r_o, with a uniform volumetric heat source term, q_g, insulated top and bottom faces, and its cylindrical boundary maintained at a uniform

temperature, T_c. The maximum centerline temperature (T_h) to boundary temperature difference is readily obtained from classical one-dimensional conduction relationships (for the case of a conducting region with uniform heat generation and a constant thermal conductivity K_s):

$$(T_h - T_c) = q_g\, r_o^2 / (4\, K_s)$$

Noting that the total heat generated in the cylinder (Q_t) is $\pi\, r_o^2\, L\, q_g$, the above temperature rise formula can be reduced to the following simplified form in terms of total heat generation per unit length (Q_t/L):

$$(T_h - T_c) = (Q_t / L) / (4\, \pi\, K_s)$$

This simple analytical approach is employed to determine an effective basket cross-sectional conductivity by applying an equivalence between the ANSYS finite element model of the basket and the analytical case. The equivalence principle employed in the HI-STAR 100 System thermal analysis is depicted in Figure 4.4.2. The 2-dimensional ANSYS finite element model of each MPC basket is solved by applying a uniform heat generation per unit length in each basket cell region and a constant basket periphery boundary temperature, T_c'. Noting that the basket region with uniformly distributed heat sources and a constant boundary temperature is equivalent to the analytical case of a cylinder with uniform volumetric heat source discussed earlier, an effective MPC basket conductivity (K_{eff}) is readily derived from the analytical formula and ANSYS solution leading to the following relationship:

$$K_{eff} = N\, (Q_f'/L) / (4\, \pi\, [T_h' - T_c'])$$

where:

N = number of fuel assemblies

(Q_f'/L) = per fuel assembly heat generation per unit length applied in ANSYS model

T_h' = peak basket cross-section temperature from ANSYS model

Cross sectional views of MPC basket ANSYS models are depicted in Figures 4.4.11 and 4.4.12. Notice that many of the basket supports and all shims have been conservatively neglected in the models. This conservative geometry simplification, coupled with the conservative neglect of thermal expansion which would minimize the gaps, yields conservative gap thermal resistances. Temperature-dependent equivalent thermal conductivities of fuel region and composite basket walls, as determined from analysis procedures described earlier, are applied to the ANSYS model. The planar ANSYS conduction model is solved by applying a constant basket periphery temperature with uniform heat generation in the fuel region. Table 4.4.7 summarizes effective thermal conductivityvalues used in subsequent cask thermal modeling. It should be noted that the planar conductivities calculated as described above are actually higher than those reported in Table 4.4.7, imparting additional conservatism to the subsequent calculations. The effective calculated basket cross sectional conductivity and the effective axial direction effective conductivity is conservatively assumed to be equal in the comprehensive HI-STAR 100 System

thermal model (see Section 4.4.1.1.11). It is recalled that the equivalent thermal conductivity values presented in Table 4.4.7 are lower bound values because, among other elements of conservatism, the effective conductivity of most resistive SNF types (Tables 4.4.5 and 4.4.6) are used in the MPC finite element simulations.

4.4.1.1.5 Heat Transfer in MPC Basket Peripheral Region

Each of the two MPC designs for storing PWR or BWR fuel are provided with relatively large regions, formed between the relatively cooler MPC shell and hot basket peripheral panels, filled with helium gas. Heat transfer in these helium-filled regions corresponds to the classical case of heat transfer in a differentially heated closed cavity. Experimental studies of this arrangement have been performed by many investigators, including Eckert and Carlson (Int. J. Heat Mass Transfer, vol. 2, p. 106, 1961) and Elder (J. Fluid Mech., vol. 23, p. 77, 1965). The peripheral region between the basket and MPC inner surface is simulated as a tall fluid-filled cavity of height H formed between two differentially heated surfaces (ΔT) separated by a small distance L. In a closed cavity, an exchange of hot and cold fluids occurs near the top and bottom ends of the cavity, resulting in a net transport of heat across the gap. The rate of heat transfer across the cavity is characterized by a Rayleigh number, Ra_L, defined as:

$$Ra_L = \frac{C_p \rho^2 g \beta \Delta T L^3}{\mu K}$$

where:

C_p	=	fluid heat capacity
ρ	=	fluid density
g	=	acceleration due to gravity
β	=	coefficient of thermal expansion (equal to reciprocal of absolute temperature for gases)
ΔT	=	temperature difference between the hot and cold surfaces
L	=	spacing between the hot and cold surfaces
μ	=	fluid viscosity
K	=	fluid conductivity

Hewitt et al. [4.4.6] recommends the following Nusselt number correlation for heat transport in tall cavities:

$$Nu_L = 0.42 \ Ra_L^{1/4} \ Pr^{0.012} \left(\frac{H}{L}\right)^{-0.3}$$

where Pr is the Prandtl number of the cavity fill gas.

A Nusselt number of unity implies heat transfer by fluid conduction only, while a higher than unity Nusselt number is due to the so-called "Rayleigh" effect which monotonically increases with increasing Rayleigh number. Nusselt numbers applicable to helium-filled PWR and BWR fueled HI-STAR 100 MPCs in the peripheral voids are provided in Table 4.4.1.

4.4.1.1.6 Effective Conductivity of Multilayered Intermediate Shell Region

Fabrication of the multi-layered overpack shell is discussed in Section 1.2 which explains how an interfacial contact between successive layers from the fabrication process is ensured. In the thermal analysis, each intermediate shell metal-to-metal interface presents an additional resistance to heat transport. The contact resistance arises from microscopic pockets of air entrapped between surface irregularities of the contacting surfaces. Since air is a relatively poor conductor of heat, this results in a reduction in the ability to transport heat across the interface compared to that of the base metal. Interfacial contact conductance depends upon three principal factors, namely: (i) base material conductivity, (ii) interfacial contact pressure, and (iii) surface finish. Rohsenow and Hartnett [4.2.2] have reported results from experimental studies of contact conductance across air entrapped stainless steel surfaces with a typical 100 μ-inch surface finish. A minimum contact conductance of 350 Btu/ft^2-hr-°F is determined from extrapolation of Rohsenow, et al. data to zero contact pressure.

Thermal conductivity of carbon steel is about three times that of stainless steel. Thus, the choice of carbon steel as base material in a multi-layered construction significantly improves heat transport across interfaces. The fabrication process, as discussed in Section 1.2, guarantees significant interfacial contact. Contact conductance values extrapolated to zero contact pressure are therefore conservative. The surface finish of the hot-rolled carbon steel plate stock is generally in the range of 250-1000 μ-inch [4.2.1]. The process of forming hot-rolled flat plate stock to cylindrical shapes to form the intermediate shells will result in additional smoothening of the surfaces (from the large surface pressures exerted by the hardened roller faces which flatten out any surface irregularities).

In the HI-STAR 100 thermal analysis, a conservatively bounding interfacial contact conductance value is determined using the following assumptions:

1. No credit is taken for higher base metal conductivity (carbon versus stainless steel).

2. No credit is taken for interfacial contact pressure.

3. No credit is taken for a smooth surface finish resulting from rolling of hot-rolled plate stock to cylindrical shapes.

4. Contact conductance is based on a uniform 2000 μ-inch (1000 μ-inch for each surface condition) interfacial air gap at all interfaces.

5. No credit for radiation heat exchange across this hypothetical inter-surface air gap.

6. Bounding low thermal conductivity at 200°F.

These assumptions guarantee a conservative assessment of heat dissipation characteristics of the multi-layered intermediate shell region. The resistance of the five carbon steel layers along with the associated interfacial resistances are combined as resistances in series to determine an effective conductivity of this region leading to the following relationship:

$$K_i = r_o \ell n \left(\frac{r_5}{r_o} \right) \left[\sum_{i=1}^{5} \frac{\delta}{K_{air}} \frac{r_o}{r_i} + \frac{r_o \ell n \frac{r_5}{r_o}}{K_{cst}} \right]^{-1}$$

where (in conventional U.S. units):

K_i	=	effective intermediate shell region thermal conductivity
r_o	=	inside radius of inner intermediate shell
r_i	=	outer radius of i^{th} intermediate shell
δ	=	interfacial air gap (2000 μ-inch)
K_{air}	=	air thermal conductivity
K_{cst}	=	carbon steel thermal conductivity

4.4.1.1.7 Heat Rejection from Overpack Exterior Surfaces

Jacob and Hawkins [4.2.9] recommend the following correlations for natural convection heat transfer to air from heated vertical or horizontal surfaces:

Turbulent range:

$$h = 0.19\,(\Delta T)^{1/3}\ (Vertical,\ GrPr > 10^9)$$

$$h = 0.22\,(\Delta T)^{1/3}\ (Horizontal,\ GrPr > 10^7)$$

(in conventional U.S. units)

Laminar Range:

$$h = 0.29\,(\frac{\Delta T}{L})^{1/4}\ (Vertical\ GrPr < 10^9)$$

$$h = 0.27\,(\frac{\Delta T}{L})^{1/4}\ (Horizontal\ GrPr < 2x10^7)$$

(in conventional U.S. units)

where ΔT is the temperature differential between the overpack surface and ambient air. The length scale L is the overpack height for vertical surfaces or the overpack diameter for the top horizontal surface. Noting that GrPr is expressed as $L^3 \Delta T Z$, where Z (from Table 4.2.7) is at least $2.6x10^5$ at a conservatively high upper bound overpack exterior air film temperature of 340°F, it is apparent that the turbulent condition is always satisfied for ΔT in excess of a small fraction of 1°F. Under turbulent conditions, the more conservative heat transfer correlation for vertical surfaces (i.e., $h = 0.19\ \Delta T^{1/3}$) is applied for thermal analysis to all exposed overpack surfaces.

Including both natural convection and thermal radiation heat loss from the overpack outer surfaces, the following relationship for surface heat flux is developed:

$$q_s = 0.19\ (T_s - T_A)^{4/3} + \sigma\ \varepsilon\ F_{1,A}\ [(T_s + 460)^4 - (T_A + 460)^4]$$

where:

T_s, T_A	=	surface, ambient temperatures (°F)
q_s	=	surface heat flux (Btu/ft^2-hr)
ε	=	surface emissivity
$F_{1,A}$	=	view factor between surface and air
σ	=	Stefan Boltzman constant (0.1714x10^{-8} Btu/ft^2-hr-°R^4)

In order to determine the view factor for vertical overpack outside surfaces, an ANSYS [4.1.1] finite-element based radiation heat transfer model is developed. The model geometry is based on a HI-STAR 100 System array layout depicted schematically in Figure 1.4.1. The design basis HI-STAR 100 System ISFSI storage square layout pitch is provided in Section 1.4. The ANSYS model developed is shown in Figure 4.4.5. In this figure, a center HI-STAR 100 System cask is shown surrounded by two rows of casks on all sides. The ANSYS solution determines view factors between this most adversely located system in the middle with all other neighboring casks. A sum of all these individual blockages gives the total blockage factor. Thus, the view factor $F_{1,A}$ between this most adversely affected HI-STAR 100 System and outside air is determined by the following relationship:

$$F_{1,A} = 1 - \sum_{K} F_{1,K}$$

where $F_{1,K}$ is the view factor between HI-STAR 100 System 1 and a neighboring system K. This factor is determined by a series of ANSYS solutions as a function of ISFSI cask array pitch, and the results are shown in Figure 4.4.6.

4.4.1.1.8 Determination of Solar Heat Input

The intensity of solar radiation incident on an exposed surface depends on a number of time varying terms. The solar heat flux strongly depends upon the time of the day as well as on latitude and day of the year. Also, the presence of clouds and other atmospheric conditions (dust, haze, etc.) can significantly attenuate solar intensity levels. Rapp [4.4.2] has discussed the influence of such factors in considerable detail.

Consistent with the guidelines in NUREG-1536 [4.1.3], solar input to the exposed surfaces of the overpack is determined based on 12-hour insolation levels recommended in 10CFR71 (averaged over a 24-hour period) and applied to the most adversely located cask after accounting for partial blockage of incident solar radiation on the lateral surfaces of the cask by surrounding casks. The blocking factor is identical to the radiative blocking considered for cooling of outside surfaces to the ambient environment. This is conservative compared to the case of an isolated cask with significantly improved radiative cooling and higher insolation levels because the cask is emitting much more heat than the insolation heat input. The imposed steady insolation level for the exposed top lid is based on a view factor equal to unity. The solar absorptivity of all exposed cask surfaces is assumed to be a conservatively bounding value of unity.

4.4.1.1.9 Effective Thermal Conductivity of Holtite Neutron Shielding Region

In order to minimize heat transfer resistance limitations due to the poor thermal conductivity of the Holtite-A neutron shield material, a large number of thick radial channels of high strength and conductivity carbon steel material are embedded in the neutron shield region. The legs of the radial channels form highly conducting heat transfer paths for efficient heat removal. Each channel leg is welded to the outside surface of the outermost intermediate shell. Enclosure shell panels are welded to the radial channels to form the external wall of the overpack, and thus provide a continuous path for heat removal to the ambient environment.

The effective thermal conductivity of the composite neutron shield and the network of radial channel legs is determined by combining the heat transfer resistance of individual components in a parallel network. In determining the heat transfer capability of this region to the outside ambient environment for normal long-term storage conditions, no credit is taken for conduction through the neutron shielding material. Thus, heat transport from the outer intermediate shell surface to the overpack outer shell is conservatively based on heat transfer through the carbon steel radial connectors alone. Thermal conductivity of the parallel neutron shield and radial channel leg region is given by the following formula:

$$K_{ne} = \frac{K_r N_r t_r \ell n\left(\frac{r_B}{r_A}\right)}{2\pi \ell_R} + \frac{K_{ns} N_r t_{ns} \ell n\left(\frac{r_B}{r_A}\right)}{2\pi \ell_R}$$

where (in consistent U.S. units):

K_{ne} = effective thermal conductivity of Holtite region

r_A = inner radius of neutron shielding

r_B = outer radius of neutron shielding

K_r = effective thermal conductivity of carbon steel radial channel leg

N_r = total number of radial channel legs (also equal to number of neutron shield sections)

t_r = minimum (nominal) thickness of each radial channel leg

ℓ_R = effective radial heat transport length through radial channel leg

K_{ns} = neutron shield thermal conductivity

t_{ns} = neutron shield thickness (between two radial channel legs)

The radial channel-to-outer intermediate shell surface weld thickness is equal to half the plate thickness. The additional weld resistance is accounted for by reducing the plate thickness in the weld region for a short radial span equal to the weld size. As a result, the conductivity of the radial carbon steel connectors based on full thickness for the entire radial span is reduced. Figure 4.4.7 depicts a resistance network developed to combine the neutron shield and radial connectors resistances to determine an effective conductivity of the neutron shield region. Note that in the resistance network analogy, only the annulus region between overpack outer enclosure inner surface and intermediate shells outer surface is considered in this analysis. The effective thermal conductivity of the neutron shield/radial channel leg region is provided in Table 4.4.8.

4.4.1.1.10 Effective Thermal Conductivity of Flexible MPC Basket-to-Shell Aluminum Heat Conduction Elements

As shown in HI-STAR 100 System MPC drawings in Section 1.5, flexible full-length heat conduction elements fabricated from thin aluminum alloy 1100 sheet metal are inserted in the large MPC basket-to-shell gaps to provide uninterrupted metal pathways to transport heat from the basket to the MPC shell. Due to the high thermal conductivity of aluminum alloy 1100 (about 15 times that of Alloy X), a significant rate of heat transfer is possible along thin flexible plates. Flexibility of the heat conduction elements is an important asset to enable a snug fit in the confined spaces and for ease of installation. Figure 4.4.13 shows the mathematical idealization of

a typical conduction element inserted in a basket periphery panel-to-MPC shell space. The aluminum heat conduction element is shown to cover the MPC basket Alloy X peripheral panel and MPC shells (Regions I and III depicted in Figure 4.4.13) surfaces along the full-length of the basket except for isolated locations where fitup or interference with other parts precludes complete basket coverage. Heat transport to and from the aluminum heat conduction element is conservatively postulated to occur across a thin helium gap as shown in the figure (i.e., no credit is taken for aluminum heat conduction element to Alloy X metal-to-metal contact). Aluminum surfaces inside the hollow region are sandblasted prior to fabrication to result in a rough surface finish which has a significantly higher emissivity compared to smooth surfaces of rolled aluminum. The untreated aluminum surfaces directly facing Alloy X panels have a smooth finish to minimize contact resistance.

Net heat transfer resistance from the hot basket periphery panel to the relatively cooler MPC shell along the aluminum heat conduction element pathway is a sum of three individual resistances in regions labeled I, II, and III as shown in Figure 4.4.13. In Region I, heat is transported from the basket to the aluminum heat conduction element surface directly facing the basket panel across a thin helium resistance gap. Longitudinal transport of heat (in the z direction) in the aluminum plate (in Region I) will result in an axially non-uniform temperature distribution. Longitudinal one-dimensional heat transfer in the Region I aluminum plate was analytically formulated to result in the following ordinary differential equation for the non-uniform temperature distribution:

$$t\,K_{Al}\,\frac{\partial^2 T}{\partial z^2} = -\,\frac{K_{He}}{h}\,(T_h - T) \qquad \text{(Equation a)}$$

Boundary Conditions

$$\frac{\partial T}{\partial z} = 0 \text{ at } z = 0$$

$$T = T_h' \text{ at } z = P \qquad \text{(Equation b)}$$

where (see Figure 4.4.13):

$T(z)$ = non-uniform aluminum metal temperature distribution

t = heat conduction element thickness

K_{Al} = heat conduction element conductivity

K_{He} = helium conductivity

h = helium gap thickness

T_h = hot basket temperature

T_h' = heat conduction element Region I boundary temperature at $z = P$

P = heat conduction element Region I length

W = conduction element Region II length

Solution of this ordinary differential equation subject to the imposed boundary condition is:

$$(T_h - T) = (T_h - T_h') \left[\frac{e^{\frac{z}{\sqrt{\alpha}}} + e^{-\frac{z}{\sqrt{\alpha}}}}{e^{\frac{P}{\sqrt{\alpha}}} + e^{-\frac{P}{\sqrt{\alpha}}}} \right] \qquad \text{(Equation c)}$$

where α is a dimensional parameter equal to $(h \times t \times K_{Al}/K_{he})$. The net heat transfer (Q_I) across the Region I helium gap can be determined by the following integrated heat flux to a heat conduction element of length L as:

$$Q_I = \int_0^P \frac{K_{He}}{h} (T_h - T)(L)\, dz \qquad \text{(Equation d)}$$

Substituting the analytical temperature distribution result obtained in Equation c, the following expression for net heat transfer is obtained:

$$Q_I = \frac{K_{He} L \sqrt{\alpha}}{h} \left(1 - \frac{1}{e^{\frac{P}{\sqrt{\alpha}}} + e^{-\frac{P}{\sqrt{\alpha}}}} \right) (T_h - T_h') \qquad \text{(Equation e)}$$

Based on this result, an expression for Region I resistance is obtained as shown below:

$$R_I = \frac{T_h - T_{h'}}{Q_I} = \frac{h}{K_{He} L \sqrt{\alpha}} \left(1 - \frac{1}{e^{\frac{P}{\sqrt{\alpha}}} + e^{-\frac{P}{\sqrt{\alpha}}}} \right)^{-1} \qquad \text{(Equation f)}$$

The Region II resistance expression can be developed from the following net heat transfer equation in the vertical leg of the conduction element as shown below:

$$Q_{II} = \frac{K_{Al} L t}{W} (T_h' - T_c') \qquad \text{(Equation g)}$$

$$R_{II} = \frac{T_h' - T_c'}{Q_{II}} = \frac{W}{K_{Al} L t} \qquad \text{(Equation h)}$$

Similarly, a Region III resistance expression can be analytically determined as shown below:

$$R_{III} = \frac{(T_c' - T_c)}{Q_{III}} = \frac{h}{K_{He} L \sqrt{\alpha}} \left(1 - \frac{1}{e^{\frac{P}{\sqrt{\alpha}}} + e^{-\frac{P}{\sqrt{\alpha}}}} \right)^{-1} \qquad \text{(Equation i)}$$

This completes the analysis for the total thermal resistance attributable to the heat conduction elements, equal to the sum of the three individual resistances. The total heat conduction element

resistance is smeared across the basket-to-MPC shell region as an effective uniform annular gap conductivity (see Figure 4.4.2). We note that heat transport along the conduction elements is an independent conduction path in parallel with conduction and radiation mechanisms in the large helium gaps. Helium conduction and radiation in the MPC basket-to-MPC shell peripheral gaps is accounted for separately in the ANSYS models for the MPCs, described earlier. Therefore, the total MPC basket-to-MPC shell peripheral gaps conductivity will be the sum of the heat conduction elements effective conductivity and the helium gap conduction-radiation effective conductivity.

4.4.1.1.11 FLUENT Model for HI-STAR 100 Temperature Field Computation

In the preceding subsection, a series of analytical and numerical models to define the thermal characteristics of the various elements of the HI-STAR 100 System are presented. The thermal modeling begins with the replacement of the SNF cross section and surrounding fuel cell space with a solid region with an equivalent conductivity. Since radiation is an important constituent of the heat transfer process in the SNF/storage cell space, and the rate of radiation heat transfer is a strong function of the surface temperatures, it is necessary to treat the equivalent region conductivity as a function of temperature. Because of the relatively large range of temperatures in a loaded HI-STAR 100 System under the design basis heat loads, the effects of variation in the thermal conductivity of materials with temperature throughout the system model are included. The presence of significant radiation effects in the storage cell spaces adds to the imperative to treat the equivalent storage cell lamina conductivity as temperature-dependent.

FLUENT finite volume simulations have been performed to establish the equivalent thermal conductivity as a function of temperature for the limiting (thermally most resistive) BWR and PWR spent fuel types. Utilizing the limiting SNF (established through a simplified analytical process for comparing conductivities) ensures that the numerical idealization for the fuel space effective conductivity is conservative for all non-limiting fuel types.

Having replaced the fuel spaces by solid square blocks with temperature-dependent conductivity essentially renders the basket into a non-homogeneous three-dimensional solid where the non-homogeneity is introduced by the honeycomb basket structure. The basket panels themselves are a composite of Alloy X cell wall, Boral neutron absorber, and Alloy X sheathing metal. A conservative approach to replace this composite section with an equivalent "solid wall" was described earlier.

In the next step, a planar section of the MPC is considered. The MPC contains a non-symmetric basket lamina wherein the equivalent fuel spaces are separated by the "equivalent" solid metal walls. The space between the basket and the MPC, called the peripheral gap, is filled with helium gas and aluminum heat conduction elements (shown in the MPC drawings in Section 1.5). The equivalent thermal conductivity of the MPC section is computed using a finite element procedure on ANSYS. To the "helium conduction-radiation" based peripheral gap conductivity, the effective conductivity of the aluminum conduction elements is added to obtain a combined peripheral gap effective conductivity. At this stage in the thermal analysis, the SNF/basket/MPC assemblage has been replaced with a two-zone (Figure 4.4.2) cylindrical solid whose thermal conductivity is a strong function of temperature.

The idealization for the overpack is considerably more straightforward. The overpack is radially symmetric except for the neutron absorber (Holtite-A) region (Figure 4.4.7). The procedure to replace the multiple shell layers, Holtite-A and radial connectors with an equivalent solid utilizes classical heat conduction analogies, as discussed in Sections 4.4.1.1.6 and 4.4.1.1.9.

In the final step of the analysis, the equivalent two-zone MPC cylinder, equivalent overpack shell, top and bottom plates, and ISFSI pad are assembled into a comprehensive finite volume model. A cross section of this axisymmetric model implemented on FLUENT is shown in Figure 4.4.15. A summary of the essential features of this model is presented in the following:

- The overpack shell is represented by 840 axisymmetric elements.
- The overpack bottom plate and bolted closure plate are modeled by 312 axisymmetric elements.
- The two-zone MPC "solid" (including the baseplate, lid and shell) is represented by 1188 axisymmetric elements.
- The ISFSI pad is conservatively modeled as a thermal resistance from a 36" thick concrete cylinder whose bottom surface is at 60°F. The portion of the concrete outside the footprint of the cask is conservatively omitted from the model.
- The space between the MPC and the overpack interior inner surface contains helium.
- Heat input due to insolation is applied to the top surface and the cylindrical surface of the overpack.
- The heat generation in the MPC is assumed to be uniform in each horizontal plane, but to vary in the axial direction to correspond to the axial power distribution listed in Table 2.1.8.
- The most disadvantageously placed cask in a HI-STAR cask array (i.e., the one subjected to maximum radiative blockage (see Subsection 4.4.1.1.7), is modeled.

The emissivity applied to the external surfaces of the HI-STAR model accounts for radiation-blockage of the outer enclosure surface and no blockage for the overpack closure plate top surface.

The finite element model constructed in this manner will produce an axisymmetric temperature distribution. The peak temperature will occur at the centerline and is expected to occur at the axial location of peak heat generation. As we will see later, the results from the finite volume solution bear out these observations.

4.4.1.1.12 MPC Temperature Distribution Under Vacuum Conditions

The initial loading of SNF in the MPC requires that the water within the MPC be drained and replaced with helium. This operation on the HI-STAR MPCs will be carried out using a conventional vacuum drying approach. In this method, removal of the last traces of residual moisture from the MPC cavity is accomplished by evacuating the MPC for a short time after draining the MPC.

Prior to the start of the MPC draining operation, both the overpack annulus and the MPC are full of water. The presence of water in the MPC ensures that the fuel cladding temperatures are lower than design basis limits by large margins. As the heat generating active fuel length is uncovered during the draining operation, the fuel and basket mass will undergo a gradual heat up from the initially cold conditions when the heated surfaces were submerged under water.

Thermal analysis of the MPC basket for bounding design basis decay heat loads is performed on the ANSYS finite element code. The ANSYS model is constructed to evaluate the heat rejection ability of the basket under evacuated conditions. The vacuum condition effective fuel assembly conductivity is determined by procedures discussed earlier (Subsection 4.4.1.1.2) after setting the thermal conductivity of the gaseous medium to a small fraction (one part in one thousand) of helium conductivity in the fuel assembly finite element model. Basket periphery-to-MPC shell heat transfer occurs through conduction and radiation. During draining and vacuum drying operations, the overpack annulus is required to be kept filled with water. Thus, the MPC thermal analysis problem is formulated with cooling of the MPC shell with water, which under worst case conditions would be slightly higher than its normal boiling temperature at the bottom of the overpack annulus. Results of vacuum condition analyses are provided in Subsection 4.4.2.2.

4.4.1.1.13 Effect of Fuel Cladding Crud Resistance

In this subsection, a conservatively bounding estimate of temperature drop across a crud film adhering to a fuel rod during dry storage conditions is determined. The evaluation is performed for a BWR fuel assembly based on an upper bound crud thickness obtained from the PNL-4835 report ([4.3.4], Table 3). The crud present on the fuel assemblies is predominately iron oxide mixed with small quantities of other metals such as cobalt, nickel, chromium, etc. Consequently, the effective conductivity of the crud mixture is expected to be in the range of typical metal alloys. However, in the interest of extreme conservatism, the crud layer thickness is replaced by a film of helium. The calculation is performed in two steps. In the first step, a crud film resistance is determined based on bounding maximum film on the fuel rod surfaces. This is followed by a peak local cladding heat flux calculation for the GE 7×7 array fuel assembly postulated to emit a conservatively bounding decay heat equal to 0.5kW. The temperature drop across the crud film obtained as a product of the heat flux and crud resistance terms is determined to be less than 0.1°F. The calculations are presented below.

Bounding Crud Thickness(s) (PNL-4835)	=	130μm (4.26×10^{-4} ft)
Crud Conductivity (K) (Conservative Assumption)	=	0.1 Btu/ft-hr-°F

GE 7×7 Fuel Assembly:

Rod O.D.	=	0.563"
Active Fuel Length	=	150"
Heat Transfer Area	=	(7×7) (π×0.563) × 150/144
	=	90.3 ft^2
Axial Peaking Factor	=	1.195 (Burnup distribution Table 2.1.8)
Decay Heat (Conservative Assumption)	=	500W

$$\text{Crud Resistance} = \frac{\delta}{K} = \frac{4.26\times10^{-4}}{0.1} = 4.26\times10^{-3}\ \frac{ft^2 - hr - {}^\circ F}{Btu}$$

$$\text{Peak Heat Flux} = \frac{(500\times3.417)\ Btu/hr}{90.3\ ft^2}\times 1.195 = 22.6\ \frac{Btu}{ft^2\ hr}$$

$$\therefore \text{ Temperature drop } (\Delta T_c) \text{ across crud film}$$

$$= 4.26\times10^{-3}\ \frac{ft^2 - hr - {}^\circ F}{Btu}\times 22.6\ \frac{Btu}{ft^2 - hr} = 0.096^\circ F$$

$$(\text{i.e., less than } 0.1^\circ F)$$

Therefore, it is concluded that deposition of crud does not materially change the SNF cladding temperature.

4.4.1.1.14 Maximum Time Limit During Wet Transfer

In accordance with NUREG-1536, water inside the MPC cavity during wet transfer operations is not permitted to boil in the HI-STAR 100 System. Consequently, uncontrolled pressures in the de-watering, purging, and recharging system which may result from two-phase condition, are completely avoided. This requirement is accomplished by imposing a limit on the maximum allowable time duration for fuel to be submerged in water after a loaded HI-STAR cask is removed from the pool and prior to the start of vacuum drying operations.

When the HI-STAR overpack and the loaded MPC under water-flooded conditions are removed from the pool, the combined mass of the water, the fuel, the MPC, and the HI-STAR will absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the entire system with time, starting from an initial temperature of the contents. The rate of temperature rise is limited by the thermal inertia of the HI-STAR system. To enable a bounding heat-up rate determination for the HI-STAR system, the following conservative assumptions are imposed:

i. Heat loss by natural convection and radiation from the exposed HI-STAR

surfaces to the pool building ambient air is neglected (i.e., an adiabatic temperature rise calculation is performed).

ii. Design Basis maximum decay heat input from the loaded fuel assemblies is imposed on the HI-STAR system.

iii. The smallest of the minimum MPC cavity-free volumes among the two MPC types is considered for flooded water mass determination.

iv. Fifty percent of the water mass in the MPC cavity is credited towards water thermal inertia evaluation.

Table 4.4.20 summarizes the weights and thermal inertias of several components in the loaded HI-STAR system. The rate of temperature rise of the HI-STAR and its contents during an adiabatic heat-up is governed by the following equation:

$$\frac{dT}{dt} = \frac{Q}{C_h}$$

where:

Q = decay heat load (Btu/hr)
[equal to Design Basis maximum (among the two MPC types) 19.0 kW (i.e., 64,847 Btu/hr)]

C_h = combined thermal inertia of the loaded HI-STAR system (Btu/°F)

T = temperature of the contents (°F)

t = time after HI-STAR system is removed from the pool (hr)

A bounding heat-up rate for the HI-STAR system contents is determined to be equal to 2.08°F/hr. From this adiabatic rate of temperature rise estimate, the maximum allowable time duration (t_{max}) for fuel to be submerged in water is determined as follows:

$$t_{max} = \frac{T_{boil} - T_{initial}}{(dT/dt)}$$

where:

T_{boil} = boiling temperature of water (equal to 212°F at the water surface in the MPC cavity)

$T_{initial}$ =initial temperature of the HI-STAR contents when removed from the pool

Table 4.4.21 provides a summary of t_{max} at several initial HI-STAR contents temperatures.

As set forth in the HI-STAR 100 operating procedures, in the unlikely event where the maximum allowable time provided in Table 4.4.21 is found to be insufficient to complete all wet transfer operations, a forced water circulation shall be initiated and maintained to remove the decay heat from the MPC cavity. In this case, relatively cooler water will enter via the MPC lid drain port connection and heated water will exit from the vent port. The minimum water flow rate required to maintain the MPC cavity water temperature below boiling with an adequate subcooling margin is determined as follows:

$$M_W = \frac{Q}{C_{pw}\,(T_{max} - T_{in})}$$

where:

M_W = minimum water flow rate (lb/hr)

C_{pw} = water heat capacity (Btu/lb-°F)

T_{max} = maximum MPC cavity water mass temperature

T_{in} = temperature of water supply to MPC

With the MPC cavity water temperature limited to 150°F, MPC inlet water maximum temperature equal to 125°F and at the design basis maximum heat load, the water flow rate is determined to be 2,594 lb/hr (5.3 gpm).

4.4.1.1.15 Cask Cooldown and Reflood Analysis During Fuel Unloading Operation

NUREG-1536 requires an evaluation of cask cooldown and reflood procedures to support fuel unloading from a dry condition. Past industry experience generally supports cooldown of cask internals and fuel from hot storage conditions by direct water quenching. However, the extremely rapid cooldown rates that are typical during water injection, to which the hot cask internals and fuel cladding are subjected to, may result in uncontrolled thermal stresses and failure in the structural members. Moreover, water injection results in large amounts of steam generation and unpredictable transient two-phase flow conditions inside the MPC cavity, which may result in over-pressurization of the confinement boundary and a potentially unacceptable reduction in the safety margins to prevent criticality. To avoid potential safety concerns related

to rapid cask cooldown by direct water quenching, the HI-STAR MPCs are designed to be cooled in a gradual manner, thereby eliminating thermal shock loads on the cask internals and fuel cladding.

In the unlikely event that a HI-STAR system is required to be unloaded, it will be transported back to the fuel handling building. Prior to reflooding the MPC cavity with water, a forced flow helium recirculation system with adequate flow capacity shall be operated to remove the decay heat and initiate a slow cask cooldown lasting for several days. The operating procedures in Chapter 8 (Section 8.3) provide a detailed description of the steps involved in the cask unloading. In this section, an analytical evaluation is presented to provide the basis for helium flow rates and time of forced cooling to meet the objective of eliminating thermal shock when the MPC cavity is eventually flooded with water.

Under a closed loop forced helium circulation condition, the helium gas is cooled via an external chiller, down to 100°F, and then introduced inside the MPC cavity from the drain line near the bottom baseplate. The helium gas enters the MPC basket from the bottom oversized flow holes and moves upwards through the hot fuel assemblies, removing heat and cooling the MPC internals. The heated helium gas exits from the basket top and collects in the top plenum, from where it is expelled through the MPC lid vent connection to the helium recirculation and cooling system. The MPC contents bulk average temperature reduction as a function of time is principally dependent upon the rate of helium circulation. The temperature transient is governed by the following heat balance equation

$$C_h \frac{dT}{dt} = Q_D - m\, C_p\, (T - T_i) - Q_c$$

Initial Condition: $T = T_o$ at $t = 0$

where:

T = MPC bulk average temperature (°F)

T_o = initial MPC bulk average temperature in the HI-STAR system (equal to 439°F)

t = time after start of forced circulation (hrs)

Q_D = decay heat load (Btu/hr) (equal to Design Basis maximum 19.0 kW (i.e., 64,847 Btu/hr))

m = helium circulation rate (lb/hr)

C_p = helium heat capacity (Btu/lb-°F) (equal to 1.24 Btu/lb-°F)

Q_c = heat rejection from cask exposed surfaces to ambient (Btu/hr) (conservatively

neglected)

C_h = thermal capacity of the loaded MPC (Btu/°F)

(For a bounding upper bound 100,000 lb loaded MPC weight, and heat capacity of Alloy X equal to 0.12 Btu/lb-°F, the heat capacity is equal to 12,000 Btu/°F.)

T_i = MPC helium inlet temperature (°F)

The differential equation is analytically solved, yielding the following expression for time-dependent MPC bulk temperature.

$$T(t) = (T_i + \frac{Q_D}{m\ C_p})\ (1 - e^{-\frac{m\ C_p}{C_h} t}) + T_o\ e^{-\frac{m\ C_p}{C_h} t}$$

This equation is used to determine the minimum helium mass flow rate which would cool the MPC cavity down from initially hot conditions to less than 200°F in 72 hours. The required helium mass flow rate is 546 lb/hr (i.e., 817 SCFM).

Once the helium gas circulation has cooled the MPC internals to less than 200°F, water can be injected to the MPC without risk of boiling and the associated thermal stress concerns. Because of the relatively long cooldown period, the thermal stress contribution to the total cladding stress would be negligible, and the total stress would therefore be bounded by the normal (dry) condition. The elimination of boiling eliminates any concern of over-pressurization due to steam production.

4.4.1.1.16 HI-STAR Temperature Field With Low Emitting Fuel

The HI-STAR 100 thermal evaluations for BWR fuel are divided in two groups of fuel assemblies proposed for storage in MPC-68. These groups are classified as Low Heat Emitting (LHE) fuel assemblies and Design Basis (DB) fuel assemblies. The LHE group of fuel assemblies are characterized by low burnup, long cooling time, and short active fuel lengths. Consequently, their heat loads are dwarfed by the DB group of fuel assemblies. The Dresden-1 (6x6 and 8x8), Quad+, and Humboldt Bay (7x7 and 6x6) fuel characteristics warrant their classification as LHE fuel. These characteristics, including burnup and cooling time limits imposed on this class of fuel, are presented in Table 2.1.6. This fuel (except Quad+) is permitted to be loaded when encased in Damaged Fuel Containers (DFCs). As a result of interruption of radiation heat exchange between the fuel assembly and the fuel basket by the DFC boundary, this loading configuration is bounding for thermal evaluation. In Subsection 4.4.1.1.2, two canister designs for encasing LHE fuel are evaluated – a previously approved Holtec Design (Holtec Drawing-1783) and an existing canister in which some of the Dresden-1 fuel is currently stored (Transnuclear D-1 canister). The most resistive fuel assembly determined by analytical evaluation is considered for thermal evaluation (see Table 4.4.6). The MPC-68 basket effective conductivity, loaded with the most resistive fuel assembly from the LHE group of fuel (encased in a canister) is provided in Table 4.4.7. To this basket, LHE decay heat load is applied and a HI-STAR 100 System temperature field obtained. The low heat load burden limits the initial peak

cladding temperature to 595°F which is substantially below the temperature limit for long-cooled fuel (~643°F).

A thoria rod canister designed to hold a maximum of 20 fuel rods arrayed in a 5x4 configuration is currently stored at the Dresden-1 spent fuel pool. The fuel rods contain a mixture of enriched UO_2 and Thorium Oxide in the fuel pellets. The fuel rods were originally constituted as part of an 8x8 fuel assembly and used in the second and third cycle of Dresden-1 operation. The maximum fuel burnup of these rods is quite low (~14,400 MWD/MTU). The thoria rod canister internal design is a honeycomb structure formed from 12 gage stainless steel plates. The rods are loaded in individual square cells and are isolated from each other by the cell walls. The few number of rods (18 per assembly) and very low burnup of fuel stored in these Dresden-1 canisters render them as miniscule sources of decay heat. The canister all-metal internal honeycomb construction serves as an additional means of heat dissipation in the fuel cell space. In accordance with preferential fuel loading requirements imposed in the Technical Specifications, low burnup fuel shall be loaded toward the basket periphery (i.e., away from the hot central core of the fuel basket). All these considerations provide ample assurance that these fuel rods will be stored in a benign thermal environment and therefore remain protected during long-term storage.

4.4.1.2 Test Model

A detailed analytical model for thermal design of the HI-STAR 100 System was developed using the FLUENT CFD code and the industry standard ANSYS modeling package, as discussed in Subsection 4.4.1.1. As discussed throughout this chapter and specifically in Section 4.4.6, the analysis incorporates significant conservatisms so as to predict the fuel cladding temperature with considerable margins. Furthermore, compliance with specified limits of operation is demonstrated with adequate margins. In view of these considerations, the HI-STAR 100 System thermal design complies with the thermal criteria set forth in the design basis (Sections 2.1 and 2.2) for long-term storage under normal conditions. Additional experimental verification of the thermal design is therefore not required.

4.4.2 Maximum Temperatures

4.4.2.1 Maximum Temperatures Under Normal Storage Conditions

The two MPC basket designs developed for the HI-STAR 100 System have been analyzed to determine the temperature distribution under long-term normal storage conditions. The MPC baskets are considered to be loaded at design basis maximum heat loads with PWR or BWR fuel assemblies, as appropriate. The systems are considered to be arranged in an ISFSI array and subjected to design basis normal ambient conditions with insolation.

Applying the radiative blocking factor applicable for the worst case cask location, converged temperature contours are shown in Figures 4.4.17 and 4.4.18 for the MPC-24, and MPC-68 basket designs. The temperatures in these two figures are in degrees Kelvin. The calculated

temperatures presented in this chapter are based on an array of analyses that incorporate many

conservatisms. As such, the calculated temperatures are upper bound values which would exceed actual temperatures.

The maximum fuel clad temperatures for zircaloy clad fuel assemblies are listed in Tables 4.4.10 and 4.4.11, which also summarize maximum calculated temperatures in different parts of the HI-STAR 100 System. Figures 4.4.21 and 4.4.22 show the axial temperature variation of the hottest fuel rod in the MPC-24 and MPC-68 basket designs, respectively. Figures 4.4.24 and 4.4.25 show the radial temperature profile in the MPC-24 and MPC-68 basket designs, respectively, in the horizontal plane where maximum fuel cladding temperature is indicated.

As discussed in Subsection 4.4.1.1.1, the thermal analysis is performed using a submodeling process where the results of an analysis on an individual component are incorporated into the analysis of a larger set of components. Specifically, the submodeling process yields directly computed fuel temperatures from which fuel basket temperatures are indirectly calculated. This modeling process differs from previous analytical approaches wherein the basket temperatures were evaluated first and then a basket-to-cladding temperature difference calculation by Wooten-Epstein or other means provided a basis for cladding temperatures. Subsection 4.4.1.1.2 describes the calculation of an effective fuel assembly thermal conductivity for an equivalent homogenous region. It is important to note that the result of this analysis is a function for thermal conductivity versus temperature. This function for fuel thermal conductivity is then input to the fuel basket effective thermal conductivity calculation described in Subsection 4.4.1.1.4. This calculation uses a finite-element methodology, wherein each fuel cell region containing multiple finite-elements has temperature varying thermal conductivity properties. The resultant temperature varying fuel basket thermal conductivity computed by this basket-fuel composite model is then input to the fuel basket region of the FLUENT cask model.

Because the FLUENT cask model incorporates the results of the fuel basket submodel, which in turn incorporates the fuel assembly submodel, the peak temperature reported from the FLUENT model is the peak temperature in any component. In a dry storage cask, the hottest components are the fuel assemblies. It should be noted that, because the fuel assembly models described in Subsection 4.4.1.1.2 include the fuel pellets, the FLUENT calculated peak temperatures reported in Tables 4.4.10 and 4.4.11 are actually peak pellet centerline temperatures which bound the peak cladding temperatures. We conservatively assume that the peak clad temperature is equal to the peak pellet centerline temperature.

The following additional observations can be derived by inspecting the temperature field obtained from the finite volume analysis:

- The maximum fuel cladding temperature is well within the PNL [4.3.1] and the LLNL [4.3.6] recommended temperature limits.

- The maximum temperature of the basket structural material is within the stipulated Design Temperature.

- The maximum temperature of the Boral neutron absorber is below the material supplier's recommended limit.

- The maximum temperatures of the MPC pressure boundary materials are well below their respective ASME Code limits.

- The maximum temperatures of the overpack pressure boundary material are well below their respective ASME Code limits.

- The neutron shielding material (Holtite-A) will not experience temperatures in excess of its qualified limit.

- The local temperatures of the mechanical seals are well below their respective long-term limits (Table 4.3.1).

Noting that the allowable maximum initial peak cladding temperature is significantly lower for older fuel, parametric peak fuel cladding temperature versus total decay heat load tables for each of the two basket designs were developed. This lower than design basis heat load performance data is presented in Tables 4.4.18 and 4.4.19. The decay heat limit curve in Figure 2.1.8 is developed based on these tables and the allowable fuel cladding temperature limits listed in Table 2.2.3.

The above observations lead us to conclude that the temperature field in the HI-STAR 100 System with a fully loaded MPC containing design-basis heat emitting SNF complies with all regulatory and industry temperature limits. In other words, the thermal environment in the HI-STAR 100 System will be conducive to long-term safe storage of spent nuclear fuel.

4.4.2.2 Maximum MPC Basket Temperature Under Vacuum Conditions

A plot of typical steady-state temperature contours under vacuum conditions is shown in Figure 4.4.19. The peak fuel clad temperature during short-term vacuum drying operations is limited to less than 950°F for both baskets at design basis maximum heat loads by a significant margin. This limit is lower than the recommended fuel cladding temperature (see Table 4.3.1) limits for short-term conditions by a large margin.

4.4.3 Minimum Temperatures

In Table 2.2.2 of this report, the minimum ambient temperature condition required to be considered for HI-STAR 100 System design is specified to be -40°F. If, conservatively, a zero decay heat load (with no solar input) is applied to the stored fuel assemblies then every component of the system at steady state would be at this minimum ambient temperature. All HI-STAR 100 System materials of construction would satisfactorily perform their intended function in the storage mode at this minimum postulated temperature condition. Structural evaluations in Chapter 3 show the acceptable performance of the overpack and MPC steel material at low

temperature. Criticality and shielding functions of the

HI-STAR 100 System materials (Chapters 5 and 6) are unaffected by exposure to this minimum temperature.

4.4.4 Maximum Internal Pressure

The MPC is initially filled with helium after fuel loading and drying prior to installing the MPC closure ring. During normal storage, the gas temperature within the MPC rises to its maximum operating basis temperature as determined based on the thermal analysis methodology described earlier. The gas pressure inside the MPC will also increase with rising temperature. The pressure rise is determined using the ideal gas law which states that the absolute pressure of a fixed volume of confined gas is proportional to its absolute temperature. In Tables 4.4.13 and 4.4.14, a summary of calculations for determining the net free volume in the MPC-24 and MPC-68 are presented.

The maximum gas pressure in the MPC is considered for a postulated accidental release of fission product gases caused by fuel rods rupture. For these fuel rod rupture conditions, the amounts of each of the release gas constituents in the MPC cavity are summed and the resulting total pressures determined from the Ideal Gas Law. Based on fission gases release fractions (per NUREG-1536 criteria [4.1.3]), minimum net free volume and maximum initial fill gas pressure, bounding maximum gas pressures with 1% (normal), 10% (off-normal), and 100% (accident condition) rod rupture are given in Table 4.4.15. The MPC maximum gas pressures listed in Table 4.4.15 are all below the MPC design internal pressure listed in Table 2.2.1.

The inclusion of PWR non-fuel hardware (BPRA control elements and thimble plugs) to the MPC-24 influences the internal pressure in two ways. The presence of non-fuel hardware enhances heat dissipation, thus lowering fuel temperatures and the gas filling the space between fuel rods. The gas volume displaced by the mass of non-fuel hardware lowers the cavity free volume. These two effects, namely, temperature lowering and free volume reduction, have opposing influence in the MPC cavity pressure. The first effect lowers gas pressure while the second effect raises it. In the HI-STAR thermal analysis, the computed temperature field (with non-fuel hardware <u>excluded</u>) provides a conservatively bounding MPC-24 temperature field. The MPC cavity free space is computed based on volume displacement by the heaviest fuel (bounding weight) with non-fuel hardware <u>included</u>).

During in-core irradiation of BPRAs, the B-10 isotope in the neutron absorbing material is transformed to helium atoms. Two different forms of the neutron absorbing material are used in BPRAs: Borasilicate glass and B_4C in a refractory solid matrix (Al_2O_3). Borosilicate glass (primarily a constituent of Westinghouse BPRAs) is used in the shape of hollow pyrex glass tubes sealed within steel rods and supported on the inside by a thin walled steel liner. To accommodate helium diffusion from the glass rod into the rod internal space, a relatively high void volume (~40%) is engineered in this type of rod design. The rod internal pressure is thus designed to remain below reactor operating conditions (2,300 psia and approximately 600°F coolant temperature). The B_4C- Al_2O_3 neutron absorber material is principally used in B&W and

CE fuel BPRA designs. The relatively low temperature of the poison material in BPRA rods (relative to fuel pellets) favor the entrapment of helium atoms in the solid matrix.

Several BPRA designs are used in PWR fuel which differ in the number, diameter, and length of poison rods. The older Westinghouse fuel (W-14x14 and AW-15x15) has used 6,12, 16, and 20 rods per assembly BPRAs and the later (W-17x17) fuel uses up to 24 rods per BPRA. The BPRA rods in the older fuel are much larger than the later fuel and, therefore, the B-10 isotope inventory in the 20-rod BPRAs bound the newer W-17x17 fuel. Based on bounding BPRA rods internal pressure, a large hypothetical quantity of helium (7.2 g-moles/BPRA) is assumed to be available for release into the MPC cavity from each fuel assembly in the MPC-24. To accommodate this quantity of helium gas† at the NUREG-1536 stipulated rods rupture assumptions, the initial helium backfill in the MPC-24 is reduced such that the final confinement boundary pressures are approximately unchanged from inclusion of non-fuel hardware. The MPC cavity pressures are summarized in Table 4.4.15

4.4.5 Maximum Thermal Stresses

Thermal expansion induced mechanical stresses due to the non-uniform temperature distribution are reported in Chapter 3. Table 4.4.16 provides a summary of HI-STAR 100 System component temperature inputs for structural evaluation.

Table 4.4.22 provides a summary of confinement boundary temperatures during normal storage conditions. Structural evaluation in Section 3.4.4 references these temperature results to demonstrate confinement boundary integrity.

4.4.6 Evaluation of System Performance for Normal Conditions of Storage

The HI-STAR 100 System thermal analysis is based on a detailed and complete heat transfer model which properly accounts for radiation, conduction and natural convection modes of heat transfer in various portions of the MPC and overpack. The thermal model incorporates many conservative features that are listed below:

1. The most severe levels of environmental factors - bounding long-term annual ambient temperature with insolation - were coincidentally imposed on the HI-STAR 100 cask. A bounding solar absorbtivity of 1.0 was applied to all surfaces exposed to insolation.

2. No credit was considered for the thermosiphon heat transfer which is intrinsic to the HI-STAR fuel baskets.

3. The most adversely located HI-STAR 100 System in an ISFSI array was considered for analysis.

4. No credit was considered for conduction through the radial neutron shielding material.

† 3,875 liters of helium gas at STP from 100% BPRA rods rupture.

5. A uniform nominal radial gap between overpack-to-MPC was applied to the cask thermal model. No credit for gap reduction due to differential thermal expansion under the hot condition was considered. The MPC is considered to be in concentric alignment inside the overpack cavity. This is a worst case scenario since any eccentricity will improve conductive heat transport in this region.

6. Not Used.

7. Interfacial contact conductance of multilayered intermediate shell contacting layers was conservatively determined to bound surface finish, contact pressure, and base metal conductivity conditions.

8. No credit was considered for contact between fuel assemblies and the MPC basket wall or between the MPC basket and the basket supports. The fuel assemblies and MPC basket were conservatively considered to be in concentric alignment.

9. The MPC is assumed to be loaded with the SNF type which has the maximum equivalent thermal resistance of all fuel types in its category (BWR or PWR), as applicable.

10. The decay heat load, which is a function of burnup and decay time, varies in a narrow range within the group of PWR assemblies considered (Table 4.4.5) and also within the group of BWR assemblies considered (Table 4.4.6). The assembly type which gives the maximum decay heat load for a given burnup is used for defining the decay heat load vs. decay time. The B&W 15×15 is the limiting PWR SNF type (see Table 2.1.5). The governing BWR fuel is GE 7×7 (see Table 2.1.5). For other than the governing fuel types, there is a small conservatism in the decay heat load term.

11. The MPC basket axial conductivity is conservatively assumed to be equal to the lower basket cross sectional effective conductivity.

12. As discussed in Section 4.3, the NUREG-1536 endorsed DCCG [4.3.6] model yields temperature limits slightly higher (approximately 10°F) than the PNL [4.3.1] limits for allowable peak cladding temperature during storage. For conservatism, the lower PNL value (Table 2.2.3) is used as the permissible limit.

Temperature distribution results obtained from this conservative thermal model show that the established maximum fuel cladding temperature limits are met with adequate margins. Expected margins during normal storage will be larger due to the many conservative assumptions incorporated in the analysis. The long-term impact of decay heat induced temperature levels on the HI-STAR 100 System structural and neutron shielding materials is considered to be negligible. The maximum local MPC basket temperature level is below the recommended limits for structural materials in terms of susceptibility to stress, corrosion and creep induced degradation. Furthermore, structural evaluation (Chapter 3) has demonstrated that stresses (including those induced due to imposed temperature gradients) are within ASME B&PV Code limits. The maximum local neutron shield temperature is lower than design limits. Section 4.5

provides a discussion of compliance with regulatory criteria 1 through 8 listed in Section 4.0. The above-mentioned considerations lead to the conclusion that the HI-STAR 100 System thermal design is in compliance with 10CFR72 requirements.

Table 4.4.1

CLOSED CAVITY NUSSELT NUMBER RESULTS
FOR HELIUM-FILLED MPC PERIPHERAL VOIDS

Temperature [°F]	Nusselt Number (PWR Baskets)	Nusselt Number (BWR Basket)
200	3.17	2.41
450	2.56	1.95
700	2.21	1.68

Table 4.4.2

RELATIONSHIP BETWEEN HI-STAR 100 SYSTEM REGIONS AND MATHEMATICAL MODEL DESCRIPTIONS

HI-STAR System Region	Mathematical Model	Subsections
Fuel Assembly	Fuel Region Effective Thermal Conductivity	4.4.1.1.2
MPC	Effective Thermal Conductivity of Boral/Sheathing/Box Wall Sandwich	4.4.1.1.3
	Basket In-Plane Conductive Heat Transport	4.4.1.1.4
	Heat Transfer in MPC Basket Peripheral Region	4.4.1.1.5
	Effective Thermal Conductivity of Flexible MPC Basket-to-Shell Aluminum Heat Conduction Elements	4.4.1.1.10
Overpack	Effective Conductivity of Multilayered Intermediate Shell Region	4.4.1.1.6
	Effective Thermal Conductivity of Holtite Neutron Shielding Region	4.4.1.1.9
Ambient Environment	Heat Rejection from Overpack Exterior Surfaces	4.4.1.1.7
	Solar Heat Input	4.4.1.1.8
Assembled Cask Model	Overview of the Thermal Model	4.4.1.1.1
	FLUENT Model for HI-STAR 100	4.4.1.1.11

Table 4.4.3

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Table 4.4.4

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Table 4.4.5

SUMMARY OF PWR FUEL ASSEMBLY EFFECTIVE THERMAL CONDUCTIVITIES

	Fuel	@ 200°F (Btu/ft-hr-°F)	@ 450°F (Btu/ft-hr-°F)	@ 700°F (Btu/ft-hr-°F)
1	W - 17×17 OFA	0.182	0.277	**0.402**
2	W - 17×17 Std	0.189	0.286	0.413
3	W - 17×17 Vantage	0.182	0.277	0.402
4	W - 15×15 Std	0.191	0.294	0.430
5	W - 14×14 Std	0.182	0.284	0.424
6	W - 14×14 OFA	**0.175**	**0.275**	0.413
7	B&W - 17×17	0.191	0.289	0.416
8	B&W - 15×15	0.195	0.298	0.436
9	CE - 16×16	0.183	0.281	0.411
10	CE - 14×14	0.189	0.293	0.435
11	HN† -15×15 SS	0.180	0.265	0.370
12	W-14×14 SS	0.170	0.254	0.361
13	B&W – 15x15	0.187	0.289	0.424
14	CE-14x14 (MP2)	0.188	0.293	0.434

Note: Boldface values denote the lowest thermal conductivity in each column.

† Haddam Neck B&W or Westinghouse stainless steel clad fuel assemblies.

Table 4.4.6
SUMMARY OF BWR FUEL ASSEMBLY EFFECTIVE THERMAL CONDUCTIVITIES

	Fuel	@ 200°F (Btu/ft-hr-°F)	@ 450°F (Btu/ft-hr-°F)	@ 700°F (Btu/ft-hr-°F)
1	Dresden 1 - 8×8†	0.119	0.201	0.319
2	Dresden 1 - 6×6†	0.126	0.215	0.345
3	GE - 7×7	0.171	0.286	0.449
4	GE - 7×7R	0.171	0.286	0.449
5	GE - 8×8	0.168	0.278	0.433
6	GE - 8×8R	**0.166**	0.275	0.430
7	GE10 - 8×8	0.168	0.280	0.437
8	GE11 - 9×9	0.167	**0.273**	**0.422**
9	AC†† -10×10 SS	0.152	0.222	0.309
10	Exxon-10×10 SS	0.151	0.221	0.308
11	Humboldt Bay-7x7†	0.127	0.215	0.343
12	Dresden-1 Thin †Clad-6x6	0.124	0.212	0.343
13	Damaged Dresden-1 8×8† (in a damaged fuel container)	0.107	0.169	0.254
14	Damaged† Dresden-1 8x8 (in TN D-1 canister)	0.107	0.168	0.252
15	8x8 QUAD+ Westinghouse†	0.164	0.276	0.435

Note: Boldface values denote the lowest thermal conductivity in each column.

† Fuel cladding temperatures for low heat emitting (intact and damaged) fuel types in the HI-STAR 100 System will be bounded by design basis fuel cladding temperatures. Therefore, these fuel assembly types are excluded from the list of design basis fuel assemblies (Zircaloy clad) evaluated to determine the most resistive SNF type.

†† Allis-Chalmers stainless steel clad fuel assemblies.

Table 4.4.7

MPC BASKET EFFECTIVE THERMAL CONDUCTIVITY VALUES†

Basket	@200°F [Btu/ft-hr-°F]	@450°F [Btu/ft-hr-°F]	@700°F [Btu/ft-hr-°F]
MPC-24 (Zircaloy Clad Fuel)	1.108	1.495	1.954
MPC-68 (Zircaloy Clad Fuel)	0.959	1.188	1.432
MPC-24 (Stainless Steel Clad Fuel)	0.995	1.321	1.700 (a)
MPC-68 (Stainless Steel Clad Fuel)	0.931	1.125	1.311 (b)
MPC-68 (Dresden-1 8x8 in canister)	0.861	1.055	1.242

(a) Conductivity is 13% less than corresponding Zircaloy fueled basket.
(b) Conductivity is 9% less than corresponding Zircaloy fueled basket.

† The values reported in this table are conservatively understated.

Table 4.4.8

EFFECTIVE THERMAL CONDUCTIVITY OF THE NEUTRON SHIELD/RADIAL CHANNEL LEG REGION

Condition/Temperature (°F)	Thermal Conductivity (Btu/ft-hr-°F)
Normal condition:	
200	1.953
450	1.812
700	1.645
Fire condition:	
200	3.012
450	2.865
700	2.689

Table 4.4.9

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Table 4.4.10

HI-STAR 100 SYSTEM LONG-TERM NORMAL STORAGE†
MAXIMUM TEMPERATURES [°F]
(24-PWR ASSEMBLIES, MPC)

	Maximum Temperature (°F)	Normal Condition Design Temperature (°F)
Fuel Cladding	709	720
MPC Basket Centerline	675	725
MPC Basket Periphery	451	725
MPC Outer Shell Surface	332	450
MPC/Overpack Helium Gap Outer Surface	292	400
Neutron Shield Inner Surface	274	300
Overpack Outer Enclosure Surface	229	350
Overpack Bolted Closure Plate††	155	400
Overpack Bottom Plate††	241	350

† Ambient Temperature = 80°F
Cask Array Pitch = 3 x Cask Radius = 12 ft.

†† Overpack closure plate and vent/drain port plug seals normal condition design temperature is 400°F. The maximum seals temperatures are bounded by the reported closure plate and bottom plate maximum temperatures. Consequently, a large margin of safety exists to permit safe operation of seals in the overpack helium retention boundary.

Table 4.4.11

HI-STAR 100 SYSTEM LONG-TERM NORMAL STORAGE[†]
MAXIMUM TEMPERATURES [°F]
(68-BWR ASSEMBLIES, MPC)

	Maximum Temperature (°F)	Normal Condition Design Temperature (°F)
Fuel Cladding	741	749
MPC Basket Centerline	725	725
MPC Basket Periphery	393	725
MPC Outer Shell Surface	331	450
MPC/Overpack Helium Gap Outer Surface	292	400
Neutron Shield Inner Surface	273	300
Overpack Outer Enclosure Surface	228	350
Overpack Bolted Closure Plate[††]	155	400
Overpack Bottom Plate[††]	213	350

† Ambient Temperature = 80°F
Cask Array Pitch = 3 x Cask Radius = 12 ft.

†† Overpack closure plate and vent/drain port plug seals normal condition design temperature is 400°F. The maximum seals temperatures are bounded by the reported closure plate and bottom plate maximum temperatures. Consequently, a large margin of safety exists to permit safe operation of seals in the overpack helium retention boundary.

Table 4.4.12

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Table 4.4.13

SUMMARY OF MPC-24 FREE VOLUME CALCULATIONS

Item	Volume (ft^3)
Cavity Volume	367.9
Basket Metal Volume	37.9
Bounding Fuel Assemblies Volume	78.8
Basket Supports and Fuel Spacers Volume	6.1
Aluminum Conduction Elements	5.9[†]
Net Free Volume	237.5 (6,724 liters)

† Bounding 1,000 lbs weight.

Table 4.4.14

SUMMARY OF MPC-68 FREE VOLUME CALCULATIONS

Item	Volume (ft^3)
Cavity Volume	367.3
Basket Metal Volume	34.8
Bounding Fuel Assemblies Volume	93.0
Basket Supports and Fuel Spacers Volume	11.3
Aluminum Conduction Elements	5.9†
Net Free Volume	222.3 (6,294 liters)

† Bounding 1,000 lbs weight.

Table 4.4.15

SUMMARY OF MPC CONFINEMENT BOUNDARY PRESSURES[†] FOR NORMAL LONG-TERM STORAGE

Condition	Pressure (psig)
MPC-24[††]:	
Initial backfill (at 70°F)	22.2
Normal condition	43.8
With 1% rods rupture	44.3
With 10% rods rupture	49.1
With 100% rods rupture	97.3
MPC-68:	
Initial backfill (at 70°F)	28.5
Normal condition	57.5
With 1% rods rupture	57.8
With 10% rods rupture	60.2
With 100% rods rupture	84.6

† Pressure analysis is based on NUREG-1536 criteria (i.e., 100% of rods fill gas and 30% of radioactive gases are available for release from a ruptured rod).

†† PWR fuel storage includes hypothetical BPRA rods rupture in the pressure calculations.

Table 4.4.16

SUMMARY OF HI-STAR 100 SYSTEM COMPONENTS
NORMAL STORAGE TEMPERATURES [°F]

Location	MPC-24	MPC-68
MPC Basket Top:		
Basket center	180	179
Basket periphery	168	168
MPC shell	166	167
Overpack inner shell	162	163
Overpack enclosure shell	159	160
MPC Basket Bottom:		
Basket center	251	220
Basket periphery	226	204
MPC shell	222	203
Overpack inner shell	218	201
Overpack enclosure shell	177	167

Table 4.4.17

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Table 4.4.18

MPC-24 BASKET PEAK FUEL CLADDING TEMPERATURE AS A FUNCTION OF TOTAL HEAT LOAD

Total Basket Decay Heat Load (kW)	Peak Cladding Temperature (°F)
19.0†	708.8
18.5	696.9
17.0	660.1
15.5	621.9

† Design Basis Maximum (equivalent to 792 watts per assembly).

Table 4.4.19

MPC-68 BASKET PEAK CLADDING TEMPERATURE AS A FUNCTION OF TOTAL DECAY HEAT LOAD

Total Basket Decay Heat Load (kW)	Peak Cladding Temperature (°F)
18.5†	741.5
17.5	713.6
15.5	656.2

† Design Basis Maximum (equivalent to 272 watts per assembly).

Table 4.4.20

SUMMARY OF LOADED HI-STAR SYSTEM
BOUNDING COMPONENT WEIGHTS AND THERMAL INERTIAS

Component	Weight (lbs)	Heat Capacity (Btu/lb-°F)	Thermal Inertia (Btu/°F)
Holtite-A	11,000	0.39	4,290
Carbon Steel	140,000	0.1	14,000
Alloy-X MPC (empty)	35,000	0.12	4,200
Fuel	40,000	0.056	2,240
MPC Cavity Water†	6,500	1.0	6,500
			31,230 (Total)

† Based on smallest MPC-68 cavity net free volume with 50% credit for flooded water mass.

Table 4.4.21

MAXIMUM ALLOWABLE TIME DURATION FOR WET TRANSFER OPERATIONS

Initial Temperature (°F)	Time Duration (hr)
115	46.7
120	44.3
125	41.9
130	39.5
135	37.1
140	34.6
145	32.3
150	29.8

Table 4.4.22

SUMMARY OF MPC CONFINEMENT BOUNDARY TEMPERATURE DISTRIBUTION DURING NORMAL STORAGE CONDITIONS

Location	Figure 3.4.44 Designation	MPC-24 [°F]	MPC-68 [°F]
MPC Lid Inside Surface at Centerline	A	179	178
MPC Lid Outside Surface at Centerline	B	173	172
MPC Lid Inside Surface at Periphery	C	166	167
MPC Lid Outside Surface at Periphery	D	164	164
MPC Baseplate Inside Surface at Centerline	E	249	218
MPC Baseplate Outside Surface at Centerline	F	241	213
MPC Baseplate Inside Surface at Periphery	G	222	203
MPC Baseplate Outside Surface at Periphery	H	219	200
MPC Shell Maximum	I	332	331

Table 4.4.23

SUMMARY OF 10×10 ARRAY TYPE BWR FUEL ASSEMBLY EFFECTIVE THERMAL CONDUCTIVITIES†

FUEL	@200°F [Btu/ft-hr-°F]	@450°F [Btu/ft-hr-°F]	@700°F [Btu/ft-hr-°F]
GE-12/14	0.166	0.269	0.412
Atrium-10	0.164	0.266	0.409
SVEA-96	0.164	0.269	0.416

† The conductivities reported in this table are obtained by the simplified method described in the beginning of the Subsection 4.4.1.1.2.

Table 4.4.24

COMPARISON OF ATRIUM-10 BWR FUEL ASSEMBLY CONDUCTIVITY† WITH THE BOUNDING†† BWR FUEL ASSEMBLY CONDUCTIVITY

Temperature [°F]	Atrium-10 BWR Assembly [Btu/ft-hr-°F]	Bounding BWR Assembly [Btu/ft-hr-°F]
200	0.225	0.171
450	0.345	0.271
700	0.504	0.410

† The reported effective conductivity has been obtained from a rigorous finite element model.

†† The bounding BWR fuel assembly conductivity applied in the MPC-68 basket thermal analysis.

Table 4.4.25

PLANT SPECIFIC BWR FUEL TYPES EFFECTIVE THERMAL CONDUCTIVITY*

Fuel	@200° F [Btu/ft-hr-°F]	@ 450° F [Btu/ft-hr-°F]	@ 700° F [Btu/ft-hr-°F]
Oyster Creek (7x7)	0.165	0.273	0.427
Oyster Creek (8x8)	0.162	0.266	0.413
TVA Browns Ferry (8x8)	0.160	0.264	0.411
SPC-5 (9x9)	0.149	0.245	0.380

* The conductivities reported in this table are obtained by a simplified analytical method described in Subsection 4.4.1.2.

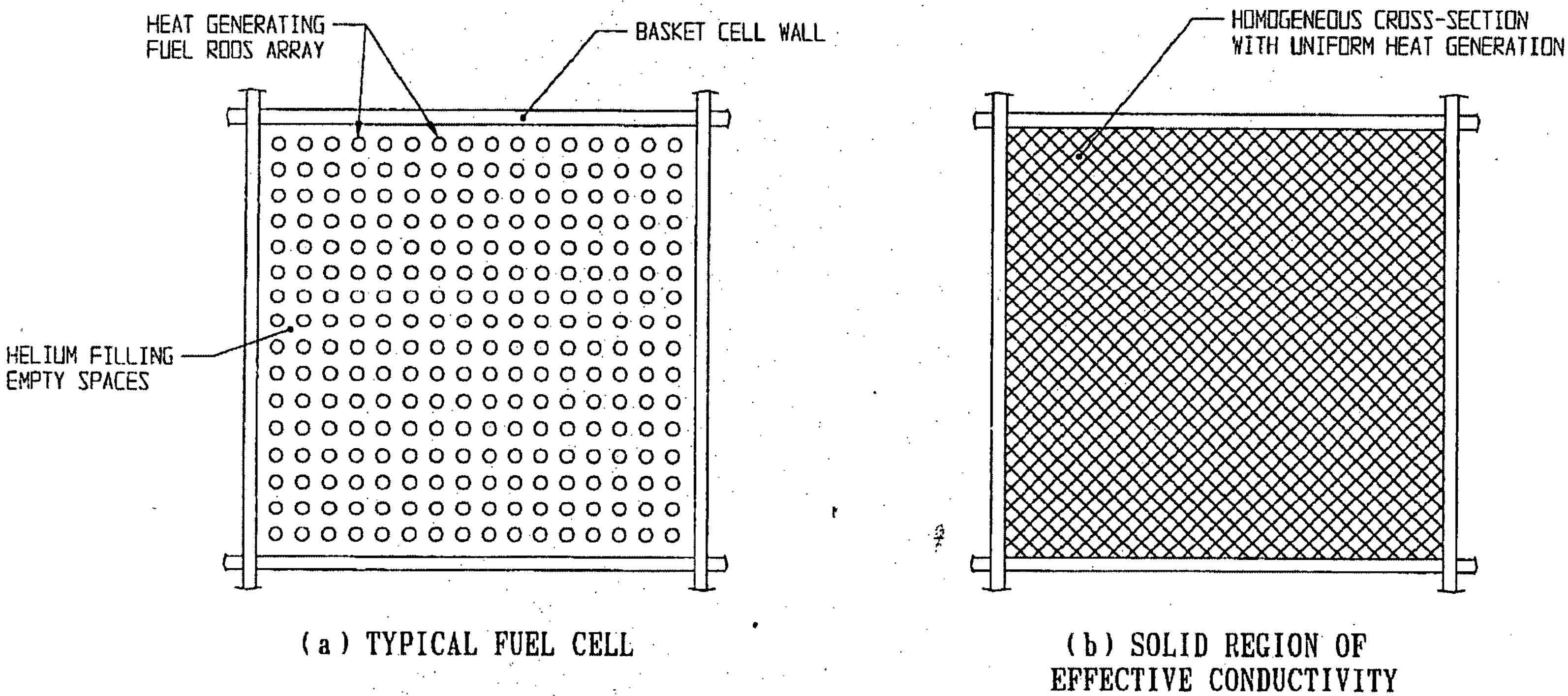
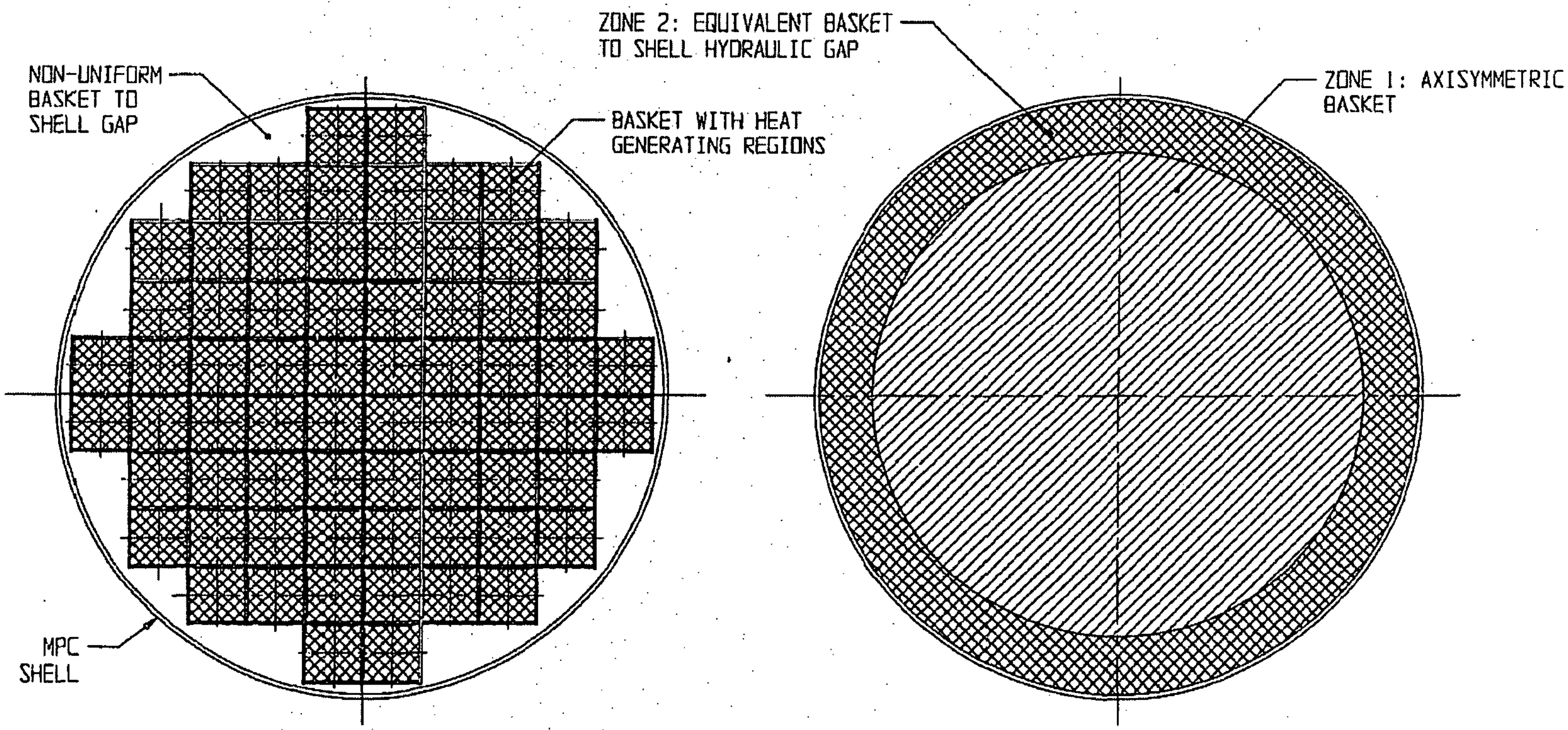


FIGURE 4.4.1; HOMOGENIZATION OF THE STORAGE CELL CROSS-SECTION

\5014\HI941184\CH_4\4_4_1



(a) TYPICAL MPC CROSS-SECTION

(b) EQUIVALENT TWO ZONE BODY

FIGURE 4.4.2; MPC CROSS-SECTION REPLACED WITH AN EQUIVALENT TWO ZONE AXISYMMETRIC BODY

HEAT CONDUCTION ELEMENTS NOT SHOWN

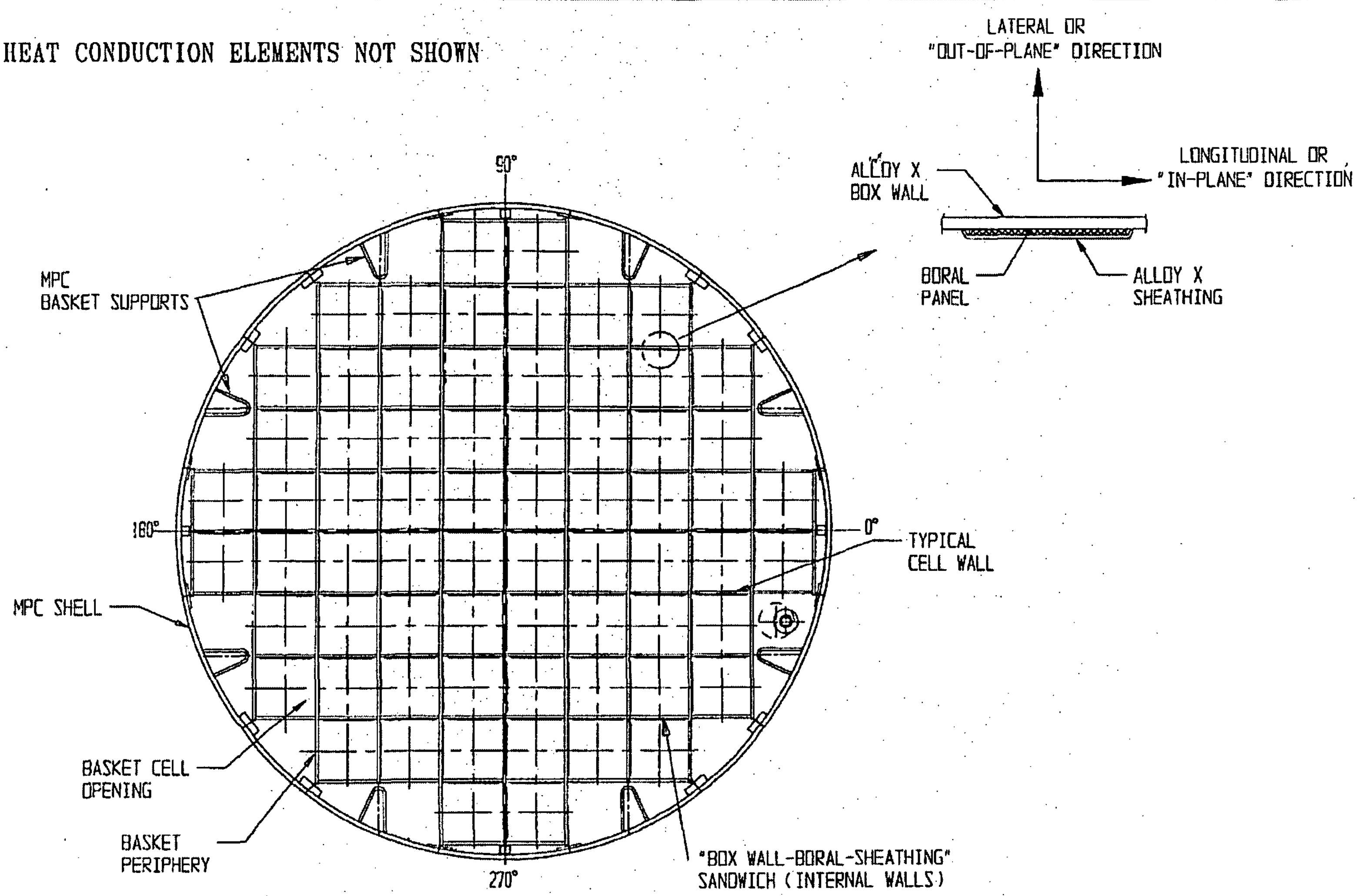


FIGURE 4.4.3; TYPICAL MPC BASKET PARTS IN A CROSS-SECTIONAL VIEW

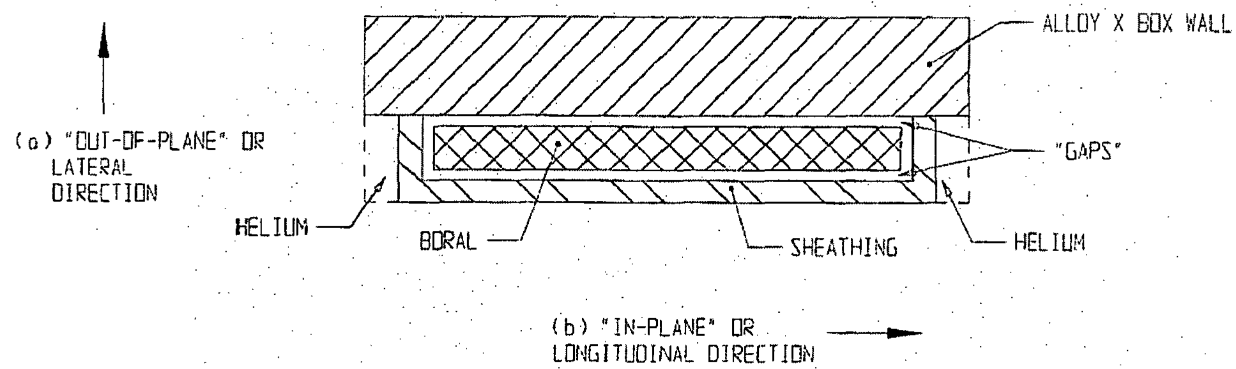


FIGURE 4.4.4; "BOX WALL-BORAL-SHEATHING" SANDWICH

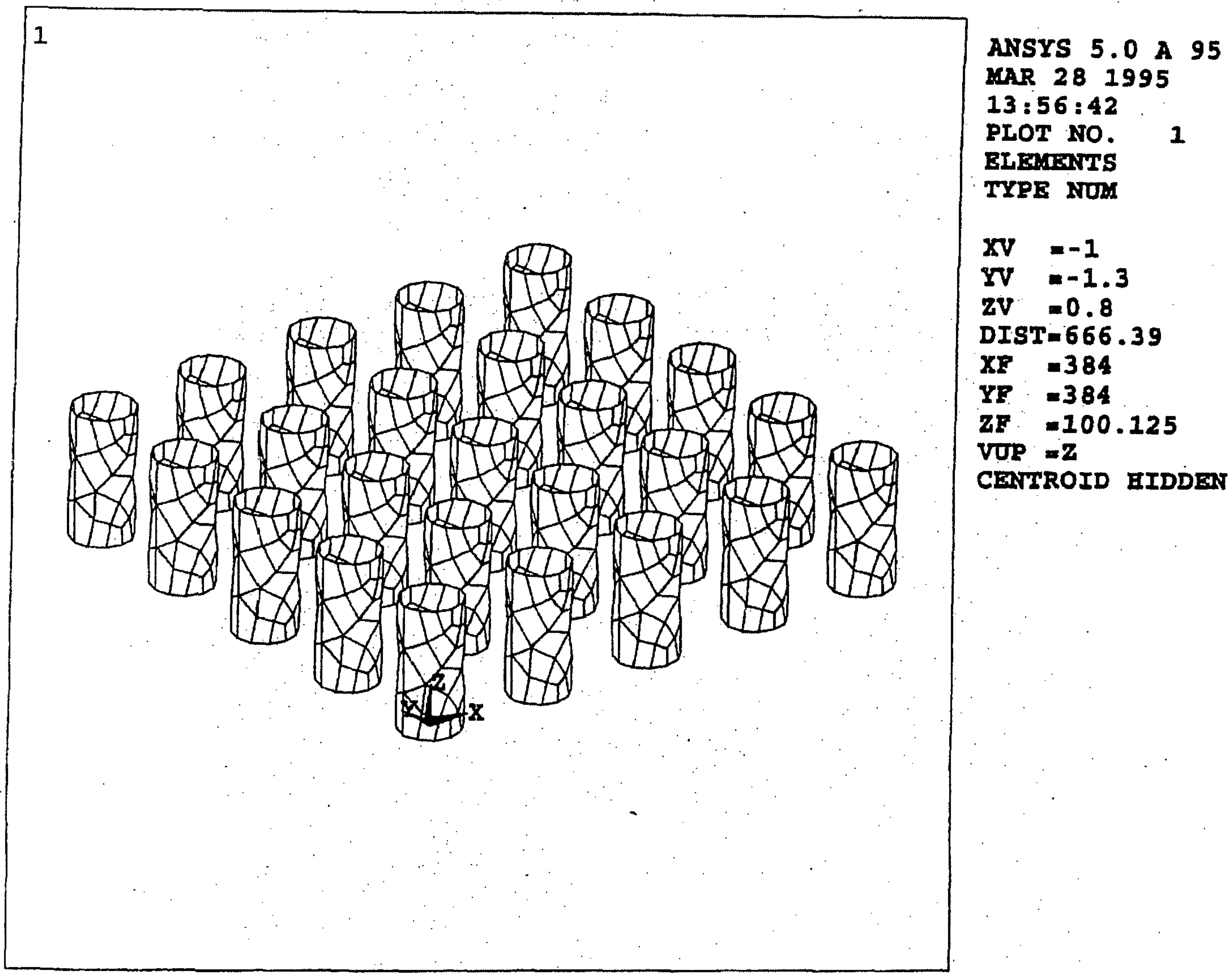


FIGURE 4.4.5; ANSYS FINITE ELEMENT MODEL FOR EVALUATION OF RADIATIVE BLOCKING FACTOR FOR A CASK ARRAY AT AN ISFSI SITE

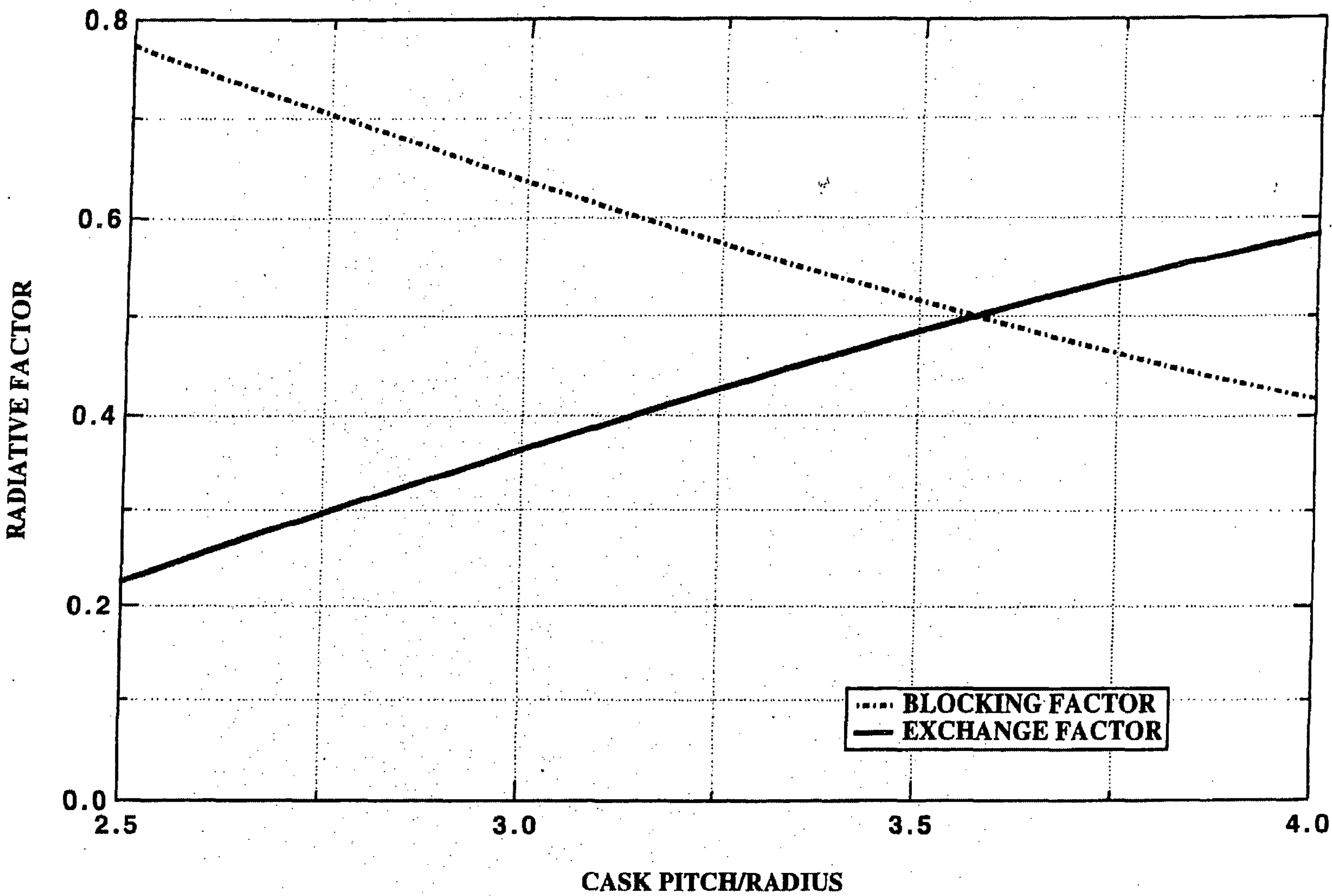


FIGURE 4.4.6; EFFECT OF ISFSI CASK ARRAY PITCH ON RADIATIVE BLOCKING AND EXCHANGE FACTORS

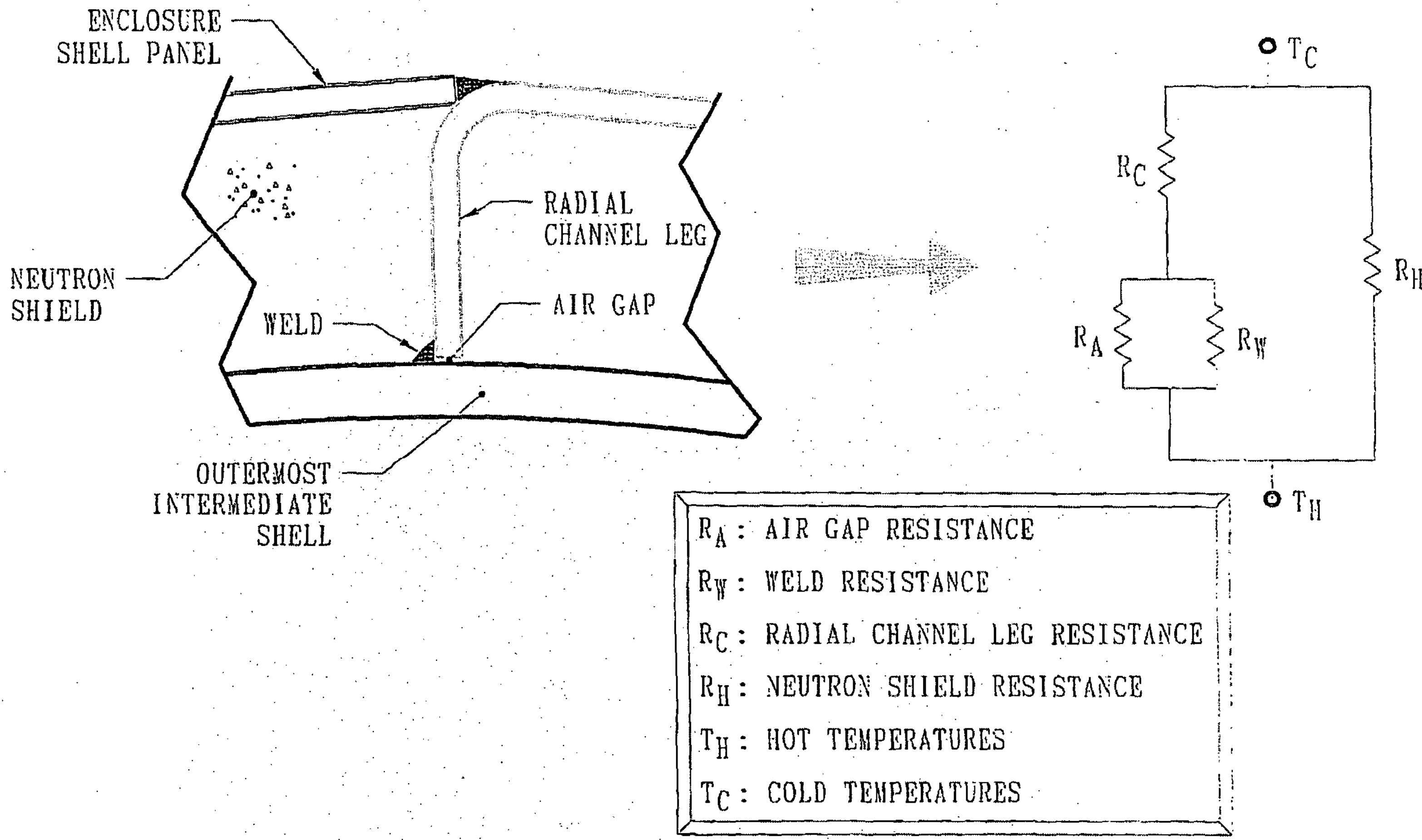


FIGURE 4.4.7; NEUTRON SHIELD REGION RESISTANCE NETWORK ANALOGY FOR EFFECTIVE CONDUCTIVITY CALCULATION

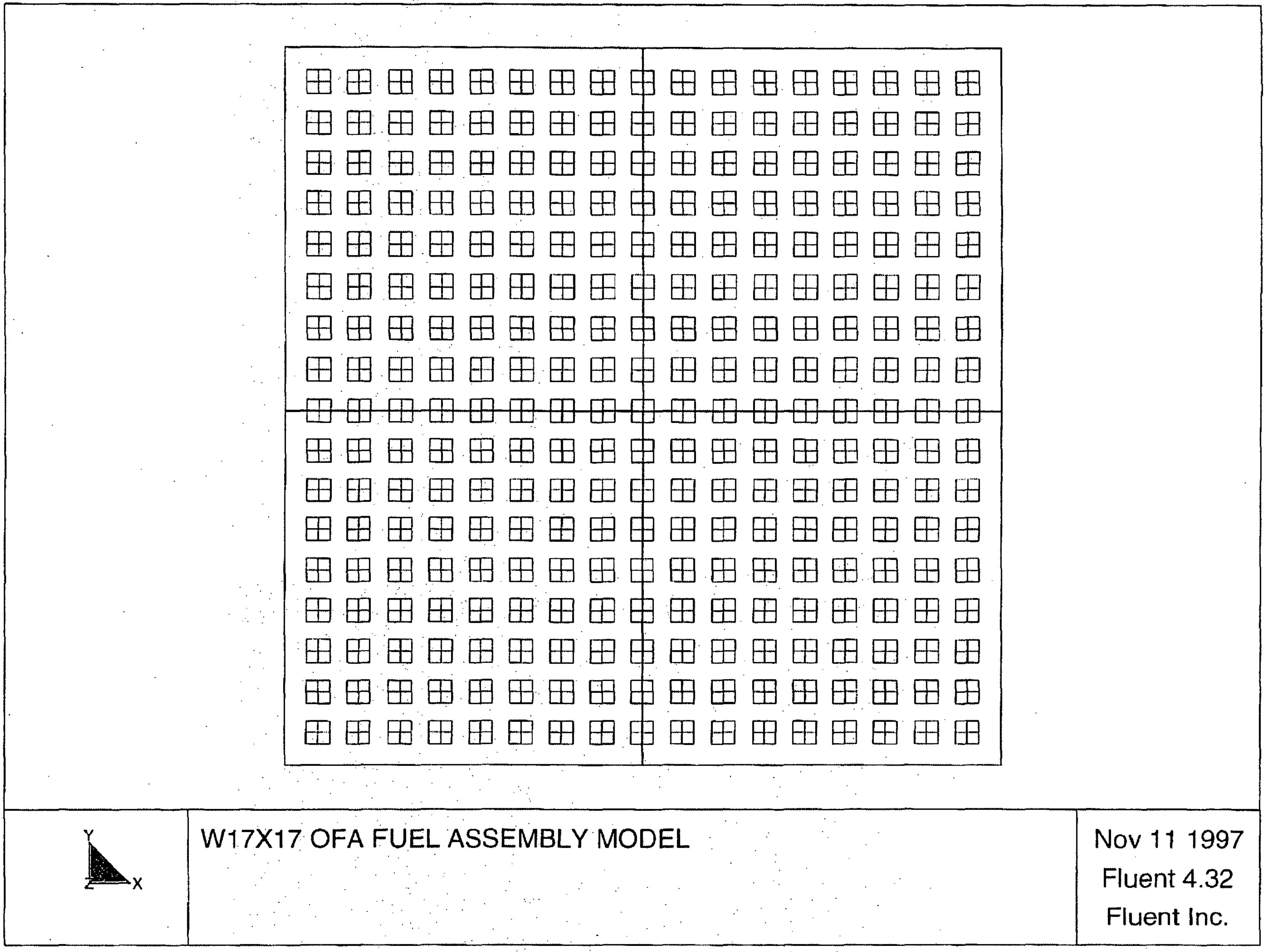


FIGURE 4.4.8: WESTINGHOUSE 17x17 OFA PWR FUEL ASSEMBLY MODEL

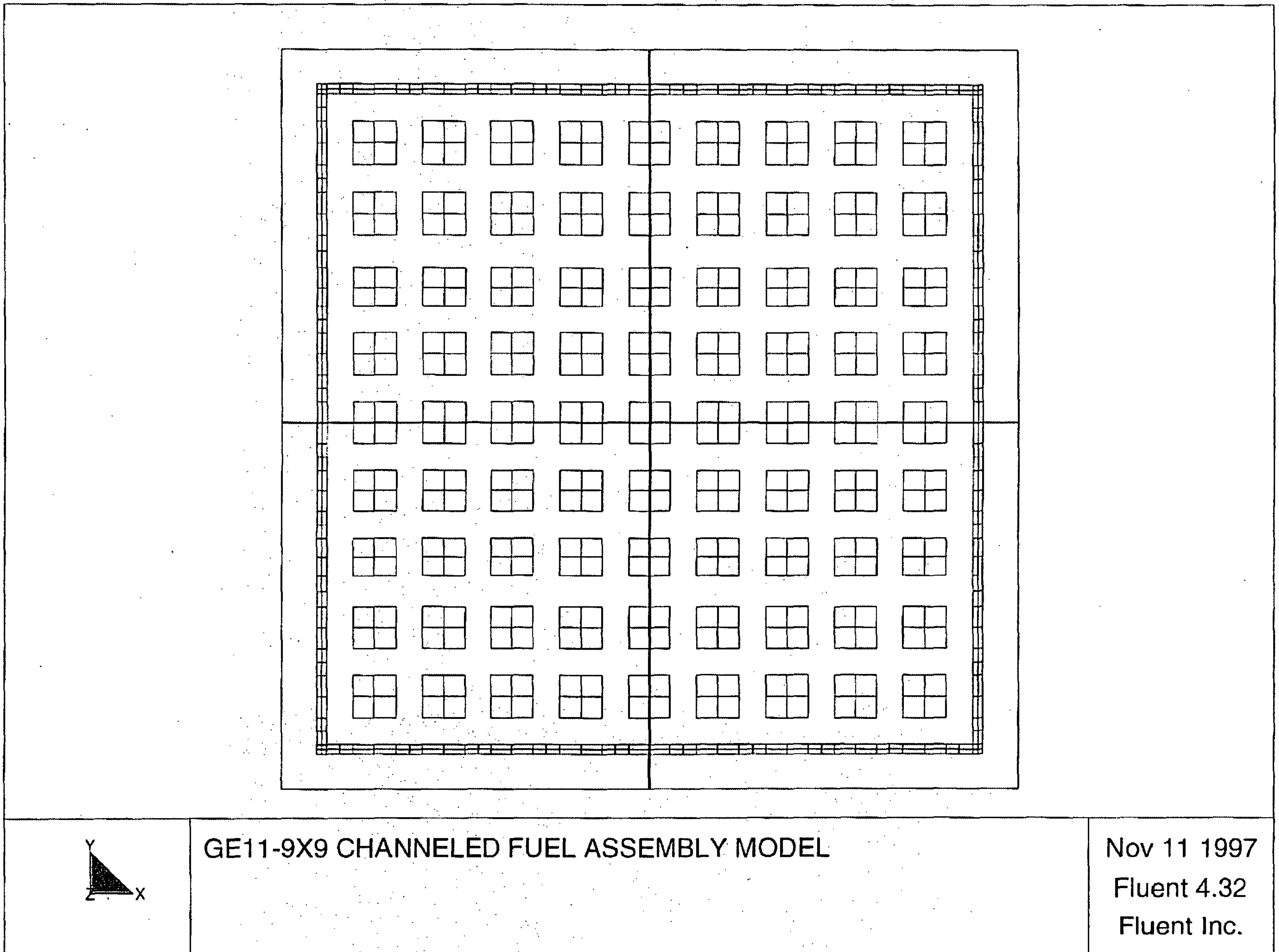


FIGURE 4.4.9: GENERAL ELECTRIC 9x9 BWR FUEL ASSEMBLY MODEL

FIGURE 4.4.10

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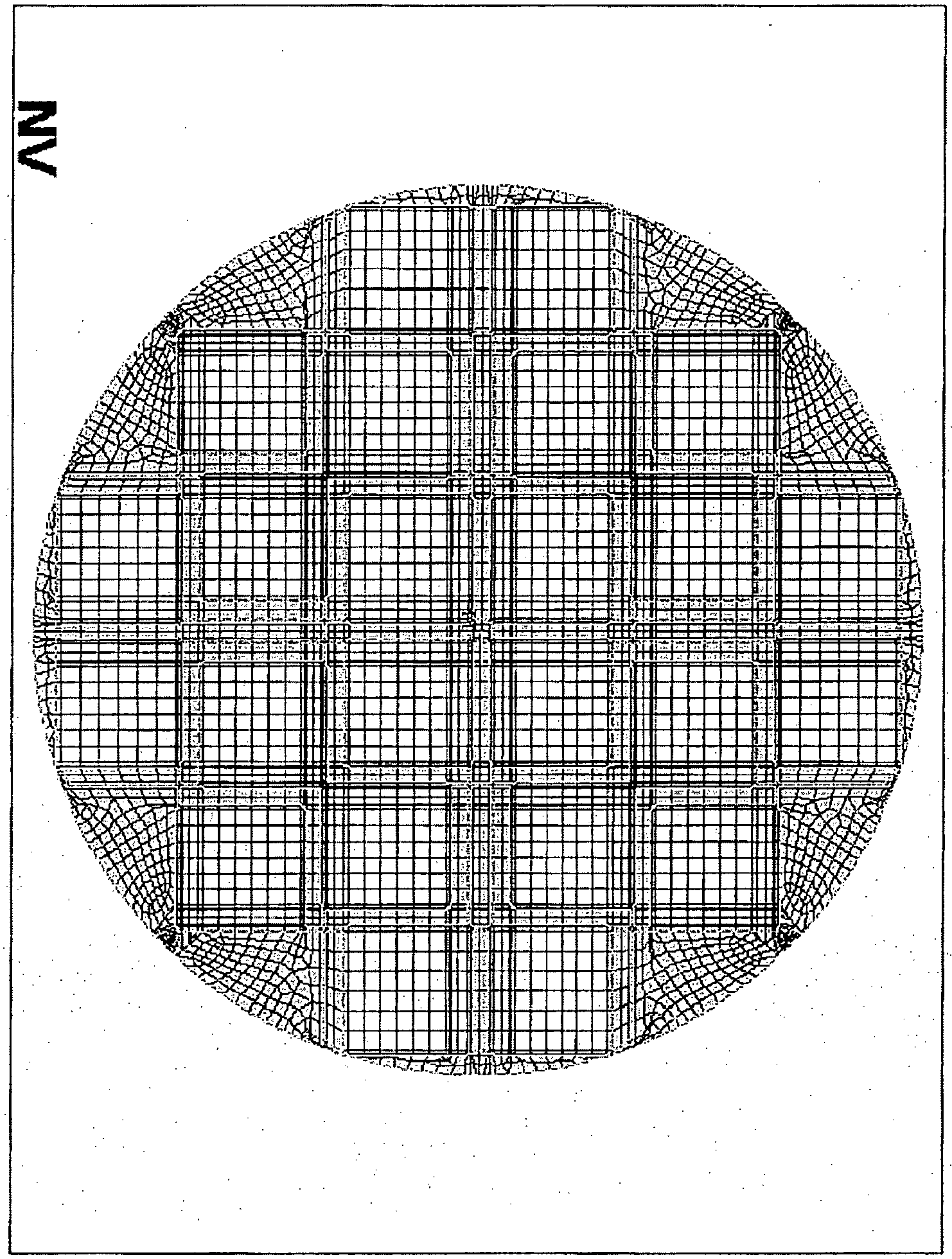


FIGURE 4.4.11; MPC-24 BASKET CROSS-SECTION ANSYS FINITE-ELEMENT MODEL

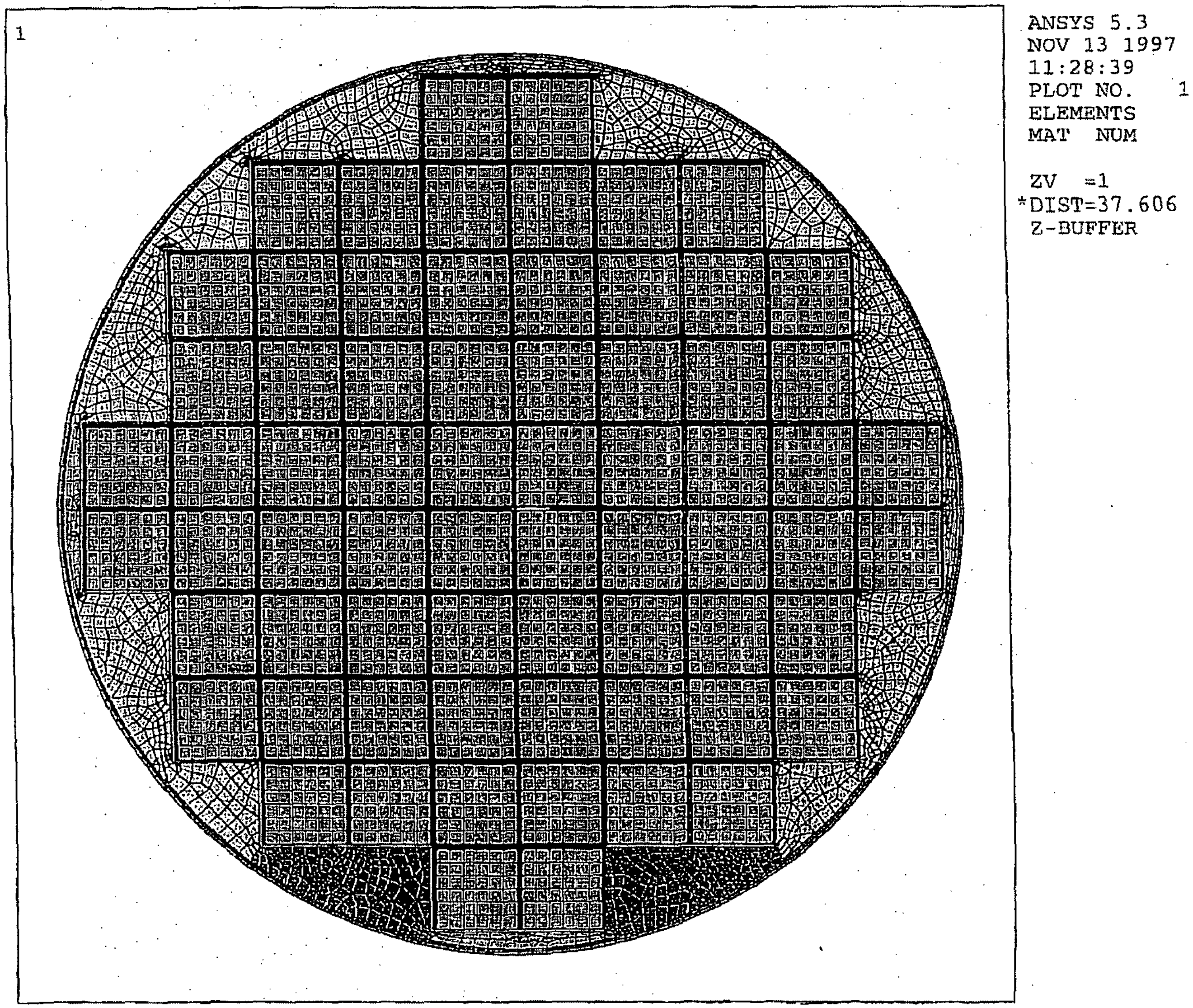


FIGURE 4.4.12; MPC-68 BASKET CROSS-SECTION ANSYS FINITE ELEMENT MODEL

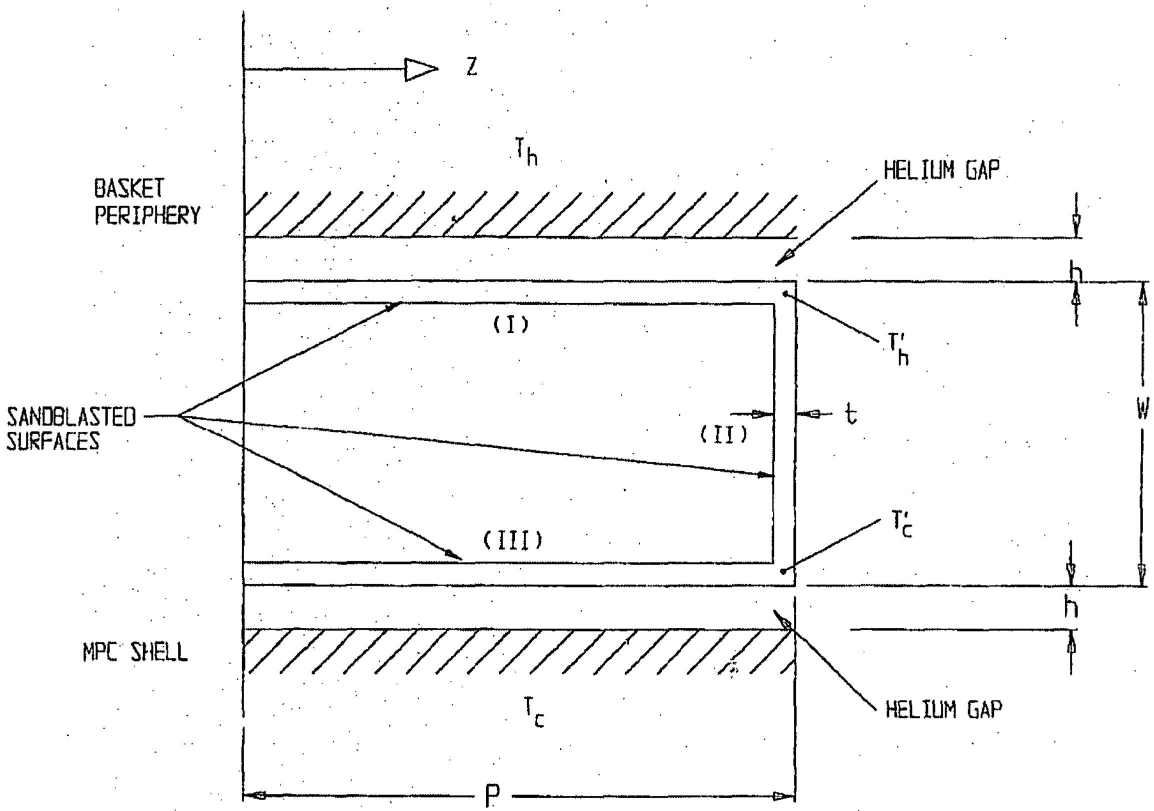
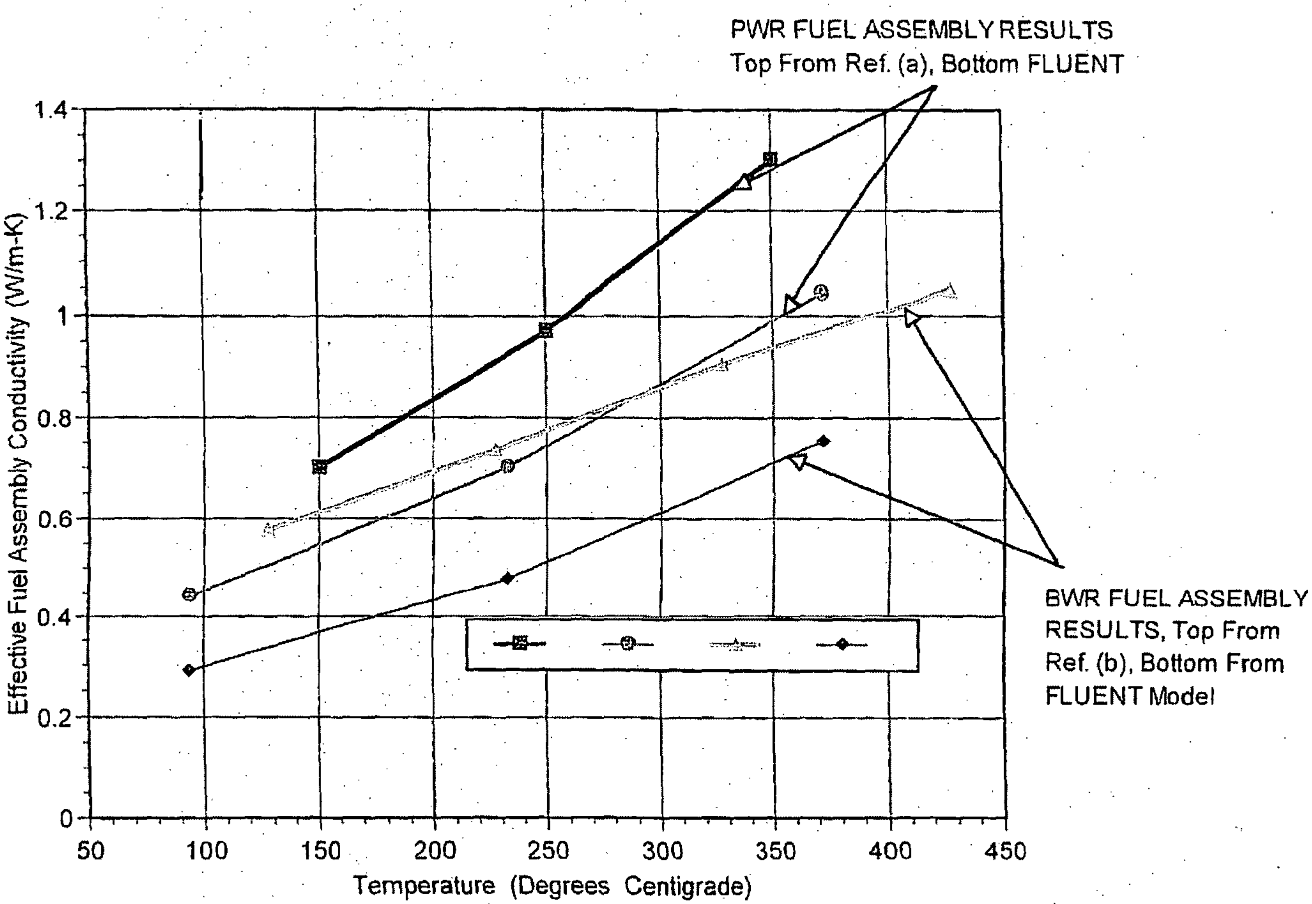


FIGURE 4.4.13; ILLUSTRATION OF AN MPC BASKET TO SHELL ALUMINUM HEAT CONDUCTION ELEMENT



(a) "Determination of SNF Peak Temperatures in the Waste Package", Bahney & Doering, *HLRWM Sixth Annual Conf.*, Pages 671-673, (April 30 - May 5, 1995)
(b) "A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements", *Sandia Report SAND90-2406*, page II-132, (1992)

FIGURE 4.4.14: COMPARISON OF FLUENT BASED FUEL ASSEMBLY EFFECTIVE CONDUCTIVITY RESULTS WITH PUBLISHED TECHNICAL DATA

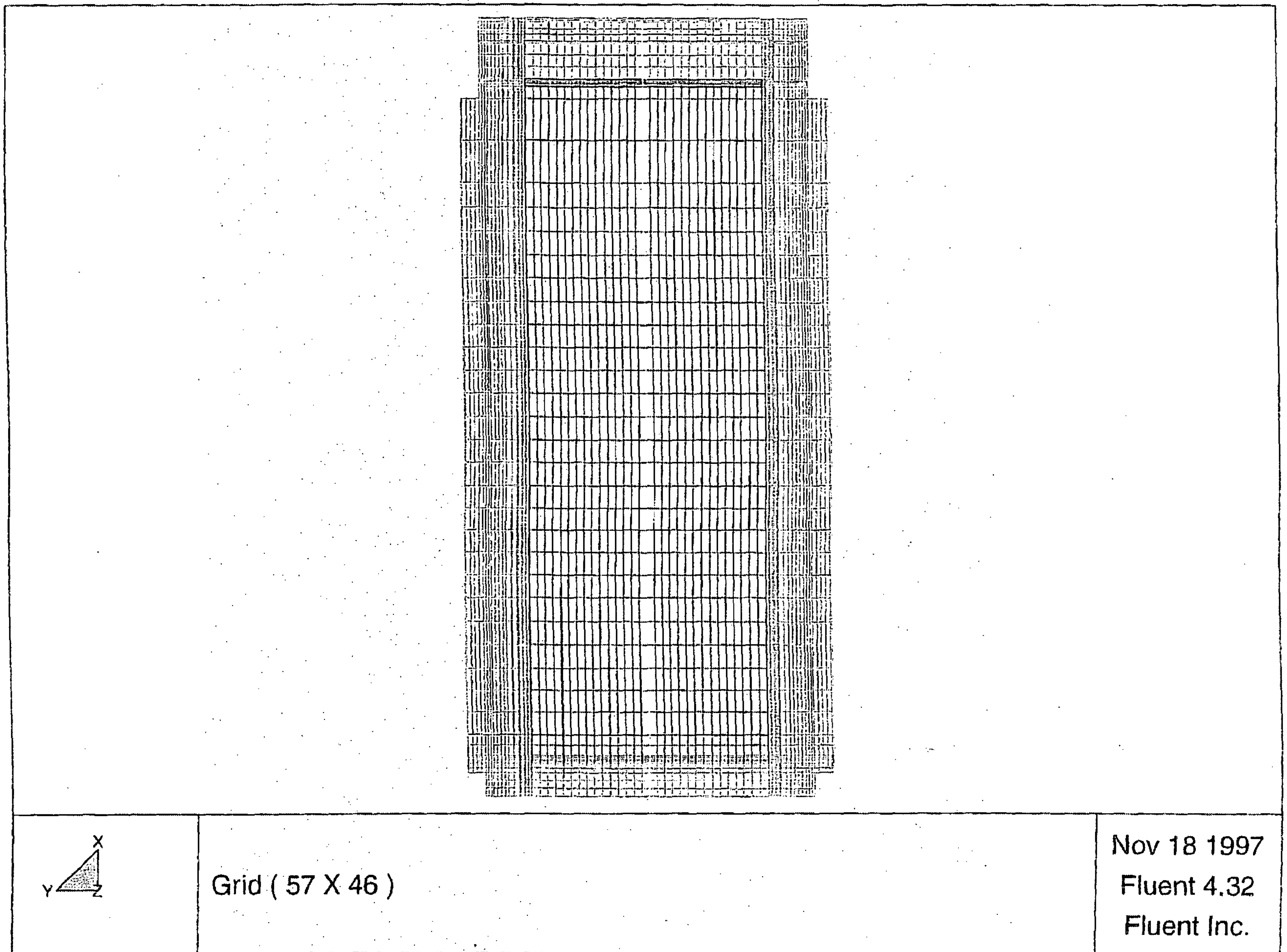


FIGURE 4.4.15: TYPICAL HI-STAR 100 SYSTEM FINITE ELEMENT MESH FOR THERMAL ANALYSIS

FIGURE 4.4.16

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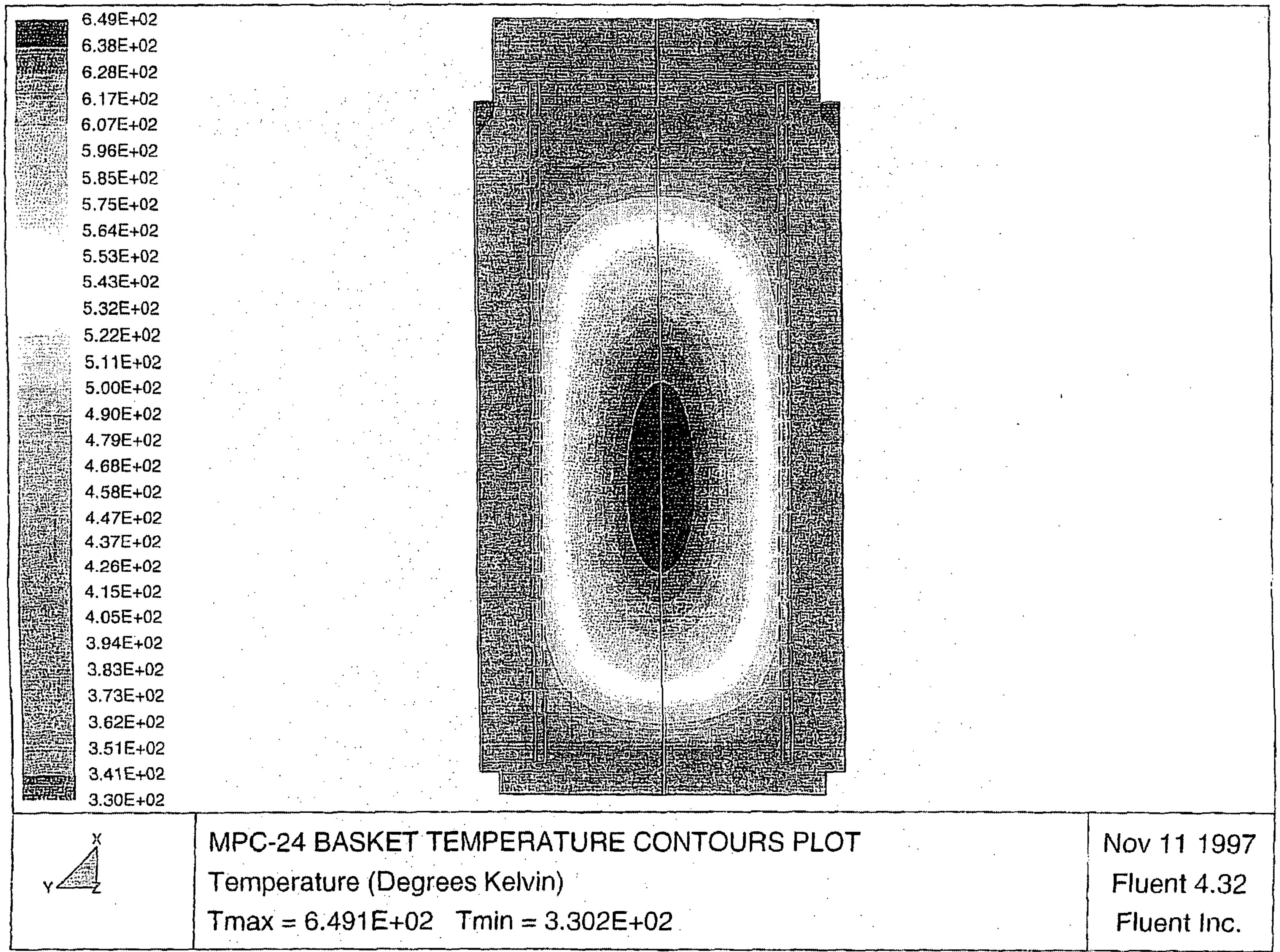

FIGURE 4.4.17: HI-STAR 100 SYSTEM NORMAL STORAGE CONDITION TEMPERATURE CONTOURS PLOT
(MPC-24 BASKET)

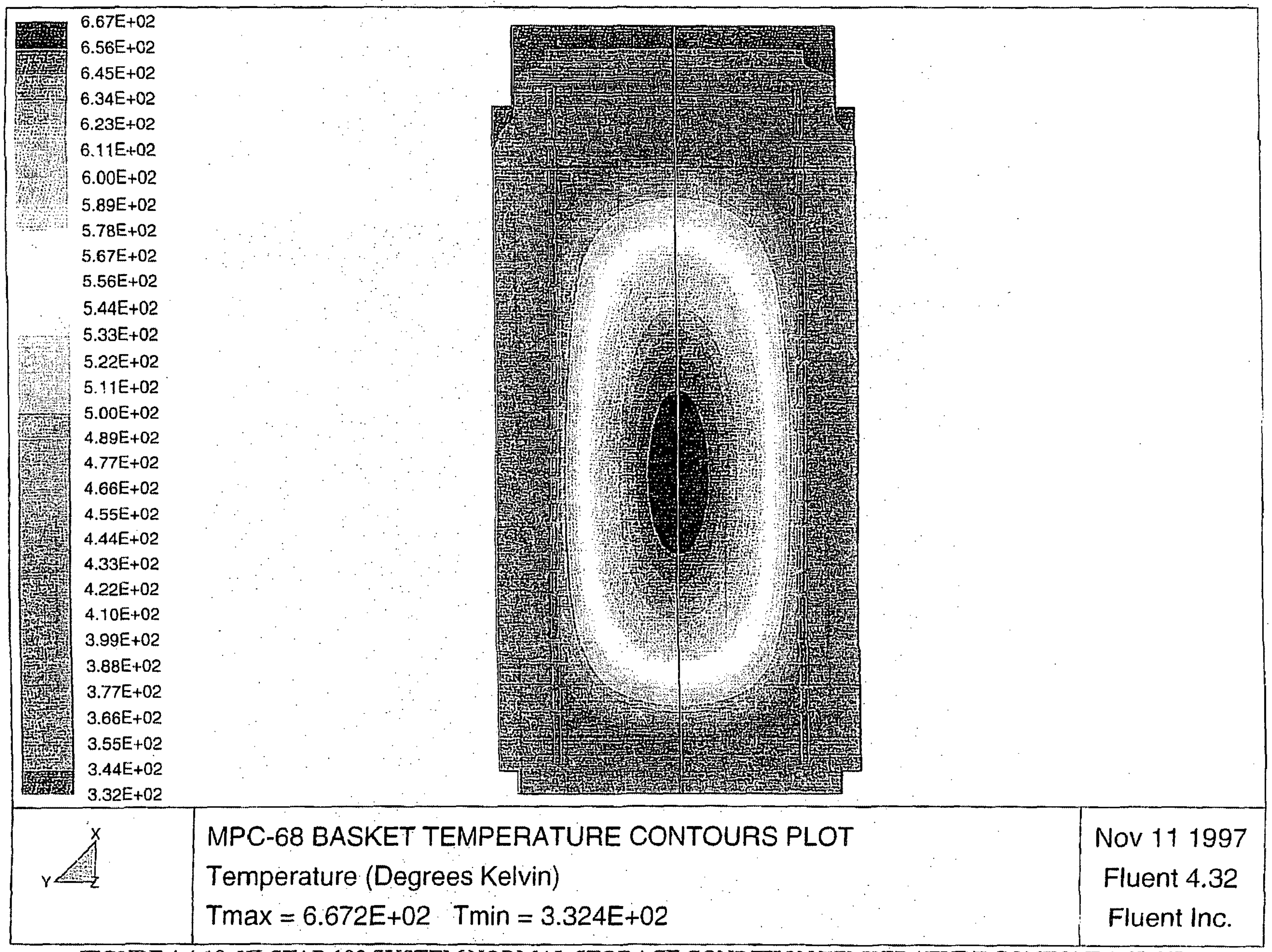

FIGURE 4.4.18: HI-STAR 100 SYSTEM NORMAL STORAGE CONDITION TEMPERATURE CONTOURS PLOT (MPC-68 BASKET)

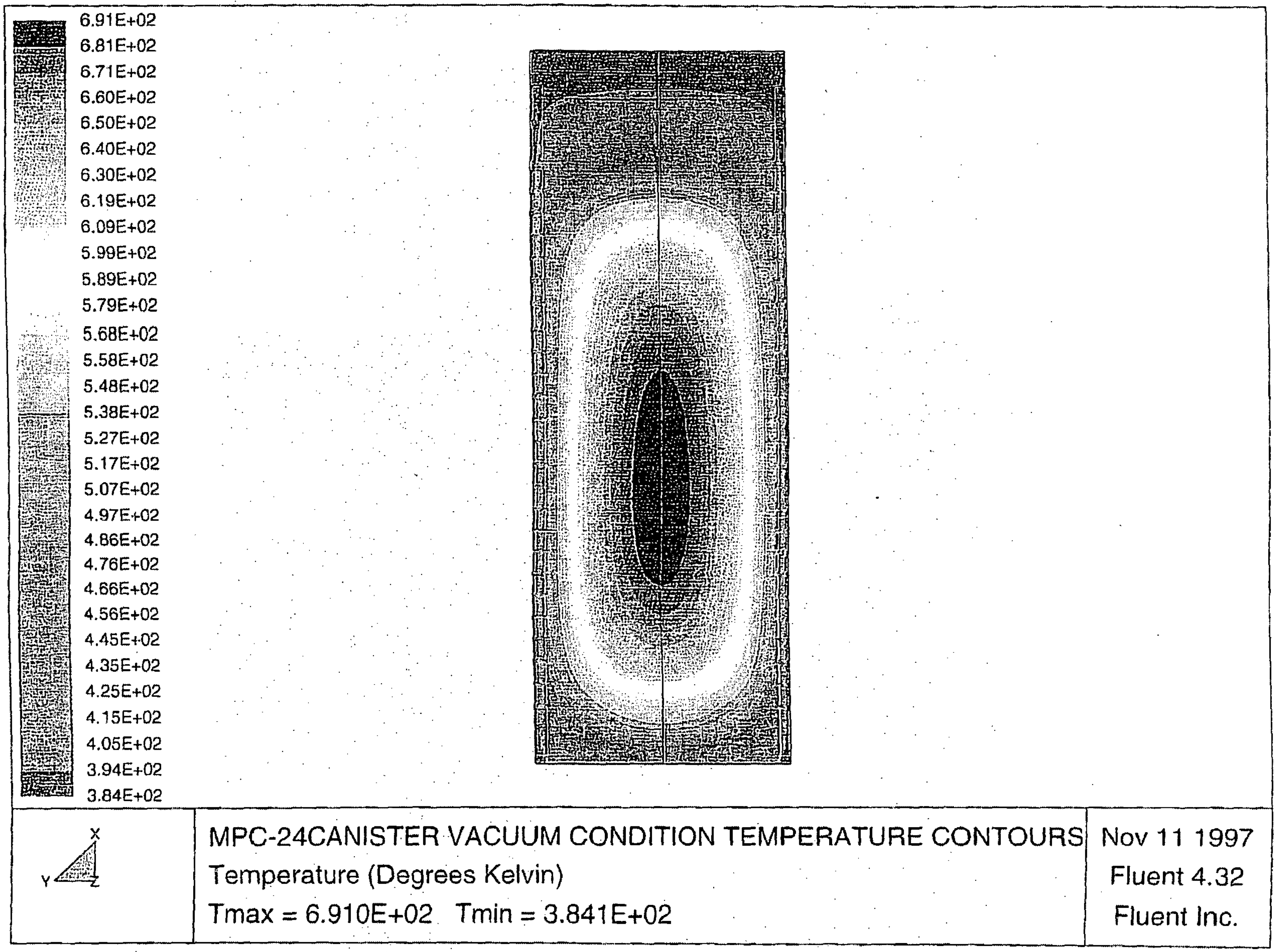

FIGURE 4.4.19: VACUUM CONDITION TEMPERATURE CONTOURS PLOT FOR BOUNDING MPC-24 BASKET

FIGURE 4.4.20

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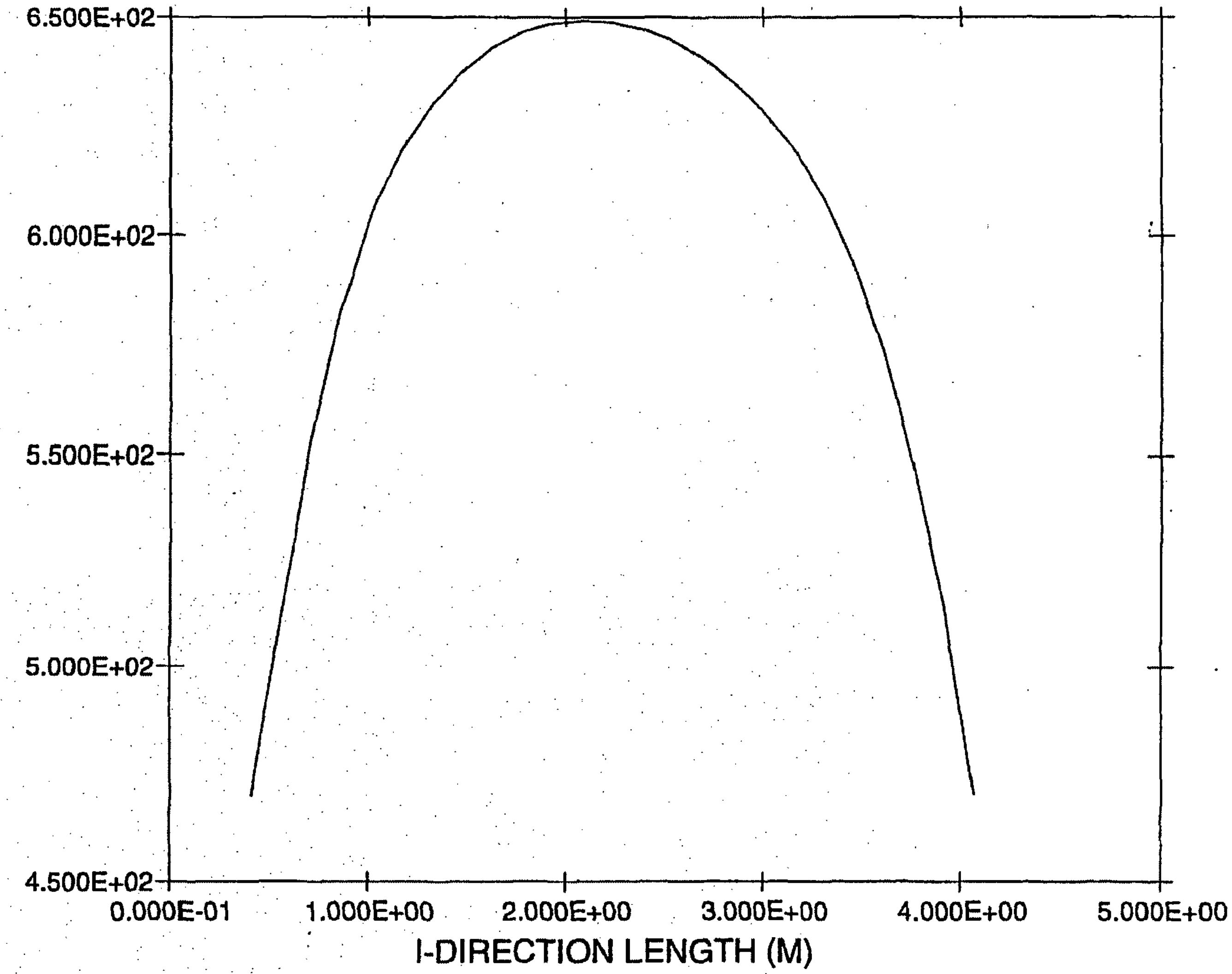
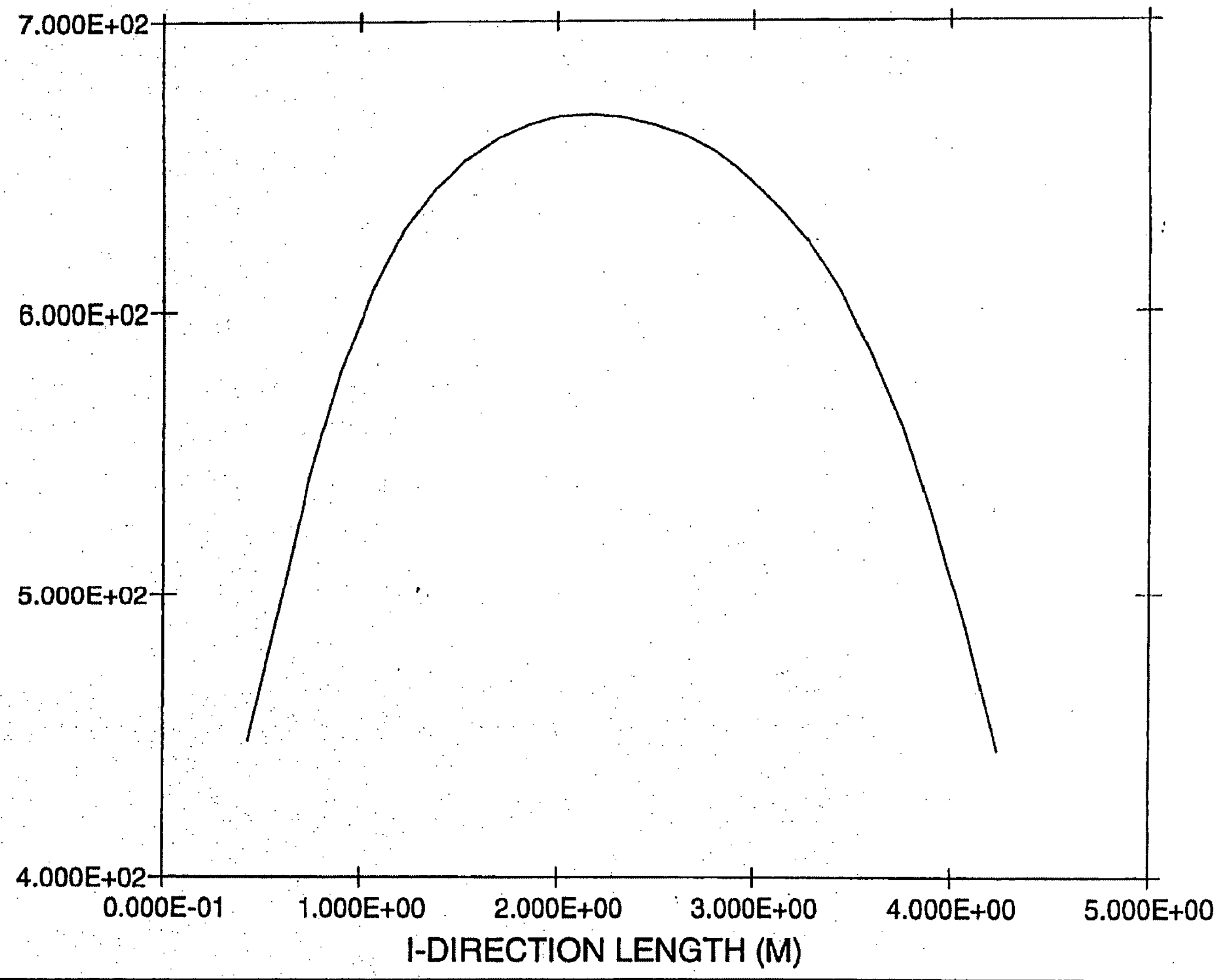


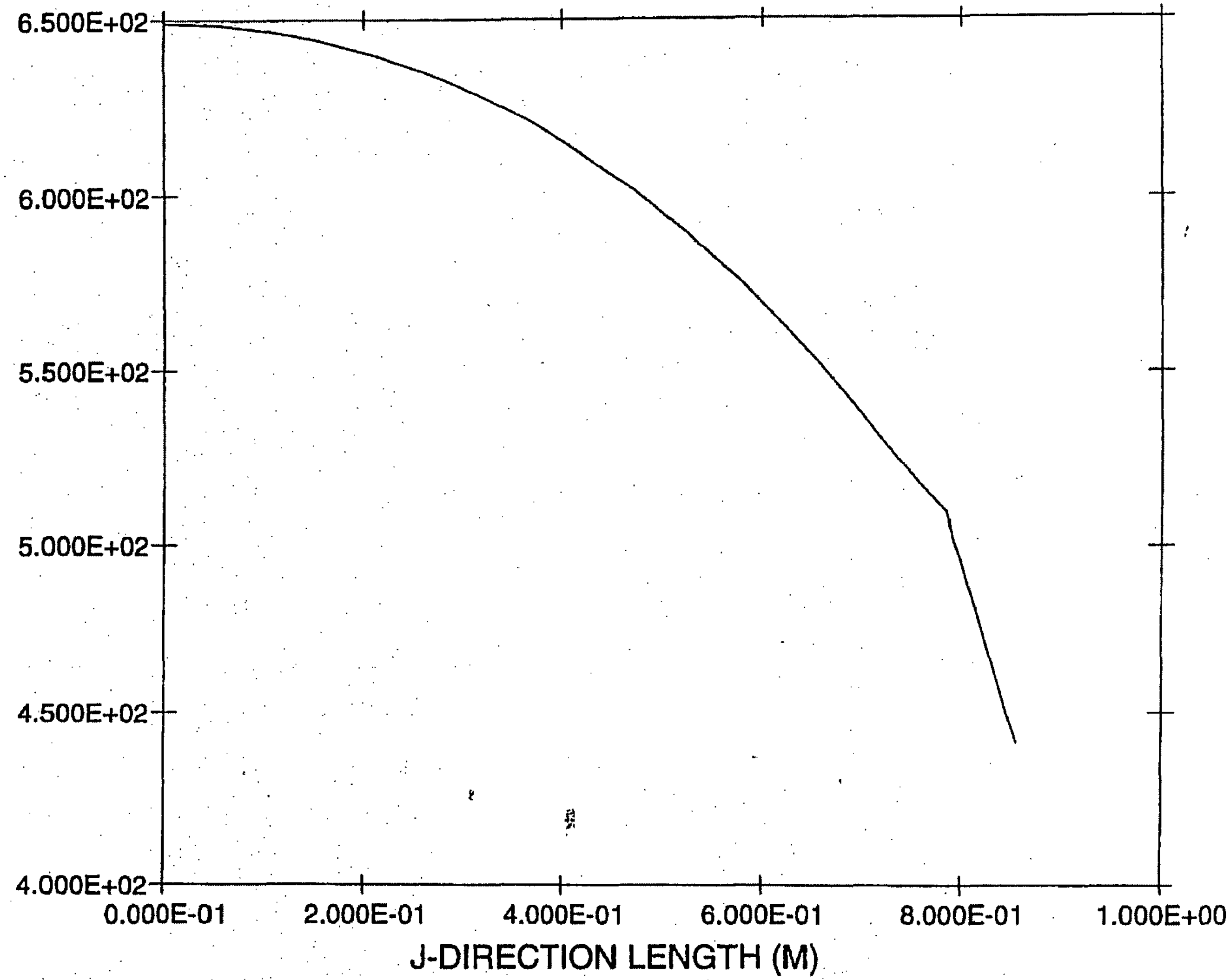
Y / Z X	FIGURE 4.4.21: MPC-24 HOTTEST ROD TEMPERATURE PROFILE Temperature (Kelvin) Vs. Axial Length (Meters)	May 14 1998 Fluent 4.32 Fluent Inc.



Y Z X	FIGURE 4.4.22: MPC-68 HOTTEST ROD TEMPERATURE PROFILE Temperature (Kelvin) Vs. Axial Length (Meters)	May 14 1998 Fluent 4.32 Fluent Inc.

FIGURE 4.4.23

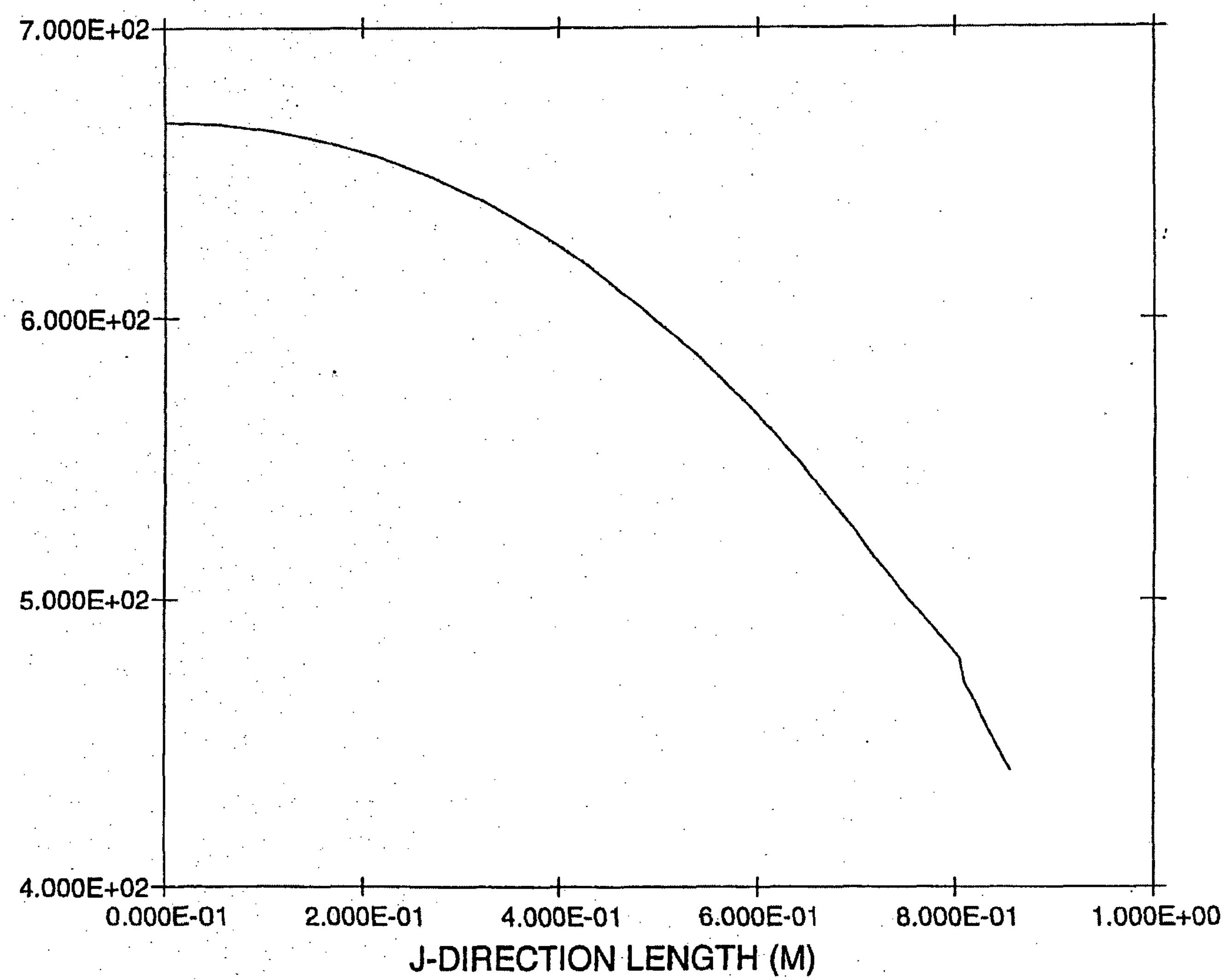
THIS FIGURE IS INTENTIONALLY DELETED



Y Z X

FIGURE 4.4.24: MPC-24 BASKET RADIAL TEMPERATURE PROFILE
(Hottest Basket Cross-Section)
Temperature (Kelvin) Vs. Radial Distance (Meters)

May 14 1998
Fluent 4.32
Fluent Inc.



Y Z X	FIGURE 4.4.25: MPC-68 BASKET RADIAL TEMPERATURE PROFILE Temperature (Kelvin) Vs. Radial Position (Meters)	May 14 1998 Fluent 4.32 Fluent Inc.

4.5 REGULATORY COMPLIANCE

NUREG-1536 ([4.1.3], IV) defines eight specific thermal acceptance criteria which are addressed in Sections 4.1 through 4.4. Each of the pertinent criteria and the conclusion of the evaluations are summarized here.

1. As required by NUREG-1536 ([4.1.3], 4.IV.1), the fuel cladding temperature at the beginning of dry cask storage is maintained below the anticipated damage-threshold temperatures for normal conditions and a minimum of 20 years of cask storage. Maximum clad temperatures for normal storage conditions are reported in Section 4.4.2.1. Anticipated damage-threshold temperatures, calculated as described in Section 4.3, are summarized in Table 2.2.3.

2. As required by NUREG-1536 ([4.1.3], 4.IV.2), the fuel cladding temperature is maintained below 570°C (1058°F) for short-term accident conditions, short-term off-normal conditions, and fuel transfer operations. Results of off-normal and accident condition evaluations presented in Chapter 11 comply with this limit. Maximum clad temperatures for vacuum drying conditions are reported in Section 4.4.2.2 which comply within this limit by large conservative margins.

3. As required by NUREG-1536 ([4.1.3], 4.IV.3), the maximum internal pressure of the cask remains within its design pressure for normal, off-normal, and accident conditions, assuming rupture of 1 percent, 10 percent, and 100 percent of the fuel rods, respectively. Assumptions for pressure calculations include release of 100 percent of the fill gas and 30 percent of the significant radioactive gases in the fuel rods. Maximum internal pressures are reported in Section 4.4.4. Design pressures are summarized in Table 2.2.1.

4. As required by NUREG-1536 ([4.1.3], 4.IV.4), all cask and fuel materials are maintained within their minimum and maximum temperatures for normal and off-normal conditions in order to enable components to perform their intended safety functions. During normal fuel handling operations (i.e., vacuum drying) the cask component temperatures are compared with short-term temperature limits (Section 4.4.2.2). Maximum and minimum temperatures for normal conditions are reported in Sections 4.4.2 and 4.4.3, respectively. Design temperature limits are summarized in Table 2.2.3. HI-STAR 100 System components defined as important to safety are listed in Table 2.2.6. Off-normal and accident condition thermal evaluations are discussed in Sections 11.1 and 11.2, respectively.

5. & 6. As required by NUREG-1536 ([4.1.3], 4.IV.5), the cask system ensures a very low probability of cladding breach during long-term storage. Further, NUREG-1536 ([4.1.3], 4.IV.6) requires that the fuel cladding damage resulting from creep cavitation should be limited to 15 percent of the original cladding cross section area during dry storage. The calculation methodology, described in Section 4.3, for determining initial dry storage fuel clad temperature limits, ensures that both of these requirements are satisfied. Maximum

fuel clad temperature limits are summarized in Table 2.2.3.

7. As required by NUREG-1536 ([4.1.3], 4.IV.7), the cask system is passively cooled. All heat rejection mechanisms described in this chapter, including conduction, natural convection, and thermal radiation, are completely passive.

8. As required by NUREG-1536 ([4.1.3], 4.IV.8), the thermal performance of the cask is within the allowable design criteria specified in FSAR Chapter 2 for normal storage and fuel handling conditions. During normal fuel handling operations (i.e., vacuum drying) the cask component temperatures are compared with short-term temperature limits. All thermal results reported in this chapter are within the design criteria allowable ranges for all normal storage and fuel handling conditions. Off-normal and fire accident condition responses are reported in Section 11.1 and 11.2, respectively.

Finally, the acceptance criteria set forth in NUREG-1536 ([4.1.3], 4.VI) can be demonstrated to have been satisfied on the strength of information provided in this FSAR. Specifically, it is noted that:

- Structures, systems, and components (SSCs) important to safety are described in sufficient detail in Chapters 1, 2 and 4 of this FSAR to enable an evaluations of their thermal effectiveness. Cask SSCs important to safety remain within their operating temperature ranges.

- The HI-STAR 100 System is designed with a heat-removal capability having verifiability and reliability consistent with its importance to safety. The cask is designed to provide adequate heat removal capacity without active cooling systems.

- The spent fuel cladding is protected against degradation leading to gross ruptures by maintaining the cladding temperature for five-year cooled fuel in an inert helium environment below 720°F for PWR fuel assemblies and below 749°F for BWR fuel assemblies. Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for further processing or disposal.

It is therefore concluded that the thermal design of the HI-STAR 100 System is in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design provides reasonable assurance that the HI-STAR 100 System will allow safe storage of spent fuel for its design life. This finding is reached on the basis of the technical data presented in this FSAR in conjunction with provisions of 10 CFR Part 72, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

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[4.3.6] Schwartz, M.W., Witte, M.C., "Spent Fuel Cladding Integrity During Dry Storage", LLNL, UCID-22181 (September 1987).

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CHAPTER 5: SHIELDING EVALUATION

5.0 INTRODUCTION

The shielding analysis of the HI-STAR 100 System is presented in this chapter. The HI-STAR 100 System is designed to accommodate different MPCs within one standard HI-STAR overpack. The MPCs are designated as MPC-24 (24 PWR fuel assemblies) and MPC-68 (68 BWR fuel assemblies).

In addition to storing intact PWR and BWR fuel assemblies, the HI-STAR 100 System is designed to store damaged BWR fuel assemblies and BWR fuel debris. Damaged fuel assemblies and fuel debris are defined in Section 2.1.3 and Appendix B to the Certificate of Compliance. Both damaged BWR fuel assemblies and BWR fuel debris are required to be loaded into Damaged Fuel Containers (DFCs) prior to being loaded into the MPC. DFCs containing fuel debris must be stored in the MPC-68F. DFCs containing damaged fuel assemblies may be stored in either the MPC-68 or the MPC-68F. Only the fuel assemblies in the Dresden 1 and Humboldt Bay fuel assembly classes identified in Table 2.1.2 are authorized as contents for storage in the HI-STAR 100 system as either damaged fuel or fuel debris.

The MPC-68 and MPC-68F are also capable of storing Dresden Unit 1 antimony-beryllium neutron sources and the single Thoria rod canister which contains 18 thoria rods that were irradiated in two separate fuel assemblies.

PWR fuel assemblies may contain burnable poison rod assemblies (BPRAs) or thimble plug devices (TPDs) or similarly named devices. These devices are an integral yet removable part of PWR fuel assemblies and therefore the HI-STAR 100 System has been designed to store PWR fuel assemblies with or without BPRAs or TPDs. Since BPRAs and TPDs occupy the same space within a fuel assembly, a single PWR fuel assembly will not contain both devices.

The sections that follow will demonstrate that the design of the HI-STAR 100 dry cask storage system fulfills the following acceptance criteria outlined in the Standard Review Plan, NUREG-1536[5.2.1]:

Acceptance Criteria

1. The minimum distance from each spent fuel handling and storage facility to the controlled area boundary must be at least 100 meters. The "controlled area" is defined in 10CFR72.3 as the area immediately surrounding an ISFSI or monitored retrievable storage (MRS) facility, for which the licensee exercises authority regarding its use and within which ISFSI operations are performed.

2. The cask vendor must show that, during both normal operations and anticipated occurrences, the radiation shielding features of the proposed dry cask storage system are sufficient to meet the radiation dose requirements in Sections 72.104(a). Specifically, the vendor must demonstrate this capability for a typical array of casks in the most bounding site configuration. For example, the most bounding configuration might be located at the minimum distance (100 meters) to the controlled area boundary, without any shielding from other structures or topography.

3. Dose rates from the cask must be consistent with a well-established "as low as reasonably achievable" (ALARA) program for activities in and around the storage site.

4. After a design-basis accident, an individual at the boundary or outside the controlled area shall not receive a dose greater than the limits specified in 10 CFR 72.106.

5. The proposed shielding features must ensure that the dry cask storage system meets the regulatory requirements for occupational and radiation dose limits for individual members of the public, as prescribed in 10 CFR Part 20, Subparts C and D.

This chapter contains the following information which demonstrates full compliance with the Standard Review Plan, NUREG-1536:

- A description of the shielding features of the HI-STAR 100 System.
- A description of the bounding source terms.
- A general description of the shielding analysis methodology.
- A description of the analysis assumptions and results for the HI-STAR 100 System.
- Analyses are presented for each MPC showing that the radiation dose rates follow As-Low-As-Reasonably-Achievable (ALARA) practices.
- The HI-STAR 100 System has been analyzed to show that the 10CFR72.104 and 10CFR72.106 controlled area boundary radiation dose limits are met during normal, off-normal, and accident conditions of storage for non-effluent radiation from illustrative ISFSI configurations at a minimum distance of 100 meters.
- Analyses are also presented which demonstrate that the storage of damaged fuel and fuel debris in the HI-STAR 100 System is bounded by the BWR intact fuel analysis during normal, off-normal, and accident conditions.

Chapter 10, Radiation Protection, contains the following information:

- A discussion of the estimated occupational exposures for the HI-STAR 100 System.
- A summary of the estimated radiation exposure to the public.

Chapter 2 contains a detailed description of structures, systems, and components important to safety.

Chapter 7 contains an analysis of the estimated dose at the controlled area boundary during normal, off-normal, and accident conditions from the release of radioactive materials. Therefore, this chapter only calculates the dose from direct neutron and gamma radiation emanating from the HI-STAR 100 System.

5.1 DISCUSSION AND RESULTS

The principal sources of radiation in the HI-STAR 100 System are:

- Gamma radiation originating from the following sources

    1. Decay of radioactive fission products
    2. Secondary photons from neutron capture in fissile and non-fissile nuclides
    3. Hardware activation products generated during core operations

- Neutron radiation originating from the following sources

    1. Spontaneous fission
    2. α,n reactions in fuel materials
    3. Secondary neutrons produced by fission from subcritical multiplication
    4. γ,n reactions (this source is negligible)
    5. Dresden Unit 1 antimony-beryllium neutron sources

Shielding from gamma radiation is provided by the steel structure of the MPC and overpack. In order for the neutron shielding to be effective, the neutrons must be thermalized and then absorbed in a material of high neutron cross section. In the HI-STAR 100 design, a neutron shielding material, Holtite-A, is used to thermalize the neutrons. Boron carbide, dispersed in the neutron shield, utilizes the high neutron absorption cross section of ^{10}B to absorb the thermalized neutrons.

The shielding analyses were performed with MCNP-4A [5.1.1] from Los Alamos National Laboratory. The source terms for the design basis fuels were calculated with the SAS2H and ORIGEN-S modules from the SCALE 4.3 system [5.1.2, 5.1.3]. A detailed description of the MCNP models and the source term calculations is presented in Sections 5.3 and 5.2, respectively.

The design basis intact zircaloy clad fuel assemblies used for calculating the dose rates presented in this chapter are B&W 15x15 and the GE 7x7, for PWR and BWR fuel types, respectively. The design basis intact 6x6, damaged, and mixed oxide (MOX) fuel assemblies are the GE 6x6. Table 2.1.6 specifies the acceptable intact zircaloy clad fuel characteristics for storage. Table 2.1.7 specifies the acceptable damaged and MOX zircaloy clad fuel characteristics for storage.

The design basis intact stainless steel clad fuels are the WE 15x15 and the A/C 10x10, for PWR and BWR fuel types, respectively. Table 2.1.11 specifies the acceptable fuel characteristics of stainless steel clad fuel for storage.

The MPC-24 and MPC-68 are qualified for storage of SNF with different combinations of maximum burnup levels and minimum cooling times. Figure 2.1.6 specifies the acceptable maximum burnup levels and minimum cooling times for storage of zircaloy clad fuel in the MPC-24 and the MPC-68 (Appendix B to the Certificate of Compliance presents this data in tabular form). Table 2.1.11 specifies the acceptable maximum burnup levels and minimum cooling times for storage of stainless steel clad fuel. The values in Figure 2.1.6 and Table 2.1.11 were chosen based on an analysis of the maximum decay heat load that could be accommodated within each MPC. The shielding analyses presented in this chapter used the burnup and cooling time combinations listed below which are either equal to or conservatively bound the acceptable burnup levels and cooling times shown in Figure 2.1.6 and Table 2.1.11.

Maximum Burnup and Minimum Cooling Times Analyzed	
Zircaloy Clad Fuel	
MPC-24	**MPC-68**
40,000 MWD/MTU 5 year cooling	35,000 MWD/MTU 5 year cooling
47,500 MWD/MTU 8 year cooling	45,000 MWD/MTU 9 year cooling
N/A	30,000 MWD/MTU 18 year cooling (6x6 intact, damaged and MOX fuel)
Stainless Steel Clad Fuel	
MPC-24	**MPC-68**
30,000 MWD/MTU 9 year cooling	22,500 MWD/MTU 10 year cooling
40,000 MWD/MTU 15 year cooling	N/A

Appendix B to the Certificate of Compliance requires that, in the MPC-24, for a minimum cooling time of 5-years, the maximum burnup is 28,700 MWD/MTU, and for 15-year cooling the maximum burnup is 42,100 MWD/MTU for PWR fuel assemblies without Burnable Poison Rod Assemblies (BPRAs). PWR fuel assemblies containing BPRAs are limited to 28,300 MWD/MTU for 5 year cooling and 41,400 MWD/MTU for 15 year cooling. Since the burnup and cooling times analyzed in this chapter for the MPC-24 were 40,000 MWD/MTU and 5-year cooling and 47,500 MWD/MTU and 8-year cooling, the shielding analysis presented is conservatively bounding for the MPC-24.

Appendix B to the Certificate of Compliance requires that, in the MPC-68, for a minimum cooling time of 5-years, the maximum burnup is 26,000 MWD/MTU, and for 15-year cooling

the maximum burnup is 37,600 MWD/MTU. Since the burnup and cooling times analyzed in this chapter for the MPC-68 were 35,000 MWD/MTU and 5-year cooling and 45,000 MWD/MTU and 9-year cooling, the shielding analysis presented is conservatively bounding for the MPC-68.

The dose rates corresponding to the burnup and cooling time combination which resulted in the highest dose rates at the midplane of the cask during normal conditions are reported in this section. Dose rates for each of the combinations are listed in Section 5.4.

5.1.1 Normal and Off-Normal Operations

Chapter 11 discusses the potential off-normal conditions and their effect on the HI-STAR 100 System. None of the off-normal conditions have any impact on the shielding analysis. Therefore, off-normal and normal conditions are identical for the purpose of the shielding evaluation.

The 10CFR72.104 criteria for radioactive materials in effluents and direct radiation during normal operations are:

1. During normal operations and anticipated occurrences, the annual dose equivalent to any real individual who is located beyond the controlled area, must not exceed 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other critical organ.

2. Operational restrictions must be established to meet as low as reasonably achievable objectives for radioactive materials in effluents and direct radiation.

10CFR20 Subparts C and D specify additional requirements for occupational dose limits and radiation dose limits for individual members of the public. Chapter 10 specifically addresses these regulations.

In accordance with ALARA practices, design objective dose rates are established for the HI-STAR 100 in Section 2.3.5.2 as: 125 mrem/hour on the radial surface of the overpack, and 375 mrem/hour in areas above and below the neutron shield in the radial direction.

The dose rates presented in this section are calculated at 40,000 MWD/MTU and 5-year cooling for the MPC-24, and 35,000 MWD/MTU and 5-year cooling for the MPC-68. Based on a comparison of the normal condition dose rates at the fuel mid-plane for the various burnup and cooling time combinations analyzed, these were chosen as the worst case for the MPC-24 and the MPC-68. Section 5.4 provides a detailed list of dose rates at several cask locations for all burnup and cooling times analyzed.

Figure 5.1.1 identifies the locations of the dose points referenced in the summary tables. The bottom shield shown in this figure is temporary shielding which may be used during on-site horizontal handling operations. Dose Point #7 is located directly below the overpack bottom plate or directly below the bottom shield when it is attached. Dose Points #1, #3, and #4 are not

contact doses, but rather, in-air doses at the locations shown. The dose values reported at the locations shown on Figure 5.1.1 are averaged over a region that is approximately 1 foot in width.

Tables 5.1.2 and 5.1.3 provide the maximum dose rates adjacent to the overpack during normal conditions for each of the MPCs. Tables 5.1.5 and 5.1.6 provide the maximum dose rates at one meter from the overpack.

The dose to any real individual at or beyond the controlled area boundary is required to be below 25 mrem per year. The minimum distance to the controlled area boundary is 100 meters from the ISFSI. Only the MPC-24 was used in the calculation of the dose rates at the controlled area boundary. The MPC-24 was chosen because its dose rates are equivalent or greater than the dose rates from the MPC-68 as shown in Tables 5.1.2, 5.1.3, 5.1.5, and 5.1.6. Table 5.1.7 presents the annual dose to an individual from a single cask and various arrays of casks, assuming 100% occupancy (8760 hours). The minimum distance required for the corresponding dose is also listed. These values were calculated for the MPC-24 with a burnup of 40,000 MWD/MTU and a 5-year cooling time. It will be shown in Section 5.4.3 that this burnup and cooling time results in the highest offsite dose for the combinations of maximum burnup and minimum cooling time analyzed. It is noted that these data are provided for illustrative purposes only. A detailed site specific evaluation of dose at the controlled area boundary will be performed for each ISFSI in accordance with 10CFR72.212, as stated in Chapter 12, Operating Controls and Limits. The site specific evaluation will consider dose from other portions of the facility and will consider the specifics of the fuel being stored (burnup and cooling time).

Figure 5.1.2 is an annual dose versus distance graph for the cask configurations provided in Table 5.1.7. This curve, which is based on 100% occupancy, is provided for illustrative purposes only and will be re-evaluated on a site-specific basis.

Section 5.2 lists the gamma and neutron sources for the design basis intact and damaged fuels. Since the source strengths of the damaged fuel and the MOX fuel are significantly smaller in all energy groups than those corresponding to the intact design basis fuel source strengths, the damaged and MOX fuel dose rates for normal conditions are bounded by the MPC-68 analysis with design basis intact fuel. Therefore, no explicit analysis is required to demonstrate that the MPC-68 with damaged or MOX fuel will meet the normal condition regulatory requirements.

Section 5.2.6 lists the gamma and neutron sources from the Dresden Unit 1 Thoria rod canister and demonstrates that the Thoria rod canister is bounded by the design basis Dresden Unit 1 6x6 intact fuel.

Section 5.2.4 presents the Co-60 sources from the BPRAs and TPDs that are permitted for storage in the HI-STAR 100. Section 5.4.6 demonstrates that the maximum dose rates presented in this section bound the dose rates from fuel assemblies containing either BPRAs or TPDs.

Section 5.4.7 demonstrates that the Dresden Unit 1 fuel assemblies containing antimony-beryllium neutron sources are bounded by the shielding analysis presented in this section.

Section 5.2.3 presents the gamma and neutron source for the design basis intact stainless steel clad fuel. The dose rates from this fuel are provided in Section 5.4.5.

The analyses summarized in this section demonstrate that the HI-STAR 100 System is in compliance with the 10CFR72.104 limits and ALARA practices.

5.1.2 Accident Conditions

The 10CFR72.106 radiation dose limits at the controlled area boundary for design basis accidents are:

> Any individual located on or beyond the nearest boundary of the controlled area may not receive from any design basis accident the more limiting of a total effective dose equivalent of 5 Rem, or the sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue (other than the lens of the eye) of 50 Rem. The lens dose equivalent shall not exceed 15 Rem and the shallow dose equivalent to skin or to any extremity shall not exceed 50 rem. The minimum distance from the spent fuel or high level radioactive waste handling and storage facilities to the nearest boundary of the controlled area shall be at least 100 meters.

The design basis accidents analyzed in Chapter 11 have one bounding consequence which affects the shielding materials. It is the damage to the neutron shield as a result of the design basis fire. Other design basis accidents result in damage to the outer enclosure shell and neutron shield; however, these accidents are localized. In a conservative fashion, the dose analysis assumes that as a result of the fire, the neutron shield is completely destroyed and replaced by a void. This is highly conservative as there will be limited sources of combustible materials stored in or around the ISFSI. Additionally, the neutron shield is assumed to be completely lost, whereas some portion of the neutron shield would be expected to remain, as the neutron shield material is fire retardant.

Throughout all design basis accident conditions the axial location of the fuel will remain fixed within the MPC because of the fuel spacers. Chapter 3 provides an analysis to show that the fuel spacers do not fail under all normal, off-normal, and accident conditions of storage. Chapter 3 also shows that the inner shell, intermediate shells, radial channels, and outer enclosure shell of the overpack remain unaltered throughout all design basis accident conditions. Localized damage of the overpack outer enclosure shell could be experienced. However, the localized deformations will have a negligible impact on the dose rate at the boundary of the controlled area.

The complete loss of the neutron shield significantly affects the dose at Dose Point #2 at the mid-height adjacent to the overpack neutron shield. Loss of the neutron shield has a small effect on the other dose points. To illustrate the impact of the design basis accident, the dose rates at Dose

Point #2 (see Figure 5.1.1) are provided in Tables 5.1.8 and 5.1.9. The normal condition dose rates are provided for reference.

Table 5.1.9 provides a comparison of the normal and accident condition dose rates at one meter from the overpack. By comparing the increase in dose rates from normal and accident conditions and the maximum normal condition controlled area dose rate, it is evident that the dose as a result of the design basis accident cannot exceed 5 Rem at the controlled area boundary for the short duration of the accident. Conservatively assuming a 1/R reduction in the dose rate, the dose rate at the 100 meter controlled area boundary would be less than 5 mrem/hr for a single HI-STAR 100 during the accident condition. At this dose rate, it would take more than 1000 hours (41 days) for the dose at the controlled area boundary to reach 5 Rem. This length of time greatly exceeds the time necessary to implement and complete the corrective actions outlined in Chapter 11 for the fire accident. Therefore, the dose requirement of 10CFR72.106 is satisfied.

The consequences of the design basis accident conditions for the MPC-68 storing damaged fuel and the MPC-68F storing damaged fuel and/or fuel debris differ slightly from those with intact fuel. It is conservatively assumed that during a drop accident (vertical, horizontal, or tip-over) the fuel collapses and the pellets rest in the bottom of the damaged fuel container. Since the damaged and MOX fuels are both Dresden 1 fuel, the MOX fuel can also be considered damaged fuel. Analysis in Section 5.4.2 demonstrates that the damaged fuel in the post-accident condition has lower source terms (both gamma and neutron) per inch than the intact BWR design basis fuel. Therefore, the damaged fuel post-accident dose rates are bounded by the BWR intact fuel post-accident dose rates.

Analyses summarized in this section demonstrate the HI-STAR 100 System's compliance with the 10CFR72.106 limits.

Table 5.1.1

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Table 5.1.2

DOSE RATES ADJACENT TO OVERPACK FOR NORMAL CONDITIONS
MPC-24 WITH DESIGN BASIS ZIRCALOY CLAD FUEL AT WORST CASE
BURNUP AND COOLING TIME
40,000 MWD/MTU AND 5-YEAR COOLING

Dose Point† Location	Fuel Gammas†† (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)
1	12.45	231.52	82.27	326.24
2	96.88	0.03	22.12	119.03
3	3.51	81.12	70.28	154.90
4	1.81	35.86	39.47	77.14
5	0.34	0.69	56.70	57.73
6 (dry MPC)†††	27.07	286.19	126.02	439.28
7 (no temp. shield)	100.36	1432.28	397.30	1929.94
7 (with temp. shield)	28.27	329.84	19.84	377.94

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

††† Overpack closure plate not present.

Table 5.1.3

DOSE RATES ADJACENT TO OVERPACK FOR NORMAL CONDITIONS
MPC-68 WITH DESIGN BASIS ZIRCALOY CLAD FUEL AT WORST CASE
BURNUP AND COOLING TIME
35,000 MWD/MTU AND 5-YEAR COOLING

Dose Point† Location	**Fuel Gammas†† (mrem/hr)**	**^{60}Co Gammas (mrem/hr)**	**Neutrons (mrem/hr)**	**Totals (mrem/hr)**
1	10.26	297.76	65.63	373.64
2	100.42	0.02	19.40	119.85
3	0.97	127.41	29.88	158.26
4	0.44	51.49	17.76	69.69
5	0.13	0.72	26.45	27.30
6 (dry MPC)†††	9.32	329.17	65.38	403.87
7 (no temp. shield)	64.46	1794.41	325.90	2184.76
7 (with temp. shield)	20.36	381.90	14.52	416.78

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

††† Overpack closure plate not present.

Table 5.1.4

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Table 5.1.5

DOSE RATES AT ONE METER FOR NORMAL CONDITIONS
MPC-24 WITH DESIGN BASIS ZIRCALOY CLAD FUEL AT WORST CASE
BURNUP AND COOLING TIME
40,000 MWD/MTU AND 5-YEAR COOLING

Dose Point† Location	Fuel Gammas†† (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	TOTALS (mrem/hr)
1	10.11	25.00	8.69	43.79
2	42.67	1.06	7.74	51.47
3	7.10	14.06	9.04	30.21
4	4.59	14.69	9.33	28.61
5	0.11	0.32	16.67	17.11
7 (no temp. shield)	52.66	720.72	116.30	889.68
7 (with temp. shield)	11.46	139.22	15.19	165.87

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.6

DOSE RATES AT ONE METER FOR NORMAL CONDITIONS
MPC-68 WITH DESIGN BASIS ZIRCALOY CLAD FUEL AT WORST CASE
BURNUP AND COOLING TIME
35,000 MWD/MTU AND 5-YEAR COOLING

Dose Point† Location	**Fuel Gammas†† (mrem/hr)**	**^{60}Co Gammas (mrem/hr)**	**Neutrons (mrem/hr)**	**Totals (mrem/hr)**
1	10.47	34.29	7.52	52.28
2	43.01	0.60	7.50	51.11
3	4.37	21.32	4.23	29.91
4	2.60	22.51	4.19	29.30
5	0.06	0.37	7.44	7.86
7 (no temp. shield)	29.91	888.15	87.01	1005.07
7 (with temp. shield)	8.10	162.56	10.52	181.19

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.7

DOSE RATES FOR ARRAYS OF MPC-24
WITH DESIGN BASIS ZIRCALOY CLAD FUEL
40,000 MWD/MTU AND 5-YEAR COOLING

Array Configuration	1 cask	2x2	2x3	2x4	2x5
Annual Dose (mrem/year)†	13.55	18.60	13.84	18.45	23.06
Distance to Controlled Area Boundary (meters)††,†††	300	350	400	400	400

† 100% occupancy is assumed.

†† Dose location is at the center of the long side of the array.

††† Actual controlled area boundary dose rates will be lower because the maximum permissible burnup for 5-year cooling as specified in the Technical Specifications is lower than the burnup analyzed for the design basis fuel used in this chapter.

Table 5.1.8

DOSE RATES ADJACENT TO OVERPACK FOR ACCIDENT CONDITIONS
DESIGN BASIS ZIRCALOY CLAD FUEL
AT WORST CASE BURNUP AND COOLING TIME

Dose Point† Location	**Fuel Gammas†† (mrem/hr)**	**^{60}Co Gammas (mrem/hr)**	**Neutrons (mrem/hr)**	**Totals (mrem/hr)**
MPC-24 (40,000 MWD/MTU AND 5-YEAR COOLING)				
2 (Accident Condition)	221.84	0.04	1149.46	1371.34
2 (Normal Condition)	96.88	0.03	22.12	119.03
MPC-68 (35,000 MWD/MTU AND 5-YEAR COOLING)				
2 (Accident Condition)	223.20	0.04	1140.57	1363.82
2 (Normal Condition)	100.42	0.02	19.40	119.85

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.9

DOSE RATES AT ONE METER FOR ACCIDENT CONDITIONS
DESIGN BASIS ZIRCALOY CLAD FUEL
AT WORST CASE BURNUP AND COOLING TIME

Dose Point† Location	Fuel Gammas†† (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)
MPC-24 (40,000 MWD/MTU AND 5-YEAR COOLING)				
2 (Accident Condition)	100.98	1.80	388.94	491.73
2 (Normal Condition)	42.67	1.06	7.74	51.47
MPC-68 (35,000 MWD/MTU AND 5-YEAR COOLING)				
2 (Accident Condition)	98.28	1.48	360.93	460.69
2 (Normal Condition)	43.01	0.60	7.50	51.11

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

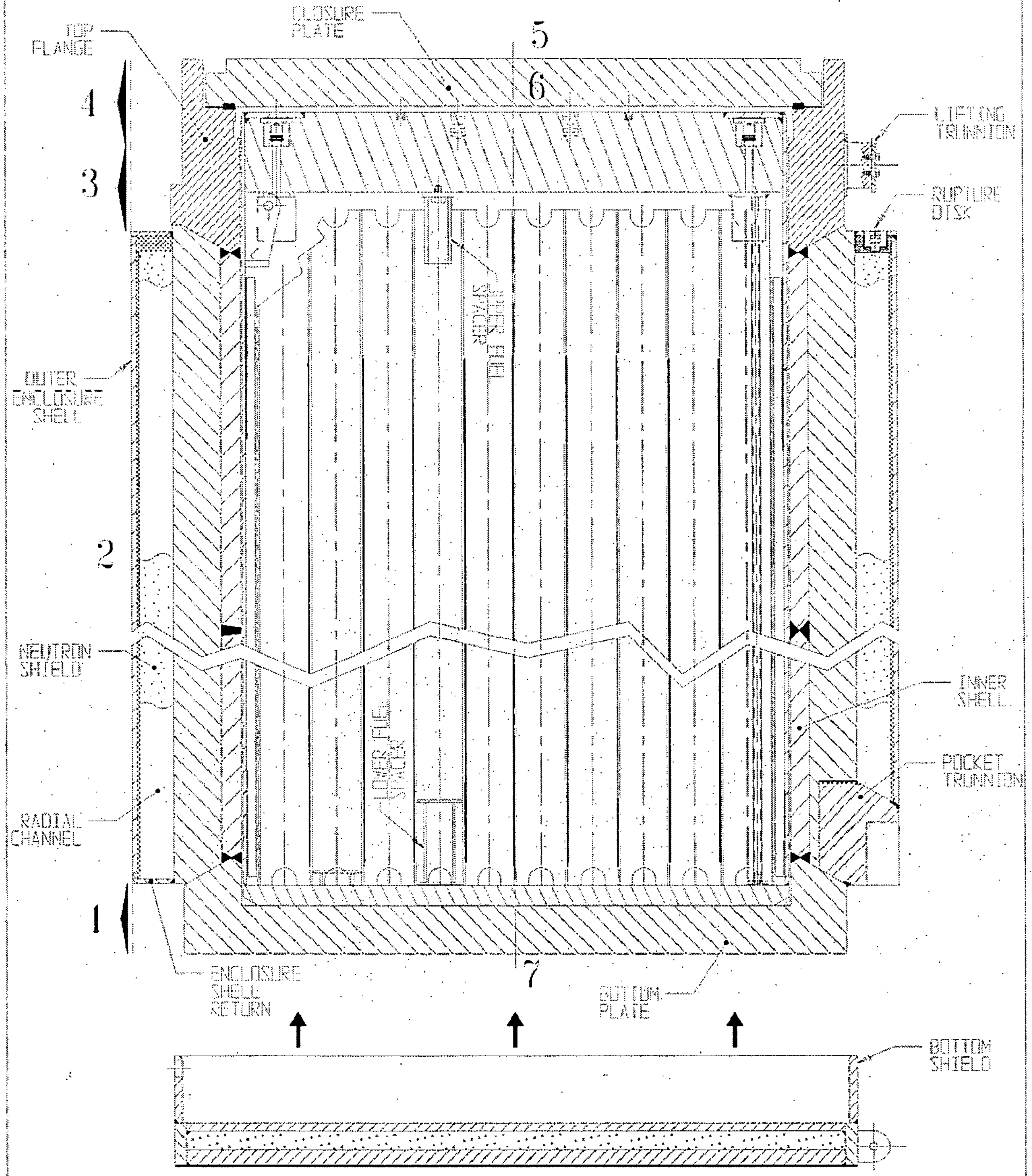

FIGURE 5.1.1; CROSS SECTION ELEVATION VIEW OF OVERPACK WITH DOSE POINT LOCATIONS

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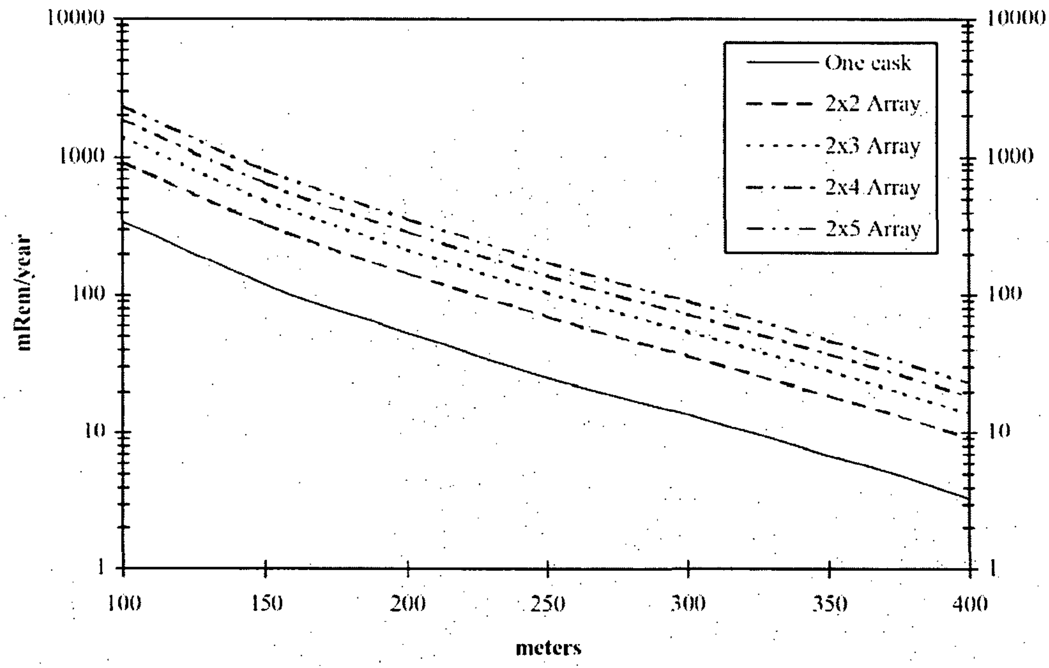

FIGURE 5.1.2; ANNUAL DOSE VERSUS DISTANCE FOR VARIOUS CONFIGURATIONS OF THE MPC-24
40,000 MWD/MTU AND 5-YEAR COOLING
100% OCCUPANCY ASSUMED

5.2 SOURCE SPECIFICATION

The neutron and gamma source terms, decay heat values, and quantities of radionuclides available for release, were calculated with the SAS2H and ORIGEN-S modules of the SCALE 4.3 system [5.1.2, 5.1.3]. Sample input files for SAS2H and ORIGEN-S are provided in Appendices 5.A and 5.B, respectively. The gamma source term is actually comprised of three distinct sources. The first is a gamma source term from the active fuel region due to decay of fission products. The second source term is from ^{60}Co activity of the steel structural material in the fuel element above and below the active fuel region. The third source is from (n,γ) reactions described below.

A description of the design basis intact zircaloy clad fuel for the source term calculations is provided in Table 5.2.1. The PWR fuel assembly described is the assembly that produces the highest neutron and gamma sources and the highest decay heat load from the following fuel assembly classes listed in Tables 2.1.1: B&W 15x15, B&W 17x17, CE 14x14, CE 16x16, WE 14x14, WE 15x15, WE 17x17, St. Lucie, and Ft. Calhoun. The BWR fuel assembly described is the assembly that produces the highest neutron and gamma sources and the highest decay heat load from the following fuel assembly classes listed in Table 2.1.2: GE BWR/2-3, GE BWR/4-6, Humboldt Bay 7x7, and Dresden 1 8x8. Multiple SAS2H and ORIGEN-S calculations were performed to confirm that the B&W 15x15 and the GE 7x7, which have the highest UO_2 mass, bound all other PWR and BWR fuel assemblies, respectively. Section 5.2.5 discusses, in detail, the determination of the design basis fuel assemblies.

The design basis Humboldt Bay and Dresden 1 6x6 fuel assembly, which is also the design basis damaged fuel assembly for the Humboldt Bay and Dresden 1 damaged fuel or fuel debris, is described in Table 5.2.2. The design basis damaged fuel assembly is also the design basis fuel assembly for fuel debris. The fuel assembly type listed produces the highest total neutron and gamma sources from the fuel assemblies at Dresden 1 and Humboldt Bay. Table 5.2.15 provides a description of the design basis Dresden 1 MOX fuel assembly used in this analysis. The design basis 6x6, damaged, and MOX fuel assemblies which are smaller than the GE 7x7, are assumed to have the same hardware characteristics as the GE 7x7. This is conservative because the larger hardware mass of the GE 7x7 results in a larger ^{60}Co activity.

The design basis stainless steel clad fuel assembly for the Haddam Neck and San Onofre 1 assembly classes is described in Table 5.2.18. This table also describes the design basis stainless steel clad LaCrosse fuel assembly.

In performing the SAS2H and ORIGEN-S calculations, a single full power cycle was used to achieve the desired burnup. This assumption, in conjunction with the above-average specific powers listed in Tables 5.2.1, 5.2.2, 5.2.15, and 5.2.18 resulted in conservative source term calculations.

Sections 5.2.1 and 5.2.2 describe the calculation of gamma and neutron source terms for zircaloy clad fuel while Section 5.2.3 discusses the calculation of the gamma and neutron source terms for the stainless steel clad fuel.

5.2.1 Gamma Source

Tables 5.2.4 through 5.2.6 provide the gamma source in MeV/s and photons/s as calculated with SAS2H and ORIGEN-S for the design bases intact fuels for the MPC-24 and MPC-68, and the design basis damaged fuel. Table 5.2.16 provides the gamma source in MeV/s and photons/s for the design basis MOX fuel. NUREG-1536 [5.2.1] states that "only gammas with energies from approximately 0.8 to 2.5 MeV will contribute significantly to the dose rate." Conservatively, only energies in the range of 0.7 MeV-3.0 MeV are used in the shielding calculations. Photons with energies below 0.7 MeV are too weak to penetrate the steel of the overpack, and photons with energies above 3.0 MeV are too few to contribute significantly to the external dose. This section provides the radiation source for each of the burnup levels and cooling times evaluated.

The primary source of activity in the non-fuel regions of an assembly arise from the activation of ^{59}Co to ^{60}Co. The primary source of ^{59}Co in a fuel assembly is the steel structural material above and below the fuel. The zircaloy in these regions is neglected since it does not have a significant ^{59}Co impurity level. Reference [5.2.2] indicates that the impurity level in steel is 800 ppm or 0.8 gm/kg. As a conservative measure, the impurity level of ^{59}Co was assumed to be 1000 ppm or 1.0 gm/kg. Therefore, Inconel and stainless steel in the non-fuel regions are both conservatively assumed to have the 1.0 gm/kg impurity level.

The gamma source from the activation of the grid spacers is negligible in comparison to the source from the active fuel. In addition, in most fuel elements that obtain high burnups, the grid spacers are manufactured from zircaloy which does not activate to produce a gamma source. Therefore, for the PWR fuel assembly, no contribution to the fuel region gamma source from activation of grid spacers is provided in the source term calculations. The BWR assembly grid spacers are zircaloy, however, some assembly designs have steel springs in conjunction with the grid spacers. The gamma source for the BWR fuel assembly includes the activation of these springs associated with the grid spacers.

The non-fuel data listed in Table 5.2.1 was taken from References [5.2.2], [5.2.4], and [5.2.5]. The BWR masses are for an 8x8 fuel assembly. These masses are also appropriate for the 7x7 assembly since the masses of the non-fuel hardware from a 7x7 and an 8x8 are approximately the same. The masses listed are those of the steel components. The zircaloy in these regions was not included because zircaloy does not produce significant activation. These masses are larger than most other fuel assemblies from other manufactures. This, in combination with the conservative ^{59}Co impurity level, results in a conservative estimate of the ^{60}Co activity.

The masses in Table 5.2.1 were used to calculate a ^{59}Co impurity level in the fuel material. The grams of impurity were then used in ORIGEN-S to calculate a ^{60}Co activity level for the desired

burnup and decay time. The methodology used to determine the activation level was developed from Reference [5.2.3] and is described here.

1. The activity of the ^{60}Co is calculated using ORIGEN-S. The flux used in the calculation was the in-core fuel region flux at full power.

2. The activity calculated in Step 1 for the region of interest was modified by the appropriate scaling factors listed in Table 5.2.7. These scaling factors were taken from Reference [5.2.3].

Tables 5.2.9 and 5.2.10 provide the ^{60}Co activity utilized in the shielding calculations in the non-fuel regions of the assemblies for the MPC-24 and the MPC-68. The design basis damaged and MOX fuel assemblies are conservatively assumed to have the same ^{60}Co source strength as the BWR intact design basis fuel. This is a conservative assumption as the design basis damaged fuel and MOX fuel are limited to a significantly lower burnup and longer cooling time than the intact design basis fuel.

In addition to the two sources already mentioned, a third source arises from (n,γ) reactions in the material of the MPC and the overpack. This source of photons is properly accounted for in MCNP when a neutron calculation is performed in a coupled neutron-gamma mode.

5.2.2 Neutron Source

It is well known that the neutron source strength increases as enrichment decreases, for a constant burnup and decay time. This is due to the increase in Pu content in the fuel which increases the inventory of other transuranium nuclides such as Cm. The gamma source also varies with enrichment, although only slightly. Because of this effect and in order to obtain conservative source terms, low initial fuel enrichments were chosen for the BWR and PWR design basis fuel assemblies. The enrichments are appropriately varied as a function of burnup. Table 5.2.23 presents the ^{235}U initial enrichments for various burnup ranges from 20,000 - 50,000 MWD/MTU for PWR and BWR zircaloy clad fuel. These enrichments are based on Reference [5.2.6]. Table 8 of this reference presents average enrichments for burnup ranges. The initial enrichments chosen in Table 5.2.23 are approximately the average enrichments for the burnup range that are 5,000 MWD/MTU less than the ranges listed in Table 5.2.23. These enrichments are below the enrichments typically required to achieve the burnups that were analyzed. Therefore, the source term calculations are conservative.

The neutron source calculated for the design basis intact fuel assemblies for the MPC-24 and MPC-68 and the design basis damaged fuel are listed in Tables 5.2.12 through 5.2.14 in neutrons/s. Table 5.2.17 provides the neutron source in neutrons/sec for the design basis MOX fuel assembly. ^{244}Cm accounts for approximately 96% of the total number of neutrons produced, with slightly over 2% originating from (α,n) reactions within the UO_2 fuel. The remaining 2% derive from spontaneous fission in various Pu and Cm radionuclides. In addition, any neutrons

generated from subcritical multiplication, (n,2n) or similar reactions are properly accounted for in the MCNP calculation.

5.2.3 Stainless Steel Clad Fuel Source

Table 5.2.18 lists the characteristics of the design basis stainless steel clad fuel. The fuel characteristics listed in this table are the input parameters that were used in the shielding calculations described in this chapter. The active fuel length listed in Table 5.2.18 is actually longer than the true active fuel length of 122 inches for the WE 15x15 and 83 inches for the A/C 10x10. Since the true active fuel length is shorter than the design basis zircaloy clad active fuel length, it would be incorrect to calculate source terms for the stainless steel fuel using the correct fuel length and compare them directly to the zircaloy clad fuel source terms because this type of approach would not reflect the potential change in dose rates at the center of the cask (center of the active fuel). As an example, if it is assumed that the source strength for both the stainless steel and zircaloy fuel is 144 photons/s and that the active fuel lengths of the stainless steel fuel and zircaloy fuel are 83 inches and 144 inches, respectively; the source strengths per inch of active fuel would be different for the two fuel types, 1.73 photons/s/inch and 1 photons/s/inch for the stainless steel and zircaloy fuel, respectively. The result would be a higher photon dose rate at the center of the cask with the stainless steel fuel than with the zircaloy clad fuel; a conclusion that would be overlooked by just comparing the source terms. This is an important consideration because the stainless steel clad fuel differs from the zircaloy clad in one important aspect: the stainless steel cladding will contain a significant photon source from Cobalt-60 which will be absent from the zircaloy clad fuel.

In order to eliminate the potential confusion when comparing source terms, the stainless steel clad fuel source terms were calculated with the same active fuel length as the design basis zircaloy clad fuel. Reference [5.2.2] indicates that the Cobalt-59 impurity level in steel is 800 ppm or 0.8 gm/kg. This impurity level was used for the stainless steel cladding in the source term calculations. It is assumed that the end fitting masses of the stainless steel clad fuel are the same as the end fitting masses of the zircaloy clad fuel. Therefore, separate source terms are not provided for the end fittings of the stainless steel fuel.

Tables 5.2.19 through 5.2.22 list the neutron and gamma source strengths for the design basis stainless steel clad fuel. It is obvious from these source terms that the neutron source strength for the stainless steel fuel is lower than for the zircaloy fuel. However, this is not true for all photon energy groups. The peak energy group is from 1.0 to 1.5 MeV which results from the large Cobalt activation in the cladding. Since some of the source strengths are higher for the stainless steel fuel, Section 5.4.5 presents the dose rates at the center of the overpack for the stainless steel fuel. The center dose location is the only location of concern since the end fittings are assumed to be the same mass as the end fittings for the zircaloy clad fuel. In addition, the burnup is lower and the cooling time is longer for the stainless steel fuel compared to the zircaloy clad fuel.

5.2.4 Non-Fuel Hardware

Rod cluster control assemblies and axial power shaping rods are not permitted for storage in the HI-STAR 100 system. However, burnable poison rod assemblies (BPRAs) and thimble plug devices (TPDs) are permitted for storage in the HI-STAR 100 System as an integral part of a PWR fuel assembly.

5.2.4.1 BPRAs and TPDs

Burnable poison rod assemblies (BPRA) (including wet annular burnable absorbers and similarly designed devices with different names) and thimble plug devices (TPD) (including orifice rod assemblies, guide tube plugs, and similarly designed devices with different names) are an integral, yet removable, part of a large portion of PWR fuel. The TPDs are not used in all assemblies in a reactor core but are reused from cycle to cycle. Therefore, these devices can achieve very high burnups. In contrast, BPRAs are burned with a fuel assembly in core and are not reused. In fact, many BPRAs are removed after one or two cycles before the fuel assembly is discharged. Therefore, the achieved burnup for BPRAs is not significantly different than fuel assemblies.

TPDs are made of stainless steel and contain a small amount of inconel. These devices extend down into the plenum region of the fuel assembly but do not extend into the active fuel region with the exception of the W 14x14 water displacement guide tube plugs. Since these devices are made of stainless steel, there is a significant amount of cobalt-60 produced during irradiation. This is the only significant radiation source from the activation of steel and inconel.

BPRAs are made of stainless steel in the region above the active fuel zone and may contain a small amount of inconel in this region. Within the active fuel zone the BPRAs may contain 2-24 rodlets which are burnable absorbers clad in either zircaloy or stainless steel. The stainless steel clad BPRAs create a significant radiation source (Co-60) while the zircaloy clad BPRAs create a negligible radiation source. Therefore the stainless steel clad BPRAs are bounding.

SAS2H and ORIGEN-S were used to calculate a radiation source term and decay heat level for the TPDs and BPRAs. In the ORIGEN-S calculations the cobalt-59 impurity level was conservatively assumed to be 0.8 gm/kg for stainless steel and 4.7 gm/kg for inconel. These calculations were performed by irradiating the appropriate mass of steel and inconel using the flux calculated for the design basis B&W 15x15 fuel assembly. The mass of material in the regions above the active fuel zone was scaled by the appropriate scaling factors listed in Table 5.2.10 in order to account for the reduced flux levels above the fuel assembly. The total curies of cobalt and the decay heat load were calculated for the TPDs and BPRAs as a function of burnup and cooling time. For burnups beyond 45,000 MWD/MTU, it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 45,000 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 45,000 MWD/MTU.

Since the HI-STAR 100 cask system is designed to store many varieties of PWR fuel, a bounding TPD and BPRA had to be determined for the purposes of the analysis. This was accomplished by analyzing all of the BPRAs and TPDs (Westinghouse and B&W 14x14 through 17x17) found in references [5.2.5] and [5.2.7] to determine the TPD and BPRA which produced the highest Cobalt-60 source term and decay heat for a specific burnup and cooling time. The bounding TPD was determined to be the Westinghouse 17x17 guide tube plug and the bounding BPRA was actually determined by combining the higher masses of the Westinghouse 17x17 and 15x15 BPRAs into a singly hypothetical BPRA. The masses of this TPD and BPRA are listed in Table 5.2.29. As mentioned above, reference [5.2.5] describes the Westinghouse 14x14 water displacement guide tube plug as having a steel portion which extends into the active fuel zone. This particular water displacement guide tube plug was analyzed and determined to be bounded by the design basis TPD and BPRA.

Once the bounding BPRA and TPD were determined, the allowable decay heat load and Co-60 source from the BPRA and TPD were specified: 0.77 watts and 50 curies Co-60 for each TPD, and 13.0 watts and 831 curies Co-60 for each BPRA. Table 5.2.30 shows the curies of Co-60 that were calculated for BPRAs and TPDs in each region of the fuel assembly (e.g. incore, plenum, top). The allowable decay heat load for the TPDs and BPRAs was subtracted from the allowable decay heat load per assembly to determine the allowable PWR fuel assembly burnup and cooling times listed in Table 1.1-6 of Appendix B of the Certificate of Compliance. Since the decay heat load of the TPDs is negligible the same burnup and cooling time is used for assemblies with or without TPDs. However, a different burnup and cooling time is used for assemblies that contain BPRAs to account for the allowable BPRA decay heat load of 13.0 watts. A separate allowable burnup and cooling time is used for BPRAs and TPDs. These burnup and cooling times assure that the decay heat load and Cobalt-60 activity remain below the allowable levels specified above. It should be noted that at very high burnups, greater than 200,000 MWD/MTU the TPD decay heat load for a given cooling time actually decreases as the burnup continues to increase. This is due to a decrease in the Cobalt-60 production rate as the initial Cobalt-59 impurity is being depleted. Conservatively, a constant cooling time has been specified for burnups from 180,000 to 630,000 MWD/MTU for the TPDs.

Section 5.4.6 demonstrates that the dose rates from fuel assemblies containing BPRAs or TPDs is bounded by the dose rates presented in Section 5.1.1.

5.2.5 Choice of Design Basis Assembly

The analysis presented in this chapter was performed to bound the fuel assembly classes listed in Tables 2.1.1 and 2.1.2. In order to perform a bounding analysis, a design basis fuel assembly must be chosen. Therefore, a fuel assembly from each fuel class was analyzed and a comparison of the neutrons/sec, photons/sec, and thermal power (watts) was performed. The fuel assembly which produced the highest source for a specified burnup, cooling time, and enrichment was

chosen as the design basis fuel assembly. A separate design basis assembly was chosen for the MPC-24 and the MPC-68.

5.2.5.1 PWR Design Basis Assembly

Table 2.1.1 lists the PWR fuel assembly classes that were evaluated to determine the design basis PWR fuel assembly. Within each class, the fuel assembly with the highest UO_2 mass was analyzed. Since the variations of fuel assemblies within a class are very minor (pellet diameter, clad thickness, etc.), it is conservative to choose the assembly with the highest UO_2 mass. For a given class of assemblies, the one with the highest UO_2 mass will produce the highest radiation source because, for a given burnup (MWD/MTU) and enrichment, the highest UO_2 mass will have produced the most energy and therefore the most fission products.

Table 5.2.24 presents the characteristics of the fuel assemblies analyzed to determine the design basis zircaloy clad PWR fuel assembly. The fuel assembly listed for each class is the assembly with the highest UO_2 mass. The St. Lucie and Ft. Calhoun classes are not present in Table 5.2.24. These assemblies are shorter versions of the CE 16x16 and CE 14x14 assembly classes, respectively. Therefore, these assemblies are bounded by the CE 16x16 and CE 14x14 classes and were not explicitly analyzed. Since the Haddam Neck and San Onofre 1 classes are stainless steel clad fuel, these classes were analyzed separately and are discussed below. All fuel assemblies in Table 5.2.24 were analyzed at the same burnup and cooling time. The initial enrichment used in the analysis is consistent with Table 5.2.23. The results of the comparison are provided in Table 5.2.26. These results indicate that the B&W 15x15 fuel assembly has the highest radiation source term of the zircaloy clad fuel assembly classes considered in Table 2.1.1. This fuel assembly also has the highest UO_2 mass (see Table 5.2.24) which confirms that, for a given initial enrichment, burnup, and cooling time, the assembly with the highest UO_2 mass produces the highest radiation source term.

The Haddam Neck and San Onofre 1 classes are shorter stainless steel clad versions of the WE 15x15 and WE 14x14 classes, respectively. Since these assemblies have stainless steel clad, they were analyzed separately as discussed in Section 5.2.3. Based on the results in Table 5.2.26, which show that the WE 15x15 assembly class has a higher source term than the WE 14x14 assembly class, the Haddam Neck, WE 15x15, fuel assembly was analyzed as the bounding PWR stainless steel clad fuel assembly.

5.2.5.2 BWR Design Basis Assembly

Table 2.1.2 lists the BWR fuel assembly classes that were evaluated to determine the design basis BWR fuel assembly. Since there are minor differences between the array types in the GE BWR/2-3 and GE BWR/4-6 assembly classes, these assembly classes were not considered individually but rather as a single class. Within that class, the array types, 7x7, 8x8, 9x9, and 10x10 were analyzed to determine the bounding BWR fuel assembly. Since the Humboldt Bay 7x7 and Dresden 1 8x8 are smaller versions of the 7x7 and 8x8 assemblies they are bounded by

the 7x7 and 8x8 assemblies in the GE BWR/2-3 and GE BWR/4-6 classes. Within each array type, the fuel assembly with the highest UO_2 mass was analyzed. Since the variations of fuel assemblies within an array type are very minor, it is conservative to choose the assembly with the highest UO_2 mass. For a given array type of assemblies, the one with the highest UO_2 mass will produce the highest radiation source because, for a given burnup (MWD/MTU) and enrichment, it will have produced the most energy and therefore the most fission products. The Humboldt Bay 6x6, Dresden 1 6x6, and LaCrosse assembly classes were not considered in the determination of the bounding fuel assembly. However, these assemblies were analyzed explicitly as discussed below.

Table 5.2.25 presents the characteristics of the fuel assemblies analyzed to determine the design basis zircaloy clad BWR fuel assembly. The fuel assembly listed for each array type is the assembly that has the highest UO_2 mass. All fuel assemblies in Table 5.2.25 were analyzed at the same burnup and cooling time. The initial enrichment used in these analyses is consistent with Table 5.2.23. The results of the comparison are provided in Table 5.2.27. These results indicate that the 7x7 fuel assembly has the highest radiation source term of the zircaloy clad fuel assembly classes considered in Table 2.1.2. This fuel assembly also has the highest UO_2 mass which confirms that, for a given initial enrichment, burnup, and cooling time, the assembly with the highest UO_2 mass produces the highest radiation source term. According to Reference [5.2.6], the last discharge of a 7x7 assembly was in 1985 and the maximum average burnup for a 7x7 during their operation was 29,000 MWD/MTU. This clearly indicates that the existing 7x7 assemblies have an average burnup and minimum cooling time that is well within the burnup and cooling time limits in Appendix B to the Certificate of Compliance. Therefore, the 7x7 assembly has never reached the burnup level analyzed in this chapter. However, in the interest of conservatism the 7x7 was chosen as the bounding fuel assembly array type.

Since the LaCrosse fuel assembly type is a stainless steel clad 10x10 assembly it was analyzed separately. The maximum burnup and minimum cooling times for this assembly are limited to 22,500 MWD/MTU and 10-year cooling as specified in Appendix B to the Certificate of Compliance. This assembly type is discussed further in Section 5.2.3.

The Humboldt Bay 6x6 and Dresden 1 6x6 fuel are older and shorter fuel than the other array types analyzed and therefore are considered separately. The Dresden 1 6x6 was chosen as the design basis fuel assembly for the Humboldt Bay 6x6 and Dresden 1 6x6 fuel assembly classes because it has the higher UO_2 mass. Dresden 1 also contains a few 6x6 MOX fuel assemblies which were explicitly analyzed as well.

Reference [5.2.6] indicates that the Dresden 1 6x6 fuel assembly has a higher UO_2 mass than the Dresden 1 8x8 or the Humboldt Bay fuel (6x6 and 7x7). Therefore, the Dresden 1 6x6 fuel assembly was also chosen as the bounding assembly for damaged fuel and fuel debris for the Humboldt Bay and Dresden 1 fuel assembly classes.

Since the design basis damaged fuel assembly and the design basis intact 6x6 fuel assembly are identical, the analysis presented in Section 5.4.2 for the damaged fuel assembly also demonstrates the acceptability of storing intact 6x6 fuel assemblies from the Dresden 1 and Humboldt Bay fuel assembly classes.

5.2.5.3 Decay Heat Loads

Section 2.1.5 describes the calculation of the burnup versus cooling time Technical Specification which is based on a maximum permissible decay heat per assembly. The decay heat values per assembly were calculated using the methodology described in Section 5.2. The design basis fuel assemblies, as described in Table 5.2.1, were used in the calculation of the burnup versus cooling time Technical Specification. The enrichments used in the calculation of the decay heats were consistent with Table 5.2.23. As demonstrated in Tables 5.2.26 and 5.2.27, the design basis fuel assembly produces a higher decay heat value than the other assembly types considered. This is due to the higher heavy metal mass in the design basis fuel assemblies. Conservatively, Appendix B of the Certificate of Compliance limits the heavy metal mass of the design basis fuel assembly classes to a value less than the design basis value utilized in this chapter. This provides additional assurance that the decay heat values are bounding values.

As further demonstration that the decay heat values (calculated using the design basis fuel assemblies) are conservative, a comparison between these calculated decay heats and the decay heats reported in Reference [5.2.7] are presented in Table 5.2.28. This comparison is made for a burnup of 30,000 MWD/MTU and a cooling time of 5 years. The burnup was chosen based on the limited burnup data available in Reference [5.2.7].

The heavy metal mass of the non-design basis fuel assembly classes in Appendix B of the Certificate of Compliance are limited to the masses used in Tables 5.2.24 and 5.2.25. No margin is applied between the allowable mass and the analyzed mass of heavy metal for the non-design basis fuel assemblies. This is acceptable because additional assurance that the decay heat values for the non-design basis fuel assemblies are bounding values is obtained by using the decay heat values for the design basis fuel assemblies to determine the acceptable storage criteria for all fuel assemblies. As mentioned above, Table 5.2.28 demonstrates the level of conservatism in applying the decay heat from the design basis fuel assembly to all fuel assemblies.

5.2.6 Thoria Rod Canister

Dresden Unit 1 has a single DFC containing 18 thoria rods which have obtained a relatively low burnup, 16,000 MWD/MTU. These rods were removed from two 8x8 fuel assemblies which contained 9 rods each. The irradiation of thorium produces an isotope which is not commonly found in depleted uranium fuel. Th-232 when irradiated produces U-233. The U-233 can undergo an (n,2n) reaction which produces U-232. The U-232 decays to produce Tl-208 which produces a 2.6 MeV gamma during Beta decay. This results in a significant source in the 2.5-3.0

MeV range which is not commonly present in depleted uranium fuel. Therefore, this single DFC container was analyzed to determine if it was bounded by the current shielding analysis.

A radiation source term was calculated for the 18 thoria rods using SAS2H and ORIGEN-S for a burnup of 16,000 MWD/MTU and a cooling time of 18 years. Table 5.2.31 describes the 8x8 fuel assembly that contains the thoria rods. Table 5.2.32 and 5.2.33 show the gamma and neutron source terms, respectively, that were calculated for the 18 thoria rods in the thoria rod canister. Comparing these source terms to the design basis 6x6 source terms for Dresden Unit 1 fuel in Tables 5.2.6 and 5.2.14 clearly indicates that the design basis source terms bound the thoria rods source terms in all neutron groups and in all gamma groups except the 2.5-3.0 MeV group. As mentioned above, the thoria rods have a significant source in this energy range due to the decay of Tl-208.

Section 5.4.8 provides a further discussion of the thoria rod cansiter and its acceptablity for storage in the HI-STAR 100 System.

5.2.7 Fuel Assembly Neutron Sources

Neutron sources are used in reactors during initial startup of reactor cores. There a different types of neutron sources (e.g. californium, americium-beryllium, plutonium-beryllium, antimony-beryllium). These neutron sources are typically inserted into the water rod of a fuel assembly and are usually removable.

Dresden Unit 1 has a few antimony-beryllium neutron sources. These sources have been analyzed in Section 5.4.7 to demonstrate that they are acceptable for storage in the HI-STAR 100 System. Currently these are the only neutron source permitted for storage in the HI-STAR 100 System.

Table 5.2.1

DESCRIPTION OF DESIGN BASIS INTACT ZIRCALOY CLAD FUEL

	PWR	**BWR**
Assembly type/class	B&W 15×15	GE 7×7
Active fuel length (in.)	144	144
No. of fuel rods	208	49
Rod pitch (in.)	0.568	0.738
Cladding material	zircaloy-4	zircaloy-2
Rod diameter (in.)	0.428	0.570
Cladding thickness (in.)	0.0230	0.0355
Pellet diameter (in.)	0.3742	0.488
Pellet material	UO_2	UO_2
Pellet density (gm/cc)	10.412 (95% of theoretical)	10.412 (95% of theoretical)
Enrichment (w/o ^{235}U)	3.4 and 3.6	2.9 and 3.2
Burnup (MWD/MTU)†	40,000 and 47,500 (MPC-24)	35,000 and 45,000 (MPC-68)
Cooling Time (years)†	5 and 8 (MPC-24)	5 and 9 (MPC-68)
Specific power (MW/MTU)	40	30
Weight of UO_2 (kg)††	562.029	225.177
Weight of U (kg)††	495.485	198.516

Notes:

1. The B&W 15x15 is the design basis assembly for the following fuel assembly classes listed in Table 2.1.1: B&W 15x15, B&W 17x17, CE 14x14, CE 16x16, WE 14x14, WE 15x15, WE 17x17, St. Lucie, and Ft. Calhoun.
2. The GE 7x7 is the design basis assembly for the following fuel assembly classes listed in Table 2.1.2: GE BWR/2-3, GE BWR/4-6, Humboldt Bay 7x7, and Dresden 1 8x8.

† Burnup and cooling time combinations conservatively bound the acceptable burnup and cooling times listed in Appendix B to the Certificate of Compliance.

†† Derived from parameters in this table.

Table 5.2.1 (continued)

DESCRIPTION OF DESIGN BASIS INTACT ZIRCALOY CLAD FUEL

	PWR	BWR
No. of Water Rods/Guide Tubes	17	0
Water Rod O.D. (in.)	0.53	N/A
Water Rod Thickness (in.)	0.0160	N/A
Lower End Fitting (kg)	9.46	4.8
Gas Plenum Springs (kg)	0.72176	1.1
Gas Plenum Spacer (kg)	0.82824	N/A
Expansion Springs (kg)	N/A	0.4
Upper End Fitting (kg)	9.28	2.0
Handle (kg)	N/A	0.5
Fuel Grid Spacer Springs (kg of steel)	N/A	0.33

Table 5.2.2

DESCRIPTION OF DESIGN BASIS DAMAGED ZIRCALOY CLAD FUEL

	BWR
Fuel type	GE 6x6
Active fuel length (in.)	110
No. of fuel rods	36
Rod pitch (in.)	0.694
Cladding material	zircaloy-2
Rod diameter (in.)	0.5645
Cladding thickness (in.)	0.035
Pellet diameter (in.)	0.494
Pellet material	UO_2
Pellet density (gm/cc)	10.412 (95% of theoretical)
Enrichment (w/o ^{235}U)	2.24
Burnup (MWD/MTU)	30,000
Cooling Time (years)	18
Specific power (MW/MTU)	16.5
Weight of UO_2 (kg)†	129.5
Weight of U (kg)†	114.2

Notes:

1. The 6x6 is the design basis damaged fuel assembly for the Humboldt Bay (all array types) and the Dresden 1 (all array types) damaged fuel assembly classes. It is also the design basis fuel assembly for the intact Humboldt Bay 6x6 and Dresden 1 6x6 fuel assembly classes.
2. This design basis damaged fuel assembly is also the design basis fuel assembly for fuel debris.

† Derived from parameters in this table.

Table 5.2.3

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Table 5.2.4

CALCULATED MPC-24 PWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

Lower Energy	**Upper Energy**	**40,000 MWD/MTU 5-Year Cooling**		**47,500 MWD/MTU 8-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)	(MeV/s)	(Photons/s)
7.0e-01	1.0	5.96e+14	7.01e+14	3.06e+14	3.60e+14
1.0	1.5	1.38e+14	1.11e+14	9.68e+13	7.74e+13
1.5	2.0	8.94e+12	5.11e+12	4.61e+12	2.64e+12
2.0	2.5	6.85e+12	3.05e+12	6.28e+11	2.79e+11
2.5	3.0	2.67e+11	9.71e+10	3.96e+10	1.44e+10
Totals		7.50e+14	8.20e+14	4.08e+14	4.40e+14

Table 5.2.5

CALCULATED MPC-68 BWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

Lower Energy	**Upper Energy**	**35,000 MWD/MTU 5-Year Cooling**		**45,000 MWD/MTU 9-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)	(MeV/s)	(Photons/s)
7.0e-01	1.0	1.84e+14	2.17e+14	7.92e+13	9.32e+13
1.0	1.5	4.28e+13	3.43e+13	2.85e+13	2.28e+13
1.5	2.0	2.81e+12	1.60e+12	1.37e+12	7.83e+11
2.0	2.5	2.13e+12	9.48e+11	9.25e+10	4.11e+10
2.5	3.0	8.50e+10	3.09e+10	6.78e+9	2.47e+9
Totals		2.32e+14	2.54e+14	1.09e+14	1.17e+14

Table 5.2.6

CALCULATED MPC-68 and MPC-68F BWR FUEL GAMMA SOURCE PER ASSEMBLY FOR DESIGN BASIS ZIRCALOY CLAD DAMAGED FUEL

Lower Energy	**Upper Energy**	**30,000 MWD/MTU 18-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)
7.0e-01	1.0	3.97e+12	4.67e+12
1.0	1.5	3.67e+12	2.94e+12
1.5	2.0	2.20e+11	1.26e+11
2.0	2.5	1.35e+9	5.99e+8
2.5	3.0	7.30e+7	2.66e+7
Totals		7.86e+12	7.74e+12

Table 5.2.7

SCALING FACTORS USED IN CALCULATING THE ^{60}Co SOURCE

Region	PWR	BWR
Handle	N/A	0.05
Upper end fitting	0.1	0.1
Gas plenum spacer	0.1	N/A
Expansion springs	N/A	0.1
Gas plenum springs	0.2	0.2
Grid spacer springs	N/A	1.0
Lower end fitting	0.2	0.15

Table 5.2.8

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Table 5.2.9

CALCULATED MPC-24 ^{60}Co SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
AT VARYING BURNUP AND COOLING TIMES

Location	**40,000 MWD/MTU 5-Year Cooling (curies)**	**47,500 MWD/MTU 8-Year Cooling (curies)**
Lower end fitting	154.95	118.06
Gas plenum springs	11.82	9.01
Gas plenum spacer	6.78	5.17
Expansion springs	N/A	N/A
Grid spacer springs	N/A	N/A
Upper end fitting	76.00	57.91
Handle	N/A	N/A

Table 5.2.10

CALCULATED MPC-68 ^{60}Co SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
AT VARYING BURNUP AND COOLING TIMES

Location	**35,000 MWD/MTU 5-Year Cooling (curies)**	**45,000 MWD/MTU 9-Year Cooling (curies)**
Lower end fitting	57.38	40.15
Gas plenum springs	17.53	12.27
Gas plenum spacer	N/A	N/A
Expansion springs	3.19	2.23
Grid spacer springs	26.30	18.40
Upper end fitting	15.94	11.15
Handle	1.99	1.39

Table 5.2.11

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Table 5.2.12

CALCULATED MPC-24 PWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUP AND COOLING TIMES

Lower Energy (MeV)	**Upper Energy (MeV)**	**40,000 MWD/MTU 5-Year Cooling (Neutrons/s)**	**47,500 MWD/MTU 8-Year Cooling (Neutrons/s)**
1.0e-01	4.0e-01	1.11e+7	1.80e+7
4.0e-01	9.0e-01	5.69e+7	9.19e+7
9.0e-01	1.4	5.21e+7	8.41e+7
1.4	1.85	3.85e+7	6.20e+7
1.85	3.0	6.80e+7	1.10e+8
3.0	6.43	6.16e+7	9.94e+7
6.43	20.0	5.45e+6	8.81e+6
Totals		2.94e+8	4.74e+8

Table 5.2.13

CALCULATED MPC-68 BWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUP AND COOLING TIMES

Lower Energy (MeV)	Upper Energy (MeV)	35,000 MWD/MTU 5-Year Cooling (Neutrons/s)	45,000 MWD/MTU 9-Year Cooling (Neutrons/s)
1.0e-01	4.0e-01	3.05e+6	6.23e+6
4.0e-01	9.0e-01	1.56e+7	3.18e+7
9.0e-01	1.4	1.43e+7	2.91e+7
1.4	1.85	1.06e+7	2.15e+7
1.85	3.0	1.87e+7	3.79e+7
3.0	6.43	1.69e+7	3.44e+7
6.43	20.0	1.49e+6	3.05e+6
Totals		8.06e+7	1.64e+8

Table 5.2.14

CALCULATED MPC-68 and MPC-68F BWR NEUTRON SOURCE PER ASSEMBLY FOR DESIGN BASIS DAMAGED ZIRCALOY CLAD FUEL

Lower Energy (MeV)	**Upper Energy (MeV)**	**30,000 MWD/MTU 18-Year Cooling (Neutrons/s)**
1.0e-01	4.0e-01	8.22e+5
4.0e-01	9.0e-01	4.20e+6
9.0e-01	1.4	3.87e+6
1.4	1.85	2.88e+6
1.85	3.0	5.18e+6
3.0	6.43	4.61e+6
6.43	20.0	4.02e+5
Totals		2.20e+7

Table 5.2.15

DESCRIPTION OF DESIGN BASIS ZIRCALOY CLAD MIXED OXIDE FUEL

	BWR
Fuel type	GE 6x6
Active fuel length (in.)	110
No. of fuel rods	36
Rod pitch (in.)	0.696
Cladding material	zircaloy-2
Rod diameter (in.)	0.5645
Cladding thickness (in.)	0.036
Pellet diameter (in.)	0.482
Pellet material	UO_2 and $PuUO_2$
No. of UO_2 Rods	27
No. of $PuUO_2$ rods	9
Pellet density (gm/cc)	10.412 (95% of theoretical)
Enrichment (w/o ^{235}U)†	2.24 (UO_2 rods) 0.711 ($PuUO_2$ rods)
Burnup (MWD/MTU)	30,000
Cooling Time (years)	18
Specific power (MW/MTU)	16.5
Weight of UO_2,$PuUO_2$ (kg)††	123.3
Weight of U,Pu (kg)††	108.7

† See Table 5.3.3 for detailed composition of $PuUO_2$ rods.

†† Derived from parameters in this table.

Table 5.2.16

CALCULATED MPC-68 BWR FUEL GAMMA SOURCE PER ASSEMBLY FOR DESIGN BASIS ZIRCALOY CLAD MIXED OXIDE FUEL

Lower Energy	**Upper Energy**	**30,000 MWD/MTU 18-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)
7.0e-01	1.0	3.87e+12	4.56e+12
1.0	1.5	3.72e+12	2.98e+12
1.5	2.0	2.18e+11	1.25e+11
2.0	2.5	1.17e+9	5.22e+8
2.5	3.0	9.25e+7	3.36e+7
Totals		7.81e+12	7.67e+12

Table 5.2.17

CALCULATED MPC-68 BWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD MIXED OXIDE FUEL

Lower Energy (MeV)	**Upper Energy (MeV)**	**30,000 MWD/MTU 18-Year Cooling (Neutrons/s)**
1.0e-01	4.0e-01	1.24e+6
4.0e-01	9.0e-01	6.36e+6
9.0e-01	1.4	5.88e+6
1.4	1.85	4.43e+6
1.85	3.0	8.12e+6
3.0	6.43	7.06e+6
6.43	20.0	6.07e+5
Totals		3.37e+7

Table 5.2.18

DESCRIPTION OF DESIGN BASIS INTACT STAINLESS STEEL CLAD FUEL

	PWR	**BWR**
Fuel type	WE 15x15	A/C 10x10
Active fuel length (in.)	144	144
No. of fuel rods	204	100
Rod pitch (in.)	0.563	0.565
Cladding material	304 SS	348H SS
Rod diameter (in.)	0.422	0.396
Cladding thickness (in.)	0.0165	0.02
Pellet diameter (in.)	0.3825	0.35
Pellet material	UO_2	UO_2
Pellet density (gm/cc)	10.412 (95% of theoretical)	10.412 (95% of theoretical)
Enrichment (w/o ^{235}U)	3.5	3.5
Burnup (MWD/MTU)	30,000 @ 9 yr (MPC-24) 40,000 @ 15 yr (MPC-24)	22,500 (MPC-68)
Cooling Time (years)	9 (MPC-24) 15 (MPC-24)	10 (MPC-68)
Specific power (MW/MTU)	37.96	29.17
No. of Water Rods	21	0
Water Rod O.D. (in.)	0.546	N/A
Water Rod Thickness (in.)	0.017	N/A

Notes:
1. The WE 15x15 is the design basis assembly for the following fuel assembly classes listed in Table 2.1.1: Haddam Neck and San Onofre 1.
2. The A/C 10x10 is the design basis assembly for the following fuel assembly class listed in Table 2.1.2: LaCrosse.

Table 5.2.19

CALCULATED BWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

Lower Energy	**Upper Energy**	**22,500 MWD/MTU 10-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)
7.0e-01	1.0	1.97e+13	2.31e+13
1.0	1.5	7.93e+13	6.34e+13
1.5	2.0	4.52e+11	2.58e+11
2.0	2.5	3.28e+10	1.46e+10
2.5	3.0	1.69e+9	6.14e+8
Totals		9.95e+13	8.68e+13

Note:
These source terms were calculated for a 144 inch active fuel length. The actual active fuel length is 83 inches.

Table 5.2.20

CALCULATED PWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

Lower Energy	**Upper Energy**	**30,000 MWD/MTU 9-Year Cooling**		**40,000 MWD/MTU 15-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)	(MeV/s)	(Photons/s)
7.0e-01	1.0	1.18e+14	1.39e+14	4.79e+13	5.63e+13
1.0	1.5	3.00e+14	2.40e+14	1.88e+14	1.50e+14
1.5	2.0	2.28e+12	1.30e+12	2.07e+12	1.18e+12
2.0	2.5	2.34e+11	1.04e+11	1.28e+10	5.71e+9
2.5	3.0	1.33e+10	4.83e+9	9.59e+8	3.49e+8
Totals		4.21e+14	3.80e+14	2.38e+14	2.07e+14

Note:
These source terms were calculated for a 144 inch active fuel length. The actual active fuel length is 122 inches.

Table 5.2.21

CALCULATED BWR NEUTRON SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

Lower Energy (MeV)	Upper Energy (MeV)	22,500 MWD/MTU 10-Year Cooling (Neutrons/s)
1.0e-01	4.0e-01	2.23e+5
4.0e-01	9.0e-01	1.14e+6
9.0e-01	1.4	1.07e+6
1.4	1.85	8.20e+5
1.85	3.0	1.56e+6
3.0	6.43	1.30e+6
6.43	20.0	1.08e+5
Total		6.22e+6

Note:
These source terms were calculated for a 144 inch active fuel length. The actual active fuel length is 83 inches.

Table 5.2.22

CALCULATED PWR NEUTRON SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

Lower Energy (MeV)	Upper Energy (MeV)	30,000 MWD/MTU 9-Year Cooling (Neutrons/s)	40,000 MWD/MTU 15-Year Cooling (Neutrons/s)
1.0e-01	4.0e-01	3.05e+6	8.02e+6
4.0e-01	9.0e-01	1.56e+7	4.10e+7
9.0e-01	1.4	1.44e+7	3.77e+7
1.4	1.85	1.07e+7	2.79e+7
1.85	3.0	1.93e+7	4.98e+7
3.0	6.43	1.71e+7	4.47e+7
6.43	20.0	1.49e+6	3.93e+6
Totals		8.16e+7	2.13e+8

Note:
These source terms were calculated for a 144 inch active fuel length. The actual active fuel length is 122 inches.

Table 5.2.23

INITIAL ENRICHMENTS USED IN THE SOURCE TERM CALCULATIONS

Burnup Range (MWD/MTU)	Initial Enrichment (wt.% ^{235}U)
BWR Fuel	
20,000-25,000	2.1
25,000-30,000	2.4
30,000-35,000	2.6
35,000-40,000	2.9
40,000-45,000	3.0
45,000-50,000	3.2
PWR Fuel	
20,000-25,000	2.3
25,000-30,000	2.6
30,000-35,000	2.9
35,000-40,000	3.2
40,000-45,000	3.4
45,000-50,000	3.6

Note: The burnup ranges do not overlap. Therefore, 20,000-25,000 MWD/MTU means 20,000-24,999.9 MWD/MTU, etc.

Table 5.2.24

DESCRIPTION OF EVALUATED INTACT ZIRCALOY CLAD PWR FUEL

Assembly class	WE 14×14	WE 15×15	WE 17×17	CE 14×14	CE 16×16	B&W 15×15	B&W 17×17
Active fuel length (in.)	144	144	144	144	150	144	144
No. of fuel rods	179	204	264	176	236	208	264
Rod pitch (in.)	0.556	0.563	0.496	0.580	0.5063	0.568	0.502
Cladding material	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4	Zr-4
Rod diameter (in.)	0.422	0.422	0.374	0.440	0.382	0.428	0.377
Cladding thickness (in.)	0.0243	0.0245	0.0225	0.0280	0.0250	0.0230	0.0220
Pellet diameter (in.)	0.3659	0.366	0.3225	0.377	0.3255	0.3742	0.3252
Pellet material	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Pellet density (gm/cc) (95% of theoretical)	10.412	10.412	10.412	10.412	10.412	10.412	10.412
Enrichment (wt.% ^{235}U)	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Burnup (MWD/MTU)	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Cooling time (years)	5	5	5	5	5	5	5
Specific power (MW/MTU)	40	40	40	40	40	40	40
Weight of UO_2 (kg)†	462.451	527.327	529.848	482.706	502.609	562.029	538.757
Weight of U (kg)†	407.697	464.891	467.114	425.554	443.100	495.485	474.968
No. of Guide Tubes	17	21	25	5	5	17	25
Guide Tube O.D. (in.)	0.539	0.546	0.474	1.115	0.98	0.53	0.564
Guide Tube Thickness (in.)	0.0170	0.0170	0.0160	0.0400	0.0400	0.0160	0.0175

† Derived from parameters in this table.

Table 5.2.25

DESCRIPTION OF EVALUATED INTACT ZIRCALOY CLAD BWR FUEL

Array Type	7×7	8×8	9×9	10×10
Active fuel length (in.)	144	144	144	144
No. of fuel rods	49	63	74	92
Rod pitch (in.)	0.738	0.640	0.566	0.510
Cladding material	Zr-2	Zr-2	Zr-2	Zr-2
Rod diameter (in.)	0.570	0.493	0.440	0.404
Cladding thickness (in.)	0.0355	0.0340	0.0280	0.0260
Pellet diameter (in.)	0.488	0.416	0.376	0.345
Pellet material	UO_2	UO_2	UO_2	UO_2
Pellet density (gm/cc) (95% of theoretical)	10.412	10.412	10.412	10.412
Enrichment (wt.% ^{235}U)	3.0	3.0	3.0	3.0
Burnup (MWD/MTU)	40,000	40,000	40,000	40,000
Cooling time (years)	5	5	5	5
Specific power (MW/MTU)	30	30	30	30
Weight of UO_2 (kg)†	225.177	210.385	201.881	211.307
Weight of U (kg)†	198.516	185.475	177.978	186.288
No. of Water Rods	0	1	2	2
Water Rod O.D. (in.)	n/a	0.493	0.980	0.980
Water Rod Thickness (in.)	n/a	0.0340	0.0300	0.0300

† Derived from parameters in this table.

Table 5.2.26

COMPARISON OF SOURCE TERMS FOR INTACT ZIRCALOY CLAD PWR FUEL
3.4 wt.% ^{235}U - 40,000 MWD/MTU - 5 years cooling

Assembly class	WE 14×14	WE 15×15	WE 17×17	CE 14×14	CE 16×16	B&W 15×15	B&W 17×17
Neutrons/sec	2.29e+8 / 2.31e+8	2.63e+8 / 2.65e+8	2.62e+8	2.31e+8	2.34e+8	2.94e+8	2.64e+8
Photons/sec (0.7-3.0 MeV)	6.64e+14/ 7.11e+14	7.54e+14/ 8.12e+14	7.60e+14	6.77e+14	7.06e+14	8.20e+14	7.71e+14
Thermal power (watts)	926.6 / 936.8	1056 / 1068	1062	956.6	995.7	1137	1077

Note:
The WE 14x14 and WE 15x15 have both zircaloy and stainless steel guide tubes. The first value presented is for the assembly with zircaloy guide tubes and the second value is for the assembly with stainless steel guide tubes.

Table 5.2.27

COMPARISON OF SOURCE TERMS FOR INTACT ZIRCALOY CLAD BWR FUEL
3.0 wt.% ^{235}U - 40,000 MWD/MTU - 5 years cooling

Assembly class	7×7	8×8	9×9	10×10
Neutrons/sec	1.33e+8	1.17e+8	1.11e+8	1.22e+8
Photons/sec (0.7-3.0 MeV)	3.10e+14	2.83e+14	2.71e+14	2.89e+14
Thermal power (watts)	435.5	402.3	385.3	407.4

Table 5.2.28

COMPARISON OF CALCULATED DECAY HEATS FOR DESIGN BASIS FUEL AND VALUES REPORTED IN THE DOE CHARACTERISTICS DATABASE † FOR 30,000 MWD/MTU AND 5-YEAR COOLING

Fuel Assembly Class	Decay Heat from the DOE Database (watts/assembly)	Decay Heat from Design Basis Fuel (watts/assembly)
PWR Fuel		
B&W 15x15	752.0	827.5
B&W 17x17	732.9	827.5
CE 16x16	653.7	827.5
CE 14x14	601.3	827.5
WE 17x17	742.5	827.5
WE 15x15	762.2	827.5
WE 14x14	649.6	827.5
BWR Fuel		
7x7	310.9	315.7
8x8	296.6	315.7
9x9	275.0	315.7

Notes:

1. The PWR and BWR design basis fuels are the B&W 15x15 and the GE 7x7, respectively.
2. The decay heat values from the database include contributions from in-core material (e.g. spacer grids).
3. Information on the 10x10 was not available in the DOE database. However, based on the results in Table 5.2.27, the actual decay heat values from the 10x10 would be very similar to the values shown above for the 8x8.

† Reference [5.2.7].

Table 5.2.29

DESCRIPTION OF DESIGN BASIS BURNABLE POISON ROD ASSEMBLY AND THIMBLE PLUG DEVICE

Region	BPRA	TPD
Upper End Fitting (kg of steel)	2.62	2.3
Upper End Fitting (kg of inconel)	0.42	0.42
Gas Plenum Spacer (kg of steel)	0.77488	1.71008
Gas Plenum Springs (kg of steel)	0.67512	1.48992
In-core (kg of steel)	13.2	N/A

Table 5.2.30

DESIGN BASIS COBALT-60 ACTIVITIES FOR BURNABLE POISON ROD ASSEMBLIES AND THIMBLE PLUG DEVICES

Region	**BPRA**	**TPD**
Upper End Fitting (curies Co-60)	30.4	25.21
Gas Plenum Spacer (curies Co-60)	4.6	9.04
Gas Plenum Springs (curies Co-60)	8.2	15.75
In-core (curies Co-60)	787.8	N/A

Table 5.2.31

DESCRIPTION OF FUEL ASSEMBLY USED TO ANNALYZE THORIA RODS IN THE THORIA ROD CANISTER

	BWR
Fuel type	8x8
Active fuel length (in.)	110.5
No. of UO_2 fuel rods	55
No. of UO_2/ThO_2 fuel rods	9
Rod pitch (in.)	0.523
Cladding material	zircaloy
Rod diameter (in.)	0.412
Cladding thickness (in.)	0.025
Pellet diameter (in.)	0.358
Pellet material	98.2% ThO_2 and 1.8% UO_2 for UO_2/ThO_2 rods
Pellet density (gm/cc)	10.412
Enrichment (w/o ^{235}U)	93.5 in UO_2 for UO_2/ThO_2 rods and 1.8 for UO_2 rods
Burnup (MWD/MTIHM)	16,000
Cooling Time (years)	18
Specific power (MW/MTIHM)	16.5
Weight of THO_2 and UO_2 (kg)†	121.46
Weight of U (kg)†	92.29
Weight of Th (kg)†	14.74

† Derived from parameters in this table.

Table 5.2.32

CALCULATED FUEL GAMMA SOURCE FOR THORIA ROD CANISTER CONTAINING EIGHTEEN THORIA RODS

Lower Energy	**Upper Energy**	**16,000 MWD/MTIHM 18-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)
7.0e-01	1.0	5.79e+11	6.81e+11
1.0	1.5	3.79e+11	3.03e+11
1.5	2.0	4.25e+10	2.43e+10
2.0	2.5	4.16e+8	1.85e+8
2.5	3.0	2.31e+11	8.39e+10
Totals		1.23e+12	1.09e+12

Table 5.2.33

CALCULATED FUEL NEUTRON SOURCE FOR THORIA ROD CANISTER CONTAINING EIGHTEEN THORIA RODS

Lower Energy (MeV)	**Upper Energy (MeV)**	**16,000 MWD/MTIHM 18-Year Cooling (Neutrons/s)**
1.0e-01	4.0e-01	5.65e+2
4.0e-01	9.0e-01	3.19e+3
9.0e-01	1.4	6.79e+3
1.4	1.85	1.05e+4
1.85	3.0	3.68e+4
3.0	6.43	1.41e+4
6.43	20.0	1.60e+2
Totals		7.21e+4

5.3 MODEL SPECIFICATIONS

The shielding analysis of the HI-STAR 100 System was performed with MCNP-4A [5.1.1]. MCNP is a Monte Carlo transport code that offers a full three-dimensional combinatorial geometry modeling capability including such complex surfaces as cones and tori. This means that no gross approximations were required to represent the HI-STAR 100 System in the shielding analysis. A sample input file for MCNP is provided in Appendix 5.C.

As discussed in Section 5.1.1, off-normal conditions do not have any implications for the shielding analysis. Therefore, the MCNP models and results developed for the normal conditions also represent the off-normal condition. Section 5.1.2 discussed the accident conditions and stated that the only accident that would impact the shielding analysis would be a loss of the neutron shield. Therefore, the MCNP models of the HI-STAR 100 System normal condition have the neutron shield in place while the accident condition replaces the neutron shield with void.

5.3.1 Description of the Radial and Axial Shielding Configuration

Section 1.5 provides the drawings that describe the HI-STAR 100 System. These drawings were used to create the MCNP models used in the radiation transport calculations. Figures 5.3.2 and 5.3.3 show cross sectional views of the HI-STAR 100 overpack and MPC as it was modeled in MCNP for each of the MPCs. These figures were created with the MCNP two-dimensional plotter and are drawn to scale. The figures clearly illustrate the radial steel fins and pocket trunnions in the neutron shield region. Since the fins and pocket trunnions were modeled explicitly, neutron streaming through these components is accounted for in the calculations of the dose adjacent to the overpack and 1 meter dose. In Section 5.4.1, the dose effect of localized streaming through these compartments is analyzed. Figures 5.3.5 and 5.3.6 show the MCNP models of the MPC-24 and MPC-68 fuel baskets including the as-modeled dimensions. Figure 5.3.9 shows a cross sectional view of the HI-STAR 100 overpack with the as-modeled thickness of the various materials. Figure 5.3.10 is an axial representation of the HI-STAR 100 overpack with the various as-modeled dimensions indicated. As Figure 5.3.10 indicates, the thickness of the MPC-68 lid and the thickness of the MPC-24 lid are 10.0 and 9.5 inches, respectively. Correspondingly, the MPC-internal cavity heights differ by 0.5 inch. In the MCNP models of the MPC-24 and MPC-68, the actual lid thickness and internal cavity height for that particular MPC was used.

Calculations were performed to determine the acceptability of homogenizing the fuel assembly versus explicit modeling. Based on these calculations it was concluded that it was acceptable to homogenize the fuel assembly without loss of accuracy. The PWR fuel assembly modeled was the design basis fuel assembly, the B&W 15x15. The width of this homogenized fuel assembly in MCNP is equal to 15 times the pitch. The BWR fuel assembly modeled was an 8x8 fuel assembly. This is different from the 7x7 design basis fuel assembly used for the source term calculations. However, it is conservative to use an 8x8 fuel assembly in the MCNP model since it contains less fuel and therefore less shielding than the 7x7 fuel assembly. The width of the BWR

homogenized fuel assembly is equal to 8 times the pitch. Homogenization of the fuel assemblies resulted in a noticeable decrease in run time.

Several conservative approximations were made in modeling the MPC. The conservative approximations are listed below.

1. The basket material in the top and bottom 0.9 inches where the MPC basket flow holes are located is not modeled. The length of the basket not modeled (0.9 inches) was determined by calculating the equivalent area removed by the flow holes. This method of approximation is conservative because no material for the basket shielding is provided in the 0.9 inch area at the top and bottom of the MPC basket.

2. The upper and lower fuel spacers are not modeled. The fuel spacers are not needed on all fuel assembly types. However, most PWR fuel assemblies will have upper and lower fuel spacers. The positioning of the fuel assembly for the shielding analysis is determined by the fuel spacer length for the design basis fuel assembly type, but the fuel spacer materials are not modeled. This is conservative since it removes steel which would provide a small amount of additional shielding.

3. For the MPC-24 and the MPC-68, the MPC basket supports are not modeled. This is conservative since it removes steel which would provide a small increase in shielding. The aluminum heat conduction elements are also conservatively not modeled.

4. The MPC-24 basket is fabricated from 5/16 inch thick cell plates. It is conservatively assumed for modeling purposes that the structural portion of the MPC-24 basket is uniformly fabricated from 9/32 inch thick steel. The Boral and sheathing are modeled explicitly. This is conservative since it removes steel which would provide a small amount of additional shielding.

5. In the modeling of the BWR fuel assemblies, the zircaloy flow channel was not represented. This was done because it cannot be guaranteed that all BWR fuel assemblies will have an associated flow channel when placed in the MPC. The flow channel does not contribute to the source, but does provide some small amount of shielding. However, no credit is taken for this additional shielding.

6. In the MPC-24, conservatively, all Boral panels on the periphery were modeled with a reduced width of 5 inches compared to 6.25 inches or 7.5 inches.

7. The MPC-68 is designed for two lid thicknesses: 9.5 inches and 10 inches. Conservatively, all calculations reported in this chapter were performed with the 9.5 inch thick lid.

During this project several design changes occurred that affected the drawings, but did not significantly affect the MCNP models. Therefore, the models may not exactly represent the drawings. The discrepancies between models and drawings are listed and discussed here.

MPC Modeling Discprepancies

1. In the MPCs, there is a sump in the baseplate to enhance draining of the MPC. This localized reduction in the thickness of the baseplate was not modeled. Since there is significant shielding and distance in the HI-STAR outside the MPC baseplate, this localized reduction in shielding will not affect the calculated dose rates outside the HI-STAR.

2. The design configuration of the MPC-24 has been enhanced for criticality purposes. The general location of the 24 assemblies remains basically the same, therefore the shielding analysis continues to use the superseded configuration. Figure 5.3.11 shows the superseded and current configuration for the MPC-24 for comparison.

3. The sheathing thickness on the new MPC-24 configuration was reduced from 0.06 inches to 0.0235 inches. However, the model still uses 0.06 inches. This discrepancy is compensated for by the use of 9/32 inch cell walls and 5 inch boral on the periphery as described above. MCNP calculations were performed with the new MPC-24 configuration under Docket No. 72-1014 in the 100-ton HI-TRAC for comparison to the superceded configuration. These results indicate that on the side of the overpack, the dose rates decrease by approximately 12% on the surface. These results demonstrate that using the superceded MPC-24 design is conservative.

5.3.1.1 Fuel Configuration

As described above, the active fuel region is modeled as a homogenous zone. The end fittings and the plenum regions are also modeled as homogenous regions of steel. The masses of steel used in these regions are shown in Table 5.2.1. The axial description of the design basis fuel assemblies is provided in Table 5.3.1. Figures 5.3.7 and 5.3.8 graphically depict the location of the PWR and BWR fuel assemblies within the HI-STAR 100 System. The axial locations of the Boral, basket, pocket trunnion, and transition areas are shown in these figures.

5.3.1.2 Streaming Considerations

The streaming from the radial steel fins and pocket trunnions in the neutron shield is evaluated in Section 5.4.1. The MCNP model of the HI-STAR 100 completely describes the radial steel fins and pocket trunnions, thereby properly accounting for the streaming effect. This is discussed further in Section 5.4.1.

The design of the HI-STAR 100 System, as described in the drawings in Section 1.5, has eliminated all other possible streaming paths. Therefore, the MCNP model does not represent any additional streaming paths. A brief justification of this assumption is provided for each penetration.

- The lifting trunnions will remain installed in the overpack top flange. No credit is taken for any part of the trunnion that extends outside of the overpack.

- The pocket trunnions are modeled as solid blocks of steel. The pocket trunnion will be filled with a solid steel rotation trunnion attached to the transport frame during handling and a shield plug when located at the ISFSI pad.

- The threaded holes in the MPC lid are plugged with solid plugs during storage and, therefore, do not create a void in the MPC lid.

- The drain and vent ports in the MPC lid are designed to eliminate streaming paths. The steel lost in the MPC lid at the port location is replaced with a block of steel approximately 6 inches thick below the port opening and attached to the underside of the lid. This design feature is shown on the drawings in Section 1.5. The MCNP model did not explicitly represent this arrangement but, rather, modeled the MPC lid as a solid piece.

- The penetrations in the overpack are filled with bolts that extend into the penetration when in storage operations, thereby eliminating any potential direct streaming paths. Cover plates are also designed in such a way as to maintain the thickness of the overpack to the maximum extent practical. Therefore, the MCNP model does not represent any streaming paths due to penetrations in the overpack.

5.3.2 Regional Densities

Composition and densities of the various materials used in the HI-STAR 100 System shielding analyses are given in Tables 5.3.2 and 5.3.3. All of the materials and their actual geometries are represented in the MCNP model.

Sections 4.4 and 4.5 demonstrate that all materials used in the HI-STAR 100 System remain below their design temperatures as specified in Table 2.2.3 during all normal conditions. Therefore, the shielding analysis does not address changes in the material density or composition as a result of temperature changes.

Chapter 11 discusses the effect of the various accident conditions on the temperatures of the shielding materials and the resultant impact on their shielding effectiveness. As stated in Section

5.1.2, there is only one accident that has any significant impact on the shielding configuration. This accident is the loss of the neutron shield in the HI-STAR 100 System as a result of fire or other damage. The change in the neutron shield was conservatively analyzed by assuming that the entire volume of the neutron shield was replaced by void.

Table 5.3.1

DESCRIPTION OF THE AXIAL MCNP MODEL OF THE FUEL ASSEMBLIES†

Region	Start (in.)	Finish (in.)	Length (in.)	Actual Material	Modeled Material
PWR					
Lower End Fitting	0.0	7.375	7.375	SS304	SS304
Space	7.375	8.375	1.0	zircaloy	void
Fuel	8.375	152.375	144	fuel & zircaloy	fuel
Gas Plenum Springs	152.375	156.1875	3.8125	SS304 & zircaloy	SS304
Gas Plenum Spacer	156.1875	160.5625	4.375	SS304 & zircaloy	SS304
Upper End Fitting	160.5625	165.625	5.0625	SS304	SS304
BWR					
Lower End Fitting	0.0	7.385	7.385	SS304	SS304
Fuel	7.385	151.385	144	fuel & zircaloy	fuel
Space	151.385	157.385	6	zircaloy	void
Gas Plenum Springs	157.385	166.865	9.48	SS304 & zircaloy	SS304
Expansion Springs	166.865	168.215	1.35	SS304	SS304
Upper End Fitting	168.215	171.555	3.34	SS304	SS304
Handle	171.555	176	4.445	SS304	SS304

† All dimensions start at the bottom of the fuel assembly. The length of the lower fuel spacer must be added to the distances to determine the distance from the top of the MPC baseplate.

Table 5.3.2

COMPOSITION OF THE MATERIALS IN THE HI-STAR 100 SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
Uranium Oxide	10.412	^{235}U	2.9971(BWR) 3.2615(PWR)
		^{238}U	85.1529(BWR) 84.8885(PWR)
		O	11.85
Boral	2.644	^{10}B	4.4226 (MPC-68) 4.367 (MPC-24)
		^{11}B	20.1474 (MPC-68) 19.893 (MPC-24)
		Al	68.61 (MPC-68) 69.01 (MPC-24)
		C	6.82 (MPC-68) 6.73 (MPC-24)
SS304	7.92	Cr	19
		Mn	2
		Fe	69.5
		Ni	9.5
Carbon Steel	7.82	C	0.5
		Fe	99.5
Zircaloy	6.55	Zr	100

Table 5.3.2 (continued)

COMPOSITION OF THE MATERIALS IN THE HI-STAR 100 SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
Neutron Shield Holtite-A	1.61	C	27.66039
		H	5.92
		Al	21.285
		N	1.98
		O	42.372
		^{10}B	0.14087
		^{11}B	0.64174
BWR Fuel Region Mixture	3.979996	^{235}U	2.4483
		^{238}U	69.5601
		O	9.6801
		Zr	18.3115
PWR Fuel Region Mixture	3.853705	^{235}U	2.6944
		^{238}U	70.1276
		O	9.7895
		Zr	17.3885
Lower End Fitting (PWR)	1.0783	SS304	100
Gas Plenum Springs (PWR)	0.1591	SS304	100
Gas Plenum Spacer (PWR)	0.1591	SS304	100

Table 5.3.2 (continued)

COMPOSITION OF THE MATERIALS IN THE HI-STAR 100 SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
Upper End Fitting (PWR)	1.5410	SS304	100
Lower End Fitting (BWR)	1.5130	SS304	100
Gas Plenum Springs (BWR)	0.2701	SS304	100
Expansion Springs (BWR)	0.6897	SS304	100
Upper End Fitting (BWR)	1.3939	SS304	100
Handle (BWR)	0.2619	SS304	100

Table 5.3.3

COMPOSITION OF THE FUEL IN THE MIXED OXIDE FUEL ASSEMBLIES IN THE MPC-68 OF THE HI-STAR 100 SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
Mixed Oxide Pellets	10.412	^{238}U	84.498
		^{235}U	0.612
		^{238}Pu	0.421
		^{239}Pu	1.455
		^{240}Pu	0.034
		^{241}Pu	0.123
		^{242}Pu	0.007
		O	11.85
Uranium Oxide Pellets	10.412	^{238}U	86.175
		^{235}U	1.975
		O	11.85

FIGURE 5.3.1

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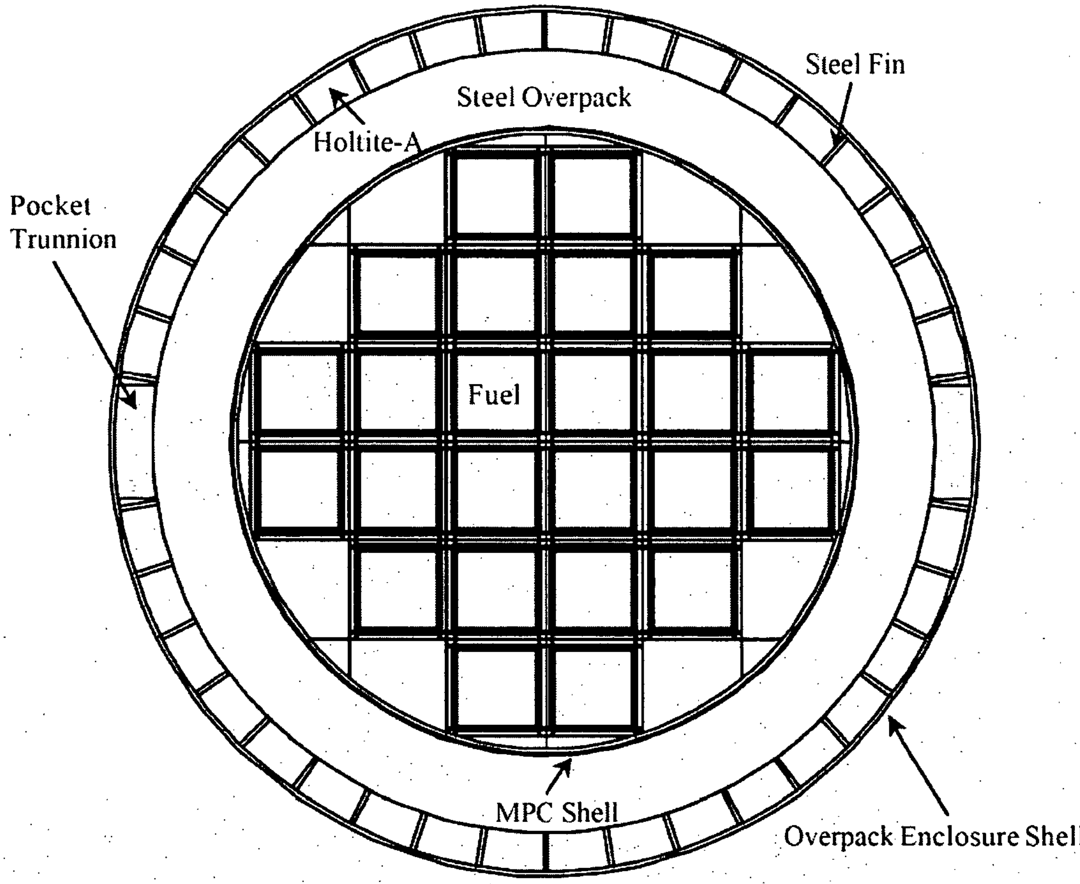


FIGURE 5.3.2; HI-STAR 100 OVERPACK WITH MPC-24 CROSS SECTIONAL VIEW AS MODELLED IN MCNP[†]

† This figure is drawn to scale using the MCNP plotter.

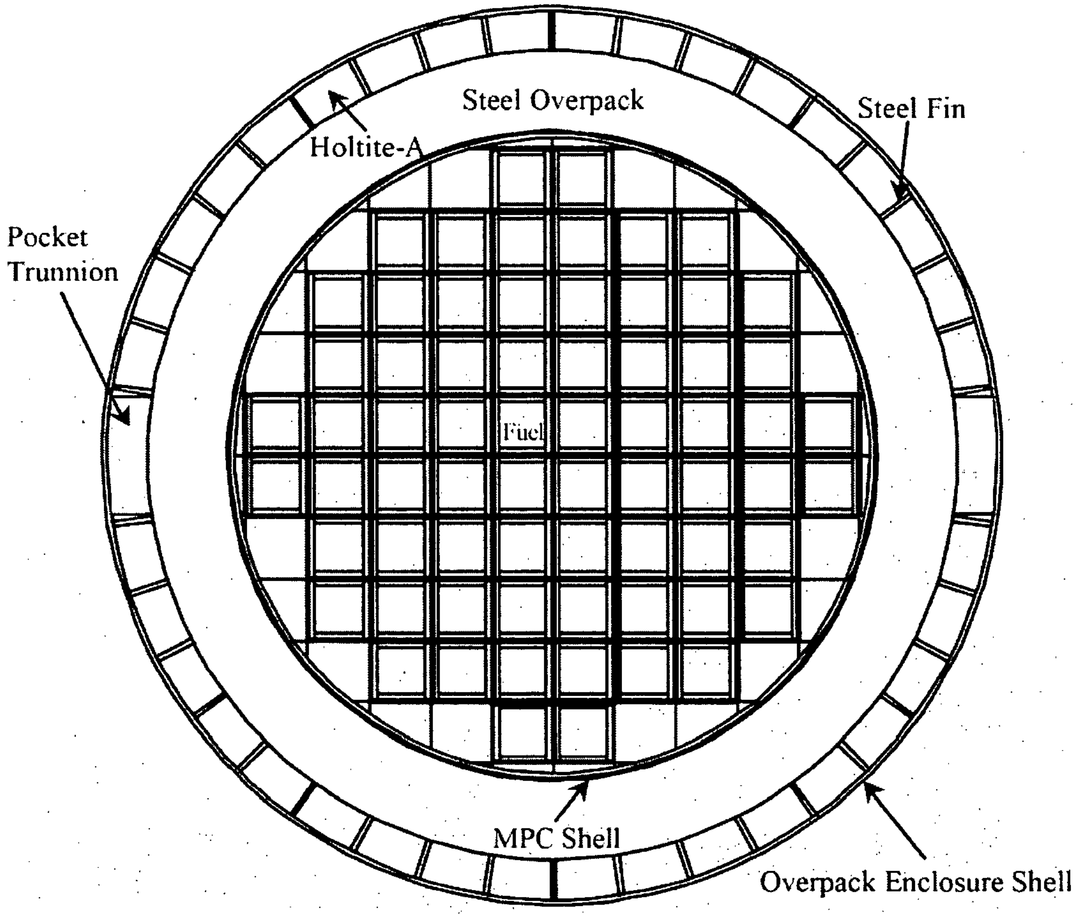


FIGURE 5.3.3; HI-STAR 100 OVERPACK WITH MPC-68 CROSS SECTIONAL VIEW AS MODELLED IN MCNP†

† This figure is drawn to scale using the MCNP plotter.

FIGURE 5.3.4

DELETED

Figure Withheld Under 10 CFR 2.390

FIGURE 5.3.5; CROSS SECTIONAL VIEW OF AN MPC-24 BASKET CELL AS MODELED IN MCNP

Figure Withheld Under 10 CFR 2.390

FIGURE 5.3.6; CROSS SECTIONAL VIEW OF AN MPC-68 BASKET CELL AS MODELED IN MCNP

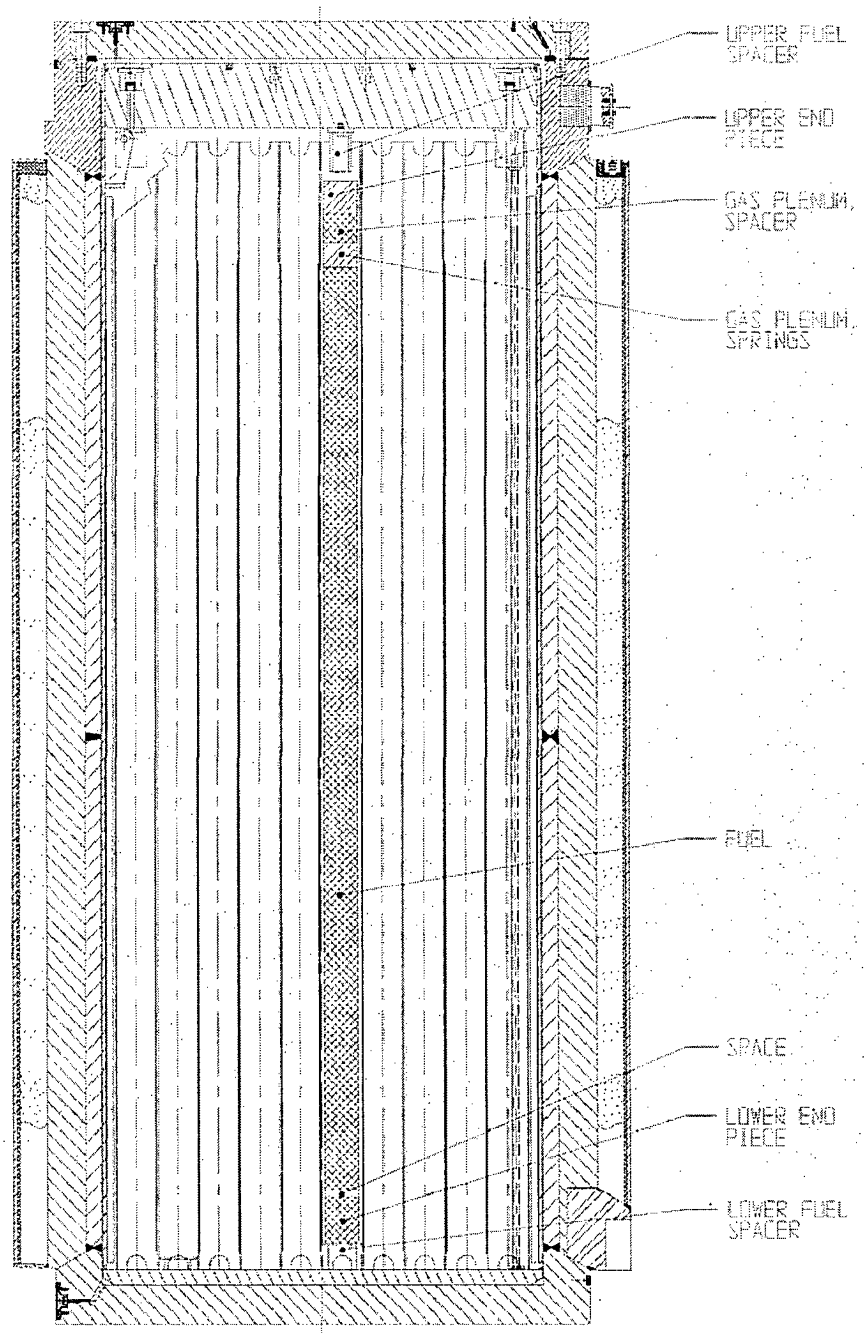


FIGURE 5.3.7; AXIAL LOCATION OF PWR DESIGN BASIS FUEL IN THE HI-STAR 100 SYSTEM

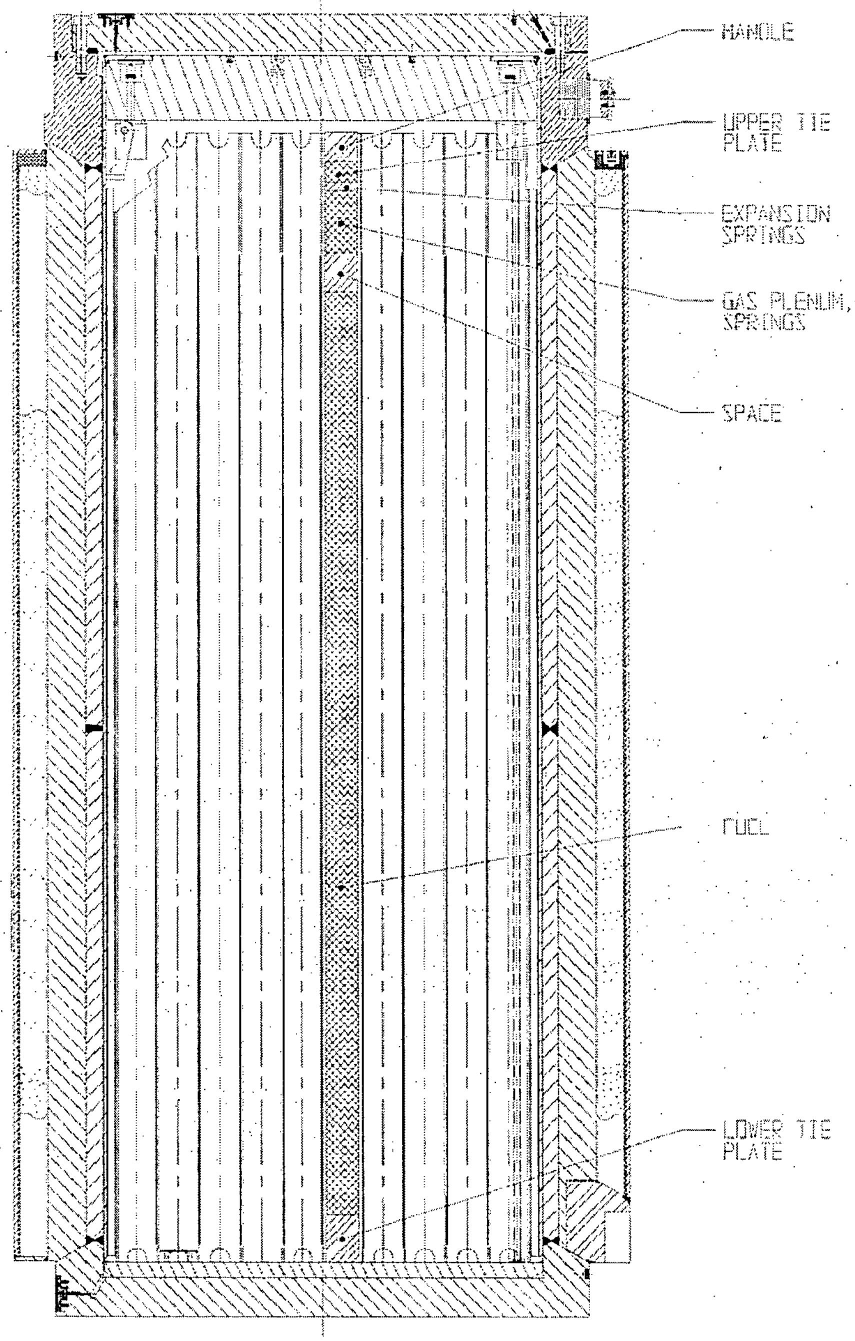
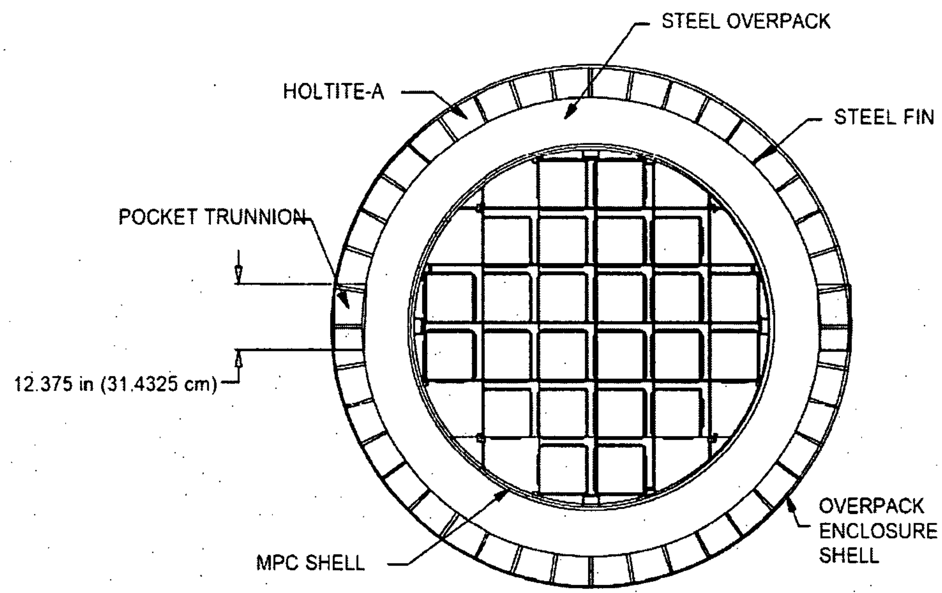


FIGURE 5.3.8; AXIAL LOCATION OF BWR DESIGN BASIS FUEL IN THE HI-STAR 100 SYSTEM



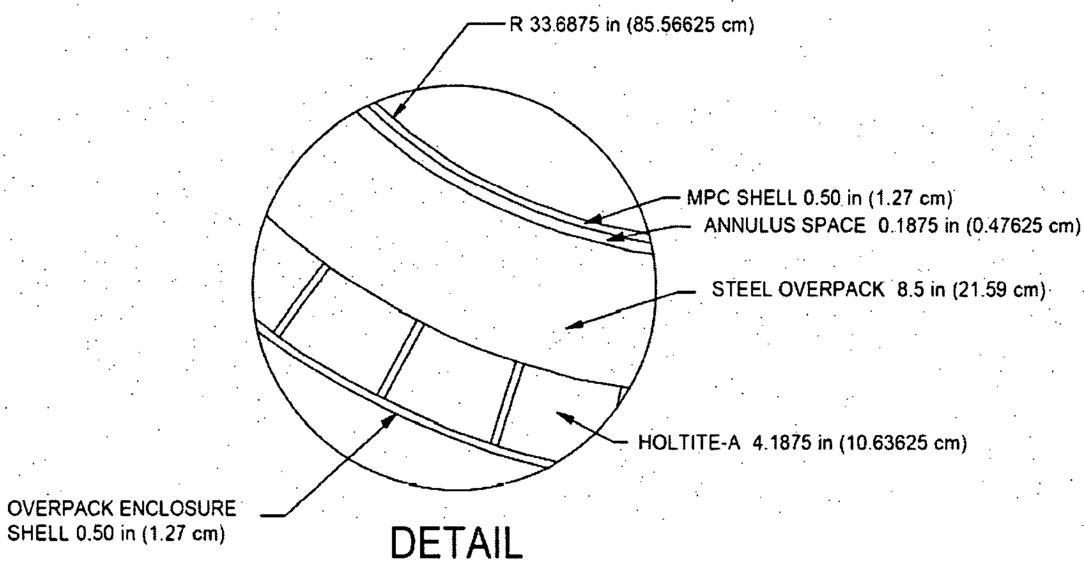
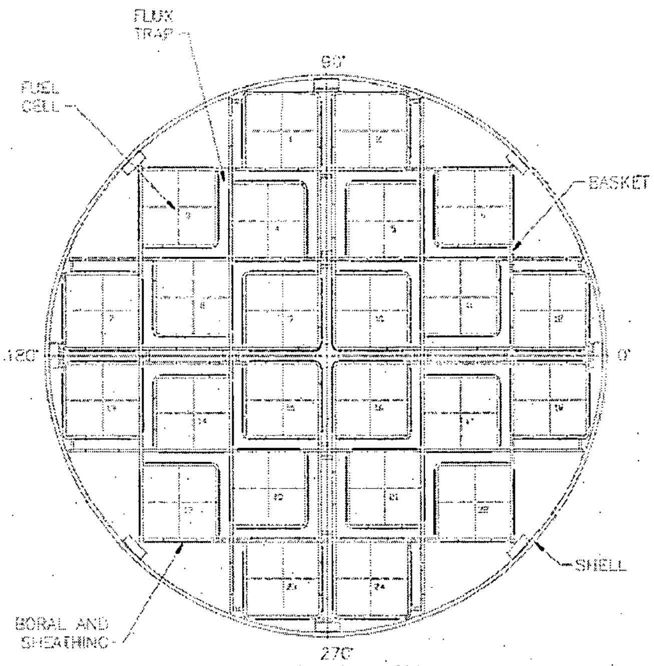


FIGURE 5.3.9; HI-STAR 100 OVERPACK WITH MPC-24 CROSS SECTIONAL VIEW SHOWING THE THICKNESS OF THE MPC SHELL AND OVERPACK AS MODELED IN MCNP

Figure Withheld Under 10 CFR 2.390

FIGURE 5.3.10; AXIAL VIEW OF HI-STAR 100 OVERPACK AND MPC WITH AXIAL DIMENSIONS SHOWN AS MODELED IN MCNP



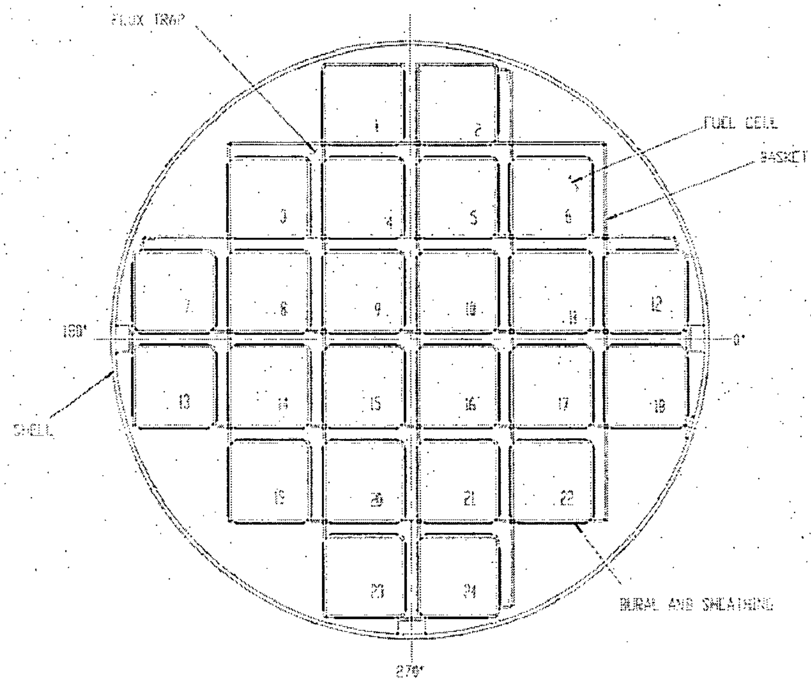


FIGURE 5.3.11; CROSS SECTIONAL VIEWS OF THE CURRENT MPC-24 DESIGN AND THE SUPERSEDED MPC-24 WHICH IS USED IN THE MCNP MODELS.

5.4 SHIELDING EVALUATION

The MCNP-4A code[5.1.1] was used for all of the shielding analyses. MCNP is a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code. Continuous energy cross-section data is represented with sufficient energy points to permit linear-linear interpolation between these points. The individual cross-section libraries used for each nuclide are those recommended by the MCNP manual. All of these data are based on ENDF/B-V data. MCNP has been extensively benchmarked against experimental data by the large user community. References [5.4.2], [5.4.3], and [5.4.4] are three examples of the benchmarking that has been performed.

The energy distribution of the source term, as described earlier, is used explicitly in the MCNP model. A different MCNP calculation is performed for each of the three source terms (neutron, decay gamma, and ^{60}Co). The axial distribution of the fuel source term is described in Table 2.1.8 and Figures 2.1.3 and 2.1.4. The PWR and BWR axial burnup distributions were obtained from References [5.4.5] and [5.4.6] respectively. These axial distributions were obtained from operating plants and are representative of PWR and BWR fuel with burnups greater than 30,000 MWD/MTU. The ^{60}Co source in the activated hardware was assumed to be uniformly distributed over the appropriate regions.

It has been shown that the neutron source strength varies as the burnup level raised by the power of 4.2. Since this relationship is non-linear and since the burnup in the axial center of a fuel assembly is greater than the average burnup, the neutron source strength in the axial center of the assembly is greater than the relative burnup times the average neutron source strength. In order to account for this effect, the neutron source strength in each of the 10 axial nodes listed in Table 2.1.8 was determined by multiplying the average source strength by the relative burnup level raised to the power of 4.2. The peak relative burnups listed in Table 2.1.8 for the PWR and BWR fuels are 1.105 and 1.195 respectively. Using the power of 4.2 relationship results in a 37.6% ($1.105^{4.2}/1.105$) and 76.8% ($1.195^{4.2}/1.195$) increase in the neutron source strength in the peak nodes for the PWR and BWR fuel respectively. The total neutron source strength increases by 15.6% for the PWR fuel assemblies and 36.9% for the BWR fuel assemblies.

MCNP was used to calculate dose at the various desired locations. MCNP calculates neutron or photon flux which can be converted into dose by the use of dose response functions. This is done internally in MCNP and the dose response functions are listed in the input file. The response functions used in these calculations are listed in Table 5.4.1 and were taken from ANSI/ANS 6.1.1, 1977 [5.4.1].

Tables 5.4.2 through 5.4.7 list the normal condition dose rates (from each of the three radiation sources) adjacent to the overpack for each of the burnup levels and cooling times evaluated for the MPC-24 and MPC-68. Tables 5.4.8 and 5.4.9 provide the total dose rate for each burnup level and cooling time for the MPC-24 and MPC-68, respectively. This information was used to determine the worst case burnup level and cooling time and corresponding maximum dose rates

reported in Section 5.1. A detailed discussion of the normal, off-normal, and accident condition dose rates was provided in Sections 5.1.1 and 5.1.2.

Since MCNP is a statistical code, there is an uncertainty associated with the calculated values. In MCNP the uncertainty is expressed as the relative error which is defined as the standard deviation of the mean divided by the mean. Therefore, the standard deviation is represented as a percentage of the mean. The relative error for the total dose rates presented in this chapter were typically less than 3% and the relative error for the individual dose components was typically less than 5%.

5.4.1 Streaming Through Radial Steel Fins and Pocket Trunnions

The HI-STAR 100 overpack utilizes 0.5 inch thick radial steel fins for structural support and cooling. The attenuation of neutrons through steel is substantially less than the attenuation of neutrons through the Holtite-A. Therefore, it is possible to have neutron streaming through the fins which could result in a localized dose peak. The reverse is true for photons which would result in a localized reduction in the photon dose. Analyses were performed to determine the magnitude of the dose peaks and depressions and the impact on localized dose as compared to average total dose. This effect was evaluated at the radial surface of the cask and a distance of one meter from the cask.

In addition to the fins, the pocket trunnions are essentially blocks of steel that are approximately 12 inches wide and 12 inches high. The effect of the pocket trunnion on neutron streaming and photon transmission will be more substantial than the effect of a single fin. Therefore, analyses were performed to quantity this effect. Figure 5.1.1 illustrates the location of the pocket trunnion and its axial position relative to the active fuel. This position will be important in the discussion that follows.

The effect of streaming through the pocket trunnion and the fins was analyzed using MCNP. The model used was an infinite height radial model which consisted of the MPC and the surrounding overpack. The active fuel region of the fuel assemblies was represented in the MPC basket when the neutron source was used and the lower steel regions of the fuel elements were presented in the MPC basket when the cobalt source was used. The pocket trunnion was represented in this infinite model as being axially adjacent to the active fuel. A calculation was not performed with the photon source. Any depression of the gamma dose due to the steel will be evident when using the cobalt source and this will conservatively bound the effects due to the photon source. This is because the average energy of the photons from ^{60}Co is higher than the average energy of decay gammas.

The MPC-24 and the MPC-68 were analyzed. Figure 5.4.1 shows a quarter of the HI-STAR 100 overpack with 91 azimuthal bins drawn. There is one bin per steel fin and 8 bins in each Holtite-A region. This azimuthal binning structure was used in an infinite height two-dimensional model of the MPC and overpack. The dose was calculated in each of these bins and then compared to

the average dose calculated over the surface to determine a peak-to-average ratio for the dose in that bin. The location of the pocket trunnion is shown in Figure 5.4.1. The pocket trunnion was modeled as solid steel. During storage, a shield plug shall be placed in the pocket trunnion recess, and during handling operations a steel rotation trunnion shall be placed in the pocket trunnion recess. To conservatively evaluate the peak-to-average ratio, the pocket trunnion is assumed to be solid steel. The peak-to-average ratio was calculated for the entire pocket trunnion which would correspond to the first seven azimuthal bins.

Table 5.4.10 provides the peak-to-average ratios that were calculated for the various dose components and locations. The peak-to-average ratios were essentially the same for all MPCs, therefore, only one set of values is shown. The values presented for the pocket trunnions are very conservative since the two-dimensional model represented the trunnion as infinite in height whereas the actual height is approximately 12 inches. In addition, the pocket trunnion was represented as being axially adjacent to the active fuel which is not completely accurate for the design basis fuel. The infinite two-dimensional model therefore does not represent any leakage out of the pocket trunnion in the axial direction which would reduce the peaking effect.

Table 5.4.11 presents the dose rates at Dose Point #2 (see Figure 5.1.1) and the adjusted dose rates at this point to account for the streaming effects. An additional dose point labeled 2a is listed in this table. This location is axially adjacent to the pocket trunnion and approximately 6 feet below Dose Point #2. Based on these results it can be concluded that the streaming effect is noticeable but is not of significant concern.

5.4.2 Damaged Fuel Post-Accident Shielding Evaluation

As discussed in Section 5.2.5.2, the analysis presented below, even though it is for damaged fuel, demonstrates the acceptability of storing intact Humboldt Bay 6x6 and intact Dresden 1 6x6 fuel assemblies.

For the damaged fuel and fuel debris accident condition, it is conservatively assumed that the damaged fuel cladding ruptures and all the fuel pellets fall and collect at the bottom of the damaged fuel container. The inner dimension of the damaged fuel container, specified in the design drawings, and the design basis damaged fuel and fuel debris assembly dimensions in Table 5.2.2 are used to calculate the axial height of the rubble in the damaged fuel container assuming 50% compaction. Neglecting the fuel pellet to cladding inner diameter gap, the volume of cladding and fuel pellets available for deposit is calculated assuming the fuel rods are solid. Using the volume in conjunction with the damaged fuel container, the axial height of rubble is calculated to be 80 inches.

Dividing the total fuel gamma source for damaged fuel in Table 5.2.6 by the 80 inch rubble height provides a gamma source per inch of 9.68e+10 photon/s. Dividing the total neutron source for damaged fuel in Table 5.2.14 by 80 inches provides a neutron source per inch of 2.75e+5 neutron/s. These values are both bounded by the BWR design basis fuel gamma source

per inch and neutron source per inch values of 1.76e+12 photon/s and 5.60e+5 neutron/s. These BWR design basis values were calculated by dividing the total source strengths in Tables 5.2.5 and 5.2.13 by the active fuel length of 144 inches. Therefore, the design basis damaged fuel assembly is bounded by the design basis intact BWR fuel assembly for accident conditions. No explicit analysis of the damaged fuel dose rates are provided as they are bounded by the intact fuel analysis.

5.4.3 Site Boundary Evaluation

Since NUREG-1536 [5.2.1] states that detailed calculations need not be presented, Chapter 12 assigns ultimate compliance responsibilities to the site licensee. Therefore, this subsection describes, by example, the general methodology for performing site boundary dose calculations. The site-specific fuel characteristics, burnup, cooling time, and the site layout and boundary characteristics would be factored into the evaluation performed by the licensee.

As an example of the methodology, the dose from a single MPC-24 cask and various arrays of MPC-24 casks at a distance greater than 100 meters was evaluated with MCNP. In the model the casks were placed on an infinite slab of concrete to account for earth-shine effects. The atmosphere was represented as dry air at a uniform density corresponding to 20 degrees C. The height of air modeled was 800 meters. This is more than sufficient to properly account for skyshine effects.

The annual dose, assuming 100% occupancy (8760 hours), at 300 meters from one cask is presented in Table 5.4.12 at the varying maximum burnup and minimum cooling times analyzed. This table indicates that the 40,000 MWD/MTU and 5-year cooling is the bounding case for these combinations.

This table also indicates that the dose due to neutrons is 21% of the total dose. This is an important observation because it implies that simplistic analytical methods such as point kernel techniques may not properly account for the neutron transmission and could lead to low estimates of the site boundary dose.

One of the features of MCNP is the ability to calculate the dose from particles that have passed through certain geometrical regions (referred to as surface or cell flagging). This technique was used to estimate the fraction of the dose at distance from particles, both neutron and gamma, passing through the upper flange region of the overpack. This region is referred to as 3 and 4 on Figure 5.1.1. It was found that, for one cask, approximately 9% of the dose comes from this upper flange region. This is a significant fraction of the total dose and one that is only accounted for using three-dimensional analysis, such as MCNP, which properly includes the effects of neutron and gamma skyshine.

Since the upper flange region is located at the top of the cask, it is reasonable to conclude that this contribution to total dose would be unaffected by placing the cask in an array configuration.

The annual dose, assuming 100% occupancy, at distance from an array of casks was calculated in three steps.

1. The annual dose from the radiation leaving the side of a single HI-STAR 100 overpack was calculated at the distance desired. The side of the HI-STAR 100 overpack is defined as any surface between the bottom of the bottom plate and the top of the closure plate including the upper flange area. Dose value = A.

2. The annual dose from the radiation leaving the top of a single HI-STAR 100 overpack was calculated at the distance desired. The top of the HI-STAR 100 overpack is defined as the top of the closure plate. Dose value = B.

3. The annual dose from the radiation leaving the side of a HI-STAR 100 overpack, when it is in the center of a 3x3 array of casks, was calculated at the distance desired. The casks in the array have a 12 foot pitch. Dose value = C.

The annual dose calculated in each of these three steps was averaged over a cylindrical surface at various distances from the source cask for ease of calculation. In step 3, the dose at the cylindrical surface included contributions from radiation that traveled between the surrounding casks and from radiation that traveled above the surrounding casks and scattered in air to reach the dose location. Therefore, the average dose values from step 3 include all possible paths for radiation to reach the dose location. The values from step 3 represent the dose from a cask in the second row of an array which is shielded by casks in the front row.

The doses calculated in the steps above are listed in Table 5.4.13 for 40,000 MWD/MTU and 5-year cooling. Using these values, the annual dose (at the center of the long side) from an arbitrary 2 by Z array of HI-STAR 100 overpacks can easily be calculated. The following formula describes the method.

Z = number of casks along long side

Dose = ZA + 2ZB + ZC

As an example, the dose from a 2x3 array at 250 meters is presented.

1. The annual dose from the side of a single cask: Dose A = 24.53
2. The annual dose from the top of a single cask: Dose B = 0.63
3. The annual dose from the side of a cask in the center of a 3x3 array: Dose C = 8.81

Using the formula shown above (Z=3) the total dose at 250 meters from a 2x3 array of filled HI-STAR 100 overpacks is 103.80 mrem/year, assuming 100% occupancy.

An important point to notice here is that the dose from the side of the back row of casks is approximately 25% of the total dose. This is a significant contribution and one that would probably not be accounted for properly by simpler methods of analysis.

The results for various arrays of filled HI-STAR 100 overpacks can be found in Section 5.1.1.

5.4.4 Mixed Oxide Fuel Evaluation

The source terms calculated for the Dresden 1 GE 6x6 MOX fuel assemblies can be compared to the design basis source terms for the GE 7x7 assemblies which demonstrates that the MOX fuel source terms are bounded by the design basis source terms and no additional shielding analysis is needed.

Since the active fuel length of the MOX fuel assemblies is shorter than the active fuel length of the design basis fuel, the source terms must be compared on a per inch basis. Dividing the total fuel gamma source for the MOX fuel in Table 5.2.16 by the 110 inch active fuel height provides a gamma source per inch of 6.97e+10 photons/s. Dividing the total neutron source for the MOX fuel assemblies in Table 5.2.17 by 110 inches provides a neutron source strength per inch of 3.06e+5 neutrons/s. These values are both bounded by the BWR design basis fuel gamma source per inch and neutron source per inch values of 1.76e+12 photons/s and 5.60e+5 neutrons/s. These BWR design basis values were calculated by dividing the total source strength in Tables 5.2.5 and 5.2.13 by the active fuel length of 144 inches. This comparison shows that the MOX fuel source terms are bound by the design basis source terms. Therefore, no explicit analysis of dose rates is provided for MOX fuel.

Since the MOX fuel assemblies are Dresden 1 6x6 assemblies, they can also be considered as damaged fuel or fuel debris. Using the same methodology as described in Section 5.4.2, the source term for the MOX fuel is calculated on a per inch basis assuming a post accident rubble height of 80 inches. The resulting gamma and neutron source strengths are 9.59e+10 photons/s and 4.21e+5 neutrons/s. These values are also bounded by the design basis fuel gamma source per inch and neutron source per inch. Therefore, no explicit analysis of dose rates is provided for MOX fuel in a post accident configuration.

5.4.5 Stainless Steel Clad Fuel Evaluation

Table 5.4.14 presents the dose rates at the center of the HI-STAR 100 overpack, adjacent and at one meter distance, for the stainless steel clad fuel. These dose rates, when compared to Tables 5.1.2, 5.1.3, 5.1.5, and 5.1.6, are very close to the dose rates from the design basis zircaloy clad fuel indicating that these fuel assemblies are acceptable for storage.

As described in Section 5.2.3, it would be incorrect to compare the total source strength from the stainless steel clad fuel assemblies to the source strength from the design basis zircaloy clad fuel assemblies since these assemblies do not have the same active fuel length and since there is a

significant gamma source from Cobalt-60 activation in the stainless steel. Therefore it is necessary to calculate the dose rates from the stainless steel clad fuel and compare them to the dose rates from the zircaloy clad fuel. In calculating the dose rates, the source term for the stainless steel fuel was calculated with an artificial active fuel length of 144 inches to permit a simple comparison of dose rates from stainless steel clad fuel and zircaloy clad fuel at the center of the HI-STAR 100 overpack. Since the true active fuel length is shorter than 144 inches and since the end fitting masses of the stainless steel clad fuel are assumed to be identical to the end fitting masses of the zircaloy clad fuel, the dose rates at the other locations on the overpack are bounded by the dose rates from the design basis zircaloy clad fuel, and therefore, no additional dose rates are presented.

5.4.6 BPRAs and TPDs

In order to verify that the BPRAs and TPDs do not affect the shielding analysis, the total dose rates were calculated for the HI-STAR 100 assuming all fuel assemblies in the MPC contained either BPRAs or TPDs. For this calculation, three separate burnups, slightly higher than the allowable burnups listed in Appendix B of the Certificate of Compliance were used with the corresponding cooling time. Tables 5.4.16 and 5.4.17 present the comparison of the total dose rates around the HI-STAR 100 overpack for PWR fuel with and without BPRAs or TPDs. The design basis dose rates are provided in these tables for easy comparison. A comparison of accident condition dose rates is only performed for assemblies with BPRAs since the TPDs, which are in the upper portion of the fuel assembly, will not have a noticeable impact on the accident dose rates at the centerline of the overpack. These tables illustrate that the dose rates for fuel assemblies containing BPRAs and TPDs are bounded by the design basis 40,000 MWD/MTU and 5 year cooling dose rates listed in Section 5.1.1 and Section 5.1.2. Therefore, the addition of BPRAs and TPDs to the MPC-24 is bounded by the shielding analysis presented in this chapter.

5.4.7 Dresden Unit 1 Antimony-Beryllium Neutron Sources

Dresden Unit 1 has antimony-beryllium neutron sources which are placed in the water rod location of their fuel assemblies. These sources are steel rods which contain a cylindrical antimony-beryllium source which is 77.25 inches in length. The steel rod is approximately 95 inches in length. Information obtained from Dresden Unit 1 characterizes these sources in the following manner: "About one-quarter pound of beryllium will be employed as a special neutron source material. The beryllium produces neutrons upon gamma irradiation. The gamma rays for the source at initial start-up will be provided by neutron-activated antimony (about 865 curies). The source strength is approximately 1E+8 neutrons/second."

As stated above, beryllium produces neutrons through gamma irradiation and in this particular case antimony is used as the gamma source. The threshold gamma energy for producing neutrons from beryllium is 1.666 MeV. The outgoing neutron energy increases as the incident gamma energy increases. Sb-124, which decays by Beta decay with a half life of 60.2 days, produces a

gamma of energy 1.69 MeV which is just energetic enough to produce a neutron from beryllium. Approximately 54% of the Beta decays for Sb-124 produce gammas with energies greater than or equal to 1.69 MeV. Therefore, the neutron production rate in the neutron source can be specified as 5.8E-6 neutrons per gamma (1E+8/865/3.7e+10/0.54) with energy greater than 1.666 MeV or 1.16E+5 neutrons/curie (1E+8/865) of Sb-124.

With the short half life of 60.2 days all of the initial Sb-124 is decayed and any Sb-124 that was produced while the neutron source was in the reactor is also decayed since these neutron sources are assumed to have the same minimum cooling time as the Dresden 1 fuel assemblies (array classes 6x6A, 6x6B, 6x6C, and 8x8A) of 18 years. Therefore, there are only two possible gamma sources which can produce neutrons from this antimony-beryllium source. The first is the gammas from the decay of fission products in the fuel assemblies in the MPC. The second gamma source is from Sb-124 which is being produced in the MPC from neutron activation from neutrons from the decay of fission products.

MCNP calculations were performed to determine the gamma source as a result of decay gammas from fuel assemblies and Sb-124 activation. The calculations explicitly modeled the 6x6 fuel assembly described in Table 5.2.2. A single fuel rod was removed and replaced by a guide tube. In order to determine the amount of Sb-124 that is being activated from neutrons in the MPC it was necessary to estimate the amount of antimony in the neutron source. The O.D. of the source was assumed to be the I.D. of the steel rod encasing the source (0.345 in.). The length of the source is 77.25 inches. The beryllium is assumed to be annular in shape encompassing the antimony. Using the assumed O.D. of the beryllium and the mass and length, the I.D. of the beryllium was calculated to be 0.24 inches. The antimony is assumed to be a solid cylinder with an O.D. equal to the I.D. of the beryllium. These assumptions are conservative since the antimony and beryllium are probably encased in another material which would reduce the mass of antimony. A larger mass of antimony is conservative since the calculated activity of Sb-124 is directly proportional to the initial mass of antimony.

The number of gammas from fuel assemblies with energies greater than 1.666 MeV entering the 77.25 inch long neutron source was calculated to be 1.04E+8 gammas/sec which would produce a neutron source of 603.2 neutrons/sec (1.04E+8 * 5.8E-6). The steady state amount of Sb-124 activated in the antimony was calculated to be 39.9 curies. This activity level would produce a neutron source of 4.63E+6 neutrons/sec (39.9 * 1.16E+5) or 6.0E+4 neutrons/sec/inch (4.63E+6/77.25). These calculations conservatively neglect the reduction in antimony and beryllium which would have occurred while the neutron sources were in the core and being irradiated at full reactor power.

Since this is a localized source (77.25 inches in length) it is appropriate to compare the neutron source per inch from the design basis Dresden Unit 1 fuel assembly, 6x6, containing an Sb-Be neutron source to the design basis fuel neutron source per inch. This comparison, presented in Table 5.4.15, demonstrates that a Dresden Unit 1 fuel assembly containing an Sb-Be neutron source is bounded by the design basis fuel.

As stated above, the Sb-Be source is encased in a steel rod. Therefore, the gamma source from the activation of the steel was considered assuming a burnup of 120,000 MWD/MTU which is the maximum burnup assuming the Sb-Be source was in the reactor for the entire 18 year life of Dresden Unit 1. The cooling time assumed was 18 years which is the minimum cooling time for Dresden Unit 1 fuel. The source from the steel was bounded by the design basis fuel assembly. In conclusion, storage of a Dresden Unit 1 Sb-Be neutron source in a Dresden Unit 1 fuel assembly is acceptable and bounded by the current analysis.

5.4.8 Thoria Rod Canister

Based on a comparison of the gamma spectra from Tables 5.2.32 and 5.2.6 for the thoria rod canister and design basis 6x6 fuel assembly, respectively, it is difficult to determine if the thoria rods will be bounded by the 6x6 fuel assemblies. However, it is obvious that the neutron spectra from the 6x6, Table 5.2.14, bounds the thoria rod neutron spectra, Table 5.2.33, with a significant margin. In order to demonstrate that the gamma spectrum from the single thoria rod canister is bounded by the gamma spectrum from the design basis 6x6 fuel assembly, the gamma dose rate on the outer radial surface of the overpack was estimated conservatively assuming an MPC full of thoria rod canisters. This gamma dose rate was compared to an estimate of the dose rate from an MPC full of design basis 6x6 fuel assemblies. The gamma dose rate from the 6x6 fuel was higher than the dose rate from an MPC full of thoria rod canisters. This in conjunction with the significant margin in neutron spectrum and the fact that there is only one thoria rod canister clearly demonstrates that the thoria rod canister is acceptable for storage in the MPC-68 or the MPC-68F.

Table 5.4.1

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Gamma Energy (MeV)	**(rem/hr)/(photon/cm^2-s)**
0.01	3.96E-06
0.03	5.82E-07
0.05	2.90E-07
0.07	2.58E-07
0.1	2.83E-07
0.15	3.79E-07
0.2	5.01E-07
0.25	6.31E-07
0.3	7.59E-07
0.35	8.78E-07
0.4	9.85E-07
0.45	1.08E-06
0.5	1.17E-06
0.55	1.27E-06
0.6	1.36E-06
0.65	1.44E-06
0.7	1.52E-06
0.8	1.68E-06
1.0	1.98E-06
1.4	2.51E-06
1.8	2.99E-06
2.2	3.42E-06

Table 5.4.1 (continued)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Gamma Energy (MeV)	(rem/hr)/ (photon/cm^2-s)
2.6	3.82E-06
2.8	4.01E-06
3.25	4.41E-06
3.75	4.83E-06
4.25	5.23E-06
4.75	5.60E-06
5.0	5.80E-06
5.25	6.01E-06
5.75	6.37E-06
6.25	6.74E-06
6.75	7.11E-06
7.5	7.66E-06
9.0	8.77E-06
11.0	1.03E-05
13.0	1.18E-05
15.0	1.33E-05

Table 5.4.1 (continued)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Neutron Energy (MeV)	Quality Factor	(rem/hr)†/(n/cm^2-s)
2.5E-8	2.0	3.67E-6
1.0E-7	2.0	3.67E-6
1.0E-6	2.0	4.46E-6
1.0E-5	2.0	4.54E-6
1.0E-4	2.0	4.18E-6
1.0E-3	2.0	3.76E-6
1.0E-2	2.5	3.56E-6
0.1	7.5	2.17E-5
0.5	11.0	9.26E-5
1.0	11.0	1.32E-4
2.5	9.0	1.25E-4
5.0	8.0	1.56E-4
7.0	7.0	1.47E-4
10.0	6.5	1.47E-4
14.0	7.5	2.08E-4
20.0	8.0	2.27E-4

† Includes the Quality Factor.

Table 5.4.2

DOSE RATES FROM FUEL GAMMAS
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES†

Dose Point†† Location	**40,000 MWD/MTU 5-Year Cooling (mrem/hr)**	**47,500 MWD/MTU 8-Year Cooling (mrem/hr)**
1	12.45	6.93
2	96.88	54.98
3	3.51	2.20
4	1.81	1.11
5	0.34	0.42
6 (dry MPC)†††	27.07	14.36
7 (no temp. shield)	100.36	50.68
7 (with temp. shield)	28.27	19.59

† Gammas generated by neutron capture are included with fuel gammas.

†† Refer to Figure 5.1.1.

††† Overpack closure plate not present.

Table 5.4.3

DOSE RATES FROM ^{60}Co GAMMAS
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES

Dose Point† Location	**40,000 MWD/MTU 5-Year Cooling (mrem/hr)**	**47,500 MWD/MTU 8-Year Cooling (mrem/hr)**
1	231.52	176.39
2	0.03	0.02
3	81.12	61.80
4	35.86	27.32
5	0.69	0.53
6 (dry MPC)††	286.19	218.05
7 (no temp. shield)	1432.28	1091.26
7 (with temp. shield)	329.84	251.30

† Refer to Figure 5.1.1.

†† Overpack closure plate not present.

Table 5.4.4

DOSE RATES FROM NEUTRONS
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES

Dose Point† Location	40,000 MWD/MTU 5-Year Cooling (mrem/hr)	47,500 MWD/MTU 8-Year Cooling (mrem/hr)
1	82.27	132.74
2	22.12	35.69
3	70.28	113.40
4	39.47	63.68
5	56.70	91.48
6 (dry MPC)††	126.02	203.29
7 (no temp. shield)	397.30	641.02
7 (with temp. shield)	19.84	32.01

† Refer to Figure 5.1.1.

†† Overpack closure plate not included.

Table 5.4.5

DOSE RATES FROM FUEL GAMMAS
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES†

Dose Point†† Location	**35,000 MWD/MTU 5-Year Cooling (mrem/hr)**	**45,000 MWD/MTU 9-Year Cooling (mrem/hr)**
1	10.26	5.47
2	100.42	52.26
3	0.97	0.81
4	0.44	0.37
5	0.13	0.20
6 (dry MPC)†††	9.32	4.52
7 (no temp. shield)	64.46	31.28
7 (with temp. shield)	20.36	16.04

† Gammas generated by neutron capture are included with fuel gammas.

†† Refer to Figure 5.1.1.

††† Overpack closure plate not included.

Table 5.4.6

DOSE RATES FROM ^{60}Co GAMMAS
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES

Dose Point† Location	**35,000 MWD/MTU 5-Year Cooling (mrem/hr)**	**45,000 MWD/MTU 9-Year Cooling (mrem/hr)**
1	297.76	208.32
2	0.02	0.01
3	127.41	89.14
4	51.49	36.02
5	0.72	0.50
6 (dry MPC)††	329.17	230.30
7 (no temp. shield)	1794.41	1255.40
7 (with temp. shield)	381.90	267.18

† Refer to Figure 5.1.1.

†† Overpack closure plate not included.

Table 5.4.7

DOSE RATES FROM NEUTRONS
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES

Dose Point[†] Location	35,000 MWD/MTU 5-Year Cooling (mrem/hr)	45,000 MWD/MTU 9-Year Cooling (mrem/hr)
1	65.63	133.56
2	19.40	43.08
3	29.88	60.80
4	17.76	36.14
5	26.45	53.81
6 (dry MPC)[††]	65.38	133.03
7 (no temp. shield)	325.90	663.17
7 (with temp. shield)	14.52	29.55

† Refer to Figure 5.1.1.

†† Overpack closure plate not included.

Table 5.4.8

TOTAL DOSE RATES
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES

Dose Point† Location	**40,000 MWD/MTU 5-Year Cooling (mrem/hr)**	**47,500 MWD/MTU 8-Year Cooling (mrem/hr)**
1	326.24	316.06
2	119.03	90.69
3	154.90	177.40
4	77.14	92.12
5	57.73	92.43
6 (dry MPC)††	439.28	435.70
7 (no temp. shield)	1929.94	1782.95
7 (with temp. shield)	377.94	302.90

† Refer to Figure 5.1.1.

†† Overpack closure plate not included.

Table 5.4.9

TOTAL DOSE RATES
DOSE LOCATION ADJACENT TO OVERPACK
NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT VARYING BURNUP AND COOLING TIMES

Dose Point† Location	35,000 MWD/MTU 5-Year Cooling (mrem/hr)	45,000 MWD/MTU 9-Year Cooling (mrem/hr)
1	373.64	347.35
2	119.85	95.35
3	158.26	150.75
4	69.69	72.52
5	27.30	54.52
6 (dry MPC)††	403.87	367.85
7 (no temp. shield)	2184.76	1949.86
7 (with temp. shield)	416.78	312.77

† Refer to Figure 5.1.1.

†† Overpack closure plate not included.

Table 5.4.10

PEAK-TO-AVERAGE RATIOS FOR THE DOSE COMPONENTS
AT VARIOUS LOCATIONS

Location	Fuel Gammas	Gammas from Neutrons	^{60}Co Gammas	Neutron
Pocket Trunnion (surface)	0.06	0.33	0.06	7.94
Steel Fin (surface)	0.74	0.95	0.74	2.16
Holtite-A (surface)	1.17	1.05	1.17	0.71
Pocket Trunnion (1 meter)	0.6	0.86	0.6	2.82
Steel Fin (1 meter)	1.0	1.0	1.0	1.05
Holtite-A (1 meter)	1.0	1.0	1.0	0.92

Table 5.4.11

DOSE RATES FOR NORMAL CONDITIONS SHOWING THE EFFECT OF PEAKING
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL
40,000 MWD/MTU 5-YEAR COOLING

Dose Point† Location	Fuel Gammas (mrem/hr)	Gammas from Neutrons (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Total (mrem/hr)
SURFACE					
2	90.55	6.33	0.03	22.12	119.03
2 (fin)	67.01	6.01	0.02	47.78	120.82
2 (Holtite)	105.94	6.65	0.04	15.71	128.34
2a (Holtite)††	12.35	1.49	77.43	10.08	101.35
2a (pocket trunnion)††	0.63	0.47	3.97	112.75	117.82
ONE METER					
2	40.47	2.20	1.06	7.74	51.47
2 (fin)	40.47	2.20	1.06	8.13	51.86
2 (Holtite)	40.47	2.20	1.06	7.12	50.85
2a (Holtite)††	14.67	0.93	16.58	6.90	39.08
2a (pocket trunnion)††	8.80	0.80	9.95	21.14	40.69

† Refer to Figure 5.1.1.

†† Dose point #2a is axially located next to either the Holtite (neutron shield) or pocket trunnion and approximately 6 feet below Dose point #2.

Table 5.4.12

ANNUAL DOSE AT 300 METERS FROM A SINGLE CASK†

	40,000 MWD/MTU 5-Year Cooling (mrem/yr)	**47,500 MWD/MTU 8-Year Cooling (mrem/yr)**
Fuel gammas††	8.15	4.34
^{60}Co Gammas	2.46	1.88
Neutrons	2.94	4.74
Total	13.55	10.96

† 100% occupancy (8760 hours) is assumed.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.4.13

DOSE VALUES USED IN CALCULATING ANNUAL DOSE FROM VARIOUS ISFSI CONFIGURATIONS 40,000 MWD/MTU AND 5-YEAR COOLING†

	A **Side of Overpack (mrem/yr)**	B **Top of Overpack (mrem/yr)**	C **Side of Shielded Overpack (mrem/yr)**
100 meters	337.58	7.40	110.31
150 meters	115.93	3.07	40.56
200 meters	51.52	1.35	17.54
250 meters	24.53	0.63	8.81
300 meters	13.28	0.27	4.15
350 meters	6.76	0.15	2.23
400 meters	3.28	0.09	1.16

† 100% occupancy (8760 hours) is assumed.

Table 5.4.14

DOSE RATES AT THE CENTERLINE OF THE OVERPACK FOR DESIGN BASIS STAINLESS STEEL CLAD FUEL

Dose Point† Location	Fuel Gammas†† (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)
MPC-24 (30,000 MWD/MTU AND 9-YEAR COOLING)				
2 (Adjacent)	101.34	0.06	5.13	106.53
2 (One Meter)	43.64	0.40	2.16	46.20
MPC-24 (40,000 MWD/MTU AND 15-YEAR COOLING)				
2 (Adjacent)	64.26	0.01	16.06	80.33
2 (One Meter)	28.38	0.19	5.63	34.19
MPC-68 (22,500 MWD/MTU AND 10-YEAR COOLING)				
2 (Adjacent)	80.71	0.01	1.51	82.23
2 (One Meter)	34.70	0.30	0.58	35.59

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.4.15

COMPARISON OF NEUTRON SOURCE PER INCH PER SECOND FOR DESIGN BASIS 7X7 FUEL AND DESIGN BASIS DRESDEN UNIT 1 FUEL

Assembly	**Active fuel length (inch)**	**Neutrons per sec per inch**	**Neutrons per sec per inch with Sb-Be source**	**Reference for neutrons per sec per inch**
7x7 design basis	144	5.60E+5	N/A	Table 5.2.13 - 35 GWD/MTU and 5 year cooling
6x6 design basis	110	2.0e+5	2.6E+5	Table 5.2.14
6x6 design basis MOX	110	3.06E+5	3.66E+5	Table 5.2.17

Table 5.4.16

COMPARISON OF TOTAL DOSE RATES FOR DESIGN BASIS PWR FUEL
AND PWR FUEL WITH BPRAS
MPC-24 NORMAL AND ACCIDENT CONDITIONS

Dose Point† Location	**40 GWD/MTU 5 year cooling DESIGN BASIS (mrem/hr)**	**29 GWD/MTU 5 year cooling (mrem/hr)**	**39 GWD/MTU 10 year cooling (mrem/hr)**	**42.5 GWD/MTU 15 year cooling (mrem/hr)**
BPRAs ?	NO	YES	YES	YES
SURFACE - NORMAL CONDITION				
1	326.24	244.72	195.95	143.2
2	119.03	99.66	69.57	61.70
3	154.90	136.39	136.84	120.32
4	77.14	64.13	67.66	60.70
5	57.73	25.15	48.25	50.53
6 (dry MPC)††	439.28	445.46	389.94	324.45
7 (no temp. shield)	1929.94	1557.87	1165.15	810.77
ONE METER - NORMAL CONDITION				
1	43.79	34.47	25.62	19.12
2	51.47	44.42	29.32	25.50
3	30.21	28.68	24.86	21.27
4	28.61	27.06	24.19	20.68
5	17.11	7.55	14.3	14.95
7 (no temp. shield)	889.68	717.64	501.61	329.5
SURFACE - ACCIDENT CONDITION				
2	1371.34	699.45	1074.98	1101.53
ONE METER - ACCIDENT CONDITION				
2	491.73	263.82	378.91	384.75

† Refer to Figure 5.1.1.

†† Overpack closure plate not present.

Table 5.4.17

COMPARISON OF TOTAL DOSE RATES FOR DESIGN BASIS PWR FUEL AND PWR FUEL WITH TPDS
MPC-24 NORMAL CONDITIONS

Dose Point[†] Location	**40 GWD/MTU 5 year cooling DESIGN BASIS (mrem/hr)**	**29 GWD/MTU 5 year cooling (mrem/hr)**	**39 GWD/MTU 10 year cooling (mrem/hr)**	**42.5 GWD/MTU 15 year cooling (mrem/hr)**
TPDs ?	NO	YES	YES	YES
SURFACE - NORMAL CONDITION				
1	326.24	241.88	193.11	140.36
2	119.03	78.00	47.91	40.04
3	154.90	134.01	134.47	117.95
4	77.14	63.09	66.62	59.66
5	57.73	25.12	48.22	50.51
6 (dry MPC)[††]	439.28	439.39	383.86	318.38
7 (no temp. shield)	1929.94	1531.39	1138.67	784.28
ONE METER - NORMAL CONDITION				
1	43.79	32.23	23.39	16.88
2	51.47	34.70	19.61	15.78
3	30.21	27.55	23.74	20.15
4	28.61	26.11	23.25	19.73
5	17.11	7.54	14.29	14.94
7 (no temp. shield)	889.68	703.89	487.86	315.76

† Refer to Figure 5.1.1.

†† Overpack closure plate not present.

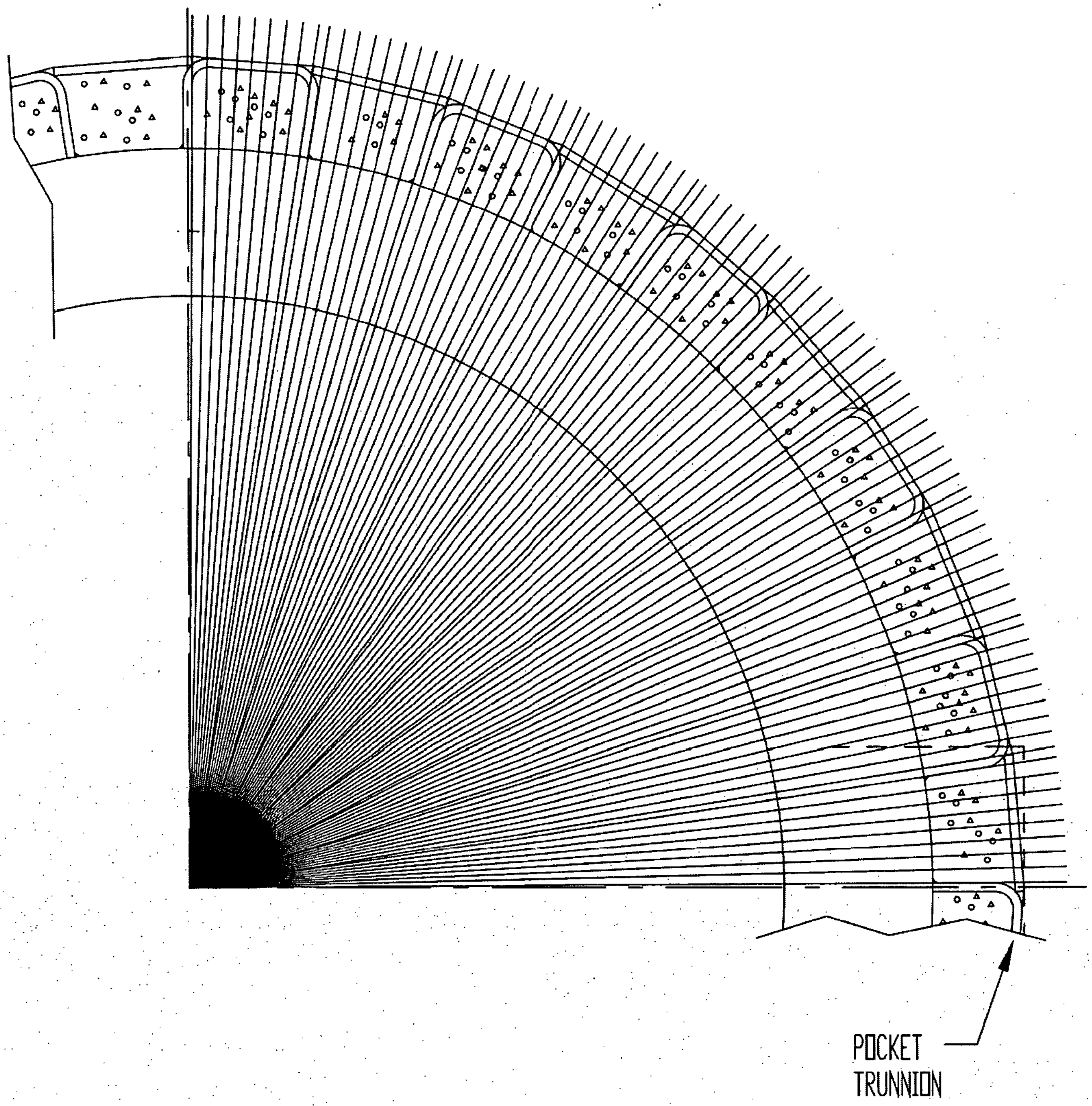


FIGURE 5.4.1; DEPICTION OF THE AZIMUTHAL SEGMENTATION OF THE OVERPACK USED IN ANALYZING NEUTRON AND PHOTON STREAMING

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5.5 REGULATORY COMPLIANCE

Chapters 1 and 2 and this chapter of this FSAR describe in detail the shielding structures, systems, and components (SSCs) important to safety.

This chapter has evaluated these shielding SSCs important to safety and has assessed the impact on health and safety resulting from operation of an independent spent fuel storage installation (ISFSI) utilizing the HI-STAR 100 System.

It has been shown that the design of the shielding system of the HI-STAR 100 System is in compliance with 10CFR72 and that the applicable design and acceptance criteria including 10CFR20 have been satisfied. Thus, this shielding evaluation provides reasonable assurance that the HI-STAR 100 System will allow safe storage of spent fuel.

5.6 REFERENCES

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[5.4.4] J. C. Wagner, et al., 'MCNP: Criticality Safety Benchmark Problems," LA-12415, Los Alamos National Laboratory, October 1992.

[5.4.5] S. E. Turner, "Uncertainty Analysis - Axial Burnup Distribution Effects," presented in "Proceedings of a Workshop on the Use of Burnup Credit in Spent Fuel Transport Casks," SAND-89-0018, Sandia National Laboratory, Oct. 1989.

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APPENDIX 5.A

SAMPLE INPUT FILE FOR SAS2H

(Total number of pages in this appendix : 3)

```
=SAS2H     PARM='halt08,skipshipdata'
bw 15x15 PWR assembly
' fuel temp 923
44groupndf5     LATTICECELL
UO2 1 0.95 923 92234 0.03026 92235 3.4 92236 0.01564
    92238 96.5541 END
'
' Zirc 4 composition
ARBM-ZIRC4 6.55 4 1 0 0 50000 1.7 26000 0.24 24000 0.13 40000 97.93
           2 1.0 595 END
'
' water with 652.5 ppm boron
H2O        3 DEN=0.7135 1  579 END
ARBM-BORMOD  0.7135 1 1 0 0 5000 100 3 652.5E-6  579  END
'
co-59   3 0 1-20 579 end
kr-83   1 0 1-20 923 end
kr-84   1 0 1-20 923 end
kr-85   1 0 1-20 923 end
kr-86   1 0 1-20 923 end
sr-90   1 0 1-20 923 end
y-89    1 0 1-20 923 end
zr-94   1 0 1-20 923 end
zr-95   1 0 1-20 923 end
mo-94   1 0 1-20 923 end
mo-95   1 0 1-20 923 end
nb-94   1 0 1-20 923 end
nb-95   1 0 1-20 923 end
tc-99   1 0 1-20 923 end
ru-106   1 0 1-20 923 end
rh-103   1 0 1-20 923 end
rh-105   1 0 1-20 923 end
sb-124   1 0 1-20 923 end
sn-126   1 0 1-20 923 end
xe-131   1 0 1-20 923 end
xe-132   1 0 1-20 923 end
xe-134   1 0 1-20 923 end
'
xe-135   1 0 1-09 923 end
'
xe-136   1 0 1-20 923 end
cs-133   1 0 1-20 923 end
cs-134   1 0 1-20 923 end
cs-135   1 0 1-20 923 end
cs-137   1 0 1-20 923 end
ba-136   1 0 1-20 923 end
la-139   1 0 1-20 923 end
ce-144   1 0 1-20 923 end
pr-143   1 0 1-20 923 end
nd-143   1 0 1-20 923 end
nd-144   1 0 1-20 923 end
nd-145   1 0 1-20 923 end
nd-146   1 0 1-20 923 end
nd-147   1 0 1-20 923 end
nd-148   1 0 1-20 923 end
nd-150   1 0 1-20 923 end
pm-147   1 0 1-20 923 end
pm-148   1 0 1-20 923 end
```

```
pm-149  1 0 1-20 923 end
sm-147  1 0 1-20 923 end
sm-148  1 0 1-20 923 end
sm-149  1 0 1-20 923 end
sm-150  1 0 1-20 923 end
sm-151  1 0 1-20 923 end
sm-152  1 0 1-20 923 end
eu-151  1 0 1-20 923 end
eu-153  1 0 1-20 923 end
eu-154  1 0 1-20 923 end
eu-155  1 0 1-20 923 end
gd-154  1 0 1-20 923 end
gd-155  1 0 1-20 923 end
gd-157  1 0 1-20 923 end
gd-158  1 0 1-20 923 end
gd-160  1 0 1-20 923 end
'
END COMP
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'  FUEL-PIN-CELL GEOMETRY:
'
SQUAREPITCH  1.44272 0.950468 1 3 1.08712 2 0.97028 0 END
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'  MTU in this model is 0.495485 based on fuel dimensions provided
'
'  1 power cycle will be used and a library will be generated every
'  2500 MWD/MTU  power level is 40 MW/MTU
'  therefore 62.5 days per 2500 MWD/MTU
'  Below
'  BURN=62.5*NLIB/CYC
'  POWER=MTU*40
'
'  Number of libraries is 17 which is 42,500 MWD/MTU burnup (17*2500)
'
'  ASSEMBLY AND CYCLE PARAMETERS:
'
NPIN/ASSM=208 FUELNGTH=365.76 NCYCLES=1 NLIB/CYC=17
PRINTLEVEL=1
LIGHTEL=5  INPLEVEL=1   NUMHOLES=17
NUMINStr= 0  ORTUBE= 0.6731  SRTUBE=0.63246   END
POWER=19.81938 BURN=1062.5 END
'
 O  66.54421
 FE  0.24240868
 ZR 98.78151  CR  0.1311304   SN  1.714782
'
END
=SAS2H    PARM='restarts,halt17,skipshipdata'
bw 15x15 PWR assembly
END
```

APPENDIX 5.B

SAMPLE INPUT FILE FOR ORIGEN-S

(Total number of pages in this appendix : 6)

```
#ORIGENS
0$$  A4 33 A8 26 A11 71  E
1$$  1 T
bw 15x15 FUEL -- FT33F001 -
'
' SUBCASE  1 LIBRARY POSITION  1
'
'   lib     pos      grms   photon group
3$$ 33  A3  1  0  A16 2   E T
35$$ 0 T
56$$  5  5  A6 3  A10  0  A13 9  A15 3 A19 1 E
57** 0.0 A3 1.E-5 0.0625 E T
 FUEL 3.4
BW 15x15 0.495485 MTU
58** 19.81938  19.81938 19.81938 19.81938  19.81938
60**  1.0000   3.0000  15.0000  30.0000  62.5
66$$ A1 2 A5 2 A9 2  E
73$$  922350  922340  922360  922380  80000  500000
      260000  240000  400000
74** 16846.48 149.9336 77.49379 478410.7 66544.21 1714.782
     242.0868 131.1304 98781.51
75$$  2  2  2  2  4  4  4  4  4  T
'
' SUBCASE  2 LIBRARY POSITION  2
'
3$$ 33  A3   2  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   5  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  3 LIBRARY POSITION  3
'
3$$ 33  A3   3  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  4 LIBRARY POSITION  4
'
3$$ 33  A3   4  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
```

```
' SUBCASE  5 LIBRARY POSITION  5
'
3$$ 33  A3   5  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  6 LIBRARY POSITION  6
'
3$$ 33  A3   6  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  7 LIBRARY POSITION  7
'
3$$ 33  A3   7  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  8 LIBRARY POSITION  8
'
3$$ 33  A3   8  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  9 LIBRARY POSITION  9
'
3$$ 33  A3   9  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
```

```
'
' SUBCASE 10 LIBRARY POSITION 10
'
3$$ 33  A3  10  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 11 LIBRARY POSITION 11
'
3$$ 33  A3  11  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 12 LIBRARY POSITION 12
'
3$$ 33  A3  12  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 13 LIBRARY POSITION 13
'
3$$ 33  A3  13  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 14 LIBRARY POSITION 14
'
3$$ 33  A3  14  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
```

```
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 15 LIBRARY POSITION 15
'
3$$ 33  A3  15  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 16 LIBRARY POSITION 16
'
3$$ 33  A3  16  A4 7 0  A16 2  A33 18  E T
35$$ 0 T
56$$  3  3  A6 1  A10  3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.0625 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE - decay
'
54$$ A8 1 E
56$$ 0 9 A6 1 A10 3 A14 3 A15 1 A19 1 E
57** 0.0 0 1.E-5  E T
 fuel enrichment above
60** 0.5 0.75 1.0 4.0 8.0 12.0 24.0 48.0 96.0
61** F0.1
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z  T
'
' SUBCASE - decay
'
54$$ A8 1 E
56$$ 0 9 A6 1 A10 9 A14 4 A15 1 A19 1 E
57** 4.0 0 1.E-5  E T
 fuel enrichment above
60** 10.0 20.0 30.0 60.0 90.0 120.0 180.0 240.0 365.0
61** F0.1
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z  T
'
' SUBCASE - decay
'
54$$ A8 0 E
56$$ 0 9 A6 1 A10 9 A14 5 A15 1 A19 1 E
57** 1.0 0 1.E-5  E T
```

```
 fuel enrichment above
60** 1.5 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
61** F1.0e-5
65$$
'GRAM-ATOMS    GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     1 0 0      1 0 0         3Z         6Z
     3Z      0  1  0     1 0 0      1 0 0         3Z         6Z
     3Z      0  1  0     1 0 0      1 0 0         3Z         6Z
81$$ 2 0 26 1 E
82$$ 0 2 2 2 2 2 2 2 2
83**  1.1E+7  8.0E+6 6.0E+6 4.0E+6 3.0E+6 2.5E+6 2.0E+6 1.5E+6
      1.0E+6  7.0E+5 4.5E+5 3.0E+5 1.5E+5 1.0E+5 7.0E+4 4.5E+4
      3.0E+4  2.0E+4 1.0E+4
84**  20.0E+6 6.43E+6 3.0E+6 1.85E+6 1.40E+6 9.00E+5 4.00E+5 1.0E+5 T
'
'
'
'
'
'
'
'
' SUBCASE - decay
'
54$$ A8 0 E
56$$ 0 10 A6 1 A10 9 A14 5 A15 1 A19 1 E
57** 10.0 0 1.E-5  E T
 fuel enrichment above
60** 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0
61** F1.0e-5
65$$
'GRAM-ATOMS    GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     1 0 0      1 0 0         3Z         6Z
     3Z      0  1  0     1 0 0      1 0 0         3Z         6Z
     3Z      0  1  0     1 0 0      1 0 0         3Z         6Z
81$$ 2 0 26 1 E
82$$ 2 2 2 2 2 2 2 2 2 2
83**  1.1E+7  8.0E+6 6.0E+6 4.0E+6 3.0E+6 2.5E+6 2.0E+6 1.5E+6
      1.0E+6  7.0E+5 4.5E+5 3.0E+5 1.5E+5 1.0E+5 7.0E+4 4.5E+4
      3.0E+4  2.0E+4 1.0E+4
84**  20.0E+6 6.43E+6 3.0E+6 1.85E+6 1.40E+6 9.00E+5 4.00E+5 1.0E+5 T
'
'
'
'
'
'
'
'
'
'
' END
'
56$$ F0 T
END
```

APPENDIX 5.C

SAMPLE INPUT FILE FOR MCNP

(Total number of pages in this appendix : 35)

```
message:   outp=m68n65ao  srctp=m68n65as  runtpe=m68n65ar
           mctal=m68n65am  wssa=m68n65aw  rssa=pt001w

m68n65a
c       HI STAR 100 MPC68
c
c
c     two pocket trunions modeled
c     holtite present
c     impact limiters not present
c     axial model
c
c     origen is at the bottom of the overpack - as an example of the origen
c     item 1 on drawing 1397 is 6 inches thick and extends
c     from 0.0 to 6.0 inches in the axial direction
c
c     only cells that contain material are split axially
c     importance splitting is not done in cells with 0 material
c
c     universe 1
c
c      egg crate
301    0            -30              -400 u=1
302    0             31              -400 u=1
303    0         30 -31 -32          -400 u=1
304    0         30 -31  33          -400 u=1
305    5 -7.92          28       400 -420 u=1
306    5 -7.92              -23  400 -420 u=1
307    5 -7.92      -15 23  -28  400 -420 u=1
308    5 -7.92  20      23  -28  400 -420 u=1
309    5 -7.92          28       420 -430 u=1
310    5 -7.92              -23  420 -430 u=1
311    5 -7.92      -15 23  -28  420 -430 u=1
312    5 -7.92  20      23  -28  420 -430 u=1
313    5 -7.92          28       430 -440 u=1
314    5 -7.92              -23  430 -440 u=1
315    5 -7.92      -15 23  -28  430 -440 u=1
316    5 -7.92  20      23  -28  430 -440 u=1
317    5 -7.92          28       440 -670 u=1
318    5 -7.92              -23  440 -670 u=1
319    5 -7.92      -15 23  -28  440 -670 u=1
320    5 -7.92  20      23  -28  440 -670 u=1
321    5 -7.92          28       670 -460 u=1
322    5 -7.92              -23  670 -460 u=1
323    5 -7.92      -15 23  -28  670 -460 u=1
324    5 -7.92  20      23  -28  670 -460 u=1
c      boral and inside of egg crate and outside of fuel
326    0         15 -30 23 -28 400 -410 u=-1
327    0         31 -20 23 -28 400 -410 u=-1
328    0         30 -31 33 -28 400 -410 u=-1
329    0         30 -31 23 -32 400 -410 u=-1
330    0         15 -18 26 -28 410 -435 u=-1
331    0         19 -20 26 -28 410 -435 u=-1
332    0         15 -17 23 -24 410 -435 u=-1
333    0         15 -17 25 -26 410 -435 u=-1
334    6 -2.644  18 -19 27 -28 410 -420 u=-1
335    5 -7.92   18 -19 26 -27 410 -420 u=-1
336    6 -2.644  15 -16 24 -25 410 -420 u=-1
337    5 -7.92   16 -17 24 -25 410 -420 u=-1
338    6 -2.644  18 -19 27 -28 420 -430 u=-1
339    5 -7.92   18 -19 26 -27 420 -430 u=-1
340    6 -2.644  15 -16 24 -25 420 -430 u=-1
341    5 -7.92   16 -17 24 -25 420 -430 u=-1
342    6 -2.644  18 -19 27 -28 430 -435 u=-1
343    5 -7.92   18 -19 26 -27 430 -435 u=-1
344    6 -2.644  15 -16 24 -25 430 -435 u=-1
345    5 -7.92   16 -17 24 -25 430 -435 u=-1
346    0         17 -30 23 -26 410 -435 u=-1
347    0         31 -20 23 -26 410 -435 u=-1
```

```
348     0          30 -31 23 -32 410 -435 u=-1
349     0          30 -31 33 -26 410 -435 u=-1
350     0          15 -30 23 -28 435 -460 u=-1
351     0          31 -20 23 -28 435 -460 u=-1
352     0          30 -31 33 -28 435 -460 u=-1
353     0          30 -31 23 -32 435 -460 u=-1
c       fuel element
354     5 -1.51304  30 -31 32 -33      -420 u=1
355     2 -3.979996 30 -31 32 -33 420 -425 u=-1
356     0           30 -31 32 -33 425 -430 u=-1
357     5 -0.270112 30 -31 32 -33 430 -440 u=-1
358     5 -0.689740 30 -31 32 -33 440 -445 u=-1
359     5 -1.393935 30 -31 32 -33 445 -450 u=-1
360     5 -0.261853 30 -31 32 -33 450 -670 u=-1
361     5 -0.261853 30 -31 32 -33 670 -455 u=-1
362     0           30 -31 32 -33 455  u=1
363     0           -30               460 u=1
364     0            31               460 u=1
365     0          30 -31 -32         460 u=1
366     0          30 -31  33         460 u=1
c
c     universe 2
c
c       egg crate
401     0           -30               -400 u=2
402     0            31               -400 u=2
403     0          30 -31 -32         -400 u=2
404     0          30 -31  33         -400 u=2
405     5 -7.92           28      400 -420 u=2
406     5 -7.92               -23 400 -420 u=2
407     5 -7.92        -15 23 -28 400 -420 u=2
408     5 -7.92   20      23 -28 400 -420 u=2
409     5 -7.92           28      420 -430 u=2
410     5 -7.92               -23 420 -430 u=2
411     5 -7.92        -15 23 -28 420 -430 u=2
412     5 -7.92   20      23 -28 420 -430 u=2
413     5 -7.92           28      430 -440 u=2
414     5 -7.92               -23 430 -440 u=2
415     5 -7.92        -15 23 -28 430 -440 u=2
416     5 -7.92   20      23 -28 430 -440 u=2
417     5 -7.92           28      440 -670 u=2
418     5 -7.92               -23 440 -670 u=2
419     5 -7.92        -15 23 -28 440 -670 u=2
420     5 -7.92   20      23 -28 440 -670 u=2
421     5 -7.92           28      670 -460 u=2
422     5 -7.92               -23 670 -460 u=2
423     5 -7.92        -15 23 -28 670 -460 u=2
424     5 -7.92   20      23 -28 670 -460 u=2
c       boral and inside of egg crate and outside of fuel
426     0          15 -30 23 -28 400 -460 u=-2
427     0          31 -20 23 -28 400 -460 u=-2
428     0          30 -31 33 -28 400 -460 u=-2
429     0          30 -31 23 -32 400 -460 u=-2
c       fuel element
454     5 -1.51304  30 -31 32 -33      -420 u=2
455     2 -3.979996 30 -31 32 -33 420 -425 u=-2
456     0           30 -31 32 -33 425 -430 u=-2
457     5 -0.270112 30 -31 32 -33 430 -440 u=-2
458     5 -0.689740 30 -31 32 -33 440 -445 u=-2
459     5 -1.393935 30 -31 32 -33 445 -450 u=-2
460     5 -0.261853 30 -31 32 -33 450 -670 u=-2
461     5 -0.261853 30 -31 32 -33 670 -455 u=-2
462     0           30 -31 32 -33 455  u=2
463     0           -30               460 u=2
464     0            31               460 u=2
465     0          30 -31 -32         460 u=2
466     0          30 -31  33         460 u=2
c
c     universe 3
```

```
c
c       egg crate
501     0              -30                  -400 u=3
502     0               31                  -400 u=3
503     0           30 -31 -32              -400 u=3
504     0           30 -31  33              -400 u=3
505     5 -7.92            28          400 -420 u=3
506     5 -7.92                -23 400 -420 u=3
507     5 -7.92        -15 23 -28 400 -420 u=3
508     5 -7.92  20        23 -28 400 -420 u=3
509     5 -7.92            28          420 -430 u=3
510     5 -7.92                -23 420 -430 u=3
511     5 -7.92        -15 23 -28 420 -430 u=3
512     5 -7.92  20        23 -28 420 -430 u=3
513     5 -7.92            28          430 -440 u=3
514     5 -7.92                -23 430 -440 u=3
515     5 -7.92        -15 23 -28 430 -440 u=3
516     5 -7.92  20        23 -28 430 -440 u=3
517     5 -7.92            28          440 -670 u=3
518     5 -7.92                -23 440 -670 u=3
519     5 -7.92        -15 23 -28 440 -670 u=3
520     5 -7.92  20        23 -28 440 -670 u=3
521     5 -7.92            28          670 -460 u=3
522     5 -7.92                -23 670 -460 u=3
523     5 -7.92        -15 23 -28 670 -460 u=3
524     5 -7.92  20        23 -28 670 -460 u=3
c       boral and inside of egg crate and outside of fuel
526     0           15 -30 23 -28 400 -410 u=-3
527     0           31 -20 23 -28 400 -410 u=-3
528     0           30 -31 33 -28 400 -410 u=-3
529     0           30 -31 23 -32 400 -410 u=-3
530     0           15 -18 26 -28 410 -435 u=-3
531     0           19 -20 26 -28 410 -435 u=-3
534     6 -2.644 18 -19 27 -28 410 -420 u=-3
535     5 -7.92  18 -19 26 -27 410 -420 u=-3
538     6 -2.644 18 -19 27 -28 420 -430 u=-3
539     5 -7.92  18 -19 26 -27 420 -430 u=-3
542     6 -2.644 18 -19 27 -28 430 -435 u=-3
543     5 -7.92  18 -19 26 -27 430 -435 u=-3
546     0           15 -30 23 -26 410 -435 u=-3
547     0           31 -20 23 -26 410 -435 u=-3
548     0           30 -31 23 -32 410 -435 u=-3
549     0           30 -31 33 -26 410 -435 u=-3
550     0           15 -30 23 -28 435 -460 u=-3
551     0           31 -20 23 -28 435 -460 u=-3
552     0           30 -31 33 -28 435 -460 u=-3
553     0           30 -31 23 -32 435 -460 u=-3
c       fuel element
554     5 -1.51304  30 -31 32 -33       -420 u=3
555     2 -3.979996 30 -31 32 -33 420 -425 u=-3
556     0           30 -31 32 -33 425 -430 u=-3
557     5 -0.270112 30 -31 32 -33 430 -440 u=-3
558     5 -0.689740 30 -31 32 -33 440 -445 u=-3
559     5 -1.393935 30 -31 32 -33 445 -450 u=-3
560     5 -0.261853 30 -31 32 -33 450 -670 u=-3
561     5 -0.261853 30 -31 32 -33 670 -455 u=-3
562     0           30 -31 32 -33 455  u=3
563     0              -30                  460 u=3
564     0               31                  460 u=3
565     0           30 -31 -32              460 u=3
566     0           30 -31  33              460 u=3
c
c      universe 4
c
c       egg crate
601     0              -30                  -400 u=4
602     0               31                  -400 u=4
603     0           30 -31 -32              -400 u=4
604     0           30 -31  33              -400 u=4
```

```
605     5 -7.92         28       400 -420 u=4
606     5 -7.92             -23  400 -420 u=4
607     5 -7.92      -15 23 -28  400 -420 u=4
608     5 -7.92  20      23 -28  400 -420 u=4
609     5 -7.92         28       420 -430 u=4
610     5 -7.92             -23  420 -430 u=4
611     5 -7.92      -15 23 -28  420 -430 u=4
612     5 -7.92  20      23 -28  420 -430 u=4
613     5 -7.92         28       430 -440 u=4
614     5 -7.92             -23  430 -440 u=4
615     5 -7.92      -15 23 -28  430 -440 u=4
616     5 -7.92  20      23 -28  430 -440 u=4
617     5 -7.92         28       440 -670 u=4
618     5 -7.92             -23  440 -670 u=4
619     5 -7.92      -15 23 -28  440 -670 u=4
620     5 -7.92  20      23 -28  440 -670 u=4
621     5 -7.92         28       670 -460 u=4
622     5 -7.92             -23  670 -460 u=4
623     5 -7.92      -15 23 -28  670 -460 u=4
624     5 -7.92  20      23 -28  670 -460 u=4
c       boral and inside of egg crate and outside of fuel
626     0        15 -30 23 -28 400 -410 u=-4
627     0        31 -20 23 -28 400 -410 u=-4
628     0        30 -31 33 -28 400 -410 u=-4
629     0        30 -31 23 -32 400 -410 u=-4
632     0        15 -17 23 -24 410 -435 u=-4
633     0        15 -17 25 -28 410 -435 u=-4
636     6 -2.644 15 -16 24 -25 410 -420 u=-4
637     5 -7.92  16 -17 24 -25 410 -420 u=-4
640     6 -2.644 15 -16 24 -25 420 -430 u=-4
641     5 -7.92  16 -17 24 -25 420 -430 u=-4
644     6 -2.644 15 -16 24 -25 430 -435 u=-4
645     5 -7.92  16 -17 24 -25 430 -435 u=-4
646     0        17 -30 23 -28 410 -435 u=-4
647     0        31 -20 23 -28 410 -435 u=-4
648     0        30 -31 23 -32 410 -435 u=-4
649     0        30 -31 33 -28 410 -435 u=-4
650     0        15 -30 23 -28 435 -460 u=-4
651     0        31 -20 23 -28 435 -460 u=-4
652     0        30 -31 33 -28 435 -460 u=-4
653     0        30 -31 23 -32 435 -460 u=-4
c       fuel element
654     5 -1.51304  30 -31 32 -33     -420 u=4
655     2 -3.979996 30 -31 32 -33 420 -425 u=-4
656     0           30 -31 32 -33 425 -430 u=-4
657     5 -0.270112 30 -31 32 -33 430 -440 u=-4
658     5 -0.689740 30 -31 32 -33 440 -445 u=-4
659     5 -1.393935 30 -31 32 -33 445 -450 u=-4
660     5 -0.261853 30 -31 32 -33 450 -670 u=-4
661     5 -0.261853 30 -31 32 -33 670 -455 u=-4
662     0           30 -31 32 -33 455  u=4
663     0           -30               460 u=4
664     0            31               460 u=4
665     0        30 -31 -32           460 u=4
666     0        30 -31  33           460 u=4
c
c      universe 5
c
701     0                 -400 u=5
702     5 -7.92 20 400 -420 u=5
703     5 -7.92 20 420 -430 u=5
704     5 -7.92 20 430 -440 u=5
705     5 -7.92 20 440 -670 u=5
706     5 -7.92 20 670 -460 u=5
707     0      -20 400 -460 u=5
708     0          460      u=5
c
c      universe 6
c
```

```
710     0                  -400 u=6
711     5 -7.92   -23 400 -420 u=6
712     5 -7.92   -23 420 -430 u=6
713     5 -7.92   -23 430 -440 u=6
714     5 -7.92   -23 440 -670 u=6
715     5 -7.92   -23 670 -460 u=6
716     0          23 400 -460 u=6
717     0             460      u=6
c
c     universe 7
c
720     0                        -400 u=7
721     5 -7.92 20        23 400 -420 u=7
722     5 -7.92     -23      400 -420 u=7
723     5 -7.92 20        23 420 -430 u=7
724     5 -7.92     -23      420 -430 u=7
725     5 -7.92 20        23 430 -440 u=7
726     5 -7.92     -23      430 -440 u=7
727     5 -7.92 20        23 440 -670 u=7
728     5 -7.92     -23      440 -670 u=7
729     5 -7.92 20        23 670 -460 u=7
730     5 -7.92     -23      670 -460 u=7
731     0           -20   23 400 -460 u=7
732     0                    460      u=7
c
c     universe 8
c
735    0                              -400 u=8
736    0          15              400 -460 u=8
747    5 -7.92        -15         400 -420 u=8
748    5 -7.92        -15         420 -430 u=8
749    5 -7.92        -15         430 -440 u=8
750    5 -7.92        -15         440 -670 u=8
751    5 -7.92        -15         670 -460 u=8
752    0                          460      u=8
c
c     universe 9
c
755    0          15      23      400 -460 u=9
766    0                              -400 u=9
767    5 -7.92        -15 23      400 -420 u=9
768    5 -7.92        -23         400 -420 u=9
769    5 -7.92        -15 23      420 -430 u=9
770    5 -7.92        -23         420 -430 u=9
771    5 -7.92        -15 23      430 -440 u=9
772    5 -7.92        -23         430 -440 u=9
773    5 -7.92        -15 23      440 -670 u=9
774    5 -7.92        -23         440 -670 u=9
775    5 -7.92        -15 23      670 -460 u=9
776    5 -7.92        -23         670 -460 u=9
777    0                          460      u=9
c
c     universe 10
c
780    0          15          -28 400 -460 u=10
799    0                              -400 u=10
800    5 -7.92        -15     -28 400 -420 u=10
801    5 -7.92            28      400 -420 u=10
802    5 -7.92        -15     -28 420 -430 u=10
803    5 -7.92            28      420 -430 u=10
804    5 -7.92        -15     -28 430 -440 u=10
805    5 -7.92            28      430 -440 u=10
806    5 -7.92        -15     -28 440 -670 u=10
807    5 -7.92            28      440 -670 u=10
808    5 -7.92        -15     -28 670 -460 u=10
809    5 -7.92            28      670 -460 u=10
810    0                          460      u=10
c
c     universe 11
```

```
c
811    0                  -28 400 -460 u=11
822    0                          -400 u=11
823    5 -7.92         28      400 -420 u=11
824    5 -7.92         28      420 -430 u=11
825    5 -7.92         28      430 -440 u=11
826    5 -7.92         28      440 -670 u=11
827    5 -7.92         28      670 -460 u=11
828    0                       460      u=11
c
c      universe 12
c
830    0             -20    -28 400 -460 u=12
841    0                          -400 u=12
842    5 -7.92      -20 28     400 -420 u=12
843    5 -7.92  20             400 -420 u=12
844    5 -7.92      -20 28     420 -430 u=12
845    5 -7.92  20             420 -430 u=12
846    5 -7.92      -20 28     430 -440 u=12
847    5 -7.92  20             430 -440 u=12
848    5 -7.92      -20 28     440 -670 u=12
849    5 -7.92  20             440 -670 u=12
850    5 -7.92      -20 28     670 -460 u=12
851    5 -7.92  20             670 -460 u=12
852    0                       460      u=12
c
c      universe 13
c
c      810   0           -420  u=13
c      811   0     420   -430  u=13
c      812   0     430   -440  u=13
c      813   0     440   -670  u=13
c      814   0     670         u=13
c      storage locations
c
201    0  -301  -106 212 620 -675
202    0  -301  106 -107 212 620 -675
          fill=6 (-8.2423 90.6653 0.0)
203    0  -301  107 -108 212 620 -675
          fill=6 ( 8.2423 90.6653 0.0)
204    0  -301  108 212 620 -675
c
205    0  -301 -104 211 620 -675
206    0  -301 104 -105 211 620 -675
          fill=6 (-41.2115 74.1807 0.0)
207    0  -301 105 -106 211 -212 620 -675
          fill=7 (-24.7269 74.1807 0.0)
c
101    0  106 -107 211 -212  620 -675
          fill=2 (-8.2423 74.1807 0.0)
102    0  107 -108 211 -212  620 -675
          fill=4 ( 8.2423 74.1807 0.0)
c
208    0  -301 108 -109 211 -212 620 -675
          fill=9 (24.7269 74.1807 0.0)
209    0  -301 109 -110 211 620 -675
          fill=6 (41.2115 74.1807 0.0)
210    0  -301 110 211 620 -675
c
211    0  -301 -103 210 620 -675
212    0  -301 103 -104 210 -211 620 -675
          fill=7 (-57.6961 57.6961 0.0)
c
103    0  104 -105 210 -211  620 -675
          fill=2 (-41.2115 57.6961 0.0)
104    0  105 -106 210 -211  620 -675
          fill=4 (-24.7269 57.6961 0.0)
105    0  106 -107 210 -211  620 -675
          fill=1 (-8.2423 57.6961 0.0)
```

```
106    0   107 -108 210 -211  620 -675
           fill=1 ( 8.2423 57.6961 0.0)
107    0   108 -109 210 -211  620 -675
           fill=4 ( 24.7269 57.6961 0.0)
108    0   109 -110 210 -211  620 -675
           fill=4 ( 41.2115 57.6961 0.0)
c
213    0   -301 110 -111 210 -211 620 -675
           fill=9 ( 57.6961 57.6961 0.0)
214    0   -301 111 210 620 -675
c
215    0   -301 -103 209 -210 620 -675
           fill=5 (-74.1807 41.2115 0.0)
c
109    0   103 -104 209 -210  620 -675
           fill=2 (-57.6961 41.2115 0.0)
110    0   104 -105 209 -210  620 -675
           fill=1 (-41.2115 41.2115 0.0)
111    0   105 -106 209 -210  620 -675
           fill=1 (-24.7269 41.2115 0.0)
112    0   106 -107 209 -210  620 -675
           fill=1 (-8.2423 41.2115 0.0)
113    0   107 -108 209 -210  620 -675
           fill=1 ( 8.2423 41.2115 0.0)
114    0   108 -109 209 -210  620 -675
           fill=1 ( 24.7269 41.2115 0.0)
115    0   109 -110 209 -210  620 -675
           fill=1 ( 41.2115 41.2115 0.0)
116    0   110 -111 209 -210  620 -675
           fill=4 ( 57.6961 41.2115 0.0)
c
216    0   -301 111 209 -210 620 -675
           fill=8 (74.1807 41.2115 0.0)
c
217    0   -301 -102 208 620 -675
218    0   -301 102 -103 208 -209 620 -675
           fill=7 (-74.1807 24.7269 0.0)
c
117    0   103 -104 208 -209  620 -675
           fill=3 (-57.6961 24.7269 0.0)
118    0   104 -105 208 -209  620 -675
           fill=1 (-41.2115 24.7269 0.0)
119    0   105 -106 208 -209  620 -675
           fill=1 (-24.7269 24.7269 0.0)
120    0   106 -107 208 -209  620 -675
           fill=1 (-8.2423 24.7269 0.0)
121    0   107 -108 208 -209  620 -675
           fill=1 ( 8.2423 24.7269 0.0)
122    0   108 -109 208 -209  620 -675
           fill=1 ( 24.7269 24.7269 0.0)
123    0   109 -110 208 -209  620 -675
           fill=1 ( 41.2115 24.7269 0.0)
124    0   110 -111 208 -209  620 -675
           fill=1 ( 57.6961 24.7269 0.0)
c
219    0   -301 111 -112 208 -209 620 -675
           fill=9 (74.1807 24.7269 0.0)
220    0   -301 112 208 620 -675
c
221    0   -301 -102 207 -208 620 -675
           fill=5 (-90.6653 8.2423 0.0)
c
125    0   102 -103 207 -208  620 -675
           fill=2 (-74.1807 8.2423 0.0)
126    0   103 -104 207 -208  620 -675
           fill=1 (-57.6961 8.2423 0.0)
127    0   104 -105 207 -208  620 -675
           fill=1 (-41.2115 8.2423 0.0)
128    0   105 -106 207 -208  620 -675
```

```
        fill=1 (-24.7269 8.2423 0.0)
129   0  106 -107 207 -208  620 -675
        fill=1 (-8.2423 8.2423 0.0)
130   0  107 -108 207 -208  620 -675
        fill=1 ( 8.2423 8.2423 0.0)
131   0  108 -109 207 -208  620 -675
        fill=1 ( 24.7269 8.2423 0.0)
132   0  109 -110 207 -208  620 -675
        fill=1 ( 41.2115 8.2423 0.0)
133   0  110 -111 207 -208  620 -675
        fill=1 ( 57.6961 8.2423 0.0)
134   0  111 -112 207 -208  620 -675
        fill=4 ( 74.1807 8.2423 0.0)
c
222   0  -301 112 207 -208 620 -675
        fill=8 (90.6653 8.2423 0.0)
c
223   0  -301 -102 206 -207 620 -675
        fill=5 (-90.6653 -8.2423 0.0)
c
135   0  102 -103 206 -207  620 -675
        fill=3 (-74.1807 -8.2423 0.0)
136   0  103 -104 206 -207  620 -675
        fill=1 (-57.6961 -8.2423 0.0)
137   0  104 -105 206 -207  620 -675
        fill=1 (-41.2115 -8.2423 0.0)
138   0  105 -106 206 -207  620 -675
        fill=1 (-24.7269 -8.2423 0.0)
139   0  106 -107 206 -207  620 -675
        fill=1 (-8.2423 -8.2423 0.0)
140   0  107 -108 206 -207  620 -675
        fill=1 ( 8.2423 -8.2423 0.0)
141   0  108 -109 206 -207  620 -675
        fill=1 ( 24.7269 -8.2423 0.0)
142   0  109 -110 206 -207  620 -675
        fill=1 ( 41.2115 -8.2423 0.0)
143   0  110 -111 206 -207  620 -675
        fill=1 ( 57.6961 -8.2423 0.0)
144   0  111 -112 206 -207  620 -675
        fill=1 ( 74.1807 -8.2423 0.0)
c
224   0  -301 112 206 -207 620 -675
        fill=8 (90.6653 -8.2423 0.0)
c
225   0  -301 -102 -206 620 -675
226   0  -301 102 -103 205 -206 620 -675
        fill=12 (-74.1807 -24.7269 0.0)
c
145   0  103 -104 205 -206  620 -675
        fill=3 (-57.6961 -24.7269 0.0)
146   0  104 -105 205 -206  620 -675
        fill=1 (-41.2115 -24.7269 0.0)
147   0  105 -106 205 -206  620 -675
        fill=1 (-24.7269 -24.7269 0.0)
148   0  106 -107 205 -206  620 -675
        fill=1 (-8.2423  -24.7269 0.0)
149   0  107 -108 205 -206  620 -675
        fill=1 ( 8.2423  -24.7269 0.0)
150   0  108 -109 205 -206  620 -675
        fill=1 ( 24.7269 -24.7269 0.0)
151   0  109 -110 205 -206  620 -675
        fill=1 ( 41.2115 -24.7269 0.0)
152   0  110 -111 205 -206  620 -675
        fill=1 ( 57.6961 -24.7269 0.0)
c
227   0  -301 111 -112 205 -206 620 -675
        fill=10 (74.1807 -24.7269 0.0)
228   0  -301 112 -206 620 -675
c
```

```
229    0   -301 -103 204 -205 620 -675
           fill=5 (-74.1807 -41.2115 0.0)
c
153    0   103 -104 204 -205  620 -675
           fill=3 (-57.6961 -41.2115 0.0)
154    0   104 -105 204 -205  620 -675
           fill=1 (-41.2115 -41.2115 0.0)
155    0   105 -106 204 -205  620 -675
           fill=1 (-24.7269 -41.2115 0.0)
156    0   106 -107 204 -205  620 -675
           fill=1 (-8.2423  -41.2115 0.0)
157    0   107 -108 204 -205  620 -675
           fill=1 ( 8.2423  -41.2115 0.0)
158    0   108 -109 204 -205  620 -675
           fill=1 ( 24.7269 -41.2115 0.0)
159    0   109 -110 204 -205  620 -675
           fill=1 ( 41.2115 -41.2115 0.0)
160    0   110 -111 204 -205  620 -675
           fill=1 ( 57.6961 -41.2115 0.0)
c
230    0   -301 111 204 -205 620 -675
           fill=8 (74.1807 -41.2115 0.0)
c
231    0   -301 -103 -204 620 -675
232    0   -301 103 -104 203 -204 620 -675
           fill=12 (-57.6961 -57.6961 0.0)
c
161    0   104 -105 203 -204  620 -675
           fill=3 (-41.2115 -57.6961 0.0)
162    0   105 -106 203 -204  620 -675
           fill=1 (-24.7269 -57.6961 0.0)
163    0   106 -107 203 -204  620 -675
           fill=1 (-8.2423 -57.6961 0.0)
164    0   107 -108 203 -204  620 -675
           fill=1 ( 8.2423 -57.6961 0.0)
165    0   108 -109 203 -204  620 -675
           fill=1 ( 24.7269 -57.6961 0.0)
166    0   109 -110 203 -204  620 -675
           fill=1 ( 41.2115 -57.6961 0.0)
c
233    0   -301 110 -111 203 -204 620 -675
           fill=10 ( 57.6961 -57.6961 0.0)
234    0   -301 111 -204 620 -675
c
235    0   -301 -104 -203 620 -675
236    0   -301 104 -105 -203 620 -675
           fill=11 (-41.2115 -74.1807 0.0)
237    0   -301 105 -106 202 -203 620 -675
           fill=12 (-24.7269 -74.1807 0.0)
c
167    0   106 -107 202 -203  620 -675
           fill=3 (-8.2423 -74.1807 0.0)
168    0   107 -108 202 -203  620 -675
           fill=1 ( 8.2423 -74.1807 0.0)
c
238    0   -301 108 -109 202 -203 620 -675
           fill=10 (24.7269 -74.1807 0.0)
239    0   -301 109 -110 -203 620 -675
           fill=11 (41.2115 -74.1807 0.0)
240    0   -301 110 -203 620 -675
c
241    0   -301  -106 -202 620 -675
242    0   -301  106 -107 -202 620 -675
           fill=11 (-8.2423 -90.6653 0.0)
243    0   -301  107 -108 -202 620 -675
           fill=11 ( 8.2423 -90.6653 0.0)
244    0   -301  108 -202 620 -675
c
1821    5 -7.92 301 -302 610 -615  $ MPC shell
```

```
1822    0          302 -501 610 -615  $ Air gap
1823    5 -7.92 301 -302 615 -630  $ MPC shell
1824    0          302 -501 615 -630  $ Air gap
1825    5 -7.92 301 -302 630 -420  $ MPC shell
1826    0          302 -501 630 -420  $ Air gap
1827    5 -7.92 301 -302 420 -430  $ MPC shell
1828    0          302 -501 420 -430  $ Air gap
1829    5 -7.92 301 -302 430 -440  $ MPC shell
1830    0          302 -501 430 -440  $ Air gap
1831    5 -7.92 301 -302 440 -670  $ MPC shell
1832    0          302 -501 440 -670  $ Air gap
1833    5 -7.92 301 -302 670 -675  $ MPC shell
1834    0          302 -501 670 -675  $ Air gap
1835    5 -7.92 301 -302 675 -651  $ MPC shell
1836    0          302 -501 675 -651  $ Air gap
1837    5 -7.92 301 -302 651 -652  $ MPC shell
1838    0          302 -501 651 -652  $ Air gap
1839    5 -7.92 301 -302 652 -653  $ MPC shell
1840    0          302 -501 652 -653  $ Air gap
1841    5 -7.92 301 -302 653 -654  $ MPC shell
1842    0          302 -501 653 -654  $ Air gap
1843    5 -7.92 301 -302 654 -655  $ MPC shell
1844    0          302 -501 654 -655  $ Air gap
1845    5 -7.92 301 -302 655 -656  $ MPC shell
1846    0          302 -501 655 -656  $ Air gap
1847    5 -7.92 301 -302 656 -657  $ MPC shell
1848    0          302 -501 656 -657  $ Air gap
1849    5 -7.92 301 -302 657 -680  $ MPC shell
1850    0          301 -302 680 -685  $ Air gap
1851    0          302 -501 657 -685  $ Air gap
c
1854    5 -7.92        -301 610 -615  $ MPC baseplate
1855    5 -7.92        -301 615 -620  $ MPC baseplate
1860    5 -7.92        -301 675 -651  $ MPC lid (both)
1861    5 -7.92        -301 651 -652  $ MPC lid (both)
1862    5 -7.92        -301 652 -653  $ MPC lid (both)
1863    5 -7.92        -301 653 -654  $ MPC lid (both)
1864    5 -7.92        -301 654 -655  $ MPC lid (both)
1865    5 -7.92        -301 655 -656  $ MPC lid (both)
1866    5 -7.92        -301 656 -657  $ MPC lid (both)
1867    5 -7.92        -301 657 -680  $ MPC lid (both)
1868    0              -301 680 -685  $ Air gap
c     OVERPACK \/ \/ \/ \/ \/
c
1001  8 -7.82 501 -508 630 -420 $ steel shell
1002  8 -7.82 501 -508 420 -430 $ steel shell
1003  8 -7.82 501 -508 430 -440 $ steel shell
1004  8 -7.82 501 -508 440 -670 $ steel shell
1005  0         508 -512 630 -420  fill=20
1006  0         508 -512 420 -430  fill=20
1007  0         508 -512 430 -440  fill=20
1008  0         508 -512 440 -670  fill=20
1009  8 -7.82 512 -513 630 -420 $ outer steel shell
1010  8 -7.82 512 -513 420 -430 $ outer steel shell
1011  8 -7.82 512 -513 430 -440 $ outer steel shell
1012  8 -7.82 512 -513 440 -670 $ outer steel shell
c     1012  8 -7.82  512 -513 640 -670               $ outer steel shell
c     1013  0         512 -513 630 -640  1103 -1102 $ air in pocket trun.
c     1014  0         512 -513 630 -640  2103 -2102 $ air in pocket trun.
c     1015  8 -7.82  512 -513 630 -640  1102  2102 $ outer steel shell
c     1016  8 -7.82  512 -513 630 -640  1102 -2103 $ outer steel shell
c     1017  8 -7.82  512 -513 630 -640 -1103 -2103 $ outer steel shell
c     1018  8 -7.82  512 -513 630 -640 -1103  2102 $ outer steel shell
c
c      steel spines and holtite
10101    8 -7.82    2000 -2002   645 -660    1000   u=20 $ steel spine
10102    7 -1.61    2002 -2011   645 -660    2000   u=20 $ holtite
10103    8 -7.82    2011 -2012   645 -660    2000   u=20 $ steel spine
10104    7 -1.61    2012 -2021   645 -660    2000   u=20 $ holtite
```

```
10105    8 -7.82    2021 -2022   645 -660    2000   u=20 $ steel spine
10106    7 -1.61    2022 -2031   645 -660    2000   u=20 $ holtite
10107    8 -7.82    2031 -2032   645 -660    2000   u=20 $ steel spine
10108    7 -1.61    2032 -2041   645 -660    2000   u=20 $ holtite
10109    8 -7.82    2041 -2042   645 -660    2000   u=20 $ steel spine
10110    7 -1.61    2042 -2051   645 -660    2000   u=20 $ holtite
10111    8 -7.82    2051 -2052   645 -660    2000   u=20 $ steel spine
10112    7 -1.61    2052 -2061   645 -660    2000   u=20 $ holtite
10113    8 -7.82    2061 -2062   645 -660    2000   u=20 $ steel spine
10114    7 -1.61    2062 -2071   645 -660    2000   u=20 $ holtite
10115    8 -7.82    2071 -2072   645 -660    2000   u=20 $ steel spine
10116    7 -1.61    2072 -2081   645 -660    2000   u=20 $ holtite
10117    8 -7.82    2081 -2082   645 -660    2000   u=20 $ steel spine
10118    7 -1.61    2082 -2091   645 -660    2000   u=20 $ holtite
10119    8 -7.82    2091 -2092   645 -660    2000   u=20 $ steel spine
10120    7 -1.61    2092  1002   645 -660    2000   u=20 $ holtite
10121    8 -7.82    1000 -1002   645 -660    2000   u=20 $ steel spine
c
10122    8 -7.82    1001 -1000   645 -660    2000   u=20 $ steel spine
10123    7 -1.61    1012 -1001   645 -660    2000   u=20 $ holtite
10124    8 -7.82    1011 -1012   645 -660    2000   u=20 $ steel spine
10125    7 -1.61    1022 -1011   645 -660    2000   u=20 $ holtite
10126    8 -7.82    1021 -1022   645 -660    2000   u=20 $ steel spine
10127    7 -1.61    1032 -1021   645 -660    2000   u=20 $ holtite
10128    8 -7.82    1031 -1032   645 -660    2000   u=20 $ steel spine
10129    7 -1.61    1042 -1031   645 -660    2000   u=20 $ holtite
10130    8 -7.82    1041 -1042   645 -660    2000   u=20 $ steel spine
10131    7 -1.61    1052 -1041   645 -660    2000   u=20 $ holtite
10132    8 -7.82    1051 -1052   645 -660    2000   u=20 $ steel spine
10133    7 -1.61    1062 -1051   645 -660    2000   u=20 $ holtite
10134    8 -7.82    1061 -1062   645 -660    2000   u=20 $ steel spine
10135    7 -1.61    1072 -1061   645 -660    2000   u=20 $ holtite
10136    8 -7.82    1071 -1072   645 -660    2000   u=20 $ steel spine
10137    7 -1.61    1082 -1071   645 -660    2000   u=20 $ holtite
10138    8 -7.82    1081 -1082   645 -660    2000   u=20 $ steel spine
10139    7 -1.61    1092 -1081   645 -660    2000   u=20 $ holtite
10140    8 -7.82    1091 -1092   645 -660    2000   u=20 $ steel spine
10141    7 -1.61    2002 -1091   645 -660    2000   u=20 $ holtite
10142    8 -7.82    2000 -2002   645 -660   -1000   u=20 $ steel spine
c
10143    8 -7.82    2001 -2000   645 -660   -1000   u=20 $ steel spine
10144    7 -1.61    2012 -2001   645 -660   -2000   u=20 $ holtite
10145    8 -7.82    2011 -2012   645 -660   -2000   u=20 $ steel spine
10146    7 -1.61    2022 -2011   645 -660   -2000   u=20 $ holtite
10147    8 -7.82    2021 -2022   645 -660   -2000   u=20 $ steel spine
10148    7 -1.61    2032 -2021   645 -660   -2000   u=20 $ holtite
10149    8 -7.82    2031 -2032   645 -660   -2000   u=20 $ steel spine
10150    7 -1.61    2042 -2031   645 -660   -2000   u=20 $ holtite
10151    8 -7.82    2041 -2042   645 -660   -2000   u=20 $ steel spine
10152    7 -1.61    2052 -2041   645 -660   -2000   u=20 $ holtite
10153    8 -7.82    2051 -2052   645 -660   -2000   u=20 $ steel spine
10154    7 -1.61    2062 -2051   645 -660   -2000   u=20 $ holtite
10155    8 -7.82    2061 -2062   645 -660   -2000   u=20 $ steel spine
10156    7 -1.61    2072 -2061   645 -660   -2000   u=20 $ holtite
10157    8 -7.82    2071 -2072   645 -660   -2000   u=20 $ steel spine
10158    7 -1.61    2082 -2071   645 -660   -2000   u=20 $ holtite
10159    8 -7.82    2081 -2082   645 -660   -2000   u=20 $ steel spine
10160    7 -1.61    2092 -2081   645 -660   -2000   u=20 $ holtite
10161    8 -7.82    2091 -2092   645 -660   -2000   u=20 $ steel spine
10162    7 -1.61   -1001 -2091   645 -660   -2000   u=20 $ holtite
10163    8 -7.82    1001 -1000   645 -660   -2000   u=20 $ steel spine
c
10164    8 -7.82    1000 -1002   645 -660   -2000   u=20 $ steel spine
10165    7 -1.61    1002 -1011   645 -660   -2000   u=20 $ holtite
10166    8 -7.82    1011 -1012   645 -660   -2000   u=20 $ steel spine
10167    7 -1.61    1012 -1021   645 -660   -2000   u=20 $ holtite
10168    8 -7.82    1021 -1022   645 -660   -2000   u=20 $ steel spine
10169    7 -1.61    1022 -1031   645 -660   -2000   u=20 $ holtite
10170    8 -7.82    1031 -1032   645 -660   -2000   u=20 $ steel spine
```

```
10171   7 -1.61   1032 -1041  645 -660  -2000  u=20 $ holtite
10172   8 -7.82   1041 -1042  645 -660  -2000  u=20 $ steel spine
10173   7 -1.61   1042 -1051  645 -660  -2000  u=20 $ holtite
10174   8 -7.82   1051 -1052  645 -660  -2000  u=20 $ steel spine
10175   7 -1.61   1052 -1061  645 -660  -2000  u=20 $ holtite
10176   8 -7.82   1061 -1062  645 -660  -2000  u=20 $ steel spine
10177   7 -1.61   1062 -1071  645 -660  -2000  u=20 $ holtite
10178   8 -7.82   1071 -1072  645 -660  -2000  u=20 $ steel spine
10179   7 -1.61   1072 -1081  645 -660  -2000  u=20 $ holtite
10180   8 -7.82   1081 -1082  645 -660  -2000  u=20 $ steel spine
10181   7 -1.61   1082 -1091  645 -660  -2000  u=20 $ holtite
10182   8 -7.82   1091 -1092  645 -660  -2000  u=20 $ steel spine
10183   7 -1.61   1092 -2001  645 -660  -2000  u=20 $ holtite
10184   8 -7.82   2001 -2000  645 -660   1000  u=20 $ steel spine
c
c    10201   8 -7.82   2000 -2002  635 -645   1000  u=20 $ steel spine
c    10202   7 -1.61   2002 -2011  635 -645   2000  u=20 $ holtite
10202   7 -1.61   2101 -2011  635 -645   2000  u=20 $ holtite
10203   8 -7.82   2011 -2012  635 -645   2000  u=20 $ steel spine
10204   7 -1.61   2012 -2021  635 -645   2000  u=20 $ holtite
10205   8 -7.82   2021 -2022  635 -645   2000  u=20 $ steel spine
10206   7 -1.61   2022 -2031  635 -645   2000  u=20 $ holtite
10207   8 -7.82   2031 -2032  635 -645   2000  u=20 $ steel spine
10208   7 -1.61   2032 -2041  635 -645   2000  u=20 $ holtite
10209   8 -7.82   2041 -2042  635 -645   2000  u=20 $ steel spine
10210   7 -1.61   2042 -2051  635 -645   2000  u=20 $ holtite
10211   8 -7.82   2051 -2052  635 -645   2000  u=20 $ steel spine
10212   7 -1.61   2052 -2061  635 -645   2000  u=20 $ holtite
10213   8 -7.82   2061 -2062  635 -645   2000  u=20 $ steel spine
10214   7 -1.61   2062 -2071  635 -645   2000  u=20 $ holtite
10215   8 -7.82   2071 -2072  635 -645   2000  u=20 $ steel spine
10216   7 -1.61   2072 -2081  635 -645   2000  u=20 $ holtite
10217   8 -7.82   2081 -2082  635 -645   2000  u=20 $ steel spine
10218   7 -1.61   2082 -2091  635 -645   2000  u=20 $ holtite
10219   8 -7.82   2091 -2092  635 -645   2000  u=20 $ steel spine
c    10220   7 -1.61   2092  1101  635 -645   2000  u=20 $ holtite
10220   7 -1.61   2092  1002  635 -645   2000  u=20 $ holtite
10221   8 -7.82   1000 -1002  635 -645   2000  u=20 $ steel spine
c
10222   8 -7.82   1001 -1000  635 -645   2000  u=20 $ steel spine
10223   7 -1.61   1012 -1001  635 -645   2000  u=20 $ holtite
c    10223   7 -1.61   1012 -1104  635 -645   2000  u=20 $ holtite
10224   8 -7.82   1011 -1012  635 -645   2000  u=20 $ steel spine
10225   7 -1.61   1022 -1011  635 -645   2000  u=20 $ holtite
10226   8 -7.82   1021 -1022  635 -645   2000  u=20 $ steel spine
10227   7 -1.61   1032 -1021  635 -645   2000  u=20 $ holtite
10228   8 -7.82   1031 -1032  635 -645   2000  u=20 $ steel spine
10229   7 -1.61   1042 -1031  635 -645   2000  u=20 $ holtite
10230   8 -7.82   1041 -1042  635 -645   2000  u=20 $ steel spine
10231   7 -1.61   1052 -1041  635 -645   2000  u=20 $ holtite
10232   8 -7.82   1051 -1052  635 -645   2000  u=20 $ steel spine
10233   7 -1.61   1062 -1051  635 -645   2000  u=20 $ holtite
10234   8 -7.82   1061 -1062  635 -645   2000  u=20 $ steel spine
10235   7 -1.61   1072 -1061  635 -645   2000  u=20 $ holtite
10236   8 -7.82   1071 -1072  635 -645   2000  u=20 $ steel spine
10237   7 -1.61   1082 -1071  635 -645   2000  u=20 $ holtite
10238   8 -7.82   1081 -1082  635 -645   2000  u=20 $ steel spine
10239   7 -1.61   1092 -1081  635 -645   2000  u=20 $ holtite
10240   8 -7.82   1091 -1092  635 -645   2000  u=20 $ steel spine
10241   7 -1.61   2101 -1091  635 -645   2000  u=20 $ holtite
c    10241   7 -1.61   2002 -1091  635 -645   2000  u=20 $ holtite
c    10242   8 -7.82   2000 -2002  635 -645  -1000  u=20 $ steel spine
c
c    10243   8 -7.82   2001 -2000  635 -645  -1000  u=20 $ steel spine
c    10244   7 -1.61   2012 -2001  635 -645  -2000  u=20 $ holtite
10244   7 -1.61   2012 -2104  635 -645  -2000  u=20 $ holtite
10245   8 -7.82   2011 -2012  635 -645  -2000  u=20 $ steel spine
10246   7 -1.61   2022 -2011  635 -645  -2000  u=20 $ holtite
10247   8 -7.82   2021 -2022  635 -645  -2000  u=20 $ steel spine
```

```
10248   7 -1.61   2032 -2021  635 -645  -2000  u=20 $ holtite
10249   8 -7.82   2031 -2032  635 -645  -2000  u=20 $ steel spine
10250   7 -1.61   2042 -2031  635 -645  -2000  u=20 $ holtite
10251   8 -7.82   2041 -2042  635 -645  -2000  u=20 $ steel spine
10252   7 -1.61   2052 -2041  635 -645  -2000  u=20 $ holtite
10253   8 -7.82   2051 -2052  635 -645  -2000  u=20 $ steel spine
10254   7 -1.61   2062 -2051  635 -645  -2000  u=20 $ holtite
10255   8 -7.82   2061 -2062  635 -645  -2000  u=20 $ steel spine
10256   7 -1.61   2072 -2061  635 -645  -2000  u=20 $ holtite
10257   8 -7.82   2071 -2072  635 -645  -2000  u=20 $ steel spine
10258   7 -1.61   2082 -2071  635 -645  -2000  u=20 $ holtite
10259   8 -7.82   2081 -2082  635 -645  -2000  u=20 $ steel spine
10260   7 -1.61   2092 -2081  635 -645  -2000  u=20 $ holtite
10261   8 -7.82   2091 -2092  635 -645  -2000  u=20 $ steel spine
c    10262   7 -1.61   -1104 -2091  635 -645  -2000  u=20 $ holtite
10262   7 -1.61  -1001 -2091  635 -645  -2000  u=20 $ holtite
10263   8 -7.82   1001 -1000  635 -645  -2000  u=20 $ steel spine
c
10264   8 -7.82   1000 -1002  635 -645  -2000  u=20 $ steel spine
10265   7 -1.61   1002 -1011  635 -645  -2000  u=20 $ holtite
c    10265   7 -1.61   1101 -1011  635 -645  -2000  u=20 $ holtite
10266   8 -7.82   1011 -1012  635 -645  -2000  u=20 $ steel spine
10267   7 -1.61   1012 -1021  635 -645  -2000  u=20 $ holtite
10268   8 -7.82   1021 -1022  635 -645  -2000  u=20 $ steel spine
10269   7 -1.61   1022 -1031  635 -645  -2000  u=20 $ holtite
10270   8 -7.82   1031 -1032  635 -645  -2000  u=20 $ steel spine
10271   7 -1.61   1032 -1041  635 -645  -2000  u=20 $ holtite
10272   8 -7.82   1041 -1042  635 -645  -2000  u=20 $ steel spine
10273   7 -1.61   1042 -1051  635 -645  -2000  u=20 $ holtite
10274   8 -7.82   1051 -1052  635 -645  -2000  u=20 $ steel spine
10275   7 -1.61   1052 -1061  635 -645  -2000  u=20 $ holtite
10276   8 -7.82   1061 -1062  635 -645  -2000  u=20 $ steel spine
10277   7 -1.61   1062 -1071  635 -645  -2000  u=20 $ holtite
10278   8 -7.82   1071 -1072  635 -645  -2000  u=20 $ steel spine
10279   7 -1.61   1072 -1081  635 -645  -2000  u=20 $ holtite
10280   8 -7.82   1081 -1082  635 -645  -2000  u=20 $ steel spine
10281   7 -1.61   1082 -1091  635 -645  -2000  u=20 $ holtite
10282   8 -7.82   1091 -1092  635 -645  -2000  u=20 $ steel spine
10283   7 -1.61   1092 -2104  635 -645  -2000  u=20 $ holtite
c    10283   7 -1.61    1092 -2001  635 -645  -2000  u=20 $ holtite
c    10284   8 -7.82   2001 -2000  635 -645   1000  u=20 $ steel spine
c
11000   0         660 -665    u=20 $ foam
11001   8 -7.82   665         u=20 $ item 17 top
c    11002   8 -7.82   1101  2101  -635  u=20 $ item 17 bot
c    11003   8 -7.82  -2104  1101  -635  u=20 $ item 17 bot
c    11004   8 -7.82  -1104 -2104  -635  u=20 $ item 17 bot
c    11005   8 -7.82   2101 -1104  -635  u=20 $ item 17 bot
11002   8 -7.82        2101  -635  u=20 $ item 17 bot
11003   8 -7.82  -2104         -635  u=20 $ item 17 bot
c
c    pocket trunion
c
c    11101   8 -7.82  -514  1104 -1101 -640  u=20 $ pocket trunion before hole
c    11102   8 -7.82   514  1104 -1103 -640  u=20 $ steel on side of hole
c    11103   8 -7.82   514  1103 -1102 -640  u=20 $ hole
c    11104   8 -7.82   514  1102 -1101 -640  u=20 $ steel on side of hole
c    11105   8 -7.82        1104 -1101  640 -645  u=20 $ steel above hole
c
11111   8 -7.82  -514  2104 -2101 -640  u=20 $ pocket trunion before hole
11112   8 -7.82   514  2104 -2103 -640  u=20 $ steel on side of hole
11113   8 -7.82   514  2103 -2102 -640  u=20 $ hole
11114   8 -7.82   514  2102 -2101 -640  u=20 $ steel on side of hole
11115   8 -7.82        2104 -2101  640 -645  u=20 $ steel above hole
c
c     overpack base plate
c
2000  8 -7.82     -501 600 -601
2001  8 -7.82     -501 601 -602
```

```
2002  8 -7.82      -501 602 -603
2003  8 -7.82      -501 603 -604
2004  8 -7.82      -501 604 -610
c
2010  8 -7.82 501 -515 600 -601
2011  8 -7.82 501 -515 601 -602
2012  8 -7.82 501 -515 602 -603
2013  8 -7.82 501 -515 603 -604
2014  8 -7.82 501 -515 604 -610
2015  8 -7.82 501 -515 610 -615
2016  8 -7.82 501 -515 615 -630
2020  0   515 -513 600 -601
2021  0   515 -513 601 -602
2022  0   515 -513 602 -603
2023  0   515 -513 603 -604
2024  0   515 -513 604 -610
2025  0   515 -513 610 -615
2026  0   515 -513 615 -630
c
c     overpack lid
c
3000  8 -7.82      -506 685 -686
3001  8 -7.82      -506 686 -687
3002  8 -7.82      -506 687 -688
3003  8 -7.82      -506 688 -689
3004  8 -7.82      -506 689 -695
3010  0   506 -513 685 -686
3011  0   506 -513 686 -687
3012  0   506 -513 687 -688
3013  0   506 -513 688 -689
3014  0   506 -513 689 -695
c
3020  8 -7.82 501 -517 675 -676
3021  8 -7.82 501 -516 676 -651
3022  8 -7.82 501 -516 651 -652
3023  8 -7.82 501 -516 652 -653
3024  8 -7.82 501 -516 653 -654
3025  8 -7.82 501 -516 654 -655
3026  8 -7.82 501 -516 655 -656
3027  8 -7.82 501 -516 656 -677
3028  8 -7.82 501 -506 677 -657
3029  8 -7.82 501 -506 657 -685
3030  0   517 -513 675 -676
3031  0   516 -513 676 -651
3032  0   516 -513 651 -652
3033  0   516 -513 652 -653
3034  0   516 -513 653 -654
3035  0   516 -513 654 -655
3036  0   516 -513 655 -656
3037  0   516 -513 656 -677
3038  0   506 -513 677 -657
3039  0   506 -513 657 -685
c
3042  8 -7.82 501 -517 670 -675
3047  0   517 -513 670 -675
c
c     surrounding air regions
9000  9 -1.17e-3        -506 695 -830
9001  9 -1.17e-3        -506 830 -831
9002  9 -1.17e-3        -506 831 -832
9003  9 -1.17e-3        -506 832 -833
9004  9 -1.17e-3        -506 833 -837
9010  0   506 -527 695 -830
9011  0   506 -527 830 -831
9012  0   506 -527 831 -832
9013  0   506 -527 832 -833
9014  0   506 -527 833 -837
c
9100  9 -1.17e-3        -515 810 -600
```

```
9101  9 -1.17e-3       -515 811 -810
9102  9 -1.17e-3       -515 812 -811
9103  9 -1.17e-3       -515 813 -812
9104  9 -1.17e-3       -515 817 -813
9110  0   515 -527 810 -600
9111  0   515 -527 811 -810
9112  0   515 -527 812 -811
9113  0   515 -527 813 -812
9114  0   515 -527 817 -813
c
9200  0   513 -527 600 -601
9201  0   513 -527 601 -602
9202  0   513 -527 602 -603
9203  0   513 -527 603 -604
9204  0   513 -527 604 -610
9205  0   513 -527 610 -615
9206  0   513 -527 615 -630
9207  0   513 -527 630 -420
9208  0   513 -527 420 -430
9209  0   513 -527 430 -440
9210  0   513 -527 440 -670
9211  0   513 -527 670 -675
9212  0   513 -527 675 -651
9213  0   513 -527 651 -652
9214  0   513 -527 652 -653
9215  0   513 -527 653 -654
9216  0   513 -527 654 -655
9217  0   513 -527 655 -656
9218  0   513 -527 656 -657
9219  0   513 -527 657 -685
9220  0   513 -527 685 -686
9221  0   513 -527 686 -687
9222  0   513 -527 687 -688
9223  0   513 -527 688 -689
9224  0   513 -527 689 -695
c
c
c
9999  0  527:-817:837
c
c     BLANK LINE

c     BLANK LINE
c
c     MPC surfaces\/ \/ \/ \/ \/
c
1     cz         0.52832
2     cz         0.53213
3     cz         0.61341
4     cz         0.67437
5     cz         0.75057
6     px         0.8128
7     px        -0.8128
8     py         0.8128
9     py        -0.8128
10    px        -4.445
11    px         4.445
12    py        -4.445
13    py         4.445
c     14    px        -8.2423
14    px        -8.242301
15    px        -7.9248
16    px        -7.66826
17    px        -7.47776
18    px        -6.0325
19    px         6.0325
20    px         7.9248
c     21    px         8.2423
c     22    py        -8.2423
```

```
21     px          8.242301
22     py         -8.242301
23     py         -7.9248
24     py         -6.0325
25     py          6.0325
26     py          7.47776
27     py          7.66826
28     py          7.9248
c      29     py          8.2423
29     py          8.242301
c
30     px    -6.5024
31     px     6.5024
32     py    -6.5024
33     py     6.5024
c
101    px   -98.9076
102    px   -82.423
103    px   -65.9384
104    px   -49.4538
105    px   -32.9692
106    px   -16.4846
107    px    0.0
108    px    16.4846
109    px    32.9692
110    px    49.4538
111    px    65.9384
112    px    82.423
113    px    98.9076
c
201    py   -98.9076
202    py   -82.423
203    py   -65.9384
204    py   -49.4538
205    py   -32.9692
206    py   -16.4846
207    py    0.0
208    py    16.4846
209    py    32.9692
210    py    49.4538
211    py    65.9384
212    py    82.423
213    py    98.9076
c
301    cz    85.4075
302    cz    86.6775
c
c      620   pz     21.59      $ MPC baseplate          - 2.5 inches
c      400   pz    24.765  $ start of egg crate
400    pz    23.876  $ start of egg crate
410    pz    33.9725  $ start of boral
420    pz    40.3479 $ beginning of fuel
425    pz    406.1079 $ end of fuel
430    pz    421.3479 $ space
435    pz    430.2125  $ end  of boral
440    pz    445.4271 $ plenum
445    pz    448.8561 $ expansion springs
450    pz    457.3397 $ top end fitting
455    pz    468.63   $ top of element
460    pz    466.344  $ top of egg crate
c
c      MPC surfaces/\ /\ /\ /\ /\
c
c
c      OVERPACK survaces \/ \/ \/ \/ \/
c
501    cz     87.3125  $ IR for overpack
502    cz     90.4875  $ item 2  1.25 inch
503    cz     93.6625  $ item 2  1.25 inch
```

```
504    cz     96.8375     $ item 12  1.25 inch
505    cz     100.0125    $ item 13  1.25 inch
506    cz     103.1875    $ item 14  1.25 inch
507    cz     106.3625    $ item 15  1.25 inch
508    cz     108.9025    $ item 16  1 inch
509    cz     111.521875  $ holtite
510    cz     114.14125   $ holtite
511    cz     116.760625  $ holtite
512    cz     119.53875      $ holtite - total 4.1875 inches
513    cz     120.80875      $ outer steel shell - 0.5 inches
c      512    cz    119.38      $ holtite - total 4.125 inches
c      513    cz    120.65      $ outer steel shell - 0.5 inches
514    cz     111.54      $ hole in pocket trunion
515    cz     105.7275    $ flange bottom of overpack
516    cz     105.7275    $ flange top    of overpack
517    cz     109.5375    $ shear ring
518    cz     103.1875    $ item 14  1.25 inch
519    cz     108.2675    $ impact limiter - 2 inch steel
c
521    cz     162.56      $ surface of impact limiters
522    cz     203.1875    $ 1 meter from 506 - upper and lower part overpack
523    cz     220.80875   $ 1 meter from 513 - outer steel
524    cz     303.1875    $ 2 meter from 506 - upper and lower part overpack
525    cz     320.80875   $ 2 meter from 513 - outer steel
526    cz     362.56      $ 2 meter from 521 - edge of impact limiters
527    cz     400.00
c
600    pz     0.0        $ bottom of overpack
601    pz     3.048
602    pz     6.096
603    pz     9.144
604    pz     12.192
610    pz     15.24      $ overpack baseplate    - 6 inches
615    pz     18.415
620    pz     21.59      $ MPC baseplate         - 2.5 inches
630    pz     22.225     $ beginning of item 17 - 0.25 inches
635    pz     23.495     $ item 17              - 0.5 inches
640    pz     41.75125   $ hole in pocket trun  - 7.6875 inches from 630
645    pz     54.61      $ top of pocket trun   - 12.75 inches from 630
660    pz     455.6125   $ top of holtite       - 170.125 inches from 635
665    pz     460.6925   $ top of foam          - 2 inches
670    pz     461.9625   $ top of item 17 on top- 0.5 inches
675    pz     473.71     $ bottom of MPC in lid - 178 inches from 620
676    pz     476.5675   $ top of shear ring
677    pz     494.03     $ top of add steel
651    pz     476.885
652    pz     480.06
653    pz     483.235
654    pz     486.41
655    pz     489.585
656    pz     492.76
657    pz     495.935
680    pz     499.11     $ top of MPC outer lid
685    pz     500.6975   $ bot of overpack lid  - 5/8 inch
686    pz     503.7455
687    pz     506.7935
688    pz     509.8415
689    pz     512.8895
695    pz     515.9375   $ top of overpack lid  - 6 inches
c
c      tally segment surfaces
c
701    pz     -121.92
702    pz     -91.44
703    pz     -60.96
704    pz     -30.48
c      600    pz    0.0        $ bottom of overpack
c      630    pz    22.225     $ beginning of item 17 - 0.25 inches
705    pz     51.5408
```

```
706    pz     80.8567
707    pz     110.1725
708    pz     139.4883
709    pz     168.8042
710    pz     198.1200
711    pz     227.4358
712    pz     256.7517
713    pz     286.0675
714    pz     315.3833
715    pz     344.6992
716    pz     374.0150
717    pz     403.3308
718    pz     432.6467
c      670    pz     461.9625   $ top of item 17 on top- 0.5 inches
719    pz     488.3150
c      695    pz     514.6675   $ top of overpack lid  - 6 inches
720    pz     545.1475
721    pz     575.6275
722    pz     606.1075
723    pz     636.5875
c
740    cz     15.24
741    cz     45.72
742    cz     76.2
743    cz     106.68
744    cz     137.16
745    cz     167.64
746    cz     198.12
747    cz     228.6
748    cz     259.08
749    cz     289.56
750    cz     320.04
751    cz     350.52
752    cz     381.0
c
801    pz     -2.54     $ steel disk
802    pz     -5.715    $ holtite
803    pz     -8.89     $ holtite
804    pz     -9.2075   $ cover over holtite
805    pz     -53.34    $ item 2 on impact limiters
810    pz     -100.0    $ 1 meter from surface overpack
811    pz     -105.7275 $ edge of impact limiter
812    pz     -200.0    $ 2 meter from surface overpack
813    pz     -305.7275 $ 2 meter from surface impact limiter
814    pz     -427.6475 $ 2 meter + 4 feet
815    pz     -488.6075 $ 2 meter + 6 feet
816    pz     -671.4875 $ 2 meter + 12 feet
817    pz     -700.00
c
821    pz     518.4775     $ steel disk
822    pz     521.6525     $ holtite
823    pz     524.8275     $ holtite
824    pz     525.145      $ cover over holtite
825    pz     569.2775     $ item 2 on impact limiters
830    pz     615.9375     $ 1 meter from surface overpack
831    pz     621.6650     $ edge of impact limiter
832    pz     715.9375     $ 2 meter from surface overpack
833    pz     821.6650     $ 2 meter from surface impact limiter
834    pz     943.5850     $ 2 meter + 4 feet
835    pz     1004.545     $ 2 meter + 6 feet
836    pz     1187.425     $ 2 meter + 12 feet
837    pz     1200.00
c
c          steel spine and holtite cells
c
1000       px     0.0
1001       px   -0.635
1002       px    0.635
1011   1   px   -0.635
```

```
1012   1  px   0.635
1021   2  px  -0.635
1022   2  px   0.635
1031   3  px  -0.635
1032   3  px   0.635
1041   4  px  -0.635
1042   4  px   0.635
1051   5  px  -0.635
1052   5  px   0.635
1061   6  px  -0.635
1062   6  px   0.635
1071   7  px  -0.635
1072   7  px   0.635
1081   8  px  -0.635
1082   8  px   0.635
1091   9  px  -0.635
1092   9  px   0.635
c
1101   px   15.71625  $ pocket trunion
1102   px    8.09625  $ pocket trunion opening
1103   px   -8.09625  $ pocket trunion opening 6 3/8 inches thick
1104   px  -15.71625  $ pocket trunion - 9 3/8 inches thick
c
2000      py   0.0
2001      py  -0.635
2002      py   0.635
2011   1  py  -0.635
2012   1  py   0.635
2021   2  py  -0.635
2022   2  py   0.635
2031   3  py  -0.635
2032   3  py   0.635
2041   4  py  -0.635
2042   4  py   0.635
2051   5  py  -0.635
2052   5  py   0.635
2061   6  py  -0.635
2062   6  py   0.635
2071   7  py  -0.635
2072   7  py   0.635
2081   8  py  -0.635
2082   8  py   0.635
2091   9  py  -0.635
2092   9  py   0.635
c
2101   py   15.71625  $ pocket trunion
2102   py    8.09625  $ pocket trunion opening
2103   py   -8.09625  $ pocket trunion opening 6 3/8 inches thick
2104   py  -15.71625  $ pocket trunion - 9 3/8 inches thick
c
c     OVERPACK surfaces /\ /\ /\ /\ /\
c
c     BLANK LINE

c     BLANK LINE
c
*tr1    0 0 0  9 279 90  99  9 90 90 90 0
*tr2    0 0 0 18 288 90 108 18 90 90 90 0
*tr3    0 0 0 27 297 90 117 27 90 90 90 0
*tr4    0 0 0 36 306 90 126 36 90 90 90 0
*tr5    0 0 0 45 315 90 135 45 90 90 90 0
*tr6    0 0 0 54 324 90 144 54 90 90 90 0
*tr7    0 0 0 63 333 90 153 63 90 90 90 0
*tr8    0 0 0 72 342 90 162 72 90 90 90 0
*tr9    0 0 0 81 351 90 171 81 90 90 90 0
c
c        PHOTON MATERIALS
c
c     fuel 3.4 w/o U235  10.412 gm/cc
```

```
c      m1             92235.01p   -0.029971
c                     92238.01p   -0.851529
c                     8016.01p    -0.1185
c      c     homogenized fuel  density 3.979996 gm/cc
c      m2             92235.01p   -0.024483
c                     92238.01p   -0.695601
c                      8016.01p   -0.096801
c                     40000.01p   -0.183115
c      c     zirconium 6.55 gm/cc
c      m3             40000.01p   1.             $ Zr Clad
c      c     stainless steel 7.92 gm/cc
c      m5             24000.01p   -0.19
c                     25055.01p   -0.02
c                     26000.01p   -0.695
c                     28000.01p   -0.095
c      c     boral  2.644 gm/cc
c      m6             5010.01p    -0.044226
c                     5011.01p    -0.201474
c                     13027.01p   -0.6861
c                     6000.01p    -0.0682
c      c     holtite 1.61 gm/cc
c      m7             6000.01p  -0.2766039
c                    13027.01p  -0.21285
c                     1001.01p  -0.0592
c                     8016.01p  -0.42372
c                     7014.01p  -0.0198
c                     5010.01p  -0.0014087
c                     5011.01p  -0.0064174
c      c     carbon steel 7.82 gm/cc
c      m8         6000.01p -0.005 26000.01p -0.995
c      c     air density 1.17e-3 gm/cc
c      m9         7014.01p 0.78 8016.01p 0.22
c      c
c      c          NEUTRON MATERIALS
c
c      fuel 3.4 w/o U235  10.412 gm/cc
m1             92235.50c   -0.029971
               92238.50c   -0.851529
               8016.50c    -0.1185
c      homogenized fuel  density 3.979996 gm/cc
m2             92235.50c   -0.024483
               92238.50c   -0.695601
                8016.50c   -0.096801
               40000.35c   -0.183115
c      helium  1e-4 gm/cc
m3      2004.50c 1.0
c      stainless steel 7.92 gm/cc
m5             24000.50c   -0.19
               25055.50c   -0.02
               26000.55c   -0.695
               28000.50c   -0.095
c      boral   2.644 gm/cc
m6             5010.50c    -0.044226
               5011.56c    -0.201474
               13027.50c   -0.6861
               6000.50c    -0.0682
c      holtite 1.61 gm/cc
m7             6000.50c  -0.2766039
              13027.50c  -0.21285
               1001.50c  -0.0592
               8016.50c  -0.42372
               7014.50c  -0.0198
               5010.50c  -0.0014087
               5011.56c  -0.0064174
mt7     lwtr.01t
c      carbon steel 7.82 gm/cc
m8        6000.50c -0.005 26000.55c -0.995
c      air density 1.17e-3 gm/cc
m9        7014.50c 0.78 8016.50c 0.22
```

```
c
phys:n   20 0.0
phys:p   100 0
c     imp:n   1 228r 0
c     imp:p   1 228r 0
nps     500000
prdmp    j   -30   1   2
c     print   10 110 160 161 20 170
print
mode n p
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
c    energy dist for gammas in the fuel
c
c    si1  h  0.7 1.0 1.5 2.0 2.5 3.0
c    sp1     0  0.31 0.31 0.15 0.15 0.08
c
c    energy dist for neutrons in the fuel
c
si1  h  0.1 0.4 0.9 1.4 1.85 3.0 6.43 20.0
sp1     0  0.03787 0.1935 0.1773 0.1310 0.2320 0.2098 0.01853
c
c    energy dist for Co60 gammas
c
c    si1  d 1.3325 1.1732
c    sp1    0.5    0.5
c
c    axial dist for neut and phot in fuel
c
si3  h 40.3479 55.5879 70.8279 101.3079 162.2679 223.2279
       284.1879 345.1479 375.6279 390.8679 406.1079
sp3    0 0.00005 0.00961 0.07031 0.23323 0.25719 0.22907
         0.16330 0.03309 0.00409 0.00005
sb3    0 1 1 1 1 1 1 1 1 1 1
c
c    axial dist for Co60 - a zero prob is in the fuel
c
c    si3  h 21.59 40.3479 421.3479 445.4271 448.8561 457.3397 468.63
c    sp3    0     0.547   0.0      0.125    0.045    0.227    0.056
c
si4  s                  15 16
                  13 14 15 16 17 18
               12 13 14 15 16 17 18 19
               12 13 14 15 16 17 18 19
            11 12 13 14 15 16 17 18 19 20
            11 12 13 14 15 16 17 18 19 20
               12 13 14 15 16 17 18 19
               12 13 14 15 16 17 18 19
                  13 14 15 16 17 18
                        15 16
sp4  1 67r
c
ds5  s                  30 30
                  29 29 29 29 29 29
               28 28 28 28 28 28 28 28
               27 27 27 27 27 27 27 27
            26 26 26 26 26 26 26 26 26 26
            25 25 25 25 25 25 25 25 25 25
               24 24 24 24 24 24 24 24
               23 23 23 23 23 23 23 23
                  22 22 22 22 22 22
                        21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
si15  -14.7447 -1.7399
```

```
si16    1.7399    14.7447
si17    18.2245   31.2293
si18    34.7091   47.7139
si19    51.1937   64.1985
si20    67.6783   80.6831
c
si21   -80.6831 -67.6783
si22   -64.1985 -51.1937
si23   -47.7139 -34.7091
si24   -31.2293 -18.2245
si25   -14.7447 -1.7399
si26    1.7399    14.7447
si27    18.2245   31.2293
si28    34.7091   47.7139
si29    51.1937   64.1985
si30    67.6783   80.6831
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp17  0 1
sp18  0 1
sp19  0 1
sp20  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
sp27  0 1
sp28  0 1
sp29  0 1
sp30  0 1
c
#          imp:n     imp:p
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10255	1	1
10256	1	1
10257	1	1
10258	1	1
10259	1	1
10260	1	1
10261	1	1
10262	1	1
10263	1	1
10264	1	1
10265	1	1
10266	1	1
10267	1	1
10268	1	1
10269	1	1
10270	1	1
10271	1	1
10272	1	1
10273	1	1
10274	1	1
10275	1	1
10276	1	1
10277	1	1
10278	1	1
10279	1	1
10280	1	1
10281	1	1
10282	1	1
10283	1	1
11000	1	1
11001	1	1
11002	1	1
11003	1	1
11111	1	1
11112	1	1
11113	1	1
11114	1	1
11115	1	1
2000	32	1
2001	16	1
2002	16	1
2003	8	1
2004	8	1
2010	32	1
2011	16	1
2012	16	1
2013	8	1

2014	8	1
2015	4	1
2016	4	1
2020	1	1
2021	1	1
2022	1	1
2023	1	1
2024	1	1
2025	1	1
2026	1	1
3000	128	1
3001	128	1
3002	256	1
3003	256	1
3004	512	1
3010	1	1
3011	1	1
3012	1	1
3013	1	1
3014	1	1
3020	8	1
3021	8	1
3022	8	1
3023	16	1
3024	16	1
3025	32	1
3026	32	1
3027	64	1
3028	64	1
3029	64	1
3030	1	1
3031	1	1
3032	1	1
3033	1	1
3034	1	1
3035	1	1
3036	1	1
3037	1	1
3038	1	1
3039	1	1
3042	4	1
3047	1	1
9000	512	1
9001	512	1
9002	512	1
9003	512	1
9004	512	1
9010	1	1
9011	1	1
9012	1	1
9013	1	1
9014	1	1
9100	32	1
9101	32	1
9102	32	1
9103	32	1
9104	32	1
9110	1	1
9111	1	1
9112	1	1
9113	1	1
9114	1	1
9200	1	1
9201	1	1
9202	1	1
9203	1	1
9204	1	1
9205	1	1
9206	1	1

```
  9207     1         1
  9208     1         1
  9209     1         1
  9210     1         1
  9211     1         1
  9212     1         1
  9213     1         1
  9214     1         1
  9215     1         1
  9216     1         1
  9217     1         1
  9218     1         1
  9219     1         1
  9220     1         1
  9221     1         1
  9222     1         1
  9223     1         1
  9224     1         1
  9999     0         0
c
c      neutron dose factors
c
c    2.5e-8   1.0e-7   1.0e-6   1.0e-5   1.0e-4   1.0e-3   1.0e-2     0.1
c        0.5      1.0      2.5      5.0      7.0      10.0      14.0      20.0
c    3.67e-6  3.67e-6  4.46e-6  4.54e-6  4.18e-6  3.76e-6  3.56e-6 2.17e-5
c        9.26e-5  1.32e-4  1.25e-4  1.56e-4  1.47e-4  1.47e-4  2.08e-4 2.27e-4
c
c      photon dose factors
c
c    0.01  0.03  0.05  0.07  0.1  0.15  0.2  0.25  0.3  0.35  0.4  0.45
c         0.5  0.55  0.6  0.65  0.7  0.8  1.0  1.4  1.8  2.2  2.6  2.8  3.25
c         3.75  4.25  4.75  5.0  5.25  5.75  6.25  6.75  7.5  9.0  11.0
c         13.0  15.0
c   3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
c        6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
c        1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
c        3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
c        5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
c        1.03e-05  1.18e-05  1.33e-05
c
f2:n    600 810 811 812 813
fs2     -740 -741 -742 -743 -744 -745 -746 -747 -748 -749 -750 -751 -752 t
fc2     1ft all
ft2     scx 1
de2    2.5e-8    1.0e-7    1.0e-6    1.0e-5    1.0e-4    1.0e-3    1.0e-2     0.1
       0.5       1.0       2.5       5.0       7.0       10.0      14.0      20.0
df2    3.67e-6   3.67e-6   4.46e-6   4.54e-6   4.18e-6   3.76e-6   3.56e-6 2.17e-5
       9.26e-5   1.32e-4   1.25e-4   1.56e-4   1.47e-4   1.47e-4   2.08e-4 2.27e-4
fq2    u s
tf2    3j 2
c
f12:n   695 830 831 832 833
fs12    -740 -741 -742 -743 -744 -745 -746 -747 -748 -749 -750 -751 -752 t
fc12     1ft all
ft12     scx 1
de12    2.5e-8    1.0e-7    1.0e-6    1.0e-5    1.0e-4    1.0e-3    1.0e-2     0.1
       0.5       1.0       2.5       5.0       7.0       10.0      14.0      20.0
df12    3.67e-6   3.67e-6   4.46e-6   4.54e-6   4.18e-6   3.76e-6   3.56e-6 2.17e-5
       9.26e-5   1.32e-4   1.25e-4   1.56e-4   1.47e-4   1.47e-4   2.08e-4 2.27e-4
fq12    u s
tf12    3j 2
c
c      PHOTON TALLIES
c
f102:p    600 810 811 812 813
fs102     -740 -741 -742 -743 -744 -745 -746 -747 -748 -749 -750 -751 -752 t
fc102     1ft all
ft102     scx 1
de102     0.01  0.03  0.05  0.07  0.1  0.15  0.2  0.25  0.3  0.35  0.4  0.45
```

```
         0.5  0.55  0.6  0.65  0.7  0.8  1.0  1.4  1.8  2.2  2.6  2.8  3.25
         3.75  4.25  4.75  5.0  5.25  5.75  6.25  6.75  7.5  9.0  11.0
         13.0  15.0
df102   3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
        6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
        1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
        3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
        5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
        1.03e-05  1.18e-05  1.33e-05
fq102   u s
tf102   3j 2
c
f112:p   695 830 831 832 833
fs112    -740 -741 -742 -743 -744 -745 -746 -747 -748 -749 -750 -751 -752 t
fc112    1ft all
ft112    scx 1
de112    0.01  0.03  0.05  0.07  0.1  0.15  0.2  0.25  0.3  0.35  0.4  0.45
         0.5  0.55  0.6  0.65  0.7  0.8  1.0  1.4  1.8  2.2  2.6  2.8  3.25
         3.75  4.25  4.75  5.0  5.25  5.75  6.25  6.75  7.5  9.0  11.0
         13.0  15.0
df112   3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
        6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
        1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
        3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
        5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
        1.03e-05  1.18e-05  1.33e-05
fq112   u s
tf112   3j 2
```

CHAPTER 6: CRITICALITY EVALUATION

This chapter documents the criticality evaluation of the HI-STAR 100 System for the storage of spent nuclear fuel in accordance with 10CFR72.124. The results of this evaluation demonstrate that the HI-STAR 100 System is consistent with the Standard Review Plan for Dry Cask Storage Systems, NUREG-1536, and thus, fulfills the following acceptance criteria:

1. The multiplication factor (k_{eff}), including all biases and uncertainties at a 95-percent confidence level, should not exceed 0.95 under all credible normal, off-normal, and accident conditions.

2. At least two unlikely, independent, and concurrent or sequential changes to the conditions essential to criticality safety, under normal, off-normal, and accident conditions, should occur before an accidental criticality is deemed to be possible.

3. When practicable, criticality safety of the design should be established on the basis of favorable geometry, permanent fixed neutron-absorbing materials (poisons), or both. Where solid neutron absorbing materials are used, the design should provide for a positive means to verify their continued efficacy during the storage period.

4. Criticality safety of the cask system should not rely on use of the following credits:

    a. burnup of the fuel
    b. fuel-related burnable neutron absorbers
    c. more than 75 percent for fixed neutron absorbers when subject to standard acceptance test.

In addition to demonstrating that the criticality safety acceptance criteria are satisfied, this chapter describes the HI-STAR 100 System design structures and components important to criticality safety and defines the limiting fuel characteristics.

6.1 DISCUSSION AND RESULTS

In conformance with the principles established in NUREG-1536 [6.1.1], 10CFR72.124 [6.1.2], and NUREG-0800 Section 9.1.2 [6.1.3], the results in this chapter demonstrate that the effective multiplication factor (k_{eff}) of the HI-STAR 100 System, including all biases and uncertainties evaluated with a 95% probability at the 95% confidence level, does not exceed 0.95 under all credible normal, off-normal, and accident conditions. Moreover, these results demonstrate that the HI-STAR 100 System is designed and maintained such that at least two unlikely, independent, and concurrent or sequential changes must occur to the conditions essential to criticality safety before a nuclear criticality accident is possible. These criteria provide a large subcritical margin, sufficient to assure the criticality safety of the HI-STAR 100 System when fully loaded with fuel of the highest permissible reactivity.

Criticality safety of the HI-STAR 100 System depends on the following three principal design parameters:

1. The inherent geometry of the fuel basket designs within the MPC (and the flux-trap water gaps in the MPC-24);

2. The incorporation of permanent fixed neutron-absorbing panels (Boral) in the fuel basket structure; and

3. An administrative limit on the maximum enrichment for PWR fuel and maximum planar-average enrichment for BWR fuel.

The normal conditions for loading/unloading, handling, packaging, transfer, and storage of the HI-STAR 100 System conservatively include: full flooding with ordinary water corresponding to the highest reactivity, and the worst case (most conservative) combination of manufacturing and fabrication tolerances. The off-normal and accident conditions defined in Chapter 2 and considered in Chapter 11 have no adverse effect on the design parameters important to criticality safety, and thus, the off-normal and accident conditions are identical to those for normal conditions.

The HI-STAR 100 System is designed such that the fixed neutron absorber (Boral) will remain effective for a storage period greater than 20 years, and there are no credible means to lose it. Therefore, in accordance with 10CFR72.124(b), there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

Criticality safety of the HI-STAR 100 System does not rely on the use of any of the following credits:

- burnup of fuel
- fuel-related burnable neutron absorbers
- more than 75 percent of the B-10 content for the fixed neutron absorber (Boral).

The following two interchangeable basket designs are available for use in the HI-STAR 100 System:

- a 24-cell basket (MPC-24), designed for intact PWR fuel assemblies with a specified maximum enrichment
- a 68-cell basket (MPC-68), designed for both intact and damaged BWR fuel assemblies with a specified maximum planar-average enrichment. Additionally, a variation in the MPC-68, designated MPC-68F, is designed for damaged BWR fuel assemblies and BWR fuel debris with a specified maximum planar-average enrichment.

The HI-STAR 100 System for storage is dry (no moderator), and thus, the reactivity is very low (k_{eff} < 0.40). However, the HI-STAR 100 System for loading and unloading operations is flooded, and thus, represents the limiting case in terms of reactivity.

Confirmation of the criticality safety of the HI-STAR 100 System under flooded conditions, when filled with fuel of the maximum permissible reactivity for which they are designed, was accomplished with the three-dimensional Monte Carlo code MCNP4a [6.1.4]. Independent confirmatory calculations were made with NITAWL-KENO5a from the SCALE-4.3 package. KENO5a [6.1.5] calculations used the 238-group SCALE cross-section library compiled with the NITAWL-II program [6.1.6], which adjusts the uranium-238 cross sections to compensate for resonance self-shielding effects. The Dancoff factors required by NITAWL-II were calculated with the CELLDAN code [6.1.13], which includes the SUPERDAN code [6.1.7] as a subroutine. K-factors for one-sided statistical tolerance limits with 95% probability at the 95% confidence level were obtained from the National Bureau of Standards (now NIST) Handbook 91 [6.1.8].

CASMO-3, a two-dimensional transport theory code [6.1.9-6.1.12] for fuel assemblies, was used to assess the incremental reactivity effects due to manufacturing tolerances. The CASMO-3 calculations identify those tolerances that cause a positive reactivity effect, enabling the Monte Carlo code input to define the worst case (most conservative) conditions. CASMO-3 was not used for quantitative information, but only to qualitatively indicate the direction and approximate magnitude of the reactivity effects of the manufacturing tolerances.

Benchmark calculations were made to compare the primary code packages (MCNP4a and KENO5a) with experimental data, using critical experiments selected to encompass, insofar as practical, the design parameters of the HI-STAR 100 System. The most important parameters are (1) the enrichment, (2) the water-gap size (MPC-24) or cell spacing (MPC-68), and (3) the ^{10}B loading of the neutron absorber panels. Benchmark calculations are presented in Appendix 6.A.

Applicable codes, standards, and regulations, or pertinent sections thereof, include the following:

- NUREG-1536, Standard Review Plan for Dry Cask Storage Systems, USNRC, Washington D.C., January 1997.

- 10CFR72.124, Criteria For Nuclear Criticality Safety.

- Code of Federal Regulations, Title 10, Part 50, Appendix A, General Design Criterion 62, Prevention of Criticality in Fuel Storage and Handling.

- USNRC Standard Review Plan, NUREG-0800, Section 9.1.2, Spent Fuel Storage, Rev. 3, July 1981.

To assure the true reactivity will always be less than the calculated reactivity, the following conservative assumptions were made:

- The MPCs are assumed to contain the most reactive fresh fuel authorized to be loaded into a specific basket design.

- Consistent with NUREG-1536, no credit for fuel burnup is assumed, either in depleting the quantity of fissile nuclides or in producing fission product poisons.

- Consistent with NUREG-1536, the criticality analyses assume 75% of the manufacturer's minimum Boron-10 content for the Boral neutron absorber.

- The fuel stack density is conservatively assumed to be 96% of theoretical (10.522 g/cm^3) for all criticality analyses. No credit is taken for fuel pellet dishing or chamfering.

- No credit is taken for the ^{234}U and ^{236}U in the fuel.

- When flooded, the moderator is assumed to be pure, unborated water at a temperature corresponding to the highest reactivity within the expected operating range (i.e., water density of 1.000 g/cc).

- Neutron absorption in minor structural members and heat conduction elements is neglected, i.e., spacer grids, basket supports, and aluminum heat conduction elements are replaced by water.

- Consistent with NUREG-1536, the worst hypothetical combination of tolerances (most conservative values within the range of acceptable values), as identified in Section 6.3, is assumed.

- When flooded, the fuel rod pellet-to-clad gap regions are assumed to be flooded.

- Planar-averaged enrichments are assumed for BWR fuel. (In accordance with NUREG-1536, analysis is presented in Appendix 6.B to demonstrate that the use of planar-average enrichments produces conservative results.)

- Consistent with NUREG-1536, fuel-related burnable neutron absorbers, such as the Gadolinia normally used in BWR fuel and IFBA normally used in PWR fuel, are neglected.

- Higher temperatures of the fuel and moderator resulting from decay heat are neglected.

- For evaluation of the bias, all benchmark calculations that result in a k_{eff} greater than 1.0 are conservatively truncated to 1.0000, consistent with NUREG-1536.

- The water reflector above and below the fuel is assumed to be unborated water.

- For fuel assemblies that contain low-enriched axial blankets, the governing enrichment is that of the highest planar average, and the blankets are not included in determining the average enrichment.

- For intact fuel assemblies, as defined in Appendix B to the Certificate of Compliance, missing fuel rods are assumed to be replaced with dummy rods that displace an amount of water greater than or equal to the original rods.

Results of the design basis criticality safety calculations for single unreflected, internally flooded casks (limiting cases) are listed in Tables 6.1.1 through 6.1.3, conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. For each of the MPC designs and

fuel assembly classes[†], Tables 6.1.1 through 6.1.3 list the bounding maximum k_{eff} value and the associated maximum allowable enrichment. The maximum allowed enrichments are defined in Appendix B to the Certificate of Compliance. Maximum k_{eff} values for each of the candidate fuel assemblies and basket configurations, that are bounded by those listed in Tables 6.1.1 through 6.1.3, are given in Section 6.2.

A table listing the maximum k_{eff} (including bias, uncertainties, and calculational statistics), calculated k_{eff}, standard deviation, and energy of the average lethargy causing fission (EALF) for each of the candidate fuel assemblies and basket configurations is provided in Appendix 6.C. These results confirm that the maximum k_{eff} values for the HI-STAR 100 System are below the limiting design criteria ($k_{eff} < 0.95$) when fully flooded and loaded with any of the candidate fuel assemblies and basket configurations. Analyses for the various conditions of flooding that support the conclusion that the fully flooded condition corresponds to the highest reactivity, and thus is most limiting, are presented in Section 6.4. The capability of the HI-STAR 100 System to safely accommodate damaged fuel and fuel debris is demonstrated in Subsection 6.4.4.

Accident conditions have also been considered and no credible accident has been identified that would result in exceeding the design criteria limit on reactivity. After the MPC is loaded with spent fuel, it is seal-welded and cannot be internally flooded. The HI-STAR 100 System for storage is dry (no moderator) and the reactivity is very low. For arrays of HI-STAR 100 casks, the radiation shielding and the physical separation between overpacks due to the large diameter and cask pitch preclude any significant neutronic coupling between the casks.

† For each array size (e.g., 6x6, 7x7, 14x14, etc.), the fuel assemblies have been subdivided into a number of assembly classes, where an assembly class is defined in terms of the (1) number of fuel rods; (2) pitch; (3) number and location of guide tubes (PWR) or water rods (BWR); and (4) cladding material. The assembly classes for BWR and PWR fuel are defined in Section 6.2.

Table 6.1.1

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-24

Fuel Assembly Class	**Maximum Allowable Enrichment (wt% ^{235}U)**	**Maximum† k_{eff}**
14x14A	4.6	0.9296
14x14B	4.6	0.9228
14x14C	4.6	0.9287
14x14D	4.0	0.8507
15x15A	4.1	0.9204
15x15B	4.1	0.9388
15x15C	4.1	0.9361
15x15D	4.1	0.9367
15x15E	4.1	0.9368
15x15F	4.1	0.9395††
15x15G	4.0	0.8876
15x15H	3.8	0.9337
16x16A	4.6	0.9287
17x17A	4.0	0.9368
17x17B	4.0	0.9324
17x17C	4.0	0.9336

Note: These calculations are for single unreflected, fully flooded casks. However, comparable reactivities were obtained for fully reflected casks and for arrays of casks.

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† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9378.

Table 6.1.2

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-68

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**	**Maximum† k_{eff}**
6x6A	2.7††	0.7888†††
6x6B‡	2.7††	0.7824†††
6x6C	2.7††	0.8021†††
7x7A	2.7††	0.7974†††
7x7B	4.2	0.9386
8x8A	2.7††	0.7697†††
8x8B	4.2	0.9416
8x8C	4.2	0.9425
8x8D	4.2	0.9403
8x8E	4.2	0.9312
8x8F	3.6	0.9153

Note: These calculations are for single unreflected, fully flooded casks. However, comparable reactivities were obtained for fully reflected casks and for arrays of casks.

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† This calculation was performed for 3.0% planar-average enrichment, however, the actual fuel is limited, as specified in Appendix B to the CoC, to a maximum planar-average enrichment of 2.7%. Therefore, the listed maximum k_{eff} value is conservative.

††† This calculation was performed for a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum ^{10}B loading of 0.0089 g/cm^2. The minimum ^{10}B loading in the MPC-68 is 0.0372 g/cm^2. Therefore, the listed maximum k_{eff} value is conservative.

‡ Assemblies in this class contain both MOX and UO_2 pins. The composition of the MOX fuel pins is given in Table 6.3.4. The maximum allowable planar-average enrichment for the MOX pins is given in the Appendix B to the Certificate of Compliance.

Table 6.1.2 (continued)

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-68

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**	**Maximum[†] k_{eff}**
9x9A	4.2	0.9417
9x9B	4.2	0.9436
9x9C	4.2	0.9395
9x9D	4.2	0.9394
9x9E	4.1	0.9424
9x9F	4.1	0.9424
10x10A	4.2	0.9457[††]
10x10B	4.2	0.9436
10x10C	4.2	0.9433
10x10D	4.0	0.9376
10x10E	4.0	0.9185

Note: These calculations are for single unreflected, fully flooded casks. However, comparable reactivities were obtained for fully reflected casks and for arrays of casks.

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9453.

Table 6.1.3

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-68F

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**	**Maximum† k_{eff}**
6x6A	2.7††	0.7888
6x6B†††	2.7	0.7824
6x6C	2.7	0.8021
7x7A	2.7	0.7974
8x8A	2.7	0.7697

Note:

1. These calculations are for single unreflected, fully flooded casks. However, comparable reactivities were obtained for fully reflected casks and for arrays of casks.

2. These calculations were performed for a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum ^{10}B loading of 0.0089 g/cm^2. The minimum ^{10}B loading in the MPC-68F is 0.010 g/cm^2. Therefore, the listed maximum k_{eff} values are conservative.

† The term "maximum k_{eff} " as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† These calculations were performed for 3.0% planar-average enrichment, however, the actual fuel is limited, as specified in Appendix B to the CoC, to a maximum planar-average enrichment of 2.7%. Therefore, the listed maximum k_{eff} values are conservative.

††† Assemblies in this class contain both MOX and UO_2 pins. The composition of the MOX fuel pins is given in Table 6.3.4. The maximum allowable planar-average enrichment for the MOX pins is specified in Appendix B to the Certificate of Compliance.

6.2 SPENT FUEL LOADING

Specifications for the BWR and PWR fuel assemblies that were analyzed in this criticality evaluation are given in Tables 6.2.1 and 6.2.2, respectively. For the BWR fuel characteristics, the number and dimensions for the water rods are the actual number and dimensions. For the PWR fuel characteristics, the actual number and dimensions of the control rod guide tubes and thimbles are used. Table 6.2.1 lists 56 unique BWR assemblies while Table 6.2.2 lists 41 unique PWR assemblies, all of which were explicitly analyzed for this evaluation. Examination of Tables 6.2.1 and 6.2.2 reveals that there are a large number of minor variations in fuel assembly dimensions.

Due to the large number of minor variations in the fuel assembly dimensions, the use of explicit dimensions in the Certificate of Compliance could limit the applicability of the HI-STAR 100 System. To resolve this limitation, bounding criticality analyses are presented in this section for a number of defined fuel assembly classes for both fuel types (PWR and BWR). The results of the bounding criticality analyses justify using bounding specifications for fuel dimensions in the Certificate of Compliance.

6.2.1 Definition of Assembly Classes

For each array size (e.g., 6x6, 7x7, 15x15, etc.), the fuel assemblies have been subdivided into a number of defined classes, where a class is defined in terms of (1) the number of fuel rods; (2) pitch; (3) number and locations of guide tubes (PWR) or water rods (BWR); and (4) cladding material. The assembly classes for BWR and PWR fuel are defined in Tables 6.2.1 and 6.2.2, respectively. It should be noted that these assembly classes are unique to this evaluation and are not known to be consistent with any class designations in the open literature.

For each assembly class, calculations have been performed for all of the dimensional variations for which data is available (i.e., all data in Tables 6.2.1 and 6.2.2). These calculations demonstrate that the maximum reactivity corresponds to:

- maximum active fuel length,
- maximum fuel pellet diameter,
- minimum cladding outside diameter (OD),
- maximum cladding inside diameter (ID),
- minimum guide tube/water rod thickness, and
- maximum channel thickness (for BWR assemblies only).

Therefore, for each assembly class, a bounding assembly was defined based on the above characteristics and a calculation for the bounding assembly was performed to demonstrate compliance with the regulatory requirement of k_{eff} < 0.95. In some assembly classes this bounding assembly corresponds directly to one of the actual (real) assemblies; while in most

assembly classes, the bounding assembly is artificial (i.e., based on bounding dimensions from more than one of the actual assemblies). In classes where the bounding assembly is artificial, the reactivity of the actual (real) assemblies is typically much less than that of the bounding assembly; thereby providing additional conservatism. As a result of these analyses, the Certificate of Compliance will define acceptability in terms of the bounding assembly parameters for each class.

To demonstrate that the aforementioned characteristics are bounding, a parametric study was performed for a reference BWR assembly, designated herein as 8x8C04 (identified generally as a GE8x8R). The results of this study are shown in Table 6.2.3, and verify the positive reactivity effect associated with (1) increasing the pellet diameter, (2) maximizing the cladding ID (while maintaining a constant cladding OD), (3) minimizing the cladding OD (while maintaining a constant cladding ID), (4) decreasing the water rod thickness, (5) artificially replacing the Zircaloy water rod tubes with water, and (6) maximizing the channel thickness. These results, and the many that follow, justify the approach for using bounding dimensions in the Certificate of Compliance. Where margins permit, the Zircaloy water rod tubes (BWR assemblies) are artificially replaced by water in the bounding cases to remove the requirement for water rod thickness from the Certificate of Compliance.

As mentioned, the bounding approach used in these analyses often results in a maximum k_{eff} value for a given class of assemblies that is much greater than the reactivity of any of the actual (real) assemblies within the class, and yet, is still below the 0.95 regulatory limit.

6.2.2 PWR Fuel Assemblies in the MPC-24

For PWR fuel assemblies (specifications listed in Table 6.2.2) the 15x15F01 fuel assembly at 4.1% enrichment has the highest reactivity (maximum k_{eff} of 0.9395). The 17x17A01 assembly (otherwise known as a Westinghouse 17x17 OFA) has a similar reactivity (see Table 6.2.17) and was used throughout this criticality evaluation as a reference PWR assembly. The 17x17A01 assembly is a representative PWR fuel assembly in terms of design and reactivity and is useful for the reactivity studies presented in Sections 6.3 and 6.4. Calculations for the various PWR fuel assemblies in the MPC-24 are summarized in Tables 6.2.4 through 6.2.19 for the fully flooded condition.

Tables 6.2.4 through 6.2.19 show the maximum k_{eff} values for the assembly classes that are acceptable for storage in the MPC-24. All maximum k_{eff} values include the bias, uncertainties, and calculational statistics, evaluated for the worst combination of manufacturing tolerances. All calculations for the MPC-24 were performed for a ^{10}B loading of 0.020 g/cm^2, which is 75% of the minimum loading, 0.0267 g/cm^2, specified on the MPC-24 drawing in Section 1.5. The maximum allowable enrichment in the MPC-24 varies from 4.0 to 4.6 wt% ^{235}U, depending on the assembly class, and is defined in Tables 6.2.4 through 6.2.19. It should be noted that the maximum allowable enrichment does not vary within an assembly class. Table 6.1.1 summarizes

the maximum allowable enrichments for each of the assembly classes that are acceptable for storage in the MPC-24.

Tables 6.2.4 through 6.2.19 are formatted with the assembly class information in the top row, the unique assembly designations, dimensions, and k_{eff} values in the following rows above the bold double lines, and the bounding dimensions selected for the Certificate of Compliance and corresponding bounding k_{eff} values in the final rows. Where the bounding assembly corresponds directly to one of the actual assemblies, the fuel assembly designation is listed in the bottom row in parentheses (e.g., Table 6.2.4). Otherwise, the bounding assembly is given a unique designation. For an assembly class that contains only a single assembly (e.g., 14x14D, see Table 6.2.7), the Certificate of Compliance dimensions are based on the assembly dimensions from that single assembly. All of the maximum k_{eff} values corresponding to the selected bounding dimensions are greater than or equal to those for the actual assembly dimensions and are below the 0.95 regulatory limit.

6.2.3 BWR Fuel Assemblies in the MPC-68

For BWR fuel assemblies (specifications listed in Table 6.2.1) the artificial bounding assembly for the 10x10A assembly class at 4.2% enrichment has the highest reactivity (maximum k_{eff} of 0.9457). Calculations for the various BWR fuel assemblies in the MPC-68 are summarized in Tables 6.2.20 through 6.2.36 for the fully flooded condition. In all cases, the gadolinia (Gd_2O_3) normally incorporated in BWR fuel was conservatively neglected.

For calculations involving BWR assemblies, the use of a uniform (planar-average) enrichment, as opposed to the distributed enrichments normally used in BWR fuel, produces conservative results. Calculations confirming this statement are presented in Appendix 6.B for several representative BWR fuel assembly designs. These calculations justify the specification of planar-average enrichments to define acceptability of BWR fuel for loading into the MPC-68.

Tables 6.2.20 through 6.2.36 show the maximum k_{eff} values for assembly classes that are acceptable for storage in the MPC-68. All maximum k_{eff} values include the bias, uncertainties, and calculational statistics, evaluated for the worst combination of manufacturing tolerances. With the exception of assembly classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A, which will be discussed in Section 6.2.4, all calculations for the MPC-68 were performed with a ^{10}B loading of 0.0279 g/cm^2, which is 75% of the minimum loading, 0.0372 g/cm^2, specified on the MPC-68 drawing in Section 1.5. Calculations for assembly classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A were conservatively performed with a ^{10}B loading of 0.0067 g/cm^2. The maximum allowable enrichment in the MPC-68 varies from 2.7 to 4.2 wt% ^{235}U, depending on the assembly class. It should be noted that the maximum allowable enrichment does not vary within an assembly class. Table 6.1.2 summarizes the maximum allowable enrichments for all assembly classes that are acceptable for storage in the MPC-68.

Tables 6.2.20 through 6.2.36 are formatted with the assembly class information in the top row, the unique assembly designations, dimensions, and k_{eff} values in the following rows above the bold double lines, and the bounding dimensions selected for the Certificate of Compliance and corresponding bounding k_{eff} values in the final rows. Where an assembly class contains only a single assembly (e.g., 8x8E, see Table 6.2.24), the Certificate of Compliance dimensions are based on the assembly dimensions from that single assembly. For assembly classes that are suspected to contain assemblies with thicker channels (e.g., 120 mils), bounding calculations are also performed to qualify the thicker channels (e.g. 7x7B, see Table 6.2.20). All of the maximum k_{eff} values corresponding to the selected bounding dimensions are shown to be greater than or equal to those for the actual assembly dimensions and are below the 0.95 regulatory limit.

For assembly classes that contain partial length rods (i.e., 9x9A, 10x10A, and 10x10B), calculations were performed for the actual (real) assembly configuration and for the axial segments (assumed to be full length) with and without the partial length rods. In all cases, the axial segment with only the full length rods present (where the partial length rods are absent) is bounding. Therefore, the bounding maximum k_{eff} values reported for assembly classes that contain partial length rods bound the reactivity regardless of the active fuel length of the partial length rods. As a result, the Certificate of Compliance have no minimum requirement for the active fuel length of the partial length rods.

For BWR fuel assembly classes where margins permit, the Zircaloy water rod tubes are artificially replaced by water in the bounding cases to remove the requirement for water rod thickness from the Certificate of Compliance. For these cases, the bounding water rod thickness is listed as zero.

As mentioned, the highest observed maximum k_{eff} value is 0.9457, corresponding to the artificial bounding assembly in the 10x10A assembly class. This assembly has the following bounding characteristics: (1) the partial length rods are assumed to be zero length (most reactive configuration); (2) the channel is assumed to be 120 mils thick; and (3) the active fuel length of the full length rods is 155 inches. Therefore, the maximum reactivity value is bounding compared to any of the real BWR assemblies listed.

6.2.4 Damaged BWR Fuel Assemblies and BWR Fuel Debris

In addition to storing intact PWR and BWR fuel assemblies, the HI-STAR 100 System is designed to store damaged BWR fuel assemblies and BWR fuel debris. Damaged fuel assemblies and fuel debris are defined in Section 2.1.3 and Appendix B to the Certificate of Compliance. Both damaged BWR fuel assemblies and BWR fuel debris are required to be loaded into Damaged Fuel Containers (DFCs) prior to being loaded into the MPC. Two different DFC types with slightly different cross sections are considered. DFCs containing fuel debris must be stored in the MPC-68F. DFCs containing damaged fuel assemblies may be stored in either the MPC-68

or MPC-68F. The criticality evaluation of various possible damaged conditions of the fuel is presented in Subsection 6.4.4 for both DFC types.

Tables 6.2.37 through 6.2.41 show the maximum k_{eff} values for the six assembly classes that may be stored as damaged fuel or fuel debris. All maximum k_{eff} values include the bias, uncertainties, and calculational statistics, evaluated for the worst combination of manufacturing tolerances. All calculations were performed for a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum loading, 0.0089 g/cm^2. However, because the practical manufacturing lower limit for minimum ^{10}B loading is 0.01 g/cm^2, the minimum ^{10}B loading of 0.01 g/cm^2 is specified on the MPC-68 drawing in Section 1.5, for the MPC-68F. As an additional level of conservatism in the analyses, the calculations were performed for an enrichment of 3.0 wt% ^{235}U, while the maximum allowable enrichment for these assembly classes is limited to 2.7 wt% ^{235}U in the Certificate of Compliance. Therefore, the maximum k_{eff} values for damaged BWR fuel assemblies and fuel debris are conservative. Calculations for the various BWR fuel assemblies in the MPC-68F are summarized in Tables 6.2.37 through 6.2.41 for the fully flooded condition.

For the assemblies that may be stored as damaged fuel or fuel debris, the 6x6C01 assembly at 3.0 wt% ^{235}U enrichment has the highest reactivity (maximum k_{eff} of 0.8021). Considering all of the conservatism built into this analysis (e.g., higher than allowed enrichment and lower than actual ^{10}B loading), the actual reactivity will be lower.

Because the analysis for the damaged BWR fuel assemblies and fuel debris was performed for a ^{10}B loading of 0.0089 g/cm^2, which conservatively bounds damaged BWR fuel assemblies in a standard MPC-68 with a minimum ^{10}B loading of 0.0372 g/cm^2, damaged BWR fuel assemblies may also be stored in the standard MPC-68. However, fuel debris is limited to the MPC-68F by Appendix B to the Certificate of Compliance.

Tables 6.2.37 through 6.2.41 are formatted with the assembly class information in the top row, the unique assembly designations, dimensions, and k_{eff} values in the following rows above the bold double lines, and the bounding dimensions selected for the Certificate of Compliance and corresponding bounding k_{eff} values in the final rows. Where an assembly class contains only a single assembly (e.g., 6x6C, see Table 6.2.39), the Certificate of Compliance dimensions are based on the assembly dimensions from that single assembly. All of the maximum k_{eff} values corresponding to the selected bounding dimensions are greater than or equal to those for the actual assembly dimensions and are well below the 0.95 regulatory limit.

6.2.5 Thoria Rod Canister

Additionally, th HI-STAR 100 System is designed to store a Thoria Rod Canister in the MPC68 or MPC68F. The canister is similar to a DFC and contains 18 intact Thoria Rods placed in a separator assembly. The reactivity of the canister in the MPC68 or MPC68F is very low compared to the reactivity of the approved fuel assemblies (The ^{235}U content of these rods corresponds to UO_2 rods with an initial enrichment of approximately 1.7 wt% ^{235}U). It is

therefore permissible to store the Thoria Rod Canister together with any other approved content in a MPC68 or MPC68F. Specifications of the canister and the Thoria Rods that are used in the criticality evaluation are given in Table 6.2.42. The criticality evaluation is presented in Subsection 6.4.6.

Table 6.2.1 (page 1 of 6)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
6x6A Assembly Class												
6x6A01	Zr	0.694	36	0.5645	0.0350	0.4940	110.0	0	n/a	n/a	0.060	4.290
6x6A02	Zr	0.694	36	0.5645	0.0360	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A03	Zr	0.694	36	0.5645	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A04	Zr	0.694	36	0.5550	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A05	Zr	0.696	36	0.5625	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A06	Zr	0.696	35	0.5625	0.0350	0.4820	110.0	1	0.0	0.0	0.060	4.290
6x6A07	Zr	0.700	36	0.5555	0.03525	0.4780	110.0	0	n/a	n/a	0.060	4.290
6x6A08	Zr	0.710	36	0.5625	0.0260	0.4980	110.0	0	n/a	n/a	0.060	4.290
6x6B (MOX) Assembly Class												
6x6B01	Zr	0.694	36	0.5645	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6B02	Zr	0.694	36	0.5625	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6B03	Zr	0.696	36	0.5625	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6B04	Zr	0.696	35	0.5625	0.0350	0.4820	110.0	1	0.0	0.0	0.060	4.290
6x6B05	Zr	0.710	35	0.5625	0.0350	0.4820	110.0	1	0.0	0.0	0.060	4.290
6x6C Assembly Class												
6x6C01	Zr	0.740	36	0.5630	0.0320	0.4880	77.5	0	n/a	n/a	0.060	4.542
7x7A Assembly Class												
7x7A01	Zr	0.631	49	0.4860	0.0328	0.4110	80	0	n/a	n/a	0.060	4.542

Table 6.2.1 (page 2 of 6)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
7x7B Assembly Class												
7x7B01	Zr	0.738	49	0.5630	0.0320	0.4870	150	0	n/a	n/a	0.080	5.278
7x7B02	Zr	0.738	49	0.5630	0.0370	0.4770	150	0	n/a	n/a	0.102	5.291
7x7B03	Zr	0.738	49	0.5630	0.0370	0.4770	150	0	n/a	n/a	0.080	5.278
7x7B04	Zr	0.738	49	0.5700	0.0355	0.4880	150	0	n/a	n/a	0.080	5.278
7x7B05	Zr	0.738	49	0.5630	0.0340	0.4775	150	0	n/a	n/a	0.080	5.278
7x7B06	Zr	0.738	49	0.5700	0.0355	0.4910	150	0	n/a	n/a	0.080	5.278
8x8A Assembly Class												
8x8A01	Zr	0.523	64	0.4120	0.0250	0.3580	110	0	n/a	n/a	0.100	4.290
8x8A02	Zr	0.523	63	0.4120	0.0250	0.3580	120	0	n/a	n/a	0.100	4.290

Table 6.2.1 (page 3 of 6)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
8x8B Assembly Class												
8x8B01	Zr	0.641	63	0.4840	0.0350	0.4050	150	1	0.484	0.414	0.100	5.278
8x8B02	Zr	0.636	63	0.4840	0.0350	0.4050	150	1	0.484	0.414	0.100	5.278
8x8B03	Zr	0.640	63	0.4930	0.0340	0.4160	150	1	0.493	0.425	0.100	5.278
8x8B04	Zr	0.642	64	0.5015	0.0360	0.4195	150	0	n/a	n/a	0.100	5.278
8x8C Assembly Class												
8x8C01	Zr	0.641	62	0.4840	0.0350	0.4050	150	2	0.484	0.414	0.100	5.278
8x8C02	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.000	no channel
8x8C03	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.080	5.278
8x8C04	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.100	5.278
8x8C05	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.120	5.278
8x8C06	Zr	0.640	62	0.4830	0.0320	0.4110	150	2	0.591	0.531	0.100	5.278
8x8C07	Zr	0.640	62	0.4830	0.0340	0.4100	150	2	0.591	0.531	0.100	5.278
8x8C08	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.493	0.425	0.100	5.278
8x8C09	Zr	0.640	62	0.4930	0.0340	0.4160	150	2	0.493	0.425	0.100	5.278
8x8C10	Zr	0.640	62	0.4830	0.0340	0.4100	150	2	0.591	0.531	0.120	5.278
8x8C11	Zr	0.640	62	0.4830	0.0340	0.4100	150	2	0.591	0.531	0.120	5.215
8x8C12	Zr	0.636	62	0.4830	0.0320	0.4110	150	2	0.591	0.531	0.120	5.215

Table 6.2.1 (page 4 of 6)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
8x8D Assembly Class												
8x8D01	Zr	0.640	60	0.4830	0.0320	0.4110	150	2 large/ 2 small	0.591/ 0.483	0.531/ 0.433	0.100	5.278
8x8D02	Zr	0.640	60	0.4830	0.0320	0.4110	150	4	0.591	0.531	0.100	5.278
8x8D03	Zr	0.640	60	0.4830	0.0320	0.4110	150	4	0.483	0.433	0.100	5.278
8x8D04	Zr	0.640	60	0.4830	0.0320	0.4110	150	1	1.34	1.26	0.100	5.278
8x8D05	Zr	0.640	60	0.4830	0.0320	0.4100	150	1	1.34	1.26	0.100	5.278
8x8D06	Zr	0.640	60	0.4830	0.0320	0.4110	150	1	1.34	1.26	0.120	5.278
8x8D07	Zr	0.640	60	0.4830	0.0320	0.4110	150	1	1.34	1.26	0.080	5.278
8x8D08	Zr	0.640	61	0.4830	0.0300	0.4140	150	3	0.591	0.531	0.080	5.278
8x8E Assembly Class												
8x8E01	Zr	0.640	59	0.4930	0.0340	0.4160	150	5	0.493	0.425	0.100	5.278
8x8F Assembly Class												
8x8F01	Zr	0.609	64	0.4576	0.0290	0.3913	150	4†	0.291†	0.228†	0.055	5.390
9x9A Assembly Class												
9x9A01	Zr	0.566	74	0.4400	0.0280	0.3760	150	2	0.98	0.92	0.100	5.278
9x9A02	Zr	0.566	66	0.4400	0.0280	0.3760	150	2	0.98	0.92	0.100	5.278
9x9A03	Zr	0.566	74/66	0.4400	0.0280	0.3760	150/90	2	0.98	0.92	0.100	5.278
9x9A04	Zr	0.566	74/66	0.4400	0.0280	0.3760	150/90	2	0.98	0.92	0.120	5.278

† Four rectangular water cross segments dividing the assembly into four quadrants

Table 6.2.1 (page 5 of 6)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
9x9B Assembly Class												
9x9B01	Zr	0.569	72	0.4330	0.0262	0.3737	150	1	1.516	1.459	0.100	5.278
9x9B02	Zr	0.569	72	0.4330	0.0260	0.3737	150	1	1.516	1.459	0.100	5.278
9x9B03	Zr	0.572	72	0.4330	0.0260	0.3737	150	1	1.516	1.459	0.100	5.278
9x9C Assembly Class												
9x9C01	Zr	0.572	80	0.4230	0.0295	0.3565	150	1	0.512	0.472	0.100	5.278
9x9D Assembly Class												
9x9D01	Zr	0.572	79	0.4240	0.0300	0.3565	150	2	0.424	0.364	0.100	5.278
9x9E Assembly Class†												
9x9E01	Zr	0.572	76	0.4170	0.0265	0.3530	150	5	0.546	0.522	0.120	5.215
9x9E02	Zr	0.572	48 28	0.4170 0.4430	0.0265 0.0285	0.3530 0.3745	150	5	0.546	0.522	0.120	5.215
9x9F Assembly Class†												
9x9F01	Zr	0.572	76	0.4430	0.0285	0.3745	150	5	0.546	0.522	0.120	5.215
9x9F02	Zr	0.572	48 28	0.4170 0.4430	0.0265 0.0285	0.3530 0.3745	150	5	0.546	0.522	0.120	5.215

† The 9x9E and 9x9F fuel assembly classes represent a single fuel type containing fuel rods with different dimensions (SPC 9x9-5). In addition to the actual configuration (9x9E02 and 9x9F02), the 9x9E class contains a hypothetical assembly with only small fuel rods (9x9E01), and the 9x9F class contains a hypothetical assembly with only large rods (9x9F01). This was done in order to simplify the specification of this assembly in the CoC.

Table 6.2.1 (page 6 of 6)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
10x10A Assembly Class												
10x10A01	Zr	0.510	92	0.4040	0.0260	0.3450	155	2	0.980	0.920	0.100	5.278
10x10A02	Zr	0.510	78	0.4040	0.0260	0.3450	155	2	0.980	0.920	0.100	5.278
10x10A03	Zr	0.510	92/78	0.4040	0.0260	0.3450	155/90	2	0.980	0.920	0.100	5.278
10x10B Assembly Class												
10x10B01	Zr	0.510	91	0.3957	0.0239	0.3413	155	1	1.378	1.321	0.100	5.278
10x10B02	Zr	0.510	83	0.3957	0.0239	0.3413	155	1	1.378	1.321	0.100	5.278
10x10B03	Zr	0.510	91/83	0.3957	0.0239	0.3413	155/90	1	1.378	1.321	0.100	5.278
10x10C Assembly Class												
10x10C01	Zr	0.488	96	0.3780	0.0243	0.3224	150	5	1.227	1.165	0.055	5.457
10x10D Assembly Class												
10x10D01	SS	0.565	100	0.3960	0.0200	0.3500	83	0	n/a	n/a	0.08	5.663
10x10E Assembly Class												
10x10E01	SS	0.557	96	0.3940	0.0220	0.3430	83	4	0.3940	0.3500	0.08	5.663

Table 6.2.2 (page 1 of 3)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
14x14A Assembly Class											
14x14A01	Zr	0.556	179	0.400	0.0243	0.3444	150	17	0.527	0.493	0.0170
14x14A02	Zr	0.556	179	0.400	0.0243	0.3444	150	17	0.528	0.490	0.0190
14x14A03	Zr	0.556	179	0.400	0.0243	0.3444	150	17	0.526	0.492	0.0170
14x14B Assembly Class											
14x14B01	Zr	0.556	179	0.422	0.0243	0.3659	150	17	0.539	0.505	0.0170
14x14B02	Zr	0.556	179	0.417	0.0295	0.3505	150	17	0.541	0.507	0.0170
14x14B03	Zr	0.556	179	0.424	0.0300	0.3565	150	17	0.541	0.507	0.0170
14x14B04	Zr	0.556	179	0.426	0.0310	0.3565	150	17	0.541	0.507	0.0170
14x14C Assembly Class											
14x14C01	Zr	0.580	176	0.440	0.0280	0.3765	150	5	1.115	1.035	0.0400
14x14C02	Zr	0.580	176	0.440	0.0280	0.3770	150	5	1.115	1.035	0.0400
14x14C03	Zr	0.580	176	0.440	0.0260	0.3805	150	5	1.111	1.035	0.0380
14x14D Assembly Class											
14x14D01	SS	0.556	180	0.422	0.0165	0.3835	144	16	0.543	0.514	0.0145
15x15A Assembly Class											
15x15A01	Zr	0.550	204	0.418	0.0260	0.3580	150	21	0.533	0.500	0.0165

Table 6.2.2 (page 2 of 3)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
15x15B Assembly Class											
15x15B01	Zr	0.563	204	0.422	0.0245	0.3660	150	21	0.533	0.499	0.0170
15x15B02	Zr	0.563	204	0.422	0.0245	0.3660	150	21	0.546	0.512	0.0170
15x15B03	Zr	0.563	204	0.422	0.0243	0.3660	150	21	0.533	0.499	0.0170
15x15B04	Zr	0.563	204	0.422	0.0243	0.3659	150	21	0.545	0.515	0.0150
15x15B05	Zr	0.563	204	0.422	0.0242	0.3659	150	21	0.545	0.515	0.0150
15x15B06	Zr	0.563	204	0.420	0.0240	0.3671	150	21	0.544	0.514	0.0150
15x15C Assembly Class											
15x15C01	Zr	0.563	204	0.424	0.0300	0.3570	150	21	0.544	0.493	0.0255
15x15C02	Zr	0.563	204	0.424	0.0300	0.3570	150	21	0.544	0.511	0.0165
15x15C03	Zr	0.563	204	0.424	0.0300	0.3565	150	21	0.544	0.511	0.0165
15x15C04	Zr	0.563	204	0.417	0.0300	0.3565	150	21	0.544	0.511	0.0165
15x15D Assembly Class											
15x15D01	Zr	0.568	208	0.430	0.0265	0.3690	150	17	0.530	0.498	0.0160
15x15D02	Zr	0.568	208	0.430	0.0265	0.3686	150	17	0.530	0.498	0.0160
15x15D03	Zr	0.568	208	0.430	0.0265	0.3700	150	17	0.530	0.499	0.0155
15x15D04	Zr	0.568	208	0.430	0.0250	0.3735	150	17	0.530	0.500	0.0150
15x15E Assembly Class											
15x15E01	Zr	0.568	208	0.428	0.0245	0.3707	150	17	0.528	0.500	0.0140
15x15F Assembly Class											
15x15F01	Zr	0.568	208	0.428	0.0230	0.3742	150	17	0.528	0.500	0.0140

Table 6.2.2 (page 3 of 3)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
15x15G Assembly Class											
15x15G01	SS	0.563	204	0.422	0.0165	0.3825	144	21	0.543	0.514	0.0145
15x15H Assembly Class											
15x15H01	Zr	0.568	208	0.414	0.0220	0.3622	150	17	0.528	0.500	0.0140
16x16A Assembly Class											
16x16A01	Zr	0.506	236	0.382	0.0250	0.3255	150	5	0.980	0.900	0.0400
16x16A02	Zr	0.506	236	0.382	0.0250	0.3250	150	5	0.980	0.900	0.0400
17x17A Assembly Class											
17x17A01	Zr	0.496	264	0.360	0.0225	0.3088	144	25	0.474	0.442	0.0160
17x17A02	Zr	0.496	264	0.360	0.0225	0.3088	150	25	0.474	0.442	0.0160
17x17A03	Zr	0.496	264	0.360	0.0250	0.3030	150	25	0.480	0.448	0.0160
17x17B Assembly Class											
17x17B01	Zr	0.496	264	0.374	0.0225	0.3225	150	25	0.482	0.450	0.0160
17x17B02	Zr	0.496	264	0.374	0.0225	0.3225	150	25	0.474	0.442	0.0160
17x17B03	Zr	0.496	264	0.376	0.0240	0.3215	150	25	0.480	0.448	0.0160
17x17B04	Zr	0.496	264	0.372	0.0205	0.3232	150	25	0.427	0.399	0.0140
17x17B05	Zr	0.496	264	0.374	0.0240	0.3195	150	25	0.482	0.450	0.0160
17x17B06	Zr	0.496	264	0.372	0.0205	0.3232	150	25	0.480	0.452	0.0140
17x17C Assembly Class											
17x17C01	Zr	0.502	264	0.379	0.0240	0.3232	150	25	0.472	0.432	0.0200
17x17C02	Zr	0.502	264	0.377	0.0220	0.3252	150	25	0.472	0.432	0.0200

Table 6.2.3
REACTIVITY EFFECT OF ASSEMBLY PARAMETER VARIATIONS
(all dimensions are in inches)

Fuel Assembly/ Parameter Variation	reactivity effect	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	water rod thickness	channel thickness
8x8C04 (GE8x8R)	reference	0.9307	0.0007	0.483	0.419	0.032	0.410	0.030	0.100
increase pellet OD (+0.001)	+0.0005	0.9312	0.0007	0.483	0.419	0.032	0.411	0.030	0.100
decrease pellet OD (-0.001)	-0.0008	0.9299	0.0009	0.483	0.419	0.032	0.409	0.030	0.100
increase clad ID (+0.004)	+0.0027	0.9334	0.0007	0.483	0.423	0.030	0.410	0.030	0.100
decrease clad ID (-0.004)	-0.0034	0.9273	0.0007	0.483	0.415	0.034	0.410	0.030	0.100
increase clad OD (+0.004)	-0.0041	0.9266	0.0008	0.487	0.419	0.034	0.410	0.030	0.100
decrease clad OD (-0.004)	+0.0023	0.9330	0.0007	0.479	0.419	0.030	0.410	0.030	0.100
increase water rod thickness (+0.015)	-0.0019	0.9288	0.0008	0.483	0.419	0.032	0.410	0.045	0.100
decrease water rod thickness (-0.015)	+0.0001	0.9308	0.0008	0.483	0.419	0.032	0.410	0.015	0.100
remove water rods (i.e., replace the water rod tubes with water)	+0.0021	0.9328	0.0008	0.483	0.419	0.032	0.410	0.000	0.100
remove channel	-0.0039	0.9268	0.0009	0.483	0.419	0.032	0.410	0.030	0.000
increase channel thickness (+0.020)	+0.0005	0.9312	0.0007	0.483	0.419	0.032	0.410	0.030	0.120

Table 6.2.4
MAXIMUM K_{EFF} VALUES FOR THE 14X14A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14A (4.6% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 179 fuel rods, 17 guide tubes, pitch=0.556, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14A01	0.9295	0.9252	0.0008	0.400	0.3514	0.0243	0.3444	150	0.017
14x14A02	0.9286	0.9242	0.0009	0.400	0.3514	0.0243	0.3444	150	0.019
14x14A03	0.9296	0.9253	0.0008	0.400	0.3514	0.0243	0.3444	150	0.017
Dimensions Listed in Certificate of Compliance				0.400 (min.)	0.3514 (max.)		0.3444 (max.)	150 (max.)	0.017 (min.)
bounding dimensions (14x14A03)	0.9296	0.9253	0.0008	0.400	0.3514	0.0243	0.3444	150	0.017

Table 6.2.5
MAXIMUM K_{EFF} VALUES FOR THE 14X14B ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14B (4.6% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 179 fuel rods, 17 guide tubes, pitch=0.556, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14B01	0.9159	0.9117	0.0007	0.422	0.3734	0.0243	0.3659	150	0.017
14x14B02	0.9169	0.9126	0.0008	0.417	0.3580	0.0295	0.3505	150	0.017
14x14B03	0.9110	0.9065	0.0009	0.424	0.3640	0.0300	0.3565	150	0.017
14x14B04	0.9084	0.9039	0.0009	0.426	0.3640	0.0310	0.3565	150	0.017
Dimensions Listed in Certificate of Compliance				0.417 (min.)	0.3734 (max.)		0.3659 (max.)	150 (max.)	0.017 (min.)
bounding dimensions (B14x14B01)	0.9228	0.9185	0.0008	0.417	0.3734	0.0218	0.3659	150	0.017

Table 6.2.6
MAXIMUM K_{EFF} VALUES FOR THE 14X14C ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14C (4.6% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 176 fuel rods, 5 guide tubes, pitch=0.580, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14C01	0.9258	0.9215	0.0008	0.440	0.3840	0.0280	0.3765	150	0.040
14x14C02	0.9265	0.9222	0.0008	0.440	0.3840	0.0280	0.3770	150	0.040
14x14C03	0.9287	0.9242	0.0009	0.440	0.3880	0.0260	0.3805	150	0.038
Dimensions Listed in Certificate of Compliance				0.440 (min.)	0.3880 (max.)		0.3805 (max.)	150 (max.)	0.038 (min.)
bounding dimensions (14x14C01)	0.9287	0.9242	0.0009	0.440	0.3880	0.0260	0.3805	150	0.038

Table 6.2.7
MAXIMUM K_{EFF} VALUES FOR THE 14X14D ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14D (4.0% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 180 fuel rods, 16 guide tubes, pitch=0.556, SS clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14D01	0.8507	0.8464	0.0008	0.422	0.3890	0.0165	0.3835	144	0.0145
Dimensions Listed in Certificate of Compliance				0.422 (min.)	0.3890 (max.)		0.3835 (max.)	144 (max.)	0.0145 (min.)

Table 6.2.8
MAXIMUM K_{EFF} VALUES FOR THE 15X15A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15A (4.1% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.550, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15A01	0.9204	0.9159	0.0009	0.418	0.3660	0.0260	0.3580	150	0.0165
Dimensions Listed in Certificate of Compliance				0.418 (min.)	0.3660 (max.)		0.3580 (max.)	150 (max.)	0.0165 (min.)

Table 6.2.9
MAXIMUM K_{EFF} VALUES FOR THE 15X15B ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15B (4.1% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.563, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15B01	0.9369	0.9326	0.0008	0.422	0.3730	0.0245	0.3660	150	0.017
15x15B02	0.9338	0.9295	0.0008	0.422	0.3730	0.0245	0.3660	150	0.017
15x15B03	0.9362	0.9318	0.0008	0.422	0.3734	0.0243	0.3660	150	0.017
15x15B04	0.9370	0.9327	0.0008	0.422	0.3734	0.0243	0.3659	150	0.015
15x15B05	0.9356	0.9313	0.0008	0.422	0.3736	0.0242	0.3659	150	0.015
15x15B06	0.9366	0.9324	0.0007	0.420	0.3720	0.0240	0.3671	150	0.015
Dimensions Listed in Certificate of Compliance				0.420 (min.)	0.3736 (max.)		0.3671 (max.)	150 (max.)	0.015 (min.)
bounding dimensions (B15x15B01)	0.9388	0.9343	0.0009	0.420	0.3736	0.0232	0.3671	150	0.015

Table 6.2.10
MAXIMUM K_{EFF} VALUES FOR THE 15X15C ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15C (4.1% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.563, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15C01	0.9255	0.9213	0.0007	0.424	0.3640	0.0300	0.3570	150	0.0255
15x15C02	0.9297	0.9255	0.0007	0.424	0.3640	0.0300	0.3570	150	0.0165
15x15C03	0.9297	0.9255	0.0007	0.424	0.3640	0.0300	0.3565	150	0.0165
15x15C04	0.9311	0.9268	0.0008	0.417	0.3570	0.0300	0.3565	150	0.0165
Dimensions Listed in Certificate of Compliance				0.417 (min.)	0.3640 (max.)		0.3570 (max.)	150 (max.)	0.0165 (min.)
bounding dimensions (B15x15C01)	0.9361	0.9316	0.0009	0.417	0.3640	0.0265	0.3570	150	0.0165

Table 6.2.11
MAXIMUM K_{EFF} VALUES FOR THE 15X15D ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15D (4.1% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15D01	0.9341	0.9298	0.0008	0.430	0.3770	0.0265	0.3690	150	0.0160
15x15D02	0.9367	0.9324	0.0008	0.430	0.3770	0.0265	0.3686	150	0.0160
15x15D03	0.9354	0.9311	0.0008	0.430	0.3770	0.0265	0.3700	150	0.0155
15x15D04	0.9339	0.9292	0.0010	0.430	0.3800	0.0250	0.3735	150	0.0150
Dimensions Listed in Certificate of Compliance				0.430 (min.)	0.3800 (max.)		0.3735 (max.)	150 (max.)	0.0150 (min.)
bounding dimensions (15x15D04)	0.9339†	0.9292	0.0010	0.430	0.3800	0.0250	0.3735	150	0.0150

† The k_{eff} value listed for the 15x15D02 case is higher than that for the case with the bounding dimensions. Therefore, the 0.9367 value from case 15x15D02 is listed in Table 6.1.1 as the maximum.

Table 6.2.12
MAXIMUM K_{EFF} VALUES FOR THE 15X15E ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15E (4.1% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15E01	0.9368	0.9325	0.0008	0.428	0.3790	0.0245	0.3707	150	0.0140
Dimensions Listed in Certificate of Compliance				0.428 (min.)	0.3790 (max.)		0.3707 (max.)	150 (max.)	0.0140 (min.)

Table 6.2.13
MAXIMUM K_{EFF} VALUES FOR THE 15X15F ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15F (4.1% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15F01	0.9395†	0.9350	0.0009	0.428	0.3820	0.0230	0.3742	150	0.0140
Dimensions Listed in Certificate of Compliance				0.428 (min.)	0.3820 (max.)		0.3742 (max.)	150 (max.)	0.0140 (min.)

† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9383.

Table 6.2.14
MAXIMUM K_{EFF} VALUES FOR THE 15X15G ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15G (4.0% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.563, SS clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15G01	0.8876	0.8833	0.0008	0.422	0.3890	0.0165	0.3825	144	0.0145
Dimensions Listed in Certificate of Compliance				0.422 (min.)	0.3890 (max.)		0.3825 (max.)	144 (max.)	0.0145 (min.)

Table 6.2.15
MAXIMUM K_{EFF} VALUES FOR THE 15X15H ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15H (3.8% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15H01	0.9337	0.9292	0.0009	0.414	0.3700	0.0220	0.3622	150	0.0140
Dimensions Listed in Certificate of Compliance				0.414 (min.)	0.3700 (max.)		0.3622 (max.)	150 (max.)	0.0140 (min.)

Table 6.2.16
MAXIMUM K_{EFF} VALUES FOR THE 16X16A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

16x16A (4.6% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 236 fuel rods, 5 guide tubes, pitch=0.506, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
16x16A01	0.9287	0.9244	0.0008	0.382	0.3320	0.0250	0.3255	150	0.0400
16x16A02	0.9263	0.9221	0.0007	0.382	0.3320	0.0250	0.3250	150	0.0400
Dimensions Listed in Certificate of Compliance				0.382 (min.)	0.3320 (max.)		0.3255 (max.)	150 (max.)	0.0400 (min.)
bounding dimensions (16x16A01)	0.9287	0.9244	0.0008	0.382	0.3320	0.0250	0.3255	150	0.0400

Table 6.2.17
MAXIMUM K_{EFF} VALUES FOR THE 17X17A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

17x17A (4.0% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 264 fuel rods, 25 guide tubes, pitch=0.496, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
17x17A01	0.9368	0.9325	0.0008	0.360	0.3150	0.0225	0.3088	144	0.016
17x17A02	0.9368	0.9325	0.0008	0.360	0.3150	0.0225	0.3088	150	0.016
17x17A03	0.9329	0.9286	0.0008	0.360	0.3100	0.0250	0.3030	150	0.016
Dimensions Listed in Certificate of Compliance				0.360 (min.)	0.3150 (max.)		0.3088 (max.)	150 (max.)	0.016 (min.)
bounding dimensions (17x17A02)	0.9368	0.9325	0.0008	0.360	0.3150	0.0225	0.3088	150	0.016

Table 6.2.18
MAXIMUM K_{EFF} VALUES FOR THE 17X17B ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

17x17B (4.0% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 264 fuel rods, 25 guide tubes, pitch=0.496, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
17x17B01	0.9288	0.9243	0.0009	0.374	0.3290	0.0225	0.3225	150	0.016
17x17B02	0.9290	0.9247	0.0008	0.374	0.3290	0.0225	0.3225	150	0.016
17x17B03	0.9243	0.9199	0.0008	0.376	0.3280	0.0240	0.3215	150	0.016
17x17B04	0.9324	0.9279	0.0009	0.372	0.3310	0.0205	0.3232	150	0.014
17x17B05	0.9266	0.9222	0.0008	0.374	0.3260	0.0240	0.3195	150	0.016
17x17B06	0.9311	0.9268	0.0008	0.372	0.3310	0.0205	0.3232	150	0.014
Dimensions Listed in Certificate of Compliance				0.372 (min.)	0.3310 (max.)		0.3232 (max.)	150 (max.)	0.014 (min.)
bounding dimensions (17x17B06)	0.9311†	0.9268	0.0008	0.372	0.3310	0.0205	0.3232	150	0.014

† The k_{eff} value listed for the 17x17B04 case is higher than that for the case with the bounding dimensions. Therefore, the 0.9324 value from case 17x17B04 is listed in Table 6.1.1 as the maximum.

Table 6.2.19
MAXIMUM K_{EFF} VALUES FOR THE 17X17C ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

17x17C (4.0% Enrichment, Boral ^{10}B minimum loading of 0.02 g/cm^2) 264 fuel rods, 25 guide tubes, pitch=0.502, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
17x17C01	0.9293	0.9250	0.0008	0.379	0.3310	0.0240	0.3232	150	0.020
17x17C02	0.9336	0.9293	0.0008	0.377	0.3330	0.0220	0.3252	150	0.020
Dimensions Listed in Certificate of Compliance				0.377 (min.)	0.3330 (max.)		0.3252 (max.)	150 (max.)	0.020 (min.)
bounding dimensions (17x17C02)	0.9336	0.9293	0.0008	0.377	0.3330	0.0220	0.3252	150	0.020

Table 6.2.20
MAXIMUM K_{EFF} VALUES FOR THE 7X7B ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

7x7B (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 49 fuel rods, 0 water rods, pitch=0.738, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
7x7B01	0.9372	0.9330	0.0007	0.5630	0.4990	0.0320	0.4870	150	n/a	0.080
7x7B02	0.9301	0.9260	0.0007	0.5630	0.4890	0.0370	0.4770	150	n/a	0.102
7x7B03	0.9313	0.9271	0.0008	0.5630	0.4890	0.0370	0.4770	150	n/a	0.080
7x7B04	0.9311	0.9270	0.0007	0.5700	0.4990	0.0355	0.4880	150	n/a	0.080
7x7B05	0.9350	0.9306	0.0008	0.5630	0.4950	0.0340	0.4775	150	n/a	0.080
7x7B06	0.9298	0.9260	0.0006	0.5700	0.4990	0.0355	0.4910	150	n/a	0.080
Dimensions Listed in Certificate of Compliance				0.5630 (min.)	0.4990 (max.)		0.4910 (max.)	150 (max.)	n/a	0.120 (max.)
bounding dimensions (B7x7B01)	0.9375	0.9332	0.0008	0.5630	0.4990	0.0320	0.4910	150	n/a	0.102
bounding dimensions with 120 mil channel (B7x7B02)	0.9386	0.9344	0.0007	0.5630	0.4990	0.0320	0.4910	150	n/a	0.120

Table 6.2.21
MAXIMUM K_{EFF} VALUES FOR THE 8X8B ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

8x8B (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 63 or 64 fuel rods†, 1 or 0 water rods†, pitch† = 0.636-0.642, Zr clad												
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	Fuel rods	pitch	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8B01	0.9310	0.9265	0.0009	63	0.641	0.4840	0.4140	0.0350	0.4050	150	0.035	0.100
8x8B02	0.9227	0.9185	0.0007	63	0.636	0.4840	0.4140	0.0350	0.4050	150	0.035	0.100
8x8B03	0.9299	0.9257	0.0008	63	0.640	0.4930	0.4250	0.0340	0.4160	150	0.034	0.100
8x8B04	0.9236	0.9194	0.0008	64	0.642	0.5015	0.4295	0.0360	0.4195	150	n/a	0.100
Dimensions Listed in Certificate of Compliance				63 or 64	0.636-0.642	0.4840 (min.)	0.4295 (max.)		0.4195 (max.)	150 (max.)	0.034	0.120 (max.)
bounding (pitch=0.636) (B8x8B01)	0.9346	0.9301	0.0009	63	0.636	0.4840	0.4295	0.02725	0.4195	150	0.034	0.120
bounding (pitch=0.640) (B8x8B02)	0.9385	0.9343	0.0008	63	0.640	0.4840	0.4295	0.02725	0.4195	150	0.034	0.120
bounding (pitch=0.642) (B8x8B03)	0.9416	0.9375	0.0007	63	0.642	0.4840	0.4295	0.02725	0.4195	150	0.034	0.120

† This assembly class was analyzed and qualified for a small variation in the pitch and a variation in the number of fuel and water rods.

Table 6.2.22
MAXIMUM K_{EFF} VALUES FOR THE 8X8C ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

8x8C (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 62 fuel rods, 2 water rods, pitch† = 0.636-0.641, Zr clad											
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8C01	0.9315	0.9273	0.0007	0.641	0.4840	0.4140	0.0350	0.4050	150	0.035	0.100
8x8C02	0.9313	0.9268	0.0009	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.000
8x8C03	0.9329	0.9286	0.0008	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.800
8x8C04	0.9348††	0.9307	0.0007	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.100
8x8C05	0.9353	0.9312	0.0007	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.120
8x8C06	0.9353	0.9312	0.0007	0.640	0.4830	0.4190	0.0320	0.4110	150	0.030	0.100
8x8C07	0.9314	0.9273	0.0007	0.640	0.4830	0.4150	0.0340	0.4100	150	0.030	0.100
8x8C08	0.9339	0.9298	0.0007	0.640	0.4830	0.4190	0.0320	0.4100	150	0.034	0.100
8x8C09	0.9301	0.9260	0.0007	0.640	0.4930	0.4250	0.0340	0.4160	150	0.034	0.100
8x8C10	0.9317	0.9275	0.0008	0.640	0.4830	0.4150	0.0340	0.4100	150	0.030	0.120
8x8C11	0.9328	0.9287	0.0007	0.640	0.4830	0.4150	0.0340	0.4100	150	0.030	0.120
8x8C12	0.9285	0.9242	0.0008	0.636	0.4830	0.4190	0.0320	0.4110	150	0.030	0.120
Dimensions Listed in Certificate of Compliance				0.636-0.641	0.4830 (min.)	0.4250 (max.)		0.4160 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding (pitch=0.636) (B8x8C01)	0.9357	0.9313	0.0009	0.636	0.4830	0.4250	0.0290	0.4160	150	0.000	0.120
bounding (pitch=0.640) (B8x8C02)	0.9425	0.9384	0.0007	0.640	0.4830	0.4250	0.0290	0.4160	150	0.000	0.120
Bounding (pitch=0.641) (B8x8C03)	0.9418	0.9375	0.0008	0.641	0.4830	0.4250	0.0290	0.4160	150	0.000	0.120

† This assembly class was analyzed and qualified for a small variation in the pitch.

†† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9343.

Table 6.2.23
MAXIMUM K_{EFF} VALUES FOR THE 8X8D ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

8x8D (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 60-61 fuel rods, 1-4 water rods†, pitch=0.640, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8D01	0.9342	0.9302	0.0006	0.4830	0.4190	0.0320	0.4110	150	0.03/0.025	0.100
8x8D02	0.9325	0.9284	0.0007	0.4830	0.4190	0.0320	0.4110	150	0.030	0.100
8x8D03	0.9351	0.9309	0.0008	0.4830	0.4190	0.0320	0.4110	150	0.025	0.100
8x8D04	0.9338	0.9296	0.0007	0.4830	0.4190	0.0320	0.4110	150	0.040	0.100
8x8D05	0.9339	0.9294	0.0009	0.4830	0.4190	0.0320	0.4100	150	0.040	0.100
8x8D06	0.9365	0.9324	0.0007	0.4830	0.4190	0.0320	0.4110	150	0.040	0.120
8x8D07	0.9341	0.9297	0.0009	0.4830	0.4190	0.0320	0.4110	150	0.040	0.080
8x8D08	0.9376	0.9332	0.0009	0.4830	0.4230	0.0300	0.4140	150	0.030	0.080
Dimensions Listed in Certificate of Compliance				0.4830 (min.)	0.4230 (max.)		0.4140 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (B8x8D01)	0.9403	0.9363	0.0007	0.4830	0.4230	0.0300	0.4140	150	0.000	0.120

† Fuel assemblies 8x8D01 through 8x8D03 have 4 water rods that are similar in size to the fuel rods, while assemblies 8x8D04 through 8x8D07 have 1 large water rod that takes the place of the 4 water rods. Fuel assembly 8x8D08 contains 3 water rods that are similar in size to the fuel rods.

Table 6.2.24
MAXIMUM K_{EFF} VALUES FOR THE 8X8E ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

8x8E (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 59 fuel rods, 5 water rods, pitch=0.640, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8E01	0.9312	0.9270	0.0008	0.4930	0.4250	0.0340	0.4160	150	0.034	0.100
Dimensions Listed in Certificate of Compliance				0.4930 (min.)	0.4250 (max.)		0.4160 (max.)	150 (max.)	0.034 (min.)	0.100 (max.)

Table 6.2.25
MAXIMUM K_{EFF} VALUES FOR THE 8X8F ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

8x8F (3.6% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 64 fuel rods, 4 rectangular water cross segments dividing the assembly into four quadrants, pitch=0.609, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8F01	0.9153	0.9111	0.0007	0.4576	0.3996	0.0290	0.3913	150	0.0315	0.055
Dimensions Listed in Certificate of Compliance				0.4576 (min.)	0.3996 (max.)		0.3913 (max.)	150 (max.)	0.0315 (min.)	0.055 (max.)

Table 6.2.26
MAXIMUM K_{EFF} VALUES FOR THE 9X9A ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

9x9A (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 74/66 fuel rods†, 2 water rods, pitch=0.566, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9A01 (axial segment with all rods)	0.9353	0.9310	0.0008	0.4400	0.3840	0.0280	0.3760	150	0.030	0.100
9x9A02 (axial segment with only the full length rods)	0.9388	0.9345	0.0008	0.4400	0.3840	0.0280	0.3760	150	0.030	0.100
9x9A03 (actual three-dimensional representation of all rods)	0.9351	0.9310	0.0007	0.4400	0.3840	0.0280	0.3760	150/90	0.030	0.100
9x9A04 (axial segment with only the full length rods)	0.9396	0.9355	0.0007	0.4400	0.3840	0.0280	0.3760	150	0.030	0.120
Dimensions Listed in Certificate of Compliance				0.4400 (min.)	0.3840 (max.)		0.3760 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (axial segment with only the full length rods) (B9x9A01)	0.9417	0.9374	0.0008	0.4400	0.3840	0.0280	0.3760	150	0.000	0.120

† This assembly class contains 66 full length rods and 8 partial length rods. In order to eliminate a requirement on the length of the partial length rods, separate calculations were performed for the axial segments with and without the partial length rods.

Table 6.2.27
MAXIMUM K_{EFF} VALUES FOR THE 9X9B ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

9x9B (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 72 fuel rods, 1 water rod (square, replacing 9 fuel rods), pitch=0.569 to 0.572†, Zr clad											
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9B01	0.9380	0.9336	0.0008	0.569	0.4330	0.3807	0.0262	0.3737	150	0.0285	0.100
9x9B02	0.9373	0.9329	0.0009	0.569	0.4330	0.3810	0.0260	0.3737	150	0.0285	0.100
9x9B03	0.9417	0.9374	0.0008	0.572	0.4330	0.3810	0.0260	0.3737	150	0.0285	0.100
Dimensions Listed in Certificate of Compliance				0.572	0.4330 (min.)	0.3810 (max.)		0.3740 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (B9x9B01)	0.9436	0.9394	0.0008	0.572	0.4330	0.3810	0.0260	0.3740††	150	0.000	0.120

† This assembly class was analyzed and qualified for a small variation in the pitch.
†† This value was conservatively defined to be larger than any of the actual pellet diameters.

Table 6.2.28
MAXIMUM K_{EFF} VALUES FOR THE 9X9C ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

9x9C (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 80 fuel rods, 1 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9C01	0.9395	0.9352	0.0008	0.4230	0.3640	0.0295	0.3565	150	0.020	0.100
Dimensions Listed in Certificate of Compliance				0.4230 (min.)	0.3640 (max.)		0.3565 (max.)	150 (max.)	0.020 (min.)	0.100 (max.)

Table 6.2.29
MAXIMUM K_{EFF} VALUES FOR THE 9X9D ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

9x9D (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 79 fuel rods, 2 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9D01	0.9394	0.9350	0.0009	0.4240	0.3640	0.0300	0.3565	150	0.0300	0.100
Dimensions Listed in Certificate of Compliance				0.4240 (min.)	0.3640 (max.)		0.3565 (max.)	150 (max.)	0.0300 (min.)	0.100 (max.)

Table 6.2.30
MAXIMUM K_{EFF} VALUES FOR THE 9X9E ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

9x9E (4.1% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 76 fuel rods, 5 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9E01	0.9402	0.9359	0.0008	0.4170	0.3640	0.0265	0.3530	150	0.0120	0.120
9x9E02	0.9424	0.9380	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120
Dimensions Listed in Certificate of Compliance†				0.4170 (min.)	0.3640 (max.)		0.3530 (max.)	150 (max.)	0.0120 (min.)	0.120 (max.)
bounding dimensions (9x9E02)	0.9424	0.9380	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120

† This fuel assembly, also known as SPC 9x9-5, contains fuel rods with different cladding and pellet diameters which do not bound each other. To be consistent in the way fuel assemblies are listed in the Certificate of Compliance, two assembly classes (9x9E and 9x9F) are required to specify this assembly. Each class contains the actual geometry (9x9E02 and 9x9F02), as well as a hypothetical geometry with either all small rods (9x9E01) or all large rods (9x9F01). The Certificate of Compliance lists the small rod dimensions for class 9x9E and the large rod dimensions for class 9x9F, and a note that both classes are used to qualify the assembly. The analyses demonstrate that all configurations, including the actual geometry, are acceptable.

Table 6.2.31
MAXIMUM K_{EFF} VALUES FOR THE 9X9F ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

9x9F (4.1% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 76 fuel rods, 5 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9F01	0.9369	0.9326	0.0007	0.4430	0.3860	0.0285	0.3745	150	0.0120	0.120
9x9F02	0.9424	0.9380	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120
Dimensions Listed in Certificate of Compliance†				0.4430 (min.)	0.3860 (max.)		0.3745 (max.)	150 (max.)	0.0120 (min.)	0.120 (max.)
bounding dimensions (9x9F02)	0.9424	0.9380	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120

† This fuel assembly, also known as SPC 9x9-5, contains fuel rods with different cladding and pellet diameters which do not bound each other. To be consistent in the way fuel assemblies are listed in the Certificate of Compliance, two assembly classes (9x9E and 9x9F) are required to specify this assembly. Each class contains the actual geometry (9x9E02 and 9x9F02), as well as a hypothetical geometry with either all small rods (9x9E01) or all large rods (9x9F01). The Certificate of Compliance lists the small rod dimensions for class 9x9E and the large rod dimensions for class 9x9F, and a note that both classes are used to qualify the assembly. The analyses demonstrate that all configurations, including the actual geometry, are acceptable.

Table 6.2.32
MAXIMUM K_{EFF} VALUES FOR THE 10X10A ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

10x10A (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 92/78 fuel rods†, 2 water rods, pitch=0.510, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10A01 (axial segment with all rods)	0.9377	0.9335	0.0008	0.4040	0.3520	0.0260	0.3450	155	0.030	0.100
10x10A02 (axial segment with only the full length rods)	0.9426	0.9386	0.0007	0.4040	0.3520	0.0260	0.3450	155	0.030	0.100
10x10A03 (actual three-dimensional representation of all rods)	0.9396	0.9356	0.0007	0.4040	0.3520	0.0260	0.3450	155/90	0.030	0.100
Dimensions Listed in Certificate of Compliance				0.4040 (min.)	0.3520 (max.)		0.3455 (max.)	150†† (max.)	0.030 (min.)	0.120 (max.)
bounding dimensions (axial segment with only the full length rods) (B10x10A01)	0.9457†††	0.9414	0.0008	0.4040	0.3520	0.0260	0.3455‡	155	0.030	0.120

† This assembly class contains 78 full-length rods and 14 partial-length rods. In order to eliminate the requirement on the length of the partial length rods, separate calculations were performed for axial segments with and without the partial length rods.

†† Although the analysis qualifies this assembly for a maximum active fuel length of 155 inches, the Certificate of Compliance limits the active fuel length to 150 inches. This is due to the fact that the Boral panels are 156 inches in length.

††† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9453.

‡ This value was conservatively defined to be larger than any of the actual pellet diameters.

Table 6.2.33
MAXIMUM K_{EFF} VALUES FOR THE 10X10B ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

10x10B (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 91/83 fuel rods†, 1 water rods (square, replacing 9 fuel rods), pitch=0.510, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10B01 (axial segment with all rods)	0.9384	0.9341	0.0008	0.3957	0.3480	0.0239	0.3413	155	0.0285	0.100
10x10B02 (axial segment with only the full length rods)	0.9416	0.9373	0.0008	0.3957	0.3480	0.0239	0.3413	155	0.0285	0.100
10x10B03 (actual three-dimensional representation of all rods)	0.9375	0.9334	0.0007	0.3957	0.3480	0.0239	0.3413	155/90	0.0285	0.100
Dimensions Listed in Certificate of Compliance				0.3957 (min.)	0.3480 (max.)		0.3420 (max.)	150†† (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (axial segment with only the full length rods) (B10x10B01)	0.9436	0.9395	0.0007	0.3957	0.3480	0.0239	0.3420†††	155	0.000	0.120

† This assembly class contains 83 full length rods and 8 partial length rods. In order to eliminate a requirement on the length of the partial length rods, separate calculations were performed for the axial segments with and without the partial length rods.

†† Although the analysis qualifies this assembly for a maximum active fuel length of 155 inches, the Certificate of Compliance limits the active fuel length to 150 inches. This is due to the fact that the Boral panels are 156 inches in length.

††† This value was conservatively defined to be larger than any of the actual pellet diameters.

Table 6.2.34
MAXIMUM K_{EFF} VALUES FOR THE 10X10C ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

10x10C (4.2% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 96 fuel rods, 5 water rods (1 center diamond and 4 rectangular), pitch=0.488, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10C01	0.9433	0.9392	0.0007	0.3780	0.3294	0.0243	0.3224	150	0.031	0.055
Dimensions Listed in Certificate of Compliance				0.3780 (min.)	0.3294 (max.)		0.3224 (max.)	150 (max.)	0.031 (min.)	0.055 (max.)

Table 6.2.35
MAXIMUM K_{EFF} VALUES FOR THE 10X10D ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

10x10D (4.0% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 100 fuel rods, 0 water rods, pitch=0.565, SS clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10D01	0.9376	0.9333	0.0008	0.3960	0.3560	0.0200	0.350	83	n/a	0.080
Dimensions Listed in Certificate of Compliance				0.3960 (min.)	0.3560 (max.)		0.350 (max.)	83 (max.)	n/a	0.080 (max.)

Table 6.2.36
MAXIMUM K_{EFF} VALUES FOR THE 10X10E ASSEMBLY CLASS IN THE MPC-68
(all dimensions are in inches)

10x10E (4.0% Enrichment, Boral ^{10}B minimum loading of 0.0279 g/cm^2) 96 fuel rods, 4 water rods, pitch=0.557, SS clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10E01	0.9185	0.9144	0.0007	0.3940	0.3500	0.0220	0.3430	83	0.022	0.080
Dimensions Listed in Certificate of Compliance				0.3940 (min.)	0.3500 (max.)		0.3430 (max.)	83 (max.)	0.022 (min.)	0.080 (max.)

Table 6.2.37
MAXIMUM K_{EFF} VALUES FOR THE 6X6A ASSEMBLY CLASS IN THE MPC-68F
(all dimensions are in inches)

6x6A (3.0% Enrichment†, Boral ^{10}B minimum loading of 0.0067 g/cm^2) 35 or 36 fuel rods††, 1 or 0 water rods††, pitch††=0.694 to 0.710, Zr clad												
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	fuel rods	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
6x6A01	0.7539	0.7498	0.0007	0.694	36	0.5645	0.4945	0.0350	0.4940	110	n/a	0.060
6x6A02	0.7517	0.7476	0.0007	0.694	36	0.5645	0.4925	0.0360	0.4820	110	n/a	0.060
6x6A03	0.7545	0.7501	0.0008	0.694	36	0.5645	0.4945	0.0350	0.4820	110	n/a	0.060
6x6A04	0.7537	0.7494	0.0008	0.694	36	0.5550	0.4850	0.0350	0.4820	110	n/a	0.060
6x6A05	0.7555	0.7512	0.0008	0.696	36	0.5625	0.4925	0.0350	0.4820	110	n/a	0.060
6x6A06	0.7618	0.7576	0.0008	0.696	35	0.5625	0.4925	0.0350	0.4820	110	0.0	0.060
6x6A07	0.7588	0.7550	0.0007	0.700	36	0.5555	0.4850	0.03525	0.4780	110	n/a	0.060
6x6A08	0.7808	0.7766	0.0007	0.710	36	0.5625	0.5105	0.0260	0.4980	110	n/a	0.060
Dimensions Listed in Certificate of Compliance				0.710 (max.)	35 or 36	0.5550 (min.)	0.5105 (max.)	0.02225	0.4980 (max.)	120 (max.)	0.0	0.060 (max.)
bounding dimensions (B6x6A01)	0.7727	0.7685	0.0007	0.694	35	0.5550	0.5105	0.02225	0.4980	120	0.0	0.060
bounding dimensions (B6x6A02)	0.7782	0.7738	0.0008	0.700	35	0.5550	0.5105	0.02225	0.4980	120	0.0	0.060
bounding dimensions (B6x6A03)	0.7888	0.7846	0.0007	0.710	35	0.5550	0.5105	0.02225	0.4980	120	0.0	0.060

† Although the calculations were performed for 3.0%, the enrichment is limited in the Certificate of Compliance to 2.7%.

†† This assembly class was analyzed and qualified for a small variation in the pitch and a variation in the number of fuel and water rods.

Table 6.2.38
MAXIMUM K_{EFF} VALUES FOR THE 6X6B ASSEMBLY CLASS IN THE MPC-68F
(all dimensions are in inches)

6x6B (3.0% Enrichment†, Boral ^{10}B minimum loading of 0.0067 g/cm^2)

35 or 36 fuel rods†† (up to 9 MOX rods), 1 or 0 water rods††, pitch††=0.694 to 0.710, Zr clad

Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	fuel rods	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
6x6B01	0.7604	0.7563	0.0007	0.694	36	0.5645	0.4945	0.0350	0.4820	110	n/a	0.060
6x6B02	0.7618	0.7577	0.0007	0.694	36	0.5625	0.4925	0.0350	0.4820	110	n/a	0.060
6x6B03	0.7619	0.7578	0.0007	0.696	36	0.5625	0.4925	0.0350	0.4820	110	n/a	0.060
6x6B04	0.7686	0.7644	0.0008	0.696	35	0.5625	0.4925	0.0350	0.4820	110	0.0	0.060
6x6B05	0.7824	0.7785	0.0006	0.710	35	0.5625	0.4925	0.0350	0.4820	110	0.0	0.060
Dimensions Listed in Certificate of Compliance				0.710 (max.)	35 or 36	0.5625 (min.)	0.4945 (max.)		0.4820 (max.)	120 (max.)	0.0	0.060 (max.)
bounding dimensions (B6x6B01)	0.7822†††	0.7783	0.0006	0.710	35	0.5625	0.4945	0.0340	0.4820	120	0.0	0.060

Note:

1. These assemblies contain up to 9 MOX pins. The composition of the MOX fuel pins is given in Table 6.3.4.

† The ^{235}U enrichment of the MOX and UO_2 pins is assumed to be 0.711% and 3.0%, respectively.

†† This assembly class was analyzed and qualified for a small variation in the pitch and a variation in the number of fuel and water rods.

††† The k_{eff} value listed for the 6x6B05 case is slightly higher than that for the case with the bounding dimensions. However, the difference (0.0002) is well within the statistical uncertainties, and thus, the two values are statistically equivalent (within 1σ). Therefore, the 0.7824 value is listed in Tables 6.1.2 and 6.1.3 as the maximum.

Table 6.2.39
MAXIMUM K_{EFF} VALUES FOR THE 6X6C ASSEMBLY CLASS IN THE MPC-68F
(all dimensions are in inches)

6x6C (3.0% Enrichment†, Boral ^{10}B minimum loading of 0.0067 g/cm^2) 36 fuel rods, 0 water rods, pitch=0.740, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
6x6C01	0.8021	0.7980	0.0007	0.5630	0.4990	0.0320	0.4880	77.5	n/a	0.060
Dimensions Listed in Certificate of Compliance				0.5630 (min.)	0.4990 (max.)		0.4880 (max.)	77.5 (max.)	n/a	0.060 (max.)

† Although the calculations were performed for 3.0%, the enrichment is limited in the Certificate of Compliance to 2.7%.

Table 6.2.40
MAXIMUM K_{EFF} VALUES FOR THE 7X7A ASSEMBLY CLASS IN THE MPC-68F
(all dimensions are in inches)

7x7A (3.0% Enrichment†, Boral ^{10}B minimum loading of 0.0067 g/cm^2) 49 fuel rods, 0 water rods, pitch=0.631, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
7x7A01	0.7974	0.7932	0.0008	0.4860	0.4204	0.0328	0.4110	80	n/a	0.060
Dimensions Listed in Certificate of Compliance				0.4860 (min.)	0.4204 (max.)		0.4110 (max.)	80 (max.)	n/a	0.060 (max.)

† Although the calculations were performed for 3.0%, the enrichment is limited in the Certificate of Compliance to 2.7%.

Table 6.2.41
MAXIMUM K_{EFF} VALUES FOR THE 8X8A ASSEMBLY CLASS IN THE MPC-68F
(all dimensions are in inches)

8x8A (3.0% Enrichment†, Boral ^{10}B minimum loading of 0.0067 g/cm^2) 63 or 64 fuel rods††, 0 water rods, pitch=0.523, Zr clad											
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	fuel rods	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8A01	0.7685	0.7644	0.0007	64	0.4120	0.3620	0.0250	0.3580	110	n/a	0.100
8x8A02	0.7697	0.7656	0.0007	63	0.4120	0.3620	0.0250	0.3580	120	n/a	0.100
Dimensions Listed in Certificate of Compliance				63	0.4120 (min.)	0.3620 (max.)		0.3580 (max.)	120 (max.)	n/a	0.100 (max.)
bounding dimensions (8x8A02)	0.7697	0.7656	0.0007	63	0.4120	0.3620	0.0250	0.3580	120	n/a	0.100

† Although the calculations were performed for 3.0%, the enrichment is limited in the Certificate of Compliance to 2.7%.
†† This assembly class was analyzed and qualified for a variation in the number of fuel rods.

Table 6.2.42

SPECIFICATION OF THE THORIA ROD CANISTER AND THE THORIA RODS

Canister ID	4.81"
Canister Wall Thickness	0.11"
Separator Assembly Plates Thickness	0.11"
Cladding OD	0.412"
Cladding ID	0.362"
Pellet OD	0.358"
Active Length	110.5"
Fuel Composition	1.8% UO_2 and 98.2% ThO_2
Initial Enrichment	93.5 wt% ^{235}U for 1.8% of the fuel
Maximum k_{eff}	0.1813
Calculated k_{eff}	0.1779
Standard Deviation	0.0004

6.3 MODEL SPECIFICATION

6.3.1 Description of Calculational Model

Figures 6.3.1 and 6.3.3 show representative horizontal cross sections of the two types of cells used in the calculations, and Figures 6.3.4 and 6.3.6 illustrate the basket configurations used. Two different MPC fuel basket designs were evaluated as follows:

- a 24 PWR assembly basket
- a 68 BWR assembly basket.

Full three-dimensional calculations were used, assuming the axial configuration shown in Figure 6.3.7, and conservatively neglecting the absorption in the overpack neutron shielding material (Holtite-A). Although the Boral neutron absorber panels are 156 inches in length, which is much longer than the active fuel length (maximum of 150 inches), they are assumed equal to the active fuel length in the calculations. As shown on the drawings in Section 1.5, 16 of the 24 periphery Boral panels on the MPC-24 have reduced width (i.e., 6.25 inches wide as opposed to 7.5 inches). However, the calculational models for the MPC-24 conservatively assume all of the periphery Boral panels are 6.25 inches in width.

The off-normal and accident conditions defined in Chapter 2 and considered in Chapter 11 have no adverse effect on the design conditions important to criticality safety, and thus from a criticality standpoint, the normal, off-normal, and accident conditions are identical and do not require individual models.

The calculational model explicitly defines the fuel rods and cladding, the guide tubes (or water rods for BWR assemblies), the water-gaps and Boral absorber panels on the stainless steel walls of the storage cells. Under the conditions of storage, when the MPC is dry, the resultant reactivity with the design basis fuel is very low (k_{eff} < 0.4). For the flooded condition (loading and unloading), water was assumed to be present in the fuel rod pellet-to-clad gaps. Appendix 6.D provides sample input files for each of the two MPC basket designs in the HI-STAR 100 System.

The water thickness above and below the fuel is intentionally maintained less than or equal to the actual water thickness. This assures that any positive reactivity effect of the steel in the MPC is conservatively included.

As indicated in Figures 6.3.1 and 6.3.3 and in Tables 6.3.1 and 6.3.2, calculations were made with dimensions assumed to be at their most conservative value with respect to criticality. CASMO-3 was used to determine the direction of the manufacturing tolerances which produced

the most adverse effect on criticality. After the directional effect (positive effect with an increase in reactivity; or negative effect with a decrease in reactivity) of the manufacturing tolerances was determined, the criticality analyses were performed using the worst case tolerances in the direction which would increase reactivity. These effects are shown in Table 6.3.1 which also identifies the approximate magnitude of the tolerances on reactivity.

The various basket dimensions are inter-dependent, and therefore cannot be individually varied (i.e., reduction in one parameter requires a corresponding reduction or increase in another parameter). Thus, it is not possible to determine the reactivity effect of each individual dimensional tolerance separately. However, it is possible to determine the reactivity effect of the dimensional tolerances by evaluating the various possible dimensional combinations. To this end, an evaluation of the various possible dimensional combinations was performed using MCNP4a. Calculated k_{eff} results (which do not include the bias, uncertainties, or calculational statistics), along with the actual dimensions, for a number of dimensional combinations are shown in Table 6.3.2 for the reference PWR and BWR assemblies. In Table 6.3.2, the box I.D. is the inner box dimension and the minimum, nominal, and maximum values correspond to those values permitted by the tolerances in the drawings in Section 1.5. For each of the MPC designs, the reactivity effects of the tolerances are very small, generally within one standard deviation. The effect of the box wall thickness tolerance is negligible, being either slightly negative or within one standard deviation of the reference.

Based on the MCNP4a and CASMO-3 calculations, the conservative dimensional assumptions listed in Table 6.3.3 were determined. Because the reactivity effect (positive or negative) of the manufacturing tolerances are not assembly dependent, these dimensional assumptions were employed for the criticality analyses.

As demonstrated in this section, design parameters important to criticality safety are: fuel enrichment, the inherent geometry of the fuel basket structure, and the fixed neutron absorbing panels (Boral). As shown in Chapter 11, none of these parameters are affected during any of the design basis off-normal or accident conditions involving handling, packaging, transfer or storage.

6.3.2 Cask Regional Densities

Composition of the various components of the principal designs of the HI-STAR 100 Systems are listed in Table 6.3.4.

The HI-STAR 100 System is designed such that the fixed neutron absorber (Boral) will remain effective for a storage period greater than 20 years, and there are no credible means to lose it. A detailed physical description, historical applications, unique characteristics, service experience, and manufacturing quality assurance of Boral are provided in Section 1.2.1.3.1.

The continued efficacy of the Boral is assured by acceptance testing, documented in Section 9.1.5.3, to validate the ^{10}B (poison) concentration in the Boral. To demonstrate that the neutron flux from the irradiated fuel results in a negligible depletion of the poison material over the storage period, an MCNP4a calculation of the number of neutrons absorbed in the ^{10}B was performed. The calculation conservatively assumed a constant neutron source for 50 years equal to the initial source for the design basis fuel, as determined in Section 5.2, and shows that the fraction of ^{10}B atoms destroyed is only 2.6E-09 in 50 years. Thus, the reduction in ^{10}B concentration in the Boral by neutron absorption is negligible. In addition, analysis in Appendix 3.M.1 demonstrates that the sheathing, which affixes the Boral panel, remains in place during all credible accident conditions, and thus, the Boral panel remains permanently fixed. Therefore, in accordance with NUREG-1536, there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber, as required by 10CFR72.124(b).

Table 6.3.1

CASMO-3 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Change in Nominal Parameter†	Δk for Maximum Tolerance		Action/Modeling Assumption
	MPC-24‡	**MPC-68**	
Reduce Boral Width to Minimum	N/A††† min.= nom.= 7.5" and 6.25"	N/A††† min. = nom. = 4.75"	Assume minimum Boral width
Increase UO_2 Density to Maximum	+0.0017 max. = 10.522 g/cc nom. = 10.412 g/cc	+0.0014 max. = 10.522 g/cc nom. = 10.412 g/cc	Assume maximum UO_2 density
Reduce Box Inside Dimension (I.D.) to Minimum	-0.0005 min.= 8.86" nom. = 8.92"	See Table 6.3.2	Assume maximum box I.D. for the MPC-24
Increase Box Inside Dimension (I.D.) to Maximum	+0.0007 max. = 8.98" nom. = 8.92"	-0.0030 max. = 6.113" nom. = 6.053"	Assume minimum box I.D. for the MPC-68
Decrease Water Gap to Minimum	+0.0069 min. = 1.09" nom. = 1.15"	N/A	Assume minimum water gap in the MPC-24

† Reduction (or increase) in a parameter indicates that the parameter is changed to its minimum (or maximum) value.

‡ Calculations for the MPC-24 were performed with CASMO-4 [6.3.1–6.3.3]

††† The Boral width for the MPC-68 is 4.75" +0.125", -0", The Boral widths for the MPC-24 are 7.5" +0.125", -0" and 6.25" +0.125", -0" (i.e., the nominal and minimum values are the same).

Table 6.3.1 (continued)

CASMO-3 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Change in Nominal Parameter	Δk Maximum Tolerance		Action/Modeling Assumption
	MPC-24	MPC-68	
Increase in Temperature			Assume 20°C
20°C	Ref.	Ref.	
40°C	-0.0030	-0.0039	
70°C	-0.0089	-0.0136	
100°C	-0.0162	-0.0193	
10% Void in Moderator			Assume no void
20°C with no void	Ref.	Ref.	
20°C	-0.0251	-0.0241	
100°C	-0.0412	-0.0432	
Removal of Flow Channel (BWR)	N/A	-0.0073	Assume flow channel present for MPC-68

Table 6.3.2

MCNP4a EVALUATION OF BASKET MANUFACTURING TOLERANCES[†]

Pitch		Box I.D.		Box Wall Thickness		MCNP4a Calculated k_{eff}
MPC-24[††] (17x17A01 @ 4.0% Enrichment)						
nominal	(10.906")	maximum	(8.98")	nominal	(5/16")	0.9325±0.0008[†††]
minimum	(10.846")	nominal	(8.92")	nominal	(5/16")	0.9300±0.0008
nominal	(10.906")	nom. - 0.04"	(8.88")	nom. + 0.05"	(0.3625")	0.9305±0.0007
MPC-68 (8x8C04 @ 4.2% Enrichment)						
minimum	(6.43")	minimum	(5.993")	nominal	(1/4")	0.9307±0.0007
nominal	(6.49")	nominal	(6.053")	nominal	(1/4")	0.9274±0.0007
maximum	(6.55")	maximum	(6.113")	nominal	(1/4")	0.9272±0.0008
nom. + 0.05"	(6.54")	nominal	(6.053")	nom. + 0.05"	(0.30")	0.9267±0.0007

Note: Values in parentheses are the actual value used.

† Tolerance for pitch and box I.D. are ± 0.06".
Tolerance for box wall thickness is +0.05", -0.00".

†† All calculations for the MPC-24 assume minimum water gap thickness (1.09").

††† Numbers are 1σ statistical uncertainties.

Table 6.3.3

BASKET DIMENSIONAL ASSUMPTIONS

Basket Type	Pitch	Box I.D.	Box Wall Thickness	Water-Gap Flux Trap
MPC-24	nominal (10.906")	maximum (8.98")	nominal (5/16")	minimum (1.09")
MPC-68	minimum (6.43")	minimum (5.993")	nominal (1/4")	N/A

Table 6.3.4

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STAR 100 SYSTEM

MPC-24		
UO_2 4.0% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.693E-02	1.185E-01
92235	9.505E-04	3.526E-02
92238	2.252E-02	8.462E-01
BORAL (0.02 g ^{10}B/cm sq), DENSITY (g/cc) = 2.660		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	8.707E-03	5.443E-02
5011	3.512E-02	2.414E-01
6012	1.095E-02	8.210E-02
13027	3.694E-02	6.222E-01

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STAR 100 SYSTEM

MPC-68		
UO_2 4.2% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.697E-02	1.185E-01
92235	9.983E-04	3.702E-02
92238	2.248E-02	8.445E-01
UO_2 3.0% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.695E-02	1.185E-01
92235	7.127E-04	2.644E-02
92238	2.276E-02	8.550E-01
MOX FUEL†, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.714E-02	1.190E-01
92235	1.719E-04	6.380E-03
92238	2.285E-02	8.584E-01
94239	3.876E-04	1.461E-02
94240	9.177E-06	3.400E-04
94241	3.247E-05	1.240E-03
94242	2.118E-06	7.000E-05

† The Pu-238, which is an absorber, was conservatively neglected in the MOX description for analysis purposes.

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STAR 100 SYSTEM

BORAL (0.0279 g ^{10}B/cm sq), DENSITY (g/cc) = 2.660		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	8.071E-03	5.089E-02
5011	3.255E-02	2.257E-01
6012	1.015E-02	7.675E-02
13027	3.805E-02	6.467E-01
FUEL IN THORIA RODS, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.798E-02	1.212E-01
92235	4.001E-04	1.484E-02
92238	2.742E-05	1.030E-03
90232	2.357E-02	8.630E-01

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STAR 100 SYSTEM

COMMON MATERIALS		
ZR CLAD, DENSITY (g/cc) = 6.550		
Nuclide	**Atom-Density**	**Wgt. Fraction**
40000	4.323E-02	1.000E+00
MODERATOR (H_2O), DENSITY (g/cc) = 1.000		
Nuclide	**Atom-Density**	**Wgt. Fraction**
1001	6.688E-02	1.119E-01
8016	3.344E-02	8.881E-01
STAINLESS STEEL, DENSITY (g/cc) = 7.840		
Nuclide	**Atom-Density**	**Wgt. Fraction**
24000	1.761E-02	1.894E-01
25055	1.761E-03	2.001E-02
26000	5.977E-02	6.905E-01
28000	8.239E-03	1.000E-01
ALUMINUM, DENSITY (g/cc) = 2.700		
Nuclide	**Atom-Density**	**Wgt. Fraction**
13027	6.026E-02	1.000E+00

Figure Withheld Under 10 CFR 2.390

FIGURE 6.3.1; TYPICAL CELL IN THE CALCULATION MODEL (PLANAR CROSS-SECTION) WITH REPRESENTATIVE FUEL IN THE MPC-24 BASKET

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

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FIGURE 6.3.2

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FIGURE 6.3.3; TYPICAL CELL IN THE CALCULATION MODEL (PLANAR CROSS-SECTION) WITH REPRESENTATIVE FUEL IN THE MPC-68 BASKET

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

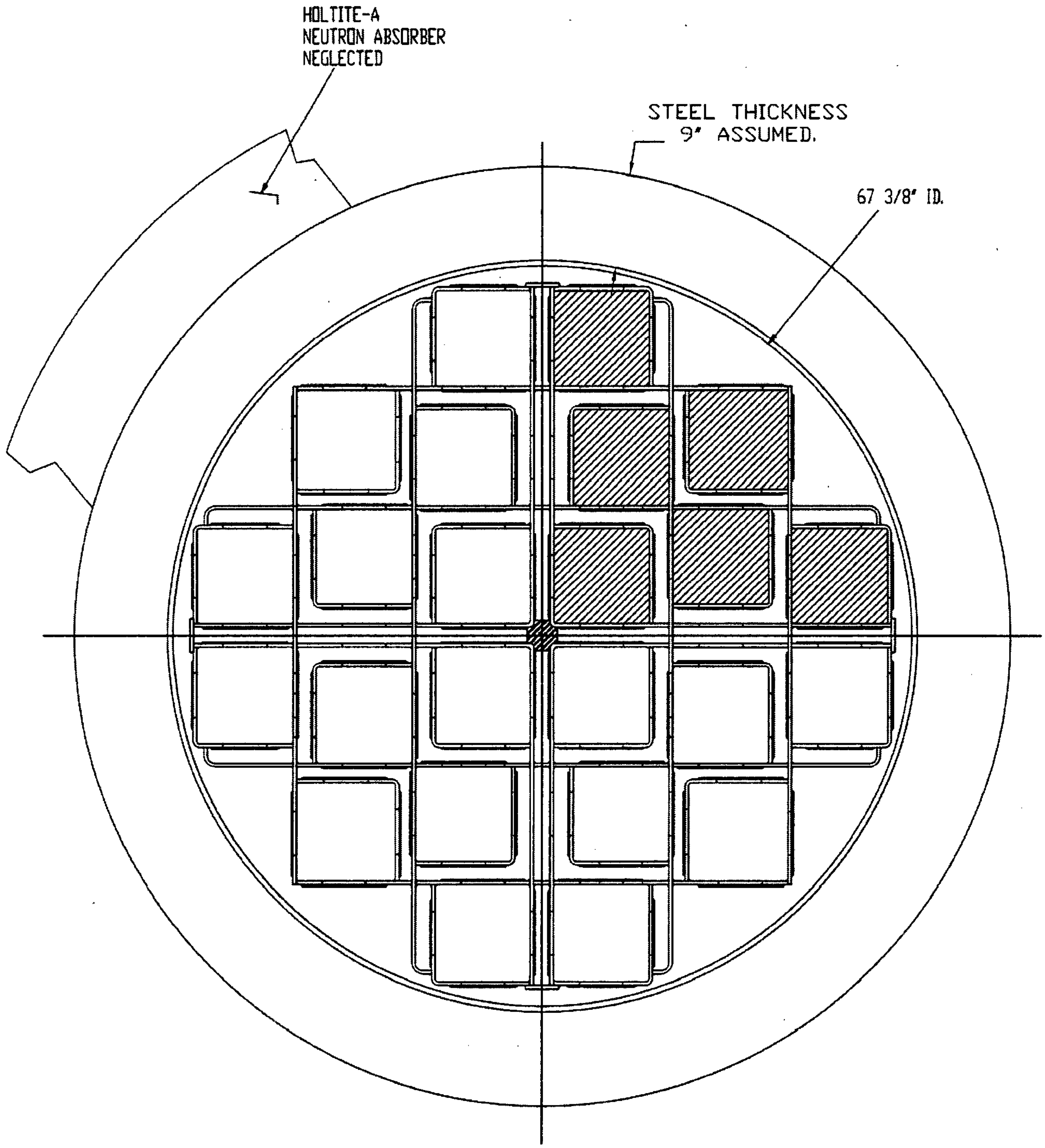

FIGURE 6.3.4; CALCULATION MODEL (PLANAR CROSS-SECTION) WITH FUEL ILLUSTRATED IN ONE QUADRANT OF THE MPC -24

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

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FIGURE 6.3.5

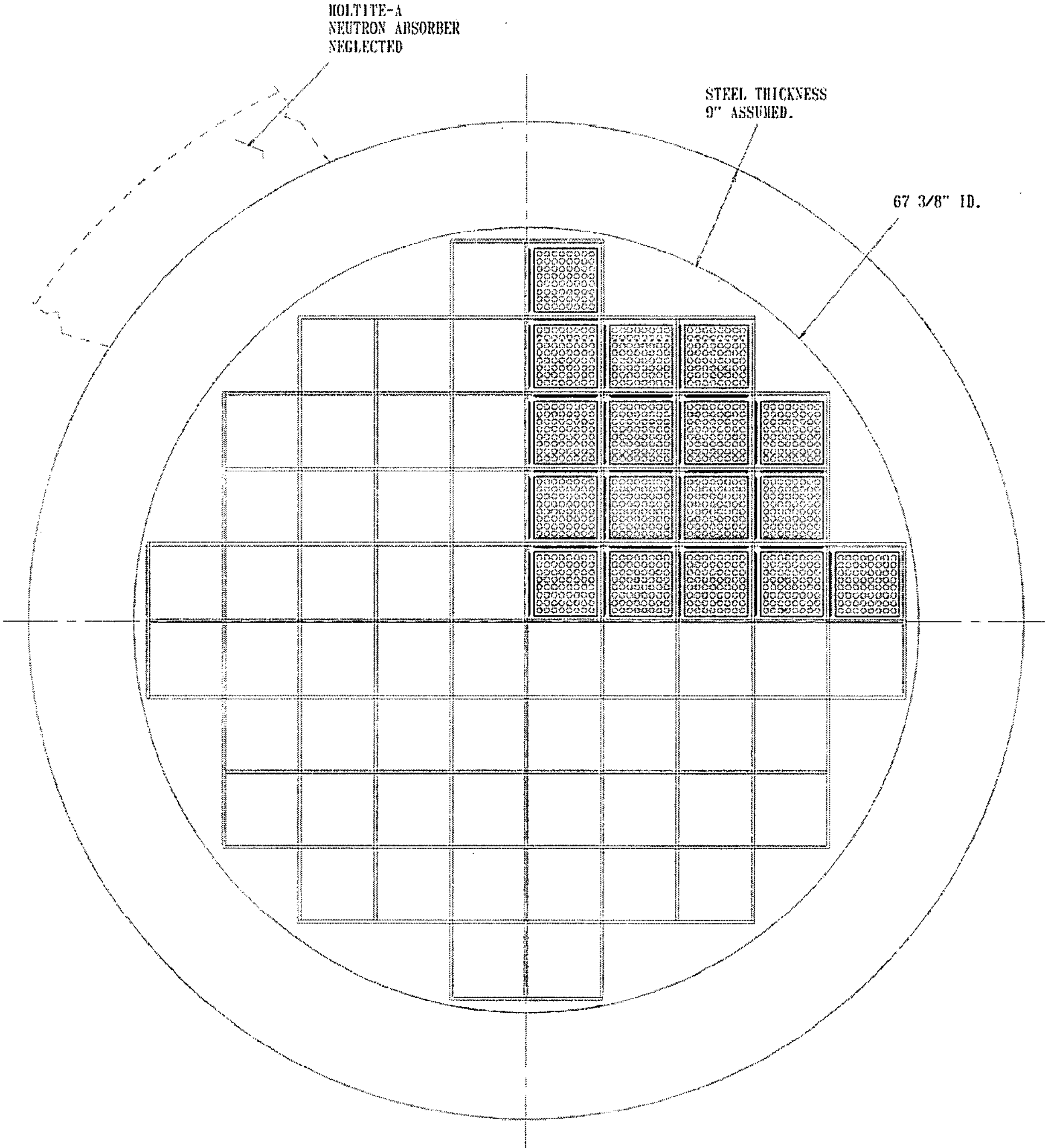

FIGURE 6.3.6; CALCULATION MODEL (PLANAR CROSS-SECTION) WITH FUEL ILLUSTRATED IN ONE QUADRANT OF THE MPC-68

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

	ACTIVE FUEL LENGTH	LOWER WATER THICKNESS	UPPER WATER THICKNESS
MPC-68	SEE TABLE 6.2.1	7.30 IN.	8.46 IN.
MPC-24	SEE TABLE 6.2.2	4.0 IN.	6.0 IN.

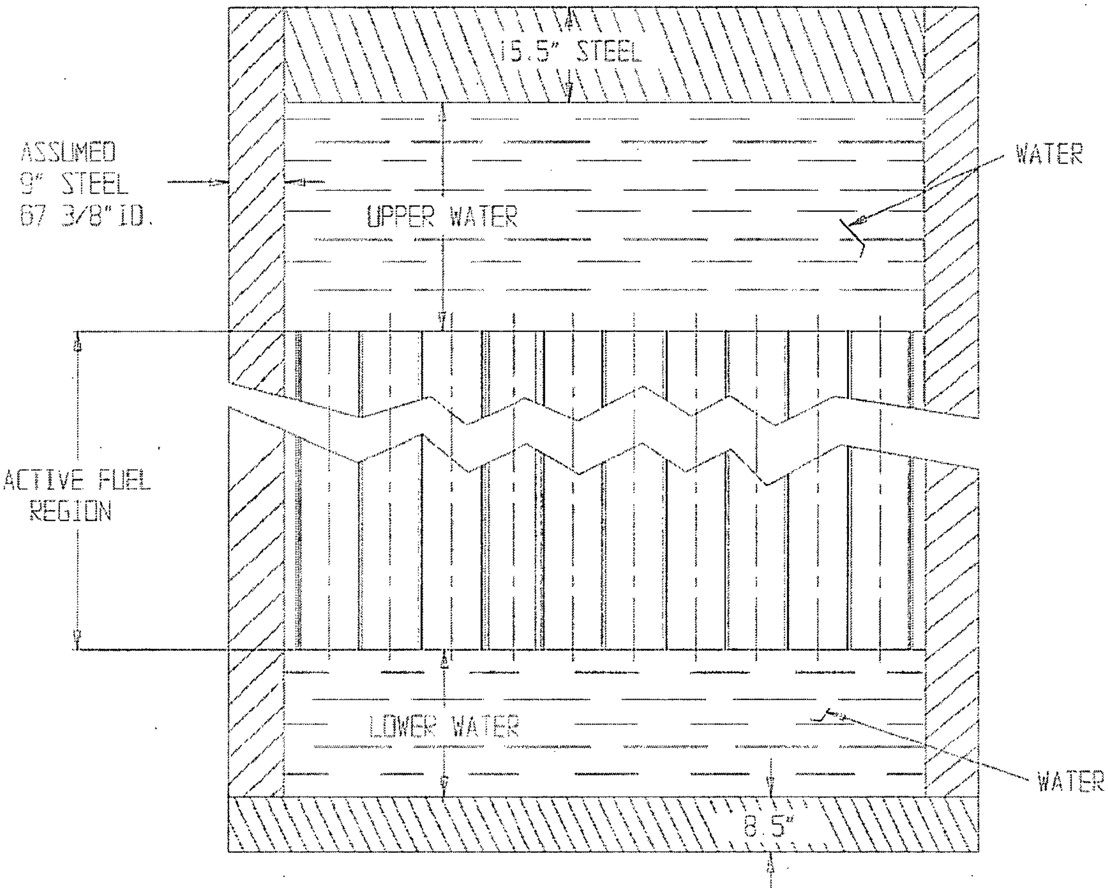

FIGURE 6.3.7; SKETCH OF THE CALCULATIONAL MODEL IN THE AXIAL DIRECTION

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6.4 CRITICALITY CALCULATIONS

6.4.1 Calculational or Experimental Method

6.4.1.1 Basic Criticality Safety Calculations

The principal method for the criticality analysis is the general three-dimensional continuous energy Monte Carlo N-Particle code MCNP4a [6.1.4] developed at the Los Alamos National Laboratory. MCNP4a was selected because it has been extensively used and verified and has all of the necessary features for this analysis. MCNP4a calculations used continuous energy cross-section data based on ENDF/B-V, as distributed with the code [6.1.4]. Independent verification calculations were performed with NITAWL-KENO5a [6.1.5], which is a three-dimensional multigroup Monte Carlo code developed at the Oak Ridge National Laboratory. The KENO5a calculations used the 238-group cross-section library, which is based on ENDF/B-V data and is distributed as part of the SCALE-4.3 package [6.4.1], compiled with the NITAWL-II program [6.1.6], which adjusts the uranium-238 cross sections to compensate for resonance self-shielding effects. The Dancoff factors required by NITAWL-II were calculated with the CELLDAN code [6.1.13], which includes the SUPERDAN code [6.1.7] as a subroutine.

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of histories per cycle, (2) the number of cycles skipped before averaging, (3) the total number of cycles and (4) the initial source distribution. The MCNP4a criticality output contains a great deal of useful information that may be used to determine the acceptability of the problem convergence. This information was used in parametric studies to develop appropriate values for the aforementioned criticality parameters to be used in the criticality calculations for this submittal. Based on these studies, a minimum of 5,000 histories were simulated per cycle, a minimum of 20 cycles were skipped before averaging, a minimum of 100 cycles were accumulated, and the initial source was specified as uniform over the fueled regions (assemblies). Further, the output was examined to ensure that each calculation achieved acceptable convergence. These parameters represent an acceptable compromise between calculational precision and computational time. Appendix 6.D provides sample input files for each of the MPC baskets in the HI-STAR 100 System.

CASMO-3 [6.1.9] was used for determining the small incremental reactivity effects of manufacturing tolerances. Although CASMO-3 has been extensively benchmarked, these calculations are used only to establish direction of reactivity uncertainties due to manufacturing tolerances (and their magnitude). This allows the MCNP4a calculational model to use the worst combination of manufacturing tolerances. Table 6.3.1 shows results of the CASMO-3 calculations.

6.4.2 Fuel Loading or Other Contents Loading Optimization

The basket designs are intended to safely accommodate fuel with enrichments indicated in Tables 6.1.1 and 6.1.2. These calculations were based on the assumption that the HI-STAR 100 System was fully flooded with clean unborated water. In all cases, the calculations include bias and calculational uncertainties, as well as the reactivity effects of manufacturing tolerances, determined by assuming the worst case geometry.

Nominally, the fuel assemblies would be centrally positioned in each MPC basket cell. However, in accordance with NUREG-1536, the consequence of eccentric positioning was also evaluated and found to be negligible. To simulate eccentric positioning (and possible closer approach to the thick steel shield), calculations were made analytically decreasing the inner radius of the steel until it was 1 cm away† from the nearest fuel. Results showed a minor increase in reactivity of 0.0026 Δk maximum (MPC-68) which implies that the effect of eccentric location of fuel is negligible at the actual reflector spacing.

6.4.2.1 Internal and External Moderation

As required by NUREG-1536, calculations in this section demonstrate that the HI-STAR 100 System remains subcritical for all credible conditions of moderation.

With a neutron absorber present (i.e., the Boral sheets or the steel walls of the storage compartments), the phenomenon of a peak in reactivity at a hypothetical low moderator density (sometimes called "optimum" moderation) does not occur to any significant extent. In a definitive study, Cano, et al. [6.4.2] has demonstrated that the phenomenon of a peak in reactivity at low moderator densities does not occur when strong neutron absorbing material is present or in the absence of large water spaces between fuel assemblies in storage. Nevertheless, calculations for a single reflected cask were made to confirm that the phenomenon does not occur with low density water inside or outside the casks.

Calculations for the MPC designs with internal and external moderators of various densities are shown in Table 6.4.1. For comparison purposes, a calculation for a single unreflected cask (Case 1) is also included in Table 6.4.1. At 100% external moderator density, Case 2 corresponds to a single fully-flooded cask, fully reflected by water. Results listed in Table 6.4.1 support the following conclusions:

† PNL critical experiments have shown a small positive reactivity effect of thick steel reflectors, with the maximum effect at 1 cm distance from the fuel. In the cask designs, the fuel is mechanically prohibited from being positioned at a 1 cm spacing from the overpack steel.

- For each type of MPC, the calculated k_{eff} for a fully-flooded cask is independent of the external moderator (the small variations in the listed values are due to statistical uncertainties which are inherent to the calculational method (Monte Carlo)), and

- For each type of MPC, reducing the internal moderation results in a monotonic reduction in reactivity, with no evidence of any optimum moderation. Thus, the fully flooded condition corresponds to the highest reactivity, and the phenomenon of optimum low-density moderation does not occur and is not applicable to the HI-STAR 100 System.

For each of the MPC designs, the maximum k_{eff} values are shown to be less than or statistically equal to that of a single internally flooded unreflected cask and are below the regulatory limit of 0.95.

6.4.2.2 Partial Flooding

As required by NUREG-1536, calculations in this section address partial flooding in the HI-STAR 100 System and demonstrate that the fully flooded condition is the most reactive.

The reactivity changes during the flooding process were evaluated in both the vertical and horizontal positions for all MPC designs. For these calculations, the cask is partially filled (at various levels) with full density (1.0 g/cc) water and the reminder of the cask is filled with steam consisting of ordinary water at partial density (0.002 g/cc), as suggested in NUREG-1536. Results of these calculations are shown in Table 6.4.2. In all cases, the reactivity increases monotonically as the water level rises, confirming that the most reactive condition is fully flooded.

6.4.2.3 Clad Gap Flooding

As required by NUREG-1536, the reactivity effect of flooding the fuel rod pellet-to-clad gap regions, in the fully flooded condition, has been investigated. Table 6.4.3 presents maximum k_{eff} values that demonstrate the positive reactivity effect associated with flooding the pellet-to-clad gap regions. These results confirm that it is conservative to assume that the pellet-to-clad gap regions are flooded. For all cases that involve flooding, the pellet-to-clad gap regions are assumed to be flooded.

6.4.2.4 Preferential Flooding

Preferential or uneven flooding within the HI-STAR 100 System was not evaluated because such a condition is not credible for any of the MPC basket designs loaded in the HI-STAR cask. Preferential flooding of any of the MPC fuel basket designs is not possible because flow holes are present on all four walls of each basket cell and on the two flux trap walls at both the top and bottom of the MPC basket. The flow holes are sized to ensure that they cannot be blocked by crud deposits (see Chapter 11). Because the fuel cladding temperatures remain below their design limits (as demonstrated in Chapter 4) and the inertial loading remains below 63g's (the inertial loadings associated with the design basis drop accidents discussed in Chapter 11 are limited to 60g's), the cladding remains intact (see Section 3.5). For damaged BWR fuel assemblies and BWR fuel debris, the assemblies or debris are pre-loaded into stainless steel Damaged Fuel Containers fitted with 250 micron fine mesh screens which prevent damaged fuel assemblies or fuel debris from blocking the basket flow holes. Therefore, the flow holes cannot be blocked.

Once established, the integrity of the MPC confinement boundary is maintained during all credible off-normal and accident conditions, and thus, the MPC cannot be flooded. Therefore, it is concluded that the MPC fuel baskets cannot be preferentially flooded.

6.4.2.5 Design Basis Accidents

The analyses presented in Chapters 3 and 11 demonstrate that the damage resulting from the design basis accidents is limited to a loss of the neutron shield material as a result of the fire accident. Because the criticality analyses do not take credit for the neutron shield material (Holtite-A), this condition has no effect on the criticality analyses.

As reported in Chapter 3, the minimum factor of safety for the MPC-24 as a result of the hypothetical cask drop or tip-over accident is 1.17 against the Level D allowables for Subsection NG, Section III of the ASME Code. Therefore, because the maximum box wall stresses are well within the ASME Level D allowables, the flux-trap gap change will be insignificant compared to the characteristic dimension of the flux trap.

In summary, the design basis accidents have no adverse effect on the design parameters important to criticality safety, and therefore, there is no increase in reactivity as a result of any of the credible off-normal or accident conditions involving handling, packaging, transfer or storage. Consequently, the HI-STAR 100 System is in full compliance with the requirement of 10CRF72.124, which states that "before a nuclear criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety."

6.4.3 Criticality Results

Results of the criticality safety calculations for the condition of flooding with clean unborated water are presented in Section 6.2 and summarized in Section 6.1. These data confirm that for each of the candidate fuel types and basket configurations the effective multiplication factor (k_{eff}), including all biases and uncertainties at a 95-percent confidence level, do not exceed 0.95 under all credible normal, off-normal, and accident conditions.

Additional calculations (CASMO-3) at elevated temperatures confirm that the temperature coefficients of reactivity are negative as shown in Table 6.3.1. This confirms that the calculations for the storage baskets are conservative.

In calculating the maximum reactivity, the analysis used the following equation:

$$k_{eff}^{max} = k_c + K_c \sigma_c + Bias + \sigma_B$$

where:

- ⇒ k_c is the calculated k_{eff} under the worst combination of tolerances;
- ⇒ K_c is the K multiplier for a one-sided statistical tolerance limit with 95% probability at the 95% confidence level [6.1.8]. Each final k_{eff} value calculated by MCNP4a (or KENO5a) is the result of averaging 100 (or more) cycle k_{eff} values, and thus, is based on a sample size of 100. The K multiplier corresponding to a sample size of 100 is 1.93. However, for this analysis a value of 2.00 was assumed for the K multiplier, which is larger (more conservative) than the value corresponding to a sample size of 100;
- ⇒ σ_c is the standard deviation of the calculated k_{eff}, as determined by the computer code (MCNP4a or KENO5a);
- ⇒ ***Bias*** is the systematic error in the calculations (code dependent) determined by comparison with critical experiments in Appendix 6.A; and
- ⇒ σ_B is the standard error of the bias (which includes the K multiplier for 95% probability at the 95% confidence level; see Appendix 6.A).

Appendix 6.A presents the critical experiment benchmarking and the derivation of the bias and standard error of the bias (95% probability at the 95% confidence level).

6.4.4 Damaged Fuel Container

Both damaged BWR fuel assemblies and BWR fuel debris are required to be loaded into Damaged Fuel Containers (DFCs) prior to being loaded into the MPC. Two different DFC types

with slightly different cross sections are analyzed. DFCs containing fuel debris must be stored in the MPC-68F. DFCs containing damaged fuel assemblies may be stored in either the MPC-68 or MPC-68F. Evaluation of the capability of storing damaged fuel and fuel debris (loaded in DFCs) is limited to very low reactivity fuel in the MPC-68F. Because the MPC-68 has a higher specified ^{10}B loading, the evaluation of the MPC-68F conservatively bounds the storage of damaged BWR fuel assemblies in a standard MPC-68 Although the maximum planar-average enrichment of the damaged fuel is limited to 2.7% ^{235}U as specified in Appendix B to the Certificate of Compliance, analyses have been made for three possible scenarios, conservatively assuming fuel†† of 3.0% enrichment. The scenarios considered included the following:

1. Lost or missing fuel rods, calculated for various numbers of missing rods in order to determine the maximum reactivity. The configurations assumed for analysis are illustrated in Figures 6.4.2 through 6.4.8.
2. Broken fuel assembly with the upper segments falling into the lower segment creating a close-packed array (described as a 8x8 array). For conservatism, the array analytically retained the same length as the original fuel assemblies in this analysis. This configuration is illustrated in Figure 6.4.9.
3. Fuel pellets lost from the assembly and forming powdered fuel dispersed through a volume equivalent to the height of the original fuel. (Flow channel and clad material assumed to disappear).

Results of the analyses, shown in Table 6.4.5, confirm that, in all cases, the maximum reactivity is well below the regulatory limit. There is no significant difference in reactivity between the two DFC types. Collapsed fuel reactivity (simulating fuel debris) is low because of the reduced moderation. Dispersed powdered fuel results in low reactivity because of the increase in ^{238}U neutron capture (higher effective resonance integral for ^{238}U absorption).

The loss of fuel rods results in a small increase in reactivity (i.e., rods assumed to collapse, leaving a smaller number of rods still intact). The peak reactivity occurs for 8 missing rods, and a smaller (or larger) number of intact rods will have a lower reactivity, as indicated in Table 6.4.5.

The analyses performed and summarized in Table 6.4.5 provides the relative magnitude of the effects on the reactivity. This information coupled with the maximum k_{eff} values listed in Table 6.1.3 and the conservatism in the analyses, demonstrate that the maximum k_{eff} of the damaged fuel in the most adverse post-accident condition will remain well below the regulatory requirement of $k_{eff} < 0.95$.

Appendix 6.D provides sample input files for the damaged fuel analysis.

†† 6x6A01 and 7x7A01 fuel assemblies were used as representative assemblies.

6.4.5 Fuel Assemblies with Missing Rods

For fuel assemblies that are qualified for damaged fuel storage, missing and/or damaged fuel rods are acceptable. However, for fuel assemblies to meet the limitations of intact fuel assembly storage, missing fuel rods must be replaced with dummy rods that displace a volume of water that is equal to, or larger than, that displaced by the original rods.

6.4.6 Thoria Rod Canister

The Thoria Rod Canister is similar to a DFC with an internal separator assembly containing 18 intact fuel rods. The configuration is illustrated in Figure 6.4.10. The k_{eff} value for an MPC-68F filled with Thoria Rod Canisters is calculated to be 0.1813. This low reactivity is attributed to the relatively low content in ^{235}U (equivalent to UO_2 fuel with an enrichment of approximately 1.7 wt% ^{235}U), the large spacing between the rods (the pitch is approximately 1", the cladding OD is 0.412") and the absorption in the separator assembly. Together with the maximum k_{eff} values listed in Tables 6.1.2 and 6.1.3 this result demonstrates, that the k_{eff} for a Thoria Rod Canister loaded into the MPC68 or the MPC68F together with other approved fuel assemblies or DFCs will remain well below the regulatory requirement of $k_{eff} < 0.95$.

6.4.7 Sealed Rods replacing BWR Water Rods

Some BWR fuel assemblies contain sealed rods filled with a non-fissile instead of water rods. Compared to the configuration with water rods, the configuration with sealed rods has a reduced amount of moderator, while the amount of fissile material is maintained. Thus, the reactivity of the configuration with sealed rods will be lower compared to the configuration with water rods. Any configuration containing sealed rods instead of water rods is therefore bounded by the analysis for the configuration with water rods and no further analysis is required to demonstrate the acceptability. Therefore, for all BWR fuel assemblies analyzed, it is permissible that water rods are replaced by sealed rods filled with a non-fissile material.

6.4.8 Inserts in PWR Fuel Assemblies

Inserts into PWR fuel assemblies such as Thimble Plugs (TPs) and Burnable Poison Rod Assemblies (BPRAs) and similar devices are permitted for storage with all PWR fuel types. The reactivity of any PWR assembly with inserts is bounded by (i.e. lower than) the reactivity of the same assembly without the insert. This is due to the fact that the insert reduces the amount of moderator in the assembly, while the amount of fissile material remains unchanged. Therefore,

from a criticality safety perspective, inserts into PWR assemblies are acceptable for all allowable PWR types, and increase the safety margin.

6.4.9 Neutron Sources in Fuel Assemblies

Fuel assemblies containing start-up neutron sources are permitted for storage in the HI-STAR 100 System. The reactivity of a fuel assembly is not affected by the presence of a neutron source (other than by the presence of the material of the source, which is discussed later). This true because in a system with a keff less than 1.0, any given neutron population at any time, regardless of its origin or size, will decrease over time. Therefore, a neutron source of any strength will not increase reactivity, but only the neutron flux in a system, and no additional criticality analyses are required. Sources are inserted as rods into fuel assemblies, i.e. they replace either a fuel rod or water rod (moderator). Therefore, the insertion of the material of the source into a fuel assembly will not lead to an increase of reactivity either.

Table 6.4.1

MAXIMUM REACTIVITIES WITH REDUCED WATER DENSITIES FOR CASK ARRAYS†

	Water Density		MCNP4a Maximum k_{eff} ††	
Case Number	**Internal**	**External**	**MPC-24 (17x17A01 @ 4.0%)**	**MPC-68 (8x8C04 @ 4.2%)**
1	100%	single cask	0.9368	0.9348
2	100%	100%	0.9354	0.9339
3	100%	70%	0.9362	0.9339
4	100%	50%	0.9352	0.9347
5	100%	20%	0.9372	0.9338
6	100%	10%	0.9380	0.9336
7	100%	5%	0.9351	0.9333
8	100%	0%	0.9342	0.9338
9	70%	0%	0.8337	0.8488
10	50%	0%	0.7426	0.7631
11	20%	0%	0.5606	0.5797
12	10%	0%	0.4834	0.5139
13	5%	0%	0.4432	0.4763
14	10%	100%	0.4793	0.4946

† For an infinite square array of casks with 60cm spacing between cask surfaces

†† Maximum k_{eff} includes the bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.2

REACTIVITY EFFECTS OF PARTIAL CASK FLOODING

MPC-24 (17x17A01 @ 4.0% ENRICHMENT)			
Flooded Condition (% Full)	Vertical Orientation	Flooded Condition (% Full)	Horizontal Orientation
25	0.9157	25	0.8766
50	0.9305	50	0.9240
75	0.9330	75	0.9329
100	0.9368	100	0.9368
MPC-68 (8x8C04 @ 4.2% ENRICHMENT)			
Flooded Condition (% Full)	Vertical Orientation	Flooded Condition (% Full)	Horizontal Orientation
25	0.9132	23.5	0.8586
50	0.9307	50	0.9088
75	0.9312	76.5	0.9275
100	0.9348	100	0.9348

Notes:

1. All values are maximum k_{eff} which include bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.3

REACTIVITY EFFECT OF FLOODING THE PELLET-TO-CLAD GAP

Pellet-to-Clad Condition	MPC-24 17x17A01 4.0% Enrichment	MPC-68 8x8C04 4.2% Enrichment
dry	0.9295	0.9279
flooded	0.9368	0.9348

Notes:

1. All values are maximum k_{eff} which includes bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.4

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Table 6.4.5

MAXIMUM k_{eff} VALUES† IN THE DAMAGED FUEL CONTAINER

Condition	MCNP4a Maximum†† k_{eff}	
	DFC Dimensions: ID 4.93" THK. 0.12"	DFC Dimensions: ID 4.81" THK. 0.11"
<u>6x6 Fuel Assembly</u>		
6x6 Intact Fuel	0.7086	0.7016
w/32 Rods Standing	0.7183	0.7117
w/28 Rods Standing	0.7315	0.7241
w/24 Rods Standing	0.7086	0.7010
w/18 Rods Standing	0.6524	0.6453
Collapsed to 8x8 array	0.7845	0.7857
Dispersed Powder	0.7628	0.7440
<u>7x7 Fuel Assembly</u>		
7x7 Intact Fuel	0.7463	0.7393
w/41 Rods Standing	0.7529	0.7481
w/36 Rods Standing	0.7487	0.7444
w/25 Rods Standing	0.6718	0.6644

† These calculations were performed with a planar-average enrichment of 3.0% and a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum ^{10}B loading of 0.0089 g/cm^2. The minimum ^{10}B loading in the MPC-68F is 0.010 g/cm^2. Therefore, the listed maximum k_{eff} values are conservative.

†† Maximum k_{eff} includes bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

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FIGURE 6.4.1

Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.2; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 4 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.3; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 8 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.4; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 12 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

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Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.5; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 18 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.6; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 7X7 ARRAY WITH 8 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

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Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.7; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 7X7 ARRAY WITH 13 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.8; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 7X7 ARRAY WITH 24 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.9; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH DAMAGED FUEL COLLAPSED INTO 8X8 ARRAY IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

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Figure Withheld Under 10 CFR 2.390

FIGURE 6.4.10; THORIA ROD CANISTER (PLANAR CROSS-SECTION) WITH 18 THORIA RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

6.5 CRITICALITY BENCHMARK EXPERIMENTS

Benchmark calculations have been made on selected critical experiments, chosen, insofar as possible, to bound the range of variables in the cask designs. The most important parameters are (1) the enrichment, (2) the water-gap size (MPC-24) or cell spacing (MPC-68), and (3) the ^{10}B loading of the neutron absorber panels. Other parameters, within the normal range of cask and fuel designs, have a smaller effect, but are also included. No significant trends were evident in the benchmark calculations or the derived bias. Detailed benchmark calculations are presented in Appendix 6.A.

The benchmark calculations were performed with the same computer codes and cross-section data, described in Section 6.4, that were used to calculate the k_{eff} values for the cask. Further, all calculations were performed on the same computer hardware, specifically, personal computers using the pentium processor.

6.6 REGULATORY COMPLIANCE

This chapter documents the criticality evaluation of the HI-STAR 100 System for the storage of spent nuclear fuel. This evaluation demonstrates that the HI-STAR 100 System is in full compliance with the criticality requirements of 10CFR72 and NUREG-1536.

Structures, systems, and components important to criticality safety are described in sufficient detail in this chapter to enable an evaluation of their effectiveness.

The HI-STAR 100 System is designed to be subcritical under all credible conditions. The criticality design is based on favorable geometry and fixed neutron poisons (Boral). An appraisal of the fixed neutron poisons has shown that they will remain effective for a storage period greater than 20 years, and there is no credible way to lose it, therefore there is no need to provide a positive means to verify their continued efficacy as required by 10CFR72.124(b).

The criticality evaluation has demonstrated that the cask will enable the storage of spent fuel for a minimum of 20 years with an adequate margin of safety. Further, the evaluation has demonstrated that the design basis accidents have no adverse effect on the design parameters important to criticality safety, and therefore, the HI-STAR 100 System is in full compliance with the double contingency requirements of 10CRF72.124. Therefore, it is concluded that the criticality design features for the HI-STAR 100 System are in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The criticality evaluation provides reasonable assurance that the HI-STAR 100 System will allow safe storage of spent fuel.

6.7 REFERENCES

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[6.1.2] 10CFR72.124, "Criteria For Nuclear Criticality Safety."

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APPENDIX 6.A: BENCHMARK CALCULATIONS

6.A.1 INTRODUCTION AND SUMMARY

Benchmark calculations have been made on selected critical experiments, chosen, in so far as possible, to bound the range of variables in the cask designs. Two independent methods of analysis were used, differing in cross section libraries and in the treatment of the cross sections. MCNP4a [6.A.1] is a continuous energy Monte Carlo code and KENO5a [6.A.2] uses group-dependent cross sections. For the KENO5a analyses reported here, the 238-group library was chosen, processed through the NITAWL-II [6.A.2] program to create a working library and to account for resonance self-shielding in uranium-238 (Nordheim integral treatment). The 238 group library was chosen to avoid or minimize the errors† (trends) that have been reported (e.g., [6.A.3 through 6.A.5]) for calculations with collapsed cross section sets.

In cask designs, the three most significant parameters affecting criticality are (1) the fuel enrichment, (2) the ^{10}B loading in the neutron absorber, and (3) the lattice spacing (or water-gap thickness if a flux-trap design is used). Other parameters, within the normal range of cask and fuel designs, have a smaller effect, but are also included in the analyses.

Table 6.A.1 summarizes results of the benchmark calculations for all cases selected and analyzed, as referenced in the table. The effect of the major variables are discussed in subsequent sections below. It is important to note that there is obviously considerable overlap in parameters since it is not possible to vary a single parameter and maintain criticality; some other parameter or parameters must be concurrently varied to maintain criticality.

One possible way of representing the data is through a spectrum index that incorporates all of the variations in parameters. KENO5a computes and prints the "energy of the average lethargy causing fission". In MCNP4a, by utilizing the tally option with the identical 238-group energy structure as in KENO5a, the number of fissions in each group may be collected and the energy of the average lethargy causing fission determined (post-processing).

Figures 6.A.1 and 6.A.2 show the calculated k_{eff} for the benchmark critical experiments as a function of the "energy of the average lethargy causing fission" for MCNP4a and KENO5a, respectively (UO_2 fuel only). The scatter in the data (even for comparatively minor variation in

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† Small but observable trends (errors) have been reported for calculations with the 27-group and 44-group collapsed libraries. These errors are probably due to the use of a single collapsing spectrum when the spectrum should be different for the various cases analyzed, as evidenced by the spectrum indices.

critical parameters) represents experimental error[†] in performing the critical experiments within each laboratory, as well as between the various testing laboratories. The B&W critical experiments show a larger experimental error than the PNL criticals. This would be expected since the B&W criticals encompass a greater range of critical parameters than the PNL criticals.

Linear regression analysis of the data in Figures 6.A.1 and 6.A.2 show that there are no trends, as evidenced by very low values of the correlation coefficient (0.13 for MCNP4a and 0.21 for KENO5a). The total bias (systematic error, or mean of the deviation from a k_{eff} of exactly 1.000) for the two methods of analysis are shown in the table below.

Calculational Bias of MCNP4a and KENO5a		
	Total	Truncated
MCNP4a	0.0009 ± 0.0011	0.0021 ± 0.0006
KENO5a	0.0030 ± 0.0012	0.0036 ± 0.0009

The values of bias shown in this table include both the bias derived directly from the calculated k_{eff} values in Table 6.A.1, and a more conservative value derived by arbitrarily truncating to 1.000 any calculated value that exceeds 1.000. The bias and standard error of the bias were calculated by the following equations[††], with the standard error multiplied by the one-sided K-factor for 95% probability at the 95% confidence level from NBS Handbook 91 [6.A.18] (for the number of cases analyzed, the K-factor is ~2.05 or slightly more than 2).

$$\bar{k} = \frac{1}{n}\sum_{i=1}^{n} k_i \qquad (6.A.1)$$

† A classical example of experimental error is the corrected enrichment in the PNL experiments, first as an addendum to the initial report and, secondly, by revised values in subsequent reports for the same fuel rods.

†† These equations may be found in any standard text on statistics, for example, reference [6.A.6] (or the MCNP4a manual) and is the same methodology used in MCNP4a and in KENO5a.

$$\sigma_{\bar{k}}^2 = \frac{\sum_{i=1}^{n} k_i^2 - (\sum_{i=1}^{n} k_i)^2 / n}{n(n-1)} \qquad (6.A.2)$$

$$\text{Bias} = (1 - \bar{k}) \pm K\sigma_{\bar{k}} \qquad (6.A.3)$$

where k_i are the calculated reactivities for n critical experiments; $\sigma_{\bar{k}}$ is the unbiased estimator of the standard deviation of the mean (also called the standard error of the bias (mean)); and K is the one-sided multiplier for 95% probability at the 95% confidence level (NBS Handbook 91 [6.A.18]).

Formula 6.A.3 is based on the methodology of the National Bureau of Standards (now NIST) and is used to calculate the values presented on page 6.A-2. The first portion of the equation, $(1-\bar{k})$, is the actual bias which is added to the MCNP4a and KENO5a results. The second term, $K\sigma_{\bar{k}}$, which corresponds to σ_B in Section 6.4.3, is the uncertainty or standard error associated with the bias. The K values used were obtained from the National Bureau of Standards Handbook 91 and are for one-sided statistical tolerance limits for 95% probability at the 95% confidence level. The actual K values for the 56 critical experiments evaluated with MCNP4a and the 53 critical experiments evaluated with KENO5a are 2.04 and 2.05, respectively.

The larger of the calculational biases (truncated bias) was used to evaluate the maximum k_{eff} values for the cask designs.

6.A.2 Effect of Enrichment

The benchmark critical experiments include those with enrichments ranging from 2.46% to 5.74% and therefore span the enrichment range for the MPC designs. Figures 6.A.3 and 6.A.4 show the calculated k_{eff} values (Table 6.A.1) as a function of the fuel enrichment reported for the critical experiments. Linear regression analyses for these data confirms that there are no trends, as indicated by low values of the correlation coefficients (0.03 for MCNP4a and 0.38 for KENO5a). Thus, there are no corrections to the bias for the various enrichments.

As further confirmation of the absence of any trends with enrichment, the MPC-68 configuration was calculated with both MCNP4a and KENO5a for various enrichments. The cross-comparison of calculations with codes of comparable sophistication is suggested in Reg. Guide 3.41. Results of this comparison, shown in Table 6.A.2 and Figure 6.A.5, confirm no significant difference in the calculated values of k_{eff} for the two independent codes as evidenced by the 45° slope of the curve. Since it is very unlikely that two independent methods of analysis would be subject to the

same error, this comparison is considered confirmation of the absence of an enrichment effect (trend) in the bias.

6.A.3 Effect of ^{10}B Loading

Several laboratories have performed critical experiments with a variety of thin absorber panels similar to the Boral panels in the cask designs. Of these critical experiments, those performed by B&W are the most representative of the cask designs. PNL has also made some measurements with absorber plates, but, with one exception (a flux-trap experiment), the reactivity worth of the absorbers in the PNL tests is very low and any significant errors that might exist in the treatment of strong thin absorbers could not be revealed.

Table 6.A.3 lists the subset of experiments using thin neutron absorbers (from Table 6.A.1) and shows the reactivity worth (Δk) of the absorber.†

No trends with reactivity worth of the absorber are evident, although based on the calculations shown in Table 6.A.3, some of the B&W critical experiments seem to have unusually large experimental errors. B&W made an effort to report some of their experimental errors. Other laboratories did not evaluate their experimental errors.

To further confirm the absence of a significant trend with ^{10}B concentration in the absorber, a cross-comparison was made with MCNP4a and KENO5a (as suggested in Reg. Guide 3.41). Results are shown in Figure 6.A.6 and Table 6.A.4 for the MPC-68 cask†† geometry. These data substantiate the absence of any error (trend) in either of the two codes for the conditions analyzed (data points fall on a 45° line, within an expected 95% probability limit).

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† The reactivity worth of the absorber panels was determined by repeating the calculation with the absorber analytically removed and calculating the incremental (Δk) change in reactivity due to the absorber.

†† The MPC-68 geometry was chosen for this comparison since it contains the greater number of Boral panels and would therefore be expected to be the most sensitive to trends (errors) in calculations.

6.A.4 Miscellaneous and Minor Parameters

6.A.4.1 Reflector Material and Spacings

PNL has performed a number of critical experiments with thick steel and lead reflectors.[†] Analysis of these critical experiments are listed in Table 6.A.5 (subset of data in Table 6.A.1). There appears to be a small tendency toward overprediction of k_{eff} at the lower spacing, although there are an insufficient number of data points in each series to allow a quantitative determination of any trends. The tendency toward overprediction at close spacing means that the cask calculations may be slightly more conservative than otherwise.

6.A.4.2 Fuel Pellet Diameter and Lattice Pitch

The critical experiments selected for analysis cover a range of fuel pellet diameters from 0.311 to 0.444 inches, and lattice spacings from 0.476 to 1.00 inches. In the cask designs, the fuel pellet diameters range from 0.303 to 0.3835 inches O.D. (0.496 to 0.580 inch lattice spacing) for PWR fuel and from 0.3224 to 0.498 inches O.D. (0.488 to 0.740 inch lattice spacing) for BWR fuel. Thus, the critical experiments analyzed provide a reasonable representation of the fuel in the MPC designs. Based on the data in Table 6.A.1, there does not appear to be any observable trend with either fuel pellet diameter or lattice pitch, at least over the range of the critical experiments or the cask designs.

6.A.4.3 Soluble Boron Concentration Effects

Various soluble boron concentrations were used in the B&W series of critical experiments and in one PNL experiment, with boron concentrations ranging up to 2550 ppm. Results of MCNP4a (and one KENO5a) calculations are shown in Table 6.A.6. Analyses of the very high boron concentration experiments (>1300 ppm) show a tendency to slightly overpredict reactivity for the three experiments exceeding 1300 ppm. In turn, this would suggest that the evaluation of the MPC-32 with various soluble boron concentration could be slightly conservative for the high soluble boron concentration.

6.A.5 MOX Fuel

The number of critical experiments with PuO_2 bearing fuel (MOX) is more limited than for UO_2 fuel. However, a number of MOX critical experiments have been analyzed and the results are

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[†] Parallel experiments with a depleted uranium reflector were also performed but not included in the present analysis since they are not pertinent to the Holtec cask design. A lead reflector is also not directly pertinent, but might be used in future designs.

shown in Table 6.A.7. Results of these analyses are generally above a k_{eff} of 1.00, indicating that when Pu is present, MCNP4a and KENO5a overpredict the reactivity.

This may indicate that calculation for MOX fuel will be expected to be conservative, especially with MCNP4a. It may be noted that for the larger lattice spacings, the KENO5a calculated reactivities are below 1.00, suggested that a small trend may exist with KENO5a. It is also possible that the overprediction in k_{eff} in both codes may be due to a small inadequacy in the determination of the Pu-241 decay and Am-241 growth. This possibility is supported by the consistency in calculated k_{eff} over a wide range of the spectral index (energy of the average lethargy causing fission).

6.A.6 References

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Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
1	B&W-1484 (6.A.7)	Core I	2.46	0.9964 ± 0.0010	0.9898 ± 0.0006	0.1759	0.1753
2	B&W-1484 (6.A.7)	Core II	2.46	1.0008 ± 0.0011	1.0015 ± 0.0005	0.2553	0.2446
3	B&W-1484 (6.A.7)	Core III	2.46	1.0010 ± 0.0012	1.0005 ± 0.0005	0.1999	0.1939
4	B&W-1484 (6.A.7)	Core IX	2.46	0.9956 ± 0.0012	0.9901 ± 0.0006	0.1422	0.1426
5	B&W-1484 (6.A.7)	Core X	2.46	0.9980 ± 0.0014	0.9922 ± 0.0006	0.1513	0.1499
6	B&W-1484 (6.A.7)	Core XI	2.46	0.9978 ± 0.0012	1.0005 ± 0.0005	0.2031	0.1947
7	B&W-1484 (6.A.7)	Core XII	2.46	0.9988 ± 0.0011	0.9978 ± 0.0006	0.1718	0.1662
8	B&W-1484 (6.A.7)	Core XIII	2.46	1.0020 ± 0.0010	0.9952 ± 0.0006	0.1988	0.1965
9	B&W-1484 (6.A.7)	Core XIV	2.46	0.9953 ± 0.0011	0.9928 ± 0.0006	0.2022	0.1986
10	B&W-1484 (6.A.7)	Core XV††	2.46	0.9910 ± 0.0011	0.9909 ± 0.0006	0.2092	0.2014
11	B&W-1484 (6.A.7)	Core XVI††	2.46	0.9935 ± 0.0010	0.9889 ± 0.0006	0.1757	0.1713
12	B&W-1484 (6.A.7)	Core XVII	2.46	0.9962 ± 0.0012	0.9942 ± 0.0005	0.2083	0.2021

Table 6.A.1

Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
13	B&W-1484 (6.A.7)	Core XVIII	2.46	1.0036 ± 0.0012	0.9931 ± 0.0006	0.1705	0.1708
14	B&W-1484 (6.A.7)	Core XIX	2.46	0.9961 ± 0.0012	0.9971 ± 0.0005	0.2103	0.2011
15	B&W-1484 (6.A.7)	Core XX	2.46	1.0008 ± 0.0011	0.9932 ± 0.0006	0.1724	0.1701
16	B&W-1484 (6.A.7)	Core XXI	2.46	0.9994 ± 0.0010	0.9918 ± 0.0006	0.1544	0.1536
17	B&W-1645 (6.A.8)	S-type Fuel, w/886 ppm B	2.46	0.9970 ± 0.0010	0.9924 ± 0.0006	1.4475	1.4680
18	B&W-1645 (6.A.8)	S-type Fuel, w/746 ppm B	2.46	0.9990 ± 0.0010	0.9913 ± 0.0006	1.5463	1.5660
19	B&W-1645 (6.A.8)	SO-type Fuel, w/1156 ppm B	2.46	0.9972 ± 0.0009	0.9949 ± 0.0005	0.4241	0.4331
20	B&W-1810 (6.A.9)	Case 1 1337 ppm B	2.46	1.0023 ± 0.0010	NC	0.1531	NC
21	B&W-1810 (6.A.9)	Case 12 1899 ppm B	2.46/4.02	1.0060 ± 0.0009	NC	0.4493	NC
22	French (6.A.10)	Water Moderator 0 gap	4.75	0.9966 ± 0.0013	NC	0.2172	NC
23	French (6.A.10)	Water Moderator 2.5 cm gap	4.75	0.9952 ± 0.0012	NC	0.1778	NC
24	French (6.A.10)	Water Moderator 5 cm gap	4.75	0.9943 ± 0.0010	NC	0.1677	NC

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
25	French (6.A.10)	Water Moderator 10 cm gap	4.75	0.9979 ± 0.0010	NC	0.1736	NC
26	PNL-3602 (6.A.11)	Steel Reflector, 0 cm separation	2.35	NC	1.0004 ± 0.0006	NC	0.1018
27	PNL-3602 (6.A.11)	Steel Reflector, 1.321 cm separation	2.35	0.9980 ± 0.0009	0.9992 ± 0.0006	0.1000	0.0909
28	PNL-3602 (6.A.11)	Steel Reflector, 2.616 cm separation	2.35	0.9968 ± 0.0009	0.9964 ± 0.0006	0.0981	0.0975
29	PNL-3602 (6.A.11)	Steel Reflector, 3.912 cm separation	2.35	0.9974 ± 0.0010	0.9980 ± 0.0006	0.0976	0.0970
30	PNL-3602 (6.A.11)	Steel Reflector, Infinite separation	2.35	0.9962 ± 0.0008	0.9939 ± 0.0006	0.0973	0.0968
31	PNL-3602 (6.A.11)	Steel Reflector, 0 cm separation	4.306	NC	1.0003 ± 0.0007	NC	0.3282
32	PNL-3602 (6.A.11)	Steel Reflector, 1.321 cm separation	4.306	0.9997 ± 0.0010	1.0012 ± 0.0007	0.3016	0.3039
33	PNL-3602 (6.A.11)	Steel Reflector, 2.616 cm separation	4.306	0.9994 ± 0.0012	0.9974 ± 0.0007	0.2911	0.2927
34	PNL-3602 (6.A.11)	Steel Reflector, 5.405 cm separation	4.306	0.9969 ± 0.0011	0.9951 ± 0.0007	0.2828	0.2860
35	PNL-3602 (6.A.11)	Steel Reflector, Infinite separation	4.306	0.9910 ± 0.0020	0.9947 ± 0.0007	0.2851	0.2864
36	PNL-3602 (6.A.11)	Steel Reflector, with Boral Sheets	4.306	0.9941 ± 0.0011	0.9970 ± 0.0007	0.3135	0.3150

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
37	PNL-3626 (6.A.12)	Lead Reflector, 0 cm sepn.	4.306	NC	1.0003 ± 0.0007	NC	0.3159
38	PNL-3626 (6.A.12)	Lead Reflector, 0.55 cm sepn.	4.306	1.0025 ± 0.0011	0.9997 ± 0.0007	0.3030	0.3044
39	PNL-3626 (6.A.12)	Lead Reflector, 1.956 cm sepn.	4.306	1.0000 ± 0.0012	0.9985 ± 0.0007	0.2883	0.2930
40	PNL-3626 (6.A.12)	Lead Reflector, 5.405 cm sepn.	4.306	0.9971 ± 0.0012	0.9946 ± 0.0007	0.2831	0.2854
41	PNL-2615 (6.A.13)	Experiment 004/032 – no absorber	4.306	0.9925 ± 0.0012	0.9950 ± 0.0007	0.1155	0.1159
42	PNL-2615 (6.A.13)	Experiment 030 – Zr plates	4.306	NC	0.9971 ± 0.0007	NC	0.1154
43	PNL-2615 (6.A.13)	Experiment 013 – Steel plates	4.306	NC	0.9965 ± 0.0007	NC	0.1164
44	PNL-2615 (6.A.13)	Experiment 014 – Steel plates	4.306	NC	0.9972 ± 0.0007	NC	0.1164
45	PNL-2615 (6.A.13)	Exp. 009 1.05% Boron Steel plates	4.306	0.9982 ± 0.0010	0.9981 ± 0.0007	0.1172	0.1162
46	PNL-2615 (6.A.13)	Exp. 009 1.62% Boron Steel plates	4.306	0.9996 ± 0.0012	0.9982 ± 0.0007	0.1161	0.1173
47	PNL-2615 (6.A.13)	Exp. 031 – Boral plates	4.306	0.9994 ± 0.0012	0.9969 ± 0.0007	0.1165	0.1171
48	PNL-7167 (6.A.14)	Experiment 214R – with flux traps	4.306	0.9991 ± 0.0011	0.9956 ± 0.0007	0.3722	0.3812

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
49	PNL-7167 (6.A.14)	Experiment 214V3 –with flux trap	4.306	0.9969 ± 0.0011	0.9963 ± 0.0007	0.3742	0.3826
50	PNL-4267 (6.A.15)	Case 173 – 0 ppm B	4.306	0.9974 ± 0.0012	NC	0.2893	NC
51	PNL-4267 (6.A.15)	Case 177 – 2550 ppm B	4.306	1.0057 ± 0.0010	NC	0.5509	NC
52	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 21	20% Pu	1.0041 ± 0.0011	1.0046 ± 0.0006	0.9171	0.8868
53	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 43	20% Pu	1.0058 ± 0.0012	1.0036 ± 0.0006	0.2968	0.2944
54	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 13	20% Pu	1.0083 ± 0.0011	0.9989 ± 0.0006	0.1665	0.1706
55	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 32	20% Pu	1.0079 ± 0.0011	0.9966 ± 0.0006	0.1339	0.1165
56	WCAP-3385 (6.A.17)	Saxton Case 52 PuO_2 0.52" pitch	6.6% Pu	0.9996 ± 0.0011	1.0005 ± 0.0006	0.8665	0.8417
57	WCAP-3385 (6.A.17)	Saxton Case 52 U 0.52" pitch	5.74	1.0000 ± 0.0010	0.9956 ± 0.0007	0.4476	0.4580
58	WCAP-3385 (6.A.17)	Saxton Case 56 PuO_2 0.56" pitch	6.6% Pu	1.0036 ± 0.0011	1.0047 ± 0.0006	0.5289	0.5197
59	WCAP-3385 (6.A.17)	Saxton Case 56 borated PuO_2	6.6% Pu	1.0008 ± 0.0010	NC	0.6389	NC
60	WCAP-3385 (6.A.17)	Saxton Case 56 U 0.56" pitch	5.74	0.9994 ± 0.0011	0.9967 ± 0.0007	0.2923	0.2954

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
61	WCAP-3385 (6.A.17)	Saxton Case 79 PuO_2 0.79" pitch	6.6% Pu	1.0063 ± 0.0011	1.0133 ± 0.0006	0.1520	0.1555
62	WCAP-3385 (6.A.17)	Saxton Case 79 U 0.79" pitch	5.74	1.0039 ± 0.0011	1.0008 ± 0.0006	0.1036	0.1047

Notes: NC stands for not calculated.

† EALF is the energy of the average lethargy causing fission

†† The experimental results appear to be statistical outliers (>3σ) suggesting the possibility of unusually large experimental error. Although they could be justifiably excluded, for conservatism, they were retained in determining the calculational basis.

Table 6.A.2

COMPARISON OF MCNP4a AND KENO5a CALCULATED REACTIVITIES[†]
FOR VARIOUS ENRICHMENTS (UO_2)

Enrichment	Calculated $k_{eff} \pm 1\sigma$	
	MCNP4a	**KENO5a**
3.0	0.8465 ± 0.0011	0.8478 ± 0.0004
3.5	0.8820 ± 0.0011	0.8841 ±0.0004
3.75	0.9019 ± 0.0011	0.8987 ± 0.0004
4.0	0.9132 ± 0.0010	0.9140 ± 0.0004
4.2	0.9276 ± 0.0011	0.9237 ± 0.0004
4.5	0.9400 ± 0.0011	0.9388 ± 0.0004

† Based on the MPC-68 with the GE 8x8R

Table 6.A.3

MCNP4a CALCULATED REACTIVITIES FOR
CRITICAL EXPERIMENTS WITH NEUTRON ABSORBERS (UO_2)

Ref.	Experiment		Δk Worth of Absorber	MCNP4a Calculated k_{eff}	EALF[†] (eV)
6.A.13	PNL-2615	Boral Sheet	0.0139	0.9994 ± 0.0012	0.1165
6.A.7	BAW-1484	Core XX	0.0165	1.0008 ± 0.0011	0.1724
6.A.13	PNL-2615	1.62% Boron-steel	0.0165	0.9996 ± 0.0012	0.1161
6.A.7	BAW-1484	Core XIX	0.0202	0.9961 ± 0.0012	0.2103
6.A.7	BAW-1484	Core XXI	0.0243	0.9994 ± 0.0010	0.1544
6.A.7	BAW-1484	Core XVII	0.0519	0.9962 ± 0.0012	0.2083
6.A.11	PNL-3602	Boral Sheet	0.0708	0.9941 ± 0.0011	0.3135
6.A.7	BAW-1484	Core XV	0.0786	0.9910 ± 0.0011	0.2092
6.A.7	BAW-1484	Core XVI	0.0845	0.9935 ± 0.0010	0.1757
6.A.7	BAW-1484	Core XIV	0.1575	0.9953 ± 0.0011	0.2022
6.A.7	BAW-1484	Core XIII	0.1738	1.0020 ± 0.0011	0.1988
6.A.14	PNL-7167	Expt 214R flux trap	0.1931	0.9991 ± 0.0011	0.3722

[†] EALF is the energy of the average lethargy causing fission

Table 6.A.4
COMPARISON OF MCNP4a AND KENO5a
CALCULATED REACTIVITIES† FOR VARIOUS BORON LOADINGS (UO_2)

^{10}B, g/cm^2	Calcualted k_{eff} ± 1σ	
	MCNP4a	**KENO5a**
0.005	1.0381 ± 0.0012	1.0340 ± 0.0004
0.010	0.9960 ±0.0010	0.9941 ± 0.0004
0.015	0.9727 ± 0.0009	0.9713 ± 0.0004
0.020	0.9541 ± 0.0012	0.9560 ± 0.0004
0.025	0.9433 ± 0.0011	0.9428 ± 0.0004
0.03	0.9325 ± 0.0011	0.9338 ± 0.0004
0.035	0.9234 ± 0.0011	0.9251 ± 0.0004
0.04	0.9173 ± 0.0011	0.9179 ± 0.0004

† based on 4.5% enrichment GE 8x8R in the MPC-68 cask.

Table 6.A.5

CALCULATIONS FOR CRITICAL EXPERIMENTS WITH THICK LEAD AND STEEL REFLECTORS[†] (UO_2)

Ref.	Case	Enrichment, wt%	Separation, cm	MCNP4a k_{eff}	KENO5a k_{eff}
6.A.11	Steel Reflector	2.35	1.321	0.9980 ± 0.0009	0.9992 ± 0.0006
		2.35	2.616	0.9968 ± 0.0009	0.9964 ± 0.0006
		2.35	3.912	0.9974 ± 0.0010	0.9980 ± 0.0006
		2.35	∞	0.9962 ± 0.0008	0.9939 ± 0.0006
6.A.11	Steel Reflector	4.306	1.321	0.9997 ± 0.0010	1.0012 ± 0.0007
		4.306	2.616	0.9994 ± 0.0012	0.9974 ± 0.0007
		4.306	3.405	0.9969 ± 0.0011	0.9951 ± 0.0007
		4.306	∞	0.9910 ± 0.0020	0.9947 ± 0.0007
6.A.11	Lead Reflector	4.306	0.55	1.0025 ± 0.0011	0.9997 ± 0.0007
		4.306	1.956	1.0000 ± 0.0012	0.9985 ± 0.0007
		4.306	5.405	0.9971 ± 0.0012	0.9946 ± 0.0007

[†] Arranged in order of increasing reflector fuel spacing.

Table 6.A.6

CALCULATIONS FOR CRITICAL EXPERIMENTS WITH VARIOUS SOLUBLE BORON CONCENTRATIONS (UO_2)

Reference	Experiment	Boron Concentration ppm	Calculated k_{eff}	
			MCNP4a	KENO5a
6.A.15	PNL-4267	0	0.9974 ± 0.0012	-
6.A.8	BAW-1645-4	886	0.9970 ± 0.0010	0.9924 ± 0.0006
6.A.9	BAW-1810	1337	1.0023 ± 0.0010	-
6.A.9	BAW-1810	1899	1.0060 ± 0.0009	-
6.A.15	PNL-4267	2550	1.0057 ± 0.0010	-

Table 6.A.7

CALCULATIONS FOR CRITICAL EXPERIMENTS WITH MOX FUEL

Reference	Case[†]	MCNP4a		KENO 5a	
		k_{eff}	EALF[††] (eV)	k_{eff}	EALF[††] (eV)
PNL-5803 [6.A.16]	MOX Fuel – Exp No 21	1.0041±0.0011	0.9171	1.0046±0.0006	0.8868
	MOX Fuel – Exp No 43	1.0058±0.0012	0.2968	1.0036±0.0006	0.2944
	MOX Fuel – Exp No 13	1.0083±0.0011	0.1665	0.9989±0.0006	0.1706
	MOX Fuel – Exp No 32	1.0079±0.0011	0.1139	0.9966±0.0006	0.1165
WCAP- 3385-54 [6.A.17]	Saxton @ 0.52" pitch	0.9996±0.0011	0.8665	1.0005±0.0006	0.8417
	Saxton @ 0.56" pitch	1.0036±0.0011	0.5289	1.0047±0.0006	0.5197
	Saxton @ 0.56" pitch borated	1.0008±0.0010	0.6389	NC	NC
	Saxton @ 0.79" pitch	1.0063±0.0011	0.1520	1.0133±0.0006	0.1555

[†] Arranged in order of increasing lattice spacing.

[††] EALF is the energy of the average lethargy causing fission.

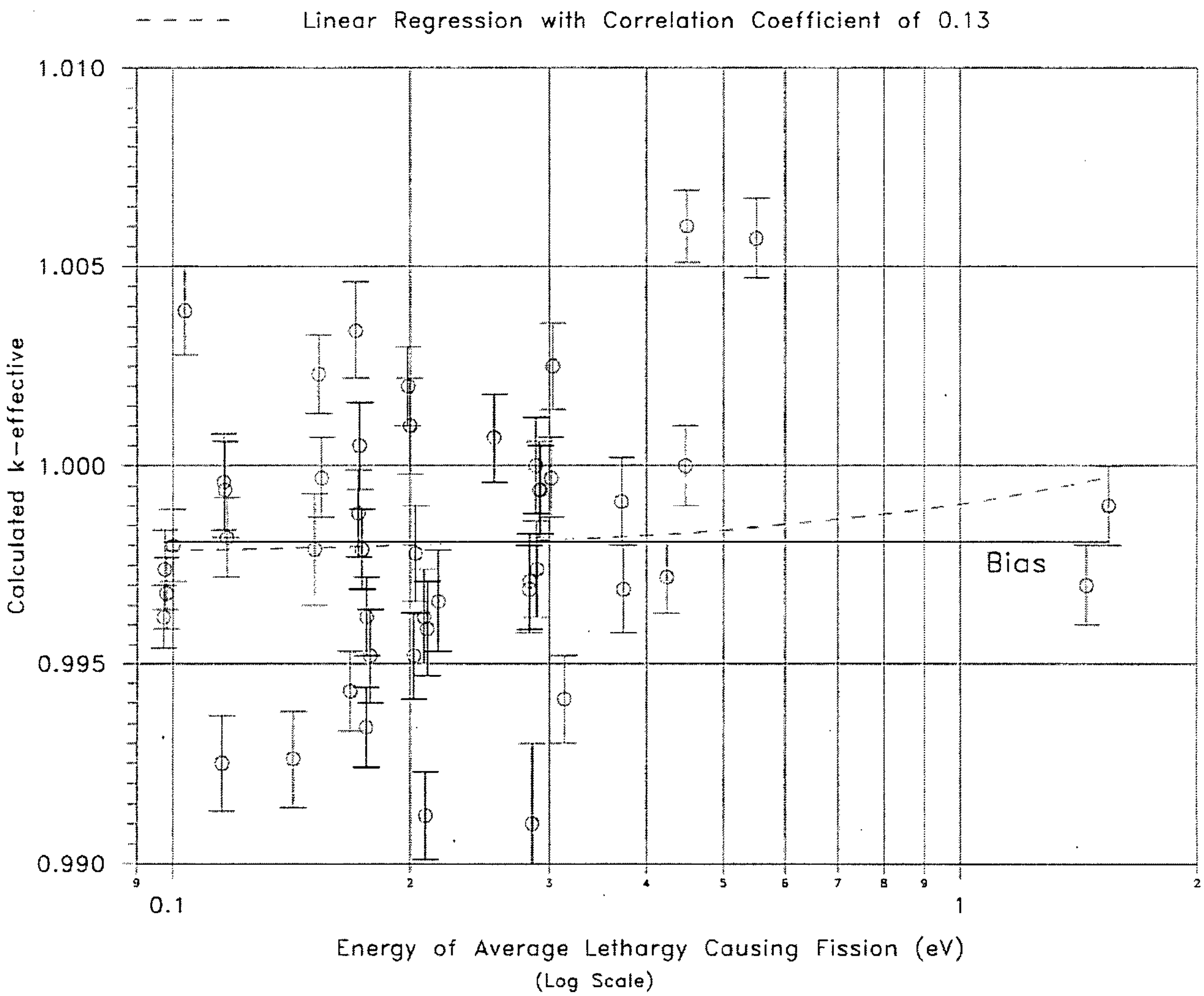

FIGURE 6.A.1 MCNP4a CALCULATED k-eff VALUES FOR VARIOUS VALUES OF THE SPECTRAL INDEX

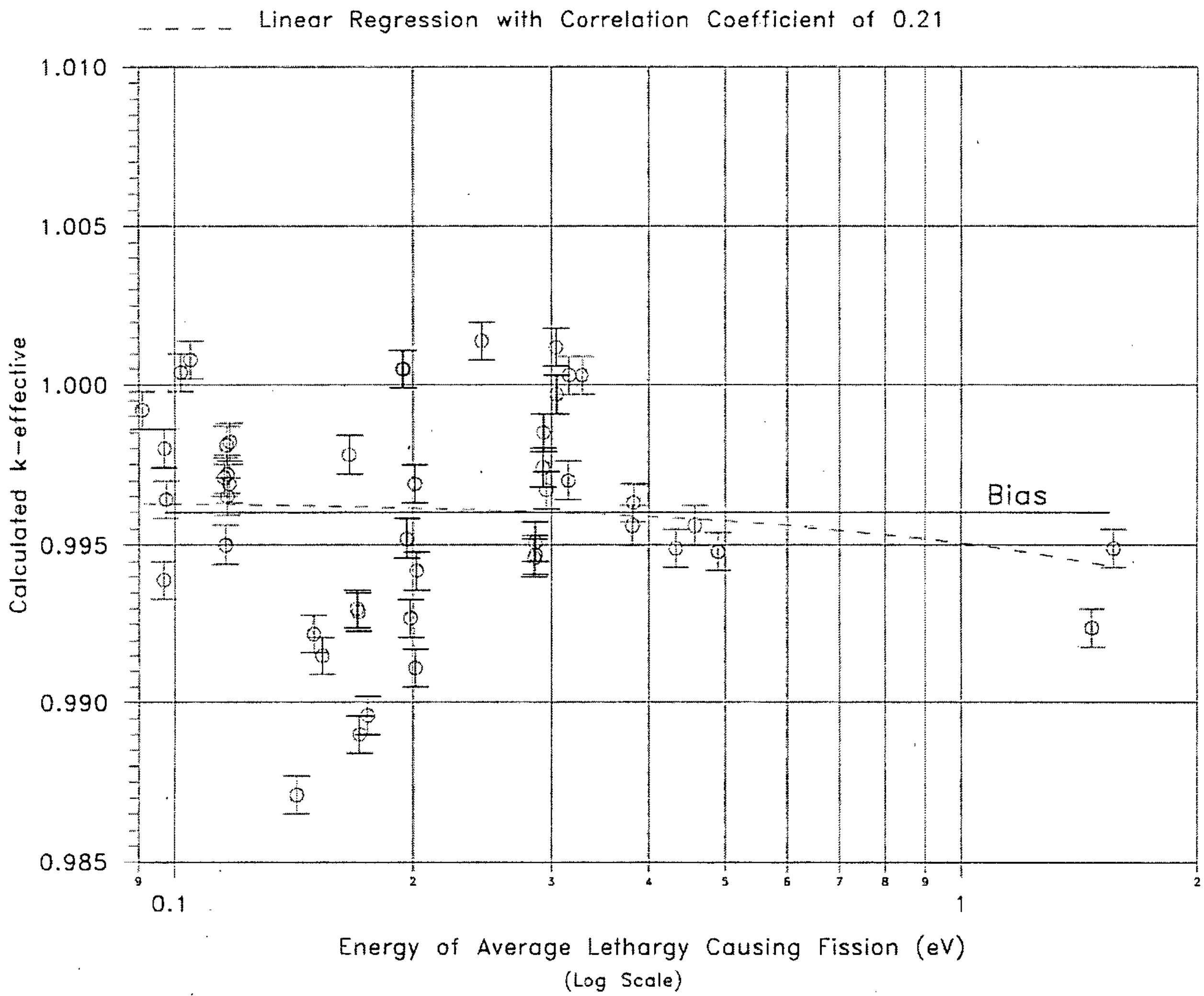

FIGURE 6.A.2 KENO5a CALCULATED k−eff VALUES FOR VARIOUS VALUES OF THE SPECTRAL INDEX

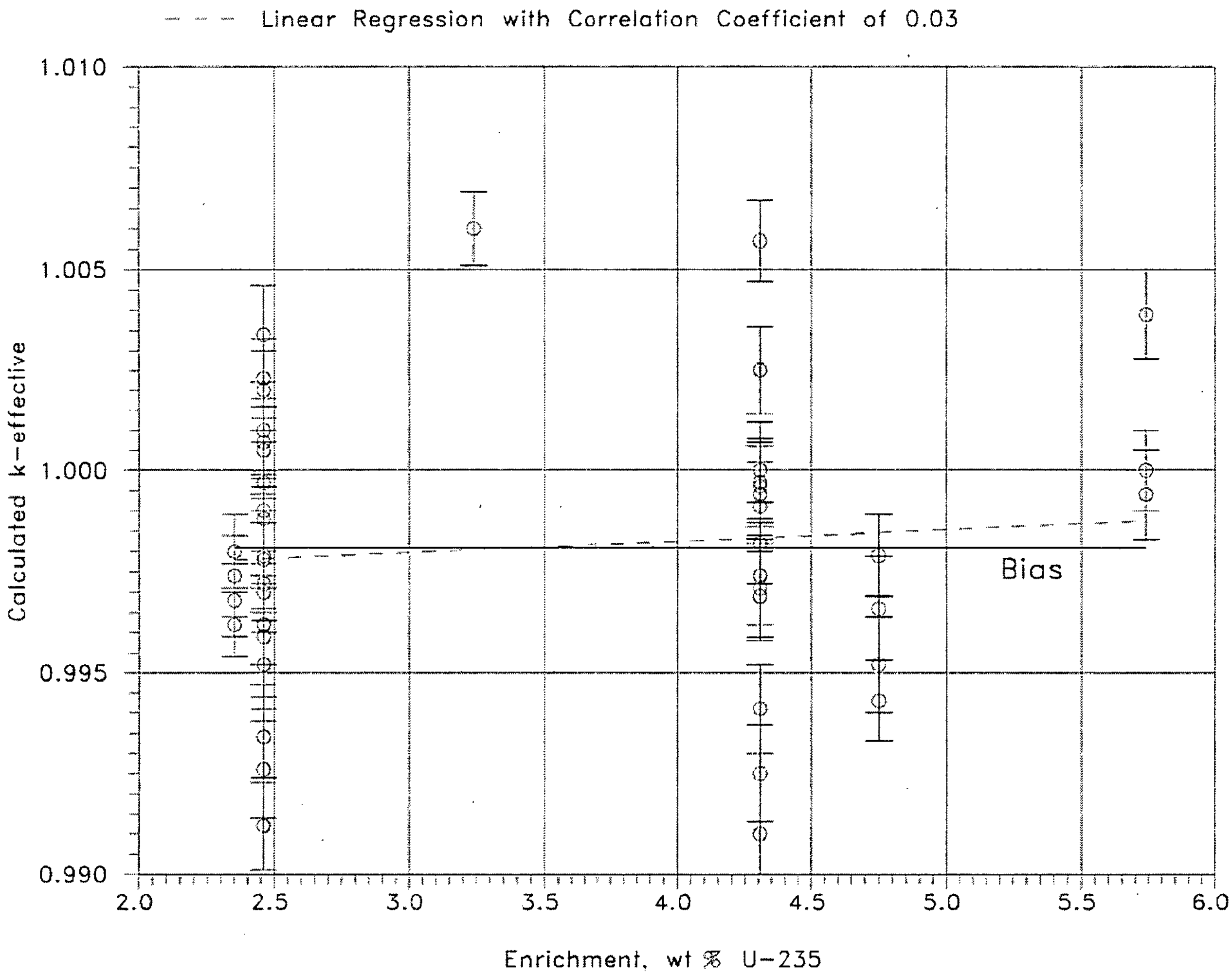

FIGURE 6.A.3 MCNP4a CALCULATED k-eff VALUES AT VARIOUS U-235 ENRICHMENTS

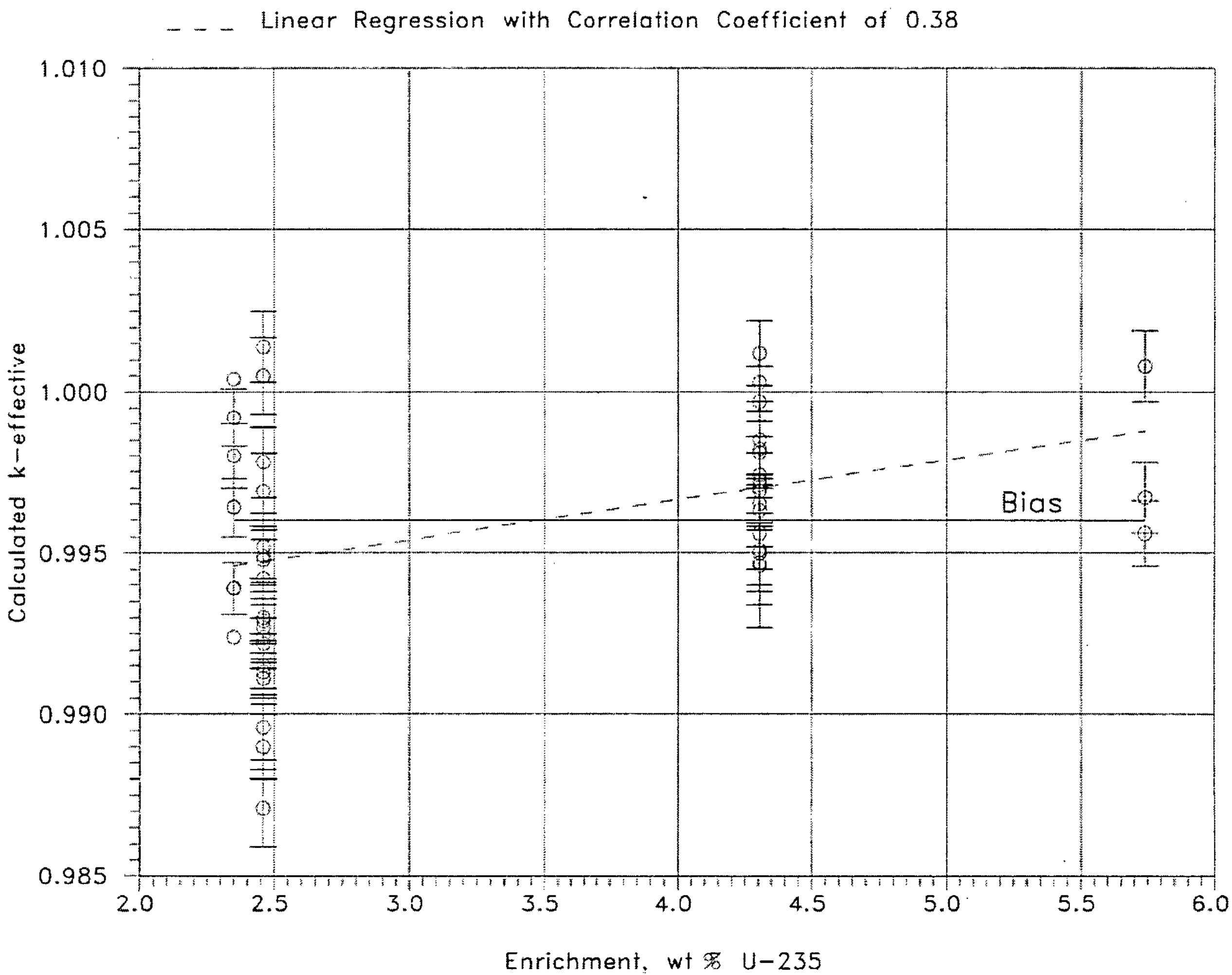

FIGURE 6.A.4 KENO5a CALCULATED k-eff VALUES
AT VARIOUS U-235 ENRICHMENTS

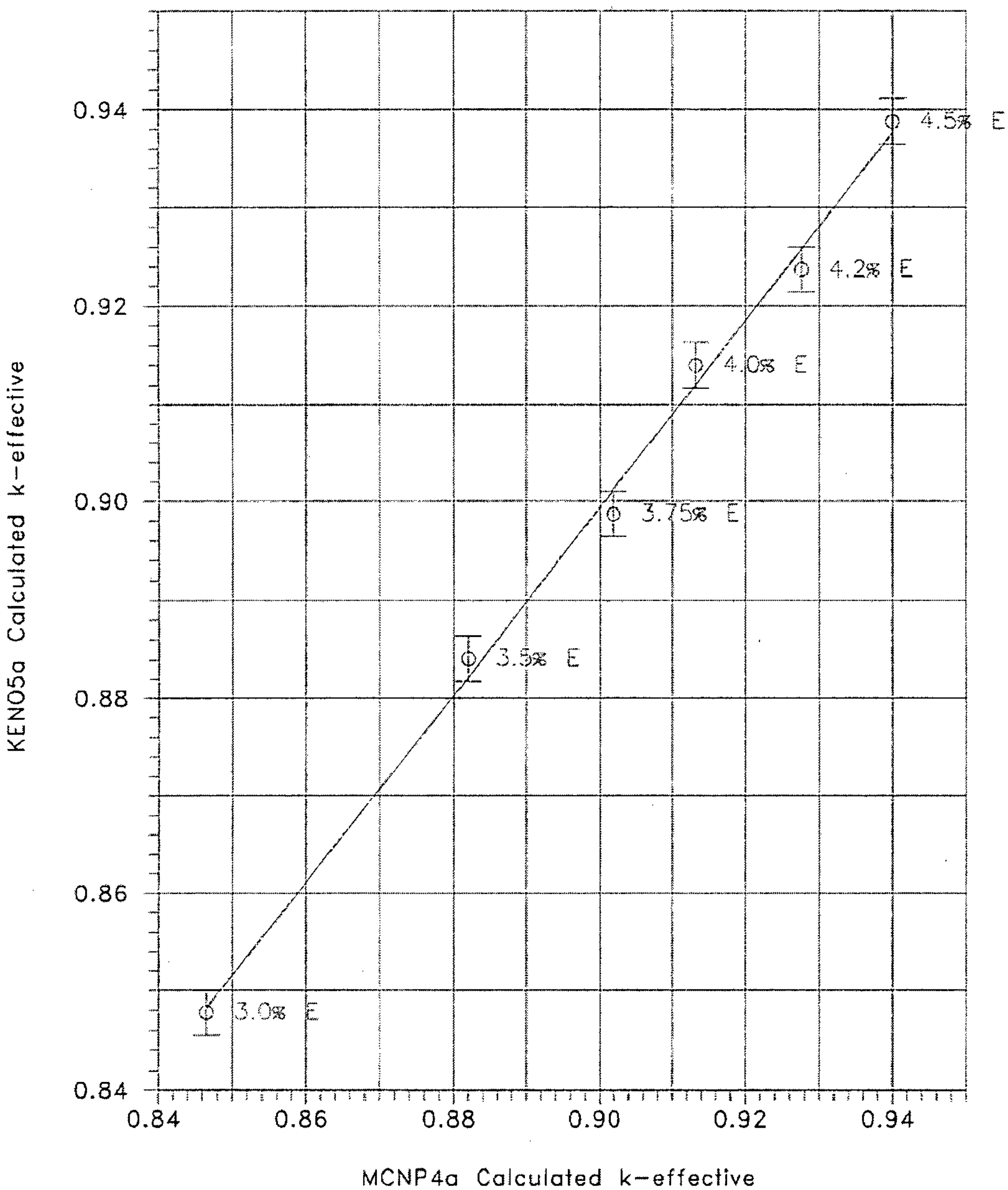

FIGURE 6.A.5 COMPARISON OF MCNP4a AND KENO5a CALCULATIONS FOR VARIOUS FUEL ENRICHMENTS

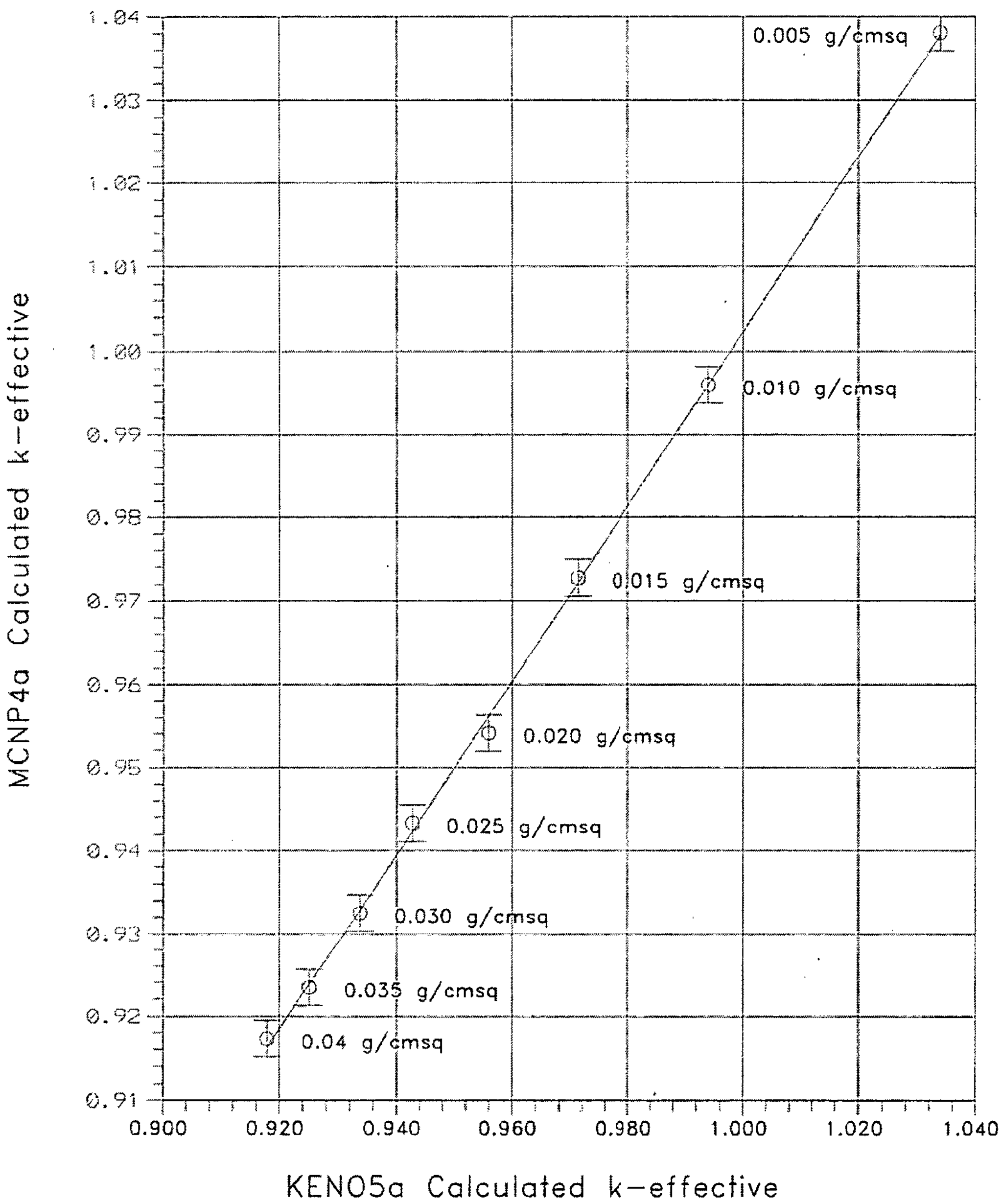

FIGURE 6.A.6 COMPARISON OF MCNP4a AND KENO5a CALCULATIONS FOR VARIOUS BORON-10 AREAL DENSITIES

APPENDIX 6.B: DISTRIBUTED ENRICHMENTS IN BWR FUEL

Fuel assemblies used in BWRs utilize fuel rods of varying enrichments as a means of controlling power peaking during in-core operation. For calculations involving BWR assemblies, the use of a uniform (planar-average) enrichment, as opposed to the distributed enrichments normally used in BWR fuel, produces conservative results. Calculations have been performed to confirm that this statement remains valid in the geometry of the MPC-68. These calculations are based on fuel assembly designs currently in use and two hypothetical distributions, all intended to illustrate that calculations with uniform average enrichments are conservative.

The average enrichment is calculated as the linear average of the various fuel rod enrichments, i.e.,

$$\overline{E} = \frac{1}{n} \sum_{i=1}^{n} E_i,$$

where E_i is the enrichment in each of the n rods, and $\overline{E}$ is the assembly average enrichment. This parameter conservatively characterizes the fuel assembly and is readily available for specific fuel assemblies in determining the acceptability of the assembly for placement in the MPC-68 cask.

The criticality calculations for average and distributed enrichment cases are compared in Table 6.B.1 to illustrate and confirm the conservatism inherent in using average enrichments. With two exceptions, the cases analyzed represent realistic designs currently in use and encompass fuel with different ratios of maximum pin enrichment to average assembly enrichment. The two exceptions are hypothetical cases intended to extend the models to higher enrichments and to demonstrate that using the average enrichment remains conservative.

Table 6.B.1 shows that, in all cases, the averaged enrichment yields conservative values of reactivity relative to distributed enrichments for both the actual fuel designs and the hypothetical higher enrichment cases. Thus, it is concluded that uniform average enrichments will always yield higher (more conservative) values for reactivity than the corresponding distributed enrichments†.

† This conclusion implicitly assumes the higher enrichment fuel rods are located internal to the assembly (as in BWR fuel), and the lower enriched rods are on the outside.

Table 6.B.1

COMPARISON CALCULATIONS FOR BWR FUEL WITH AVERAGE AND DISTRIBUTED ENRICHMENTS

Case	Average %E	Peak Rod E%	Calculated k_{eff}	
			Average E	**Distributed E**
8x8C04	3.01	3.80	0.8549	0.8429
8x8C04	3.934	4.9	0.9128	0.9029
8x8D05	3.42	3.95	0.8790	0.8708
8x8D05	3.78	4.40	0.9030	0.8974
8x8D05	3.90	4.90	0.9062	0.9042
9x9B01	4.34	4.71	0.9347	0.9285
9x9D01	3.35	4.34	0.8793	0.8583
Hypothetical #1 (48 outer rods of 3.967%E,14 inner rods of 5.0%)	4.20	5.00	0.9289	0.9151
Hypothetical #2 (48 outer rods of 4.354%E,14 inner rods of 5.0%)	4.50	5.00	0.9422	0.9384

APPENDIX 6.C: CALCULATIONAL SUMMARY

The following table lists the maximum k_{eff} (including bias, uncertainties, and calculational statistics), MCNP calculated k_{eff}, standard deviation, and energy of average lethargy causing fission (EALF) for each of the candidate fuel types and basket configurations.

Table 6.C.1
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES AND BASKET CONFIGURATIONS

MPC-24				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A01	0.9295	0.9252	0.0008	0.2084
14x14A02	0.9286	0.9242	0.0008	0.2096
14x14A03	0.9296	0.9253	0.0008	0.2093
14x14B01	0.9159	0.9117	0.0007	0.2727
14x14B02	0.9169	0.9126	0.0008	0.2345
14x14B03	0.9110	0.9065	0.0009	0.2545
14x14B04	0.9084	0.9039	0.0009	0.2563
B14x14B01	0.9228	0.9185	0.0008	0.2675
14x14C01	0.9258	0.9215	0.0008	0.2729
14x14C02	0.9265	0.9222	0.0008	0.2765
14x14C03	0.9287	0.9242	0.0009	0.2825
14x14D01	0.8507	0.8464	0.0008	0.3308
15x15A01	0.9204	0.9159	0.0009	0.2608
15x15B01	0.9369	0.9326	0.0008	0.2632
15C15B02	0.9338	0.9295	0.0008	0.2640
15x15B03	0.9362	0.9318	0.0008	0.2632
15x15B04	0.9370	0.9327	0.0008	0.2612
15x15B05	0.9356	0.9313	0.0008	0.2606
15x15B06	0.9366	0.9324	0.0007	0.2638
B15x15B01	0.9388	0.9343	0.0009	0.2626
15x15C01	0.9255	0.9213	0.0007	0.2493

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
15x15C02	0.9297	0.9255	0.0007	0.2457
15x15C03	0.9297	0.9255	0.0007	0.2440
15x15C04	0.9311	0.9268	0.0008	0.2435
B15x15C01	0.9361	0.9316	0.0009	0.2385
15x15D01	0.9341	0.9298	0.0008	0.2822
15x15D02	0.9367	0.9324	0.0008	0.2802
15x15D03	0.9354	0.9311	0.0008	0.2844
15x15D04	0.9339	0.9292	0.0010	0.2958
15x15E01	0.9368	0.9325	0.0008	0.2826
15x15F01	0.9395	0.9350	0.0009	0.2903
15x15G01	0.8876	0.8833	0.0008	0.3357
15x15H01	0.9337	0.9292	0.0009	0.2349
16x16A01	0.9287	0.9244	0.0008	0.2704
16x16A02	0.9263	0.9221	0.0007	0.2702
17x17A01	0.9368	0.9325	0.0008	0.2131
17x17A02	0.9368	0.9325	0.0008	0.2131
17x17A03	0.9329	0.9286	0.0008	0.2018
17x17B01	0.9288	0.9243	0.0009	0.2607
17x17B02	0.9290	0.9247	0.0008	0.2596
17x17B03	0.9243	0.9199	0.0008	0.2625
17x17B04	0.9324	0.9279	0.0009	0.2576
17x17B05	0.9266	0.9222	0.0008	0.2539

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
17x17B06	0.9311	0.9268	0.0008	0.2593
17x17C01	0.9293	0.9250	0.0008	0.2595
17x17C02	0.9336	0.9293	0.0008	0.2624

MPC-68				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
6x6A01	0.7539	0.7498	0.0007	0.2754
6x6A02	0.7517	0.7476	0.0007	0.2510
6x6A03	0.7545	0.7501	0.0008	0.2494
6x6A04	0.7537	0.7494	0.0008	0.2494
6x6A05	0.7555	0.7512	0.0008	0.2470
6x6A06	0.7618	0.7576	0.0008	0.2298
6x6A07	0.7588	0.7550	0.0005	0.2360
6x6A08	0.7808	0.7766	0.0007	0.2527
B6x6A01	0.7888	0.7846	0.0007	0.2310
6x6B01	0.7604	0.7563	0.0007	0.2461
6x6B02	0.7618	0.7577	0.0006	0.2450
6x6B03	0.7619	0.7578	0.0007	0.2439
6x6B04	0.7686	0.7644	0.0008	0.2286
6x6B05	0.7824	0.7785	0.0006	0.2184
B6x6B01	0.7822	0.7783	0.0006	0.2190

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
6x6C01	0.8021	0.7980	0.0007	0.2139
7x7A01	0.7973	0.7930	0.0008	0.2015
7x7B01	0.9372	0.9330	0.0007	0.3658
7x7B02	0.9301	0.9260	0.0007	0.3524
7x7B03	0.9313	0.9271	0.0008	0.3438
7x7B04	0.9311	0.9270	0.0007	0.3816
7x7B05	0.9350	0.9306	0.0008	0.3382
7x7B06	0.9298	0.9260	0.0006	0.3957
B7x7B01	0.9375	0.9332	0.0008	0.3887
B7x7B02	0.9386	0.9344	0.0007	0.3983
8x8A01	0.7685	0.7644	0.0007	0.2227
8x8A02	0.7697	0.7656	0.0007	0.2158
8x8B01	0.9310	0.9265	0.0009	0.2935
8x8B02	0.9227	0.9185	0.0007	0.2993
8x8B03	0.9299	0.9257	0.0008	0.3319
8x8B04	0.9236	0.9194	0.0008	0.3700
B8x8B01	0.9346	0.9301	0.0009	0.3389
B8x8B02	0.9385	0.9343	0.0008	0.3329
B8x8B03	0.9416	0.9375	0.0007	0.3293
8x8C01	0.9315	0.9273	0.0007	0.2822
8x8C02	0.9313	0.9268	0.0009	0.2716
8x8C03	0.9329	0.9286	0.0008	0.2877

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
8x8C04	0.9348	0.9307	0.0007	0.2915
8x8C05	0.9353	0.9312	0.0007	0.2971
8x8C06	0.9353	0.9312	0.0007	0.2944
8x8C07	0.9314	0.9273	0.0007	0.2972
8x8C08	0.9339	0.9298	0.0007	0.2915
8x8C09	0.9301	0.9260	0.0007	0.3183
8x8C10	0.9317	0.9275	0.0008	0.3018
8x8C11	0.9328	0.9287	0.0007	0.3001
8x8C12	0.9285	0.9242	0.0008	0.3062
B8x8C01	0.9357	0.9313	0.0009	0.3141
B8x8C02	0.9425	0.9384	0.0007	0.3081
B8x8C03	0.9418	0.9375	0.0008	0.3056
8x8D01	0.9342	0.9302	0.0006	0.2733
8x8D02	0.9325	0.9284	0.0007	0.2750
8x8D03	0.9351	0.9309	0.0008	0.2731
8x8D04	0.9338	0.9296	0.0007	0.2727
8x8D05	0.9339	0.9294	0.0009	0.2700
8x8D06	0.9365	0.9324	0.0007	0.2777
8x8D07	0.9341	0.9297	0.0009	0.2694
8x8D08	0.9376	0.9332	0.0009	0.2841
B8x8D01	0.9403	0.9363	0.0007	0.2778
8x8E01	0.9312	0.9270	0.0008	0.2831

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
8x8F01	0.9153	0.9111	0.0007	0.2143
9x9A01	0.9353	0.9310	0.0008	0.2875
9x9A02	0.9388	0.9345	0.0008	0.2228
9x9A03	0.9351	0.9310	0.0007	0.2837
9x9A04	0.9396	0.9355	0.0007	0.2262
B9x9A01	0.9417	0.9374	0.0008	0.2236
9x9B01	0.9380	0.9336	0.0008	0.2576
9x9B02	0.9373	0.9329	0.0009	0.2578
9x9B03	0.9417	0.9374	0.0008	0.2545
B9x9B01	0.9436	0.9394	0.0008	0.2506
9x9C01	0.9395	0.9352	0.0008	0.2698
9x9D01	0.9394	0.9350	0.0009	0.2625
9x9E01	0.9402	0.9359	0.0008	0.2249
9x9E02	0.9424	0.9380	0.0008	0.2088
9x9F01	0.9369	0.9326	0.0008	0.2954
9x9F02	0.9424	0.9380	0.0008	0.2088
10x10A01	0.9377	0.9335	0.0008	0.3170
10x10A02	0.9426	0.9386	0.0007	0.2159
10x10A03	0.9396	0.9356	0.0007	0.3169
B10x10A01	0.9457	0.9414	0.0008	0.2212
10x10B01	0.9384	0.9341	0.0008	0.2881
10x10B02	0.9416	0.9373	0.0008	0.2333

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68				
Fuel Assembly Designation	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
10x10B03	0.9375	0.9334	0.0007	0.2856
B10x10B01	0.9436	0.9395	0.0007	0.2366
10x10C01	0.9433	0.9392	0.0007	0.2416
10x10D01	0.9376	0.9333	0.0008	0.3355
10x10E01	0.9185	0.9144	0.0007	0.2936

Note: Maximum k_{eff} = Calculated k_{eff} + $K_c \times \sigma_c$ + Bias + σ_B
where:
K_c = 2.0
σ_c = Std. Dev. (1-sigma)
Bias = 0.0021
σ_B = 0.0006
See Subsection 6.4.3 for further explanation.

APPENDIX 6.D: SAMPLE INPUT FILES

(Total number of pages in this appendix : 46)

```
c
c Bounding Assembly in Class 15x15F
c
c MPC-24/24E cell configuration
c
c HI-STAR with active length 150 inch
c
c Cask Input Preprocessor
c cskinp 15f 15f mpc24n mpc24n histar star150 4.1 4rf5f45 pure
c ------     cpp\15f.bat
c   added 15f.co
c   added 15f.ce
c   added 15f.su
c   added 15f.sp
c ------     cpp\mpc24n.bat
c   added mpc24n.co
c   added mpc24n.ce
c   added mpc24n.su
c   added mpc24n.sp
c ------     cpp\histar.bat
c   added histar.co
c   added histar.ce
c   added histar.su
c   added histar.sp
c end of comments
c
c start of cells
c
c 15x15f
c
c number of cells: 6
c cell numbers:       1 to 7 and 201 to 299
c univers numbers:    1 to 3 and 201 to 299
c surface numbers:    1 to 9 and 201 to 299
c
c number of cells: 1
1      1 -10.522      -1   u=2        $ fuel
2      4 -1.0      1   -2   u=2        $ gap
3      3 -6.55     2   -3   u=2        $ Zr Clad
4      4 -1.0          3   u=2        $ water in fuel region
5      4 -1.0   -4:5      u=3        $ water in guide tubes
6      3 -6.55    4 -5     u=3        $ guide tubes
7      4 -1.0   -6    +7    -8    +9    u=1  lat=1
       fill= -8:8     -8:8    0:0
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 2 2 2 3 2 2 2 3 2 2 2 2 2 1
       1 2 2 2 3 2 2 2 2 2 2 2 3 2 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 3 2 2 3 2 2 2 3 2 2 3 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 2 2 2 2 2 3 2 2 2 2 2 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 3 2 2 3 2 2 2 3 2 2 3 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 2 3 2 2 2 2 2 2 2 3 2 2 2 1
       1 2 2 2 2 2 3 2 2 2 3 2 2 2 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
       1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
```

```
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
c
c     MPC-24
c
c number of cells: 102
c cell numbers :       400   to  699
c universe numbers :    4   to    9
c surface numbers :   400   to  699
c
c     Right Side
c
408      0          -410    411  -412   413     u=4 fill=1 (1)
409      5  -7.84     410  -424   413  -426     u=4
410    4 -1.0      424  -428   448  -445     u=4
411    7  -2.7      428  -528  448  -445     u=4
412    6  -2.66    528  -532  448  -445     u=4
413    7  -2.7     532  -432   448  -445     u=4
414    4 -1.0      432  -436   448  -445     u=4
415    5  -7.84     436  -440   448  -445     u=4
416    4 -1.0      440          413          u=4
417    4 -1.0      424  -440   413  -447     u=4
418    4 -1.0      424  -440   446           u=4
419    5  -7.84     424  -440   447  -448     u=4
420    5  -7.84     424  -440   445  -446     u=4
c
c    Left Side
c
421    5  -7.84     425  -411   413           u=4
422    4 -1.0      429  -425   448  -445     u=4
423    7  -2.7     529  -429   448  -445     u=4
424    6  -2.66    533 -529   448  -445     u=4
425    7  -2.7      433 -533   448  -445     u=4
426    4 -1.0      437  -433   448  -445     u=4
427    5  -7.84     441  -437   448  -445     u=4
428    4 -1.0         -441   413          u=4
429    4 -1.0      441  -425   413  -447     u=4
430    4 -1.0      441  -425   446           u=4
431    5  -7.84     441  -425   447  -448     u=4
432    5  -7.84     441  -425   445  -446     u=4
c
c     Top
c
433    5  -7.84     411  -410   412  -426     u=4
434    4 -1.0      451  -452   426  -430     u=4
435    7  -2.7      451  -452   430 -530     u=4
436    6  -2.66     451  -452   530 -534     u=4
437    7  -2.7      451  -452   534  -434     u=4
438    4 -1.0      451  -452   434  -438     u=4
439    5  -7.84     451  -452   438  -442     u=4
440    4 -1.0      411  -424   442           u=4
441    4 -1.0      411  -450   426  -442     u=4
442    4 -1.0      453  -424   426  -442     u=4
443    5  -7.84     450  -451   426  -442     u=4
444    5  -7.84     452  -453   426  -442     u=4
c
c     Bottom
c
445    5  -7.84     427              -413     u=4
446    4 -1.0      451  -452   431  -427     u=4
447    7  -2.7      451  -452   531  -431     u=4
448    6  -2.66     451  -452   535 -531     u=4
```

```
449    7  -2.7      451  -452   435 -535    u=4
450    4 -1.0      451  -452   439  -435    u=4
451    5  -7.84     451  -452   443  -439    u=4
452    4 -1.0      411              -443    u=4
453    4 -1.0      411  -450   443  -427    u=4
454    4 -1.0      453         443  -427    u=4
455    5  -7.84     450  -451   443  -427    u=4
456    5  -7.84     452  -453   443  -427    u=4
457    5  -7.84     425  -411         -427    u=4
458    4 -1.0          -425        -427    u=4
c
c     TYPE B CELL  -  Short Boral on top and right
c
c     Right Side
c
459    0           -410   411  -412   413    u=5 fill=1 (1)
460    5  -7.84     410  -424   413  -426    u=5
470    4 -1.0      424  -428  548 -545    u=5
471    7  -2.7      428  -528 548 -545    u=5
472    6  -2.66    528  -532 548 -545    u=5
473    7  -2.7     532  -432  548 -545    u=5
474    4 -1.0      432  -436  548 -545    u=5
475    5  -7.84     436  -440  548 -545    u=5
476    4 -1.0      440         413         u=5
477    4 -1.0      424  -440   413 -547    u=5
478    4 -1.0      424  -440  546          u=5
479    5  -7.84     424  -440  547 -548    u=5
480    5  -7.84     424  -440  545 -546    u=5
c
c    Left Side
c
481    5  -7.84     425  -411   413          u=5
482    4 -1.0      429  -425   448  -445    u=5
483    7  -2.7     529  -429   448  -445    u=5
484    6  -2.66    533 -529   448  -445    u=5
485    7  -2.7      433 -533   448  -445    u=5
486    4 -1.0      437  -433   448  -445    u=5
487    5  -7.84     441  -437   448  -445    u=5
488    4 -1.0          -441   413          u=5
489    4 -1.0      441  -425   413  -447    u=5
490    4 -1.0      441  -425   446          u=5
491    5  -7.84     441  -425   447  -448    u=5
492    5  -7.84     441  -425   445  -446    u=5
c
c     Top
c
493    5  -7.84     411  -410   412  -426    u=5
494    4 -1.0     551 -552   426  -430    u=5
495    7  -2.7     551 -552   430 -530    u=5
496    6  -2.66    551 -552  530 -534    u=5
497    7  -2.7     551 -552  534  -434    u=5
498    4 -1.0     551 -552   434  -438    u=5
499    5  -7.84    551 -552   438  -442    u=5
500   4 -1.0     411  -424   442          u=5
501   4 -1.0     411 -550   426  -442    u=5
502   4 -1.0    553  -424   426  -442    u=5
503   5  -7.84   550 -551   426  -442    u=5
504   5  -7.84   552 -553   426  -442    u=5
c
c     Bottom
c
```

```
505   5  -7.84    427               -413    u=5
506   4 -1.0     451  -452   431  -427    u=5
507   7  -2.7     451  -452  531  -431    u=5
508   6  -2.66    451  -452  535 -531    u=5
509   7  -2.7     451  -452   435 -535    u=5
510   4 -1.0     451  -452   439  -435    u=5
511   5  -7.84    451  -452   443  -439    u=5
512   4 -1.0     411               -443    u=5
513   4 -1.0     411  -450   443  -427    u=5
514   4 -1.0     453          443  -427    u=5
515   5  -7.84    450  -451   443  -427    u=5
516   5  -7.84    452  -453   443  -427    u=5
517   5  -7.84    425  -411         -427    u=5
518   4 -1.0          -425         -427    u=5
c
c
c
c     TYPE D CELL  -  Short Boral on left and bottom, different cell ID
c
c number of cells: 51
c
c     Right Side
c
1570   0          -1410   1411  -1412   1413    u=17 fill=1 (1)
1571   5  -7.84    1410  -1424   1413  -1426    u=17
1572   4 -1.0     1424  -1428   1448  -1445    u=17
1573   7  -2.7     1428  -1528  1448  -1445    u=17
1574   6  -2.66    1528  -1532  1448  -1445    u=17
1575   7  -2.7     1532  -1432   1448  -1445    u=17
1576   4 -1.0     1432  -1436   1448  -1445    u=17
1577   5  -7.84    1436  -1440   1448  -1445    u=17
1578   4 -1.0     1440          1413          u=17
1579   4 -1.0     1424  -1440   1413  -1447    u=17
1580   4 -1.0     1424  -1440   1446          u=17
1581   5  -7.84    1424  -1440   1447  -1448    u=17
1582   5  -7.84    1424  -1440   1445  -1446    u=17
c
c    Left Side
c
1583   5  -7.84    1425  -1411   1413          u=17
1584   4 -1.0     1429  -1425  1548 -1545    u=17
1585   7  -2.7     1529  -1429  1548 -1545    u=17
1586   6  -2.66    1533 -1529  1548 -1545    u=17
1587   7  -2.7     1433 -1533  1548 -1545    u=17
1588   4 -1.0     1437  -1433  1548 -1545    u=17
1589   5  -7.84    1441  -1437  1548 -1545    u=17
1590   4 -1.0          -1441   1413          u=17
1591   4 -1.0     1441  -1425   1413 -1547    u=17
1592   4 -1.0     1441  -1425  1546          u=17
1593   5  -7.84    1441  -1425  1547 -1548    u=17
1594   5  -7.84    1441  -1425  1545 -1546    u=17
c
c     Top
c
1595   5  -7.84    1411  -1410   1412  -1426    u=17
1596   4 -1.0     1451  -1452   1426  -1430    u=17
1597   7  -2.7     1451  -1452   1430 -1530    u=17
1598   6  -2.66    1451  -1452  1530 -1534    u=17
1599   7  -2.7     1451  -1452  1534  -1434    u=17
1600   4 -1.0     1451  -1452   1434  -1438    u=17
1601   5  -7.84    1451  -1452   1438  -1442    u=17
```

```
1602   4 -1.0      1411  -1424   1442          u=17
1603   4 -1.0      1411  -1450   1426  -1442    u=17
1604   4 -1.0      1453  -1424   1426  -1442    u=17
1605   5  -7.84     1450  -1451   1426  -1442    u=17
1606   5  -7.84     1452  -1453   1426  -1442    u=17
c
c     Bottom
c
1607   5  -7.84     1427             -1413    u=17
1608   4 -1.0     1551 -1552   1431  -1427    u=17
1609   7  -2.7     1551 -1552  1531  -1431    u=17
1610   6  -2.66    1551 -1552  1535 -1531    u=17
1611   7  -2.7     1551 -1552   1435 -1535    u=17
1612   4 -1.0     1551 -1552   1439  -1435    u=17
1613   5  -7.84    1551 -1552   1443  -1439    u=17
1614   4 -1.0      1411            -1443    u=17
1615   4 -1.0      1411 -1550   1443  -1427    u=17
1616   4 -1.0     1553         1443  -1427    u=17
1617   5  -7.84    1550 -1551   1443  -1427    u=17
1618   5  -7.84    1552 -1553   1443  -1427    u=17
1619   5  -7.84     1425  -1411        -1427    u=17
1620   4 -1.0         -1425        -1427    u=17
c
c number of cells: 29
c
c empty cell no boral, no top
c
c
751     4 -1.0    -410   411  -412   413    u=14
752     5  -7.84    410  -424   413  -426    u=14
753    5  -7.84    425  -411   413         u=14
754    4 -1.0     411  -410   412  -426    u=14
755    5  -7.84    427             -413    u=14
756    5  -7.84    425  -411       -427    u=14
757    4 -1.0     411   426              u=14
758    4 -1.0     411  -427              u=14
759    4 -1.0    -425   413              u=14
760    4 -1.0     424   413   -426       u=14
761    4 -1.0    -425  -427              u=14
c
c
701    5    -7.84    701 -702 711 -713     u=9   $ steel post
702    5    -7.84    702 -703 711 -712     u=9   $ steel post
c
711    0             701 -705 711 -715 (702:713) (703:712)
                     fill=4 (13.8506 13.8506 0) u=9
712    0             704 (-706:-716) (705:715) -717 -710
                     fill=4 (17.9489 41.5518 0  0 1 0  -1 0 0   0 0 1) u=9
713    0             (705:715) -707 714 (-706:-716)  710
                     fill=4 (41.5518 17.9489 0  0 -1 0  1 0 0   0 0 1) u=9
714    0             701 -705 717 -719
                     fill=5 (13.8506 69.253 0) u=9
715    0             707 -709 711 -715
                     fill=5 (69.253 13.8506 0) u=9
716    0             706 -708 716 -718
                     fill=17 (45.6501 45.6501 0  -1 0 0  0 -1 0  0 0 1) u=9
717    0             705 -706 717 -719
                     fill=14 (41.5518 69.253 0) u=9
718    0             707 -709 715 -716
                     fill=14 (69.253 41.5518 0 0 1 0   1 0 0   0 0 1) u=9
719    0             701 -704 715 -717
```

```
                 fill=14 (-9.75233 41.5518 0  -1 0 0  0 1 0   0 0 1) u=9
720   0          705 -707 711 -714
                 fill=14 (41.5518 -9.75233 0   0 -1 0  1 0 0   0 0 1) u=9
721   4 -1.0     (706:719) (708:718) (709:716) u=9
c
c
c q-offset  0 inch
c
731   4 -1.0      720  721   fill=9 (0 0 0) u=19
732   4 -1.0     -720  721   fill=9 (0 0 0
                              -1 0 0  0  1 0  0 0 1) u=19
733   4 -1.0      720 -721   fill=9 (0 0 0
                               1 0 0  0 -1 0  0 0 1) u=19
734   4 -1.0     -720 -721   fill=9 (0 0 0
                              -1 0 0  0 -1 0  0 0 1) u=19
c
673   0           -41              39  -40  fill=19
c
c number of cells: 6
102   4  -1.0    -41       40  -44             $ 6.0" Water above Fuel
103   5  -7.84   -41       44  -45             $ 15.5" Steel above Fuel
104   4  -1.0    -41      -39   43             $ 7.3" Water below Fuel
105   5  -7.84   -41      -43   46             $ 8.5" Steel below Fuel
106   5  -7.84   46  -45 41 -42                $ 6.0" Radial Steel Shield
107   0            -46:45:42                   $ Outside world
c end of cells
c --- empty line

c --- empty line
c start of surfaces
1     cz         0.4752    $ fuel
2     cz         0.4851    $ clad ID
3     cz         0.5436    $ clad OD
4     cz         0.6350    $ guide ID
5     cz         0.6706    $ guide OD
6     px         0.7214    $ pin pitch
7     px        -0.7214
8     py         0.7214
9     py        -0.7214
c
c
c cell-id        8.98
c cell-pitch     10.906
c wall-thkns     5/16
c angle-thkns    5/16
c boral-gap      0.0035
c boral-gap-o    0.0035
c boral-thkns    0.075
c boral-clad     0.01
c sheathing      0.0235
c boral-wide     7.5
c boral-narrow   6.25
c
c gap size       1.09
c basket-od      67.335
c
410    px         11.40460 $x 8.98/2
411    px        -11.40460 $x {410} *-1
412    py         11.40460 $x {410}
413    py        -11.40460 $x {411}
424    px         12.19835 $x {410} + 5/16     $ angle
```

```
425    px        -12.19835 $x {411} - 5/16      $ box wall
426    py         12.19835 $x {412} + 5/16
427    py        -12.19835 $x {413} - 5/16
428    px         12.20724 $x {424} + 0.0035    $ wall to boral gap
429    px        -12.20724 $x {425} - 0.0035
430    py         12.20724 $x {426} + 0.0035
431    py        -12.20724 $x {427} - 0.0035
432    px         12.39774 $x {428} + 0.075     $ boral
433    px        -12.39774 $x {429} - 0.075
434    py         12.39774 $x {430} + 0.075
435    py        -12.39774 $x {431} - 0.075
436    px         12.40663 $x {432} + 0.0035    $ boral to sheathing gap
437    px        -12.40663 $x {433} - 0.0035
438    py         12.40663 $x {434} + 0.0035
439    py        -12.40663 $x {435} - 0.0035
440    px         12.46632 $x {436} + 0.0235    $ sheathing
441    px        -12.46632 $x {437} - 0.0235
442    py         12.46632 $x {438} + 0.0235
443    py        -12.46632 $x {439} - 0.0235
445    py          9.52500 $x 7.5/2
446    py          9.58469 $x {445} + 0.0235    $ sheathing
447    py         -9.58469 $x {446} *-1
448    py         -9.52500 $x {445} *-1
450    px         -9.58469 $x {447}
451    px         -9.52500 $x {448}
452    px          9.52500 $x {445}
453    px          9.58469 $x {446}
528   px        12.23264 $x {428} + 0.01  $ Aluminum on the outside of boral
529   px       -12.23264 $x {429} - 0.01
530   py        12.23264 $x {430} + 0.01
531   py       -12.23264 $x {431} - 0.01
532   px        12.37234 $x {432} - 0.01
533   px       -12.37234 $x {433} + 0.01
534   py        12.37234 $x {434} - 0.01
535   py       -12.37234 $x {435} + 0.01
545   py        7.93750 $x 6.25/2
546   py        7.99719 $x {545} + 0.0235   $ sheathing
547   py       -7.99719 $x {546} *-1
548   py       -7.93750 $x {545} *-1
550   px       -7.99719 $x {547}
551   px       -7.93750 $x {548}
552   px        7.93750 $x {545}
553   px        7.99719 $x {546}
c
c cell-id-2 8.98
c gap-o     1.09
c
701   px       -5.0
702   px       1.90627 $x (10.906 - 8.98)/2 - 5/16 + 0.1
703   px       3.45694 $x 2.722/2
704   px       4.09829 $x 10.906 - 8.98 - 5/16
705   px       27.70124 $x 10.906
706   px       31.79953 $x 2 * 10.906 - (8.98+8.98)/2 - 5/16
707   px       55.40248 $x 2 * 10.906
708   px       59.50077 $x {707} + {704}
709   px       83.10372 $x 3 * 10.906
710   p     1  -1  0  0.1 $ diagonal x=y, offset by 0.1 to avoid intersecting corners
711   py       -4.99999 $x {701}
712   py       1.90627 $x {702}
713   py       3.45694 $x {703}
714   py       4.09829 $x {704}
```

```
715    py        27.70124 $x {705}
716    py        31.79953 $x {706}
717    py        55.40248 $x {707}
718    py        59.50077 $x {708}
719    py        83.10372 $x {709}
720    px        0.0
721    py        0.0
1410     px        11.40460 $x 8.98/2
1411     px       -11.40460 $x {1410} *-1
1412     py        11.40460 $x {1410}
1413     py       -11.40460 $x {1411}
1424     px        12.19835 $x {1410} + 5/16     $ angle
1425     px       -12.19835 $x {1411} - 5/16     $ box wall
1426     py        12.19835 $x {1412} + 5/16
1427     py       -12.19835 $x {1413} - 5/16
1428     px        12.20724 $x {1424} + 0.0035   $ wall to boral gap
1429     px       -12.20724 $x {1425} - 0.0035
1430     py        12.20724 $x {1426} + 0.0035
1431     py       -12.20724 $x {1427} - 0.0035
1432     px        12.39774 $x {1428} + 0.075    $ boral
1433     px       -12.39774 $x {1429} - 0.075
1434     py        12.39774 $x {1430} + 0.075
1435     py       -12.39774 $x {1431} - 0.075
1436     px        12.40663 $x {1432} + 0.0035   $ boral to sheathing gap
1437     px       -12.40663 $x {1433} - 0.0035
1438     py        12.40663 $x {1434} + 0.0035
1439     py       -12.40663 $x {1435} - 0.0035
1440     px        12.46632 $x {1436} + 0.0235   $ sheathing
1441     px       -12.46632 $x {1437} - 0.0235
1442     py        12.46632 $x {1438} + 0.0235
1443     py       -12.46632 $x {1439} - 0.0235
1445     py         9.52500 $x 7.5/2
1446     py         9.58469 $x {1445} + 0.0235   $ sheathing
1447     py        -9.58469 $x {1446} *-1
1448     py        -9.52500 $x {1445} *-1
1450     px        -9.58469 $x {1447}
1451     px        -9.52500 $x {1448}
1452     px         9.52500 $x {1445}
1453     px         9.58469 $x {1446}
1528    px        12.23264 $x {1428} + 0.01  $ Aluminum on the outside of boral
1529    px       -12.23264 $x {1429} - 0.01
1530    py        12.23264 $x {1430} + 0.01
1531    py       -12.23264 $x {1431} - 0.01
1532    px        12.37234 $x {1432} - 0.01
1533    px       -12.37234 $x {1433} + 0.01
1534    py        12.37234 $x {1434} - 0.01
1535    py       -12.37234 $x {1435} + 0.01
1545    py         7.93750 $x 6.25/2
1546    py         7.99719 $x {1545} + 0.0235   $ sheathing
1547    py        -7.99719 $x {1546} *-1
1548    py        -7.93750 $x {1545} *-1
1550    px        -7.99719 $x {1547}
1551    px        -7.93750 $x {1548}
1552    px         7.93750 $x {1545}
1553    px         7.99719 $x {1546}
46     pz        -31.75         $ 8.5"  lower steel thickness
43     pz        -10.16         $ lower water thickness
39     pz          0.0          $ bottom of active fuel assembly
40     pz        381.0          $ top of active fuel assembly
44     pz        396.24         $ upper water thickness
45     pz        435.61         $ 15.5" upper steel thickness
```

```
41    cz          85.57        $ mpc steel ID
42    cz         108.43        $ mpc water
c end of surfaces
c --- empty line

c --- empty line
tr1 0 0 0
kcode    10000  .94  20  120
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1  -2 1.2895
c
sp3  0 1
c
si4  s         13 14
            12 13 14 15
         11 12 13 14 15 16
         11 12 13 14 15 16
            12 13 14 15
               13 14
sp4  1 23r
c
ds5  s               26 26
                  25 25 25 25
               24 24 24 24 24 24
               23 23 23 23 23 23
                  22 22 22 22
                     21 21
c
si11  -79.25435 -57.61355
si12  -51.88077 -30.23997
si13  -24.50719 -2.86639
si14   2.86639   24.50719
si15   30.23997  51.88077
si16   57.61355  79.25435
c
si21  -79.25435 -57.61355
si22  -51.88077 -30.23997
si23  -24.50719 -2.86639
si24   2.86639   24.50719
si25   30.23997  51.88077
si26   57.61355  79.25435
c
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
c
m3          40000.56c   1.           $ Zr Clad
m4          1001.50c    0.6667       $ Water
            8016.50c    0.3333
m5          24000.50c   0.01761      $ Steel
            25055.50c   0.001761
```

```
              26000.55c    0.05977
              28000.50c    0.008239
m6            5010.50c    -0.054427      $ Boral Central Section @ 0.02 g/cmsq
              5011.50c    -0.241373
              13027.50c   -0.6222
              6000.50c    -0.0821
m7            13027.50c    1.0
mt4          lwtr.01t
prdmp     j    -120    j    2
fm4       1000    1    -6
f4:n    1
sd4       1000
e4     1.000E-11    1.000E-10    5.000E-10    7.500E-10    1.000E-09    1.200E-09
       1.500E-09    2.000E-09    2.500E-09    3.000E-09
       4.700E-09    5.000E-09    7.500E-09    1.000E-08    2.530E-08
       3.000E-08    4.000E-08    5.000E-08    6.000E-08    7.000E-08
       8.000E-08    9.000E-08    1.000E-07    1.250E-07    1.500E-07
       1.750E-07    2.000E-07    2.250E-07    2.500E-07    2.750E-07
       3.000E-07    3.250E-07    3.500E-07    3.750E-07    4.000E-07
       4.500E-07    5.000E-07    5.500E-07    6.000E-07    6.250E-07
       6.500E-07    7.000E-07    7.500E-07    8.000E-07    8.500E-07
       9.000E-07    9.250E-07    9.500E-07    9.750E-07    1.000E-06
       1.010E-06    1.020E-06    1.030E-06    1.040E-06    1.050E-06
       1.060E-06    1.070E-06    1.080E-06    1.090E-06    1.100E-06
       1.110E-06    1.120E-06    1.130E-06    1.140E-06    1.150E-06
       1.175E-06    1.200E-06    1.225E-06    1.250E-06    1.300E-06
       1.350E-06    1.400E-06    1.450E-06    1.500E-06    1.590E-06
       1.680E-06    1.770E-06    1.860E-06    1.940E-06    2.000E-06
       2.120E-06    2.210E-06    2.300E-06    2.380E-06    2.470E-06
       2.570E-06    2.670E-06    2.770E-06    2.870E-06    2.970E-06
       3.000E-06    3.050E-06    3.150E-06    3.500E-06    3.730E-06
       4.000E-06    4.750E-06    5.000E-06    5.400E-06    6.000E-06
       6.250E-06    6.500E-06    6.750E-06    7.000E-06    7.150E-06
       8.100E-06    9.100E-06    1.000E-05    1.150E-05    1.190E-05
       1.290E-05    1.375E-05    1.440E-05    1.510E-05    1.600E-05
       1.700E-05    1.850E-05    1.900E-05    2.000E-05    2.100E-05
       2.250E-05    2.500E-05    2.750E-05    3.000E-05    3.125E-05
       3.175E-05    3.325E-05    3.375E-05    3.460E-05    3.550E-05
       3.700E-05    3.800E-05    3.910E-05    3.960E-05    4.100E-05
       4.240E-05    4.400E-05    4.520E-05    4.700E-05    4.830E-05
       4.920E-05    5.060E-05    5.200E-05    5.340E-05    5.900E-05
       6.100E-05    6.500E-05    6.750E-05    7.200E-05    7.600E-05
       8.000E-05    8.200E-05    9.000E-05    1.000E-04    1.080E-04
       1.150E-04    1.190E-04    1.220E-04    1.860E-04    1.925E-04
       2.075E-04    2.100E-04    2.400E-04    2.850E-04    3.050E-04
       5.500E-04    6.700E-04    6.830E-04    9.500E-04    1.150E-03
       1.500E-03    1.550E-03    1.800E-03    2.200E-03    2.290E-03
       2.580E-03    3.000E-03    3.740E-03    3.900E-03    6.000E-03
       8.030E-03    9.500E-03    1.300E-02    1.700E-02    2.500E-02
       3.000E-02    4.500E-02    5.000E-02    5.200E-02    6.000E-02
       7.300E-02    7.500E-02    8.200E-02    8.500E-02    1.000E-01
       1.283E-01    1.500E-01    2.000E-01    2.700E-01    3.300E-01
       4.000E-01    4.200E-01    4.400E-01    4.700E-01    4.995E-01
       5.500E-01    5.730E-01    6.000E-01    6.700E-01    6.790E-01
       7.500E-01    8.200E-01    8.611E-01    8.750E-01    9.000E-01
       9.200E-01    1.010E+00    1.100E+00    1.200E+00    1.250E+00
       1.317E+00    1.356E+00    1.400E+00    1.500E+00    1.850E+00
       2.354E+00    2.479E+00    3.000E+00    4.304E+00    4.800E+00
       6.434E+00    8.187E+00    1.000E+01    1.284E+01    1.384E+01
       1.455E+01    1.568E+01    1.733E+01    2.000E+01
si3  h 0 381.00
```

```
imp:n 1 193r 0
c fuel enrichment 4.1 %
m1       92235.50c     -0.03614
         92238.50c     -0.84536
          8016.50c     -0.11850
c end of file
c
```

```
HI-STAR containing MPC68, 08x08 @ 4.2 wt% Enrich.
c      4.20 % uniform enrichment,  unreflected cask, 0.0279 g/cmsq B-10 in Boral
c
c
1      1 -10.522     -1   u=2        $ fuel
2      4 -1.0      1  -2  u=2        $ gap
3      3 -6.55     2  -3  u=2        $ Zr Clad
4      4 -1.0          3  u=2        $ water in fuel region
5      4 -1.0    -4:5     u=3        $ water in guide tubes
6      3 -6.55    4 -5    u=3        $ guide tubes
7      4 -1.0    -6   +7   -8   +9   u=1  lat=1
       fill= -5:4    -5:4   0:0
       1  1 1 1 1 1 1 1 1  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 3 2 2 2 2  1
       1  2 2 2 2 3 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  1 1 1 1 1 1 1 1  1
c
C  BOX TYPE R
c
8      0  -10   11  -12   13          u=4 fill=1 (0.8128  0.8128  0)
9      3  -6.55    60   -61    62   -63  #8      u=4     $ Zr flow channel
10     4  -1.      64   -65    66   -67  #8 #9   u=4     $ water
11     5  -7.84    20   -23    67   -14          u=4     $ 0.075" STEEL
12     4  -1.      20   -23    14   -15          u=4     $ WATER POCKET
13     7  -2.7     20   -23    15   -16          u=4     $ Al CLAD
14     6  -2.66    20   -23    16   -17          u=4     $ BORAL Absorber
15     7  -2.7     20   -23    17   -18          u=4     $ Al Clad
16     4  -1.      20   -23    18  -118          u=4     $ Water
17     5  -7.84    118:-129:65:-66               u=4     $ Steel
18     4  -1.      64   -21    67  -118          u=4     $ Water
19     4  -1.      24   -65    67  -118          u=4     $ water
20     5  -7.84    21   -20    67  -118          u=4     $ Steel
21     5  -7.84    23   -24    67  -118          u=4     $ Steel
22     4  -1.     129   -64    33  -118          u=4     $ Water
c
23     5  -7.84    25   -64    30   -31          u=4     $ Steel
24     4  -1.      26   -25    30   -31          u=4     $ Water
25     7  -2.7     27   -26    30   -31          u=4     $ Al clad
26     6  -2.66    28   -27    30   -31          u=4     $ Boral
27     7  -2.7     29   -28    30   -31          u=4     $ Al clad
28     4  -1.     129   -29    30   -31          u=4     $ water
29     5  -7.84   129   -64    32   -30          u=4     $ Steel ends
30     5  -7.84   129   -64    31   -33          u=4     $ Steel ends
31     4  -1.     129   -64    66   -32          u=4     $ Water
c
c    Type A box - Boral only on left side
c
32     0  -10   11  -12   13          u=6 fill=1 (0.8128  0.8128  0)
33     3  -6.55    60   -61    62   -63  #8      u=6     $ Zr flow channel
34     4  -1.      64   -65    66  -118  #8 #9   u=6     $ water
35     5  -7.84    118:-129:65:-66               u=6     $ Steel
36     4  -1.     129   -64    67  -118          u=6     $ Water
c
37     5  -7.84    25   -64    30   -31          u=6     $ Steel
38     4  -1.      26   -25    30   -31          u=6     $ Water
```

```
39    7  -2.7      27    -26    30    -31          u=6     $ Al clad
40    6  -2.66     28    -27    30    -31          u=6     $ Boral
41    7  -2.7      29    -28    30    -31          u=6     $ Al clad
42    4  -1.      129    -29    30    -31          u=6     $ water
43    4  -1.      129    -64    33    -67          u=6     $ Water
44    5  -7.84    129    -64    32    -30          u=6     $ Steel ends
45    5  -7.84    129    -64    31    -33          u=6     $ Steel ends
46    4  -1.      129    -64    66    -32          u=6     $ Water
c
c    Type B box -  Boral on Top only
c
47    0  -10   11  -12   13          u=7 fill=1 (0.8128  0.8128  0)
48    3  -6.55     60    -61    62    -63  #8      u=7     $ Zr flow channel
49    4  -1.       64    -65    66    -67  #8 #9   u=7     $ water
50    5  -7.84     20    -23    67    -14          u=7     $ 0.075" STEEL
51    4  -1.       20    -23    14    -15          u=7     $ WATER POCKET
52    7  -2.7      20    -23    15    -16          u=7     $ Al CLAD
53    6  -2.66     20    -23    16    -17          u=7     $ BORAL Absorber
54    7  -2.7      20    -23    17    -18          u=7     $ water
55    4  -1.       20    -23    18   -118          u=7     $ Water
56    5  -7.84     118:-129:65:-66               u=7     $ Steel
57    4  -1.       64    -21    67   -118          u=7     $ Water
58    4  -1.       24    -65    67   -118          u=7     $ water
59    5  -7.84     21    -20    67   -118          u=7     $ Steel
60    5  -7.84     23    -24    67   -118          u=7     $ Steel
61    4  -1.      129    -64    66   -118          u=7     $ Water
c
c    Type E box  - No Boral Panels
c
62    0  -10   11  -12   13          u=8 fill=1 (0.8128  0.8128  0)
63    3  -6.55     60    -61    62    -63  #8      u=8     $ Zr flow channel
64    4  -1.      129    -65    66   -118  #8 #9   u=8     $ water
65    5  -7.84     118:-129:65:-66               u=8     $ Steel
c
c    Type F box  - No Boral Panels or fuel
c
66    4  -1.      129    -65    66   -118          u=9     $ water
67    5  -7.84     118:-129:65:-66               u=9     $ Steel
c
68    4  -1.0    -34  35  -36  37  u=5  lat=1  fill=-7:6  -7:6  0:0
                5 5 5 5 5 5 5 5 5 5 5 5 5 5
                5 9 9 9 9 9 9 9 9 9 9 9 9 5
                5 9 9 9 9 9 7 4 9 9 9 9 9 5
                5 9 9 9 7 4 4 4 4 4 9 9 9 5
                5 9 9 7 4 4 4 4 4 4 4 9 9 5
                5 9 9 7 4 4 4 4 4 4 4 9 9 5
                5 9 7 4 4 4 4 4 4 4 4 4 9 5
                5 9 8 4 4 4 4 4 4 4 4 6 9 5
                5 9 9 7 4 4 4 4 4 4 4 9 9 5
                5 9 9 8 4 4 4 4 4 4 6 9 9 5
                5 9 9 9 8 4 4 4 6 6 9 9 9 5
                5 9 9 9 9 9 8 6 9 9 9 9 9 5
                5 9 9 9 9 9 9 9 9 9 9 9 9 5
                5 5 5 5 5 5 5 5 5 5 5 5 5 5
69    0            -41                 50  -49  fill=5 (8.1661  8.1661  0)
70    4  -1.0    -41        43  -50            $ Water below Fuel
71    4  -1.0    -41        49  -44            $ Water above Fuel
72    5  -7.84   -42        68  -43            $ Steel below Fuel
73    5  -7.84   -42        44  -69            $ Steel above Fuel
74    5  -7.84    41  -42   43  -44            $ Radial Steel
75    0            42 :-68:  69                $ outside world
```

```
1      cz          0.5207      $ Fuel OD
2      cz          0.5321      $ Clad ID
3      cz          0.6134      $ Clad OD
4      cz          0.6744      $ Thimble ID
5      cz          0.7506      $ Thimble OD
6      px          0.8128      $ Pin Pitch
7      px         -0.8128
8      py          0.8128
9      py         -0.8128
10     px          6.7031      $ Channel ID
11     px         -6.7031
12     py          6.7031
13     py         -6.7031
14     py          7.8016
15     py          7.8155
16     py          7.8410
17     py          8.0467
18     py          8.0721
118    py          8.0861
20     px         -6.0325
21     px         -6.2230
23     px          6.0325
24     px          6.2230
25     px         -7.8016
26     px         -7.8155
27     px         -7.8410
28     px         -8.0467
29     px         -8.0721
129    px         -8.0861
30     py         -6.0325
31     py          6.0325
32     py         -6.2230
33     py          6.2230
34     px          7.6111
35     px         -8.7211
36     py          8.7211
37     py         -7.6111
41     cz          85.57
42     cz          108.43
43     pz         -18.54
44     pz          402.5
49     pz          381.         $ Top of Active Fuel
50     pz            0          $ Start of Active Fuel
60     px          -6.9571      $ Channel OD
61     px           6.9571
62     py          -6.9571
63     py           6.9571
64     px          -7.6111      $ Cell Box ID
65     px           7.6111
66     py          -7.6111
67     py           7.6111
68     pz          -40.13
69     pz           441.9

imp:n     1 73r 0
kcode   10000  0.94   20  120
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1 -2 1.2895
```

```
c
c
si3  h 0 365.76
sp3  0 1
c
c
si4  s             15 16
             13 14 15 16 17 18
          12 13 14 15 16 17 18 19
          12 13 14 15 16 17 18 19
       11 12 13 14 15 16 17 18 19 20
       11 12 13 14 15 16 17 18 19 20
          12 13 14 15 16 17 18 19
          12 13 14 15 16 17 18 19
             13 14 15 16 17 18
                   15 16
sp4  1 67r
c
ds5  s             30 30
             29 29 29 29 29 29
          28 28 28 28 28 28 28 28
          27 27 27 27 27 27 27 27
       26 26 26 26 26 26 26 26 26 26
       25 25 25 25 25 25 25 25 25 25
          24 24 24 24 24 24 24 24
          23 23 23 23 23 23 23 23
             22 22 22 22 22 22
                   21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
si15  -14.7447 -1.7399
si16   1.7399   14.7447
si17   18.2245  31.2293
si18   34.7091  47.7139
si19   51.1937  64.1985
si20   67.6783  80.6831
c
si21  -80.6831 -67.6783
si22  -64.1985 -51.1937
si23  -47.7139 -34.7091
si24  -31.2293 -18.2245
si25  -14.7447 -1.7399
si26   1.7399   14.7447
si27   18.2245  31.2293
si28   34.7091  47.7139
si29   51.1937  64.1985
si30   67.6783  80.6831
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp17  0 1
sp18  0 1
sp19  0 1
sp20  0 1
sp21  0 1
```

```
sp22   0 1
sp23   0 1
sp24   0 1
sp25   0 1
sp26   0 1
sp27   0 1
sp28   0 1
sp29   0 1
sp30   0 1
c
m1             92235.50c    9.98343E-04   $ 4.20% E Fuel
               92238.50c    0.022484
               8016.50c     0.046965
m2             8016.50c     1.            $ Void
m3             40000.56c    1.            $ Zr Clad
m4             1001.50c     0.6667        $ Water
               8016.50c     0.3333
m5             24000.50c    0.01761       $ Steel
               25055.50c    0.001761
               26000.55c    0.05977
               28000.50c    0.008239
m6             5010.50c     8.0707E-03    $ Boral
               5011.50c     3.2553E-02
               6000.50c     1.0146E-02
               13027.50c    3.8054E-02
m7             13027.50c     1.            $ Al Clad
mt4           lwtr.01t
prdmp     j    -30    1    2
fm4        1000    1    -6
f4:n    1
sd4        1000
e4     1.000E-11    1.000E-10    5.000E-10    7.500E-10    1.000E-09    1.200E-09
       1.500E-09    2.000E-09    2.500E-09    3.000E-09
       4.700E-09    5.000E-09    7.500E-09    1.000E-08    2.530E-08
       3.000E-08    4.000E-08    5.000E-08    6.000E-08    7.000E-08
       8.000E-08    9.000E-08    1.000E-07    1.250E-07    1.500E-07
       1.750E-07    2.000E-07    2.250E-07    2.500E-07    2.750E-07
       3.000E-07    3.250E-07    3.500E-07    3.750E-07    4.000E-07
       4.500E-07    5.000E-07    5.500E-07    6.000E-07    6.250E-07
       6.500E-07    7.000E-07    7.500E-07    8.000E-07    8.500E-07
       9.000E-07    9.250E-07    9.500E-07    9.750E-07    1.000E-06
       1.010E-06    1.020E-06    1.030E-06    1.040E-06    1.050E-06
       1.060E-06    1.070E-06    1.080E-06    1.090E-06    1.100E-06
       1.110E-06    1.120E-06    1.130E-06    1.140E-06    1.150E-06
       1.175E-06    1.200E-06    1.225E-06    1.250E-06    1.300E-06
       1.350E-06    1.400E-06    1.450E-06    1.500E-06    1.590E-06
       1.680E-06    1.770E-06    1.860E-06    1.940E-06    2.000E-06
       2.120E-06    2.210E-06    2.300E-06    2.380E-06    2.470E-06
       2.570E-06    2.670E-06    2.770E-06    2.870E-06    2.970E-06
       3.000E-06    3.050E-06    3.150E-06    3.500E-06    3.730E-06
       4.000E-06    4.750E-06    5.000E-06    5.400E-06    6.000E-06
       6.250E-06    6.500E-06    6.750E-06    7.000E-06    7.150E-06
       8.100E-06    9.100E-06    1.000E-05    1.150E-05    1.190E-05
       1.290E-05    1.375E-05    1.440E-05    1.510E-05    1.600E-05
       1.700E-05    1.850E-05    1.900E-05    2.000E-05    2.100E-05
       2.250E-05    2.500E-05    2.750E-05    3.000E-05    3.125E-05
       3.175E-05    3.325E-05    3.375E-05    3.460E-05    3.550E-05
       3.700E-05    3.800E-05    3.910E-05    3.960E-05    4.100E-05
       4.240E-05    4.400E-05    4.520E-05    4.700E-05    4.830E-05
       4.920E-05    5.060E-05    5.200E-05    5.340E-05    5.900E-05
       6.100E-05    6.500E-05    6.750E-05    7.200E-05    7.600E-05
```

8.000E-05	8.200E-05	9.000E-05	1.000E-04	1.080E-04
1.150E-04	1.190E-04	1.220E-04	1.860E-04	1.925E-04
2.075E-04	2.100E-04	2.400E-04	2.850E-04	3.050E-04
5.500E-04	6.700E-04	6.830E-04	9.500E-04	1.150E-03
1.500E-03	1.550E-03	1.800E-03	2.200E-03	2.290E-03
2.580E-03	3.000E-03	3.740E-03	3.900E-03	6.000E-03
8.030E-03	9.500E-03	1.300E-02	1.700E-02	2.500E-02
3.000E-02	4.500E-02	5.000E-02	5.200E-02	6.000E-02
7.300E-02	7.500E-02	8.200E-02	8.500E-02	1.000E-01
1.283E-01	1.500E-01	2.000E-01	2.700E-01	3.300E-01
4.000E-01	4.200E-01	4.400E-01	4.700E-01	4.995E-01
5.500E-01	5.730E-01	6.000E-01	6.700E-01	6.790E-01
7.500E-01	8.200E-01	8.611E-01	8.750E-01	9.000E-01
9.200E-01	1.010E+00	1.100E+00	1.200E+00	1.250E+00
1.317E+00	1.356E+00	1.400E+00	1.500E+00	1.850E+00
2.354E+00	2.479E+00	3.000E+00	4.304E+00	4.800E+00
6.434E+00	8.187E+00	1.000E+01	1.284E+01	1.384E+01
1.455E+01	1.568E+01	1.733E+01	2.000E+01	

```
HI-STAR containing MPC68F, 06x06 @ 3.0 wt% Enrich.
c     3.00 % uniform enrichment, unreflected cask, 0.0067 g/cmsq B-10 in Boral
c     Dresden-1 6x6
c
c
1     1 -10.522     -1  u=2       $ fuel
2     4 -1.0     1  -2  u=2       $ gap
3     3 -6.55    2  -3  u=2       $ Zr Clad
4     4 -1.0         3  u=2       $ water in fuel region
5     4 -1.0   -4:5     u=3       $ water in guide tubes
6     3 -6.55   4 -5    u=3       $ guide tubes
7     4 -1.0   -6   +7   -8   +9   u=1  lat=1
      fill= -4:3    -4:3   0:0
      1  1 1 1 1 1 1  1
      1  2 2 2 2 2 2  1
      1  2 2 2 2 2 2  1
      1  2 2 2 2 2 2  1
      1  2 2 2 2 2 2  1
      1  2 2 2 2 2 2  1
      1  2 2 2 2 2 2  1
      1  1 1 1 1 1 1  1
c
C  BOX TYPE R
c
8     0  -10   11  -12   13         u=4 fill=1 (0.8814  0.8814  0)
9     3  -6.55    60   -61    62    -63  #8       u=4     $ Zr flow channel
10    4  -1.      64   -65    66    -67  #8 #9    u=4     $ water
11    5  -7.84    20   -23    67    -14           u=4     $ 0.075" STEEL
12    4  -1.      20   -23    14    -15           u=4     $ WATER POCKET
13    7  -2.7     20   -23    15    -16           u=4     $ Al CLAD
14    6  -2.66    20   -23    16    -17           u=4     $ BORAL Absorber
15    7  -2.7     20   -23    17    -18           u=4     $ Al Clad
16    4  -1.      20   -23    18   -118           u=4     $ Water
17    5  -7.84    118:-129:65:-66                 u=4     $ Steel
18    4  -1.      64   -21    67   -118           u=4     $ Water
19    4  -1.      24   -65    67   -118           u=4     $ water
20    5  -7.84    21   -20    67   -118           u=4     $ Steel
21    5  -7.84    23   -24    67   -118           u=4     $ Steel
22    4  -1.     129   -64    33   -118           u=4     $ Water
c
23    5  -7.84    25   -64    30    -31           u=4     $ Steel
24    4  -1.      26   -25    30    -31           u=4     $ Water
25    7  -2.7     27   -26    30    -31           u=4     $ Al clad
26    6  -2.66    28   -27    30    -31           u=4     $ Boral
27    7  -2.7     29   -28    30    -31           u=4     $ Al clad
28    4  -1.     129   -29    30    -31           u=4     $ water
29    5  -7.84   129   -64    32    -30           u=4     $ Steel ends
30    5  -7.84   129   -64    31    -33           u=4     $ Steel ends
31    4  -1.     129   -64    66    -32           u=4     $ Water
c
c    Type A box - Boral only on left side
c
32    0  -10   11  -12   13         u=6 fill=1 (0.8814  0.8814  0)
33    3  -6.55    60   -61    62    -63  #8       u=6     $ Zr flow channel
34    4  -1.      64   -65    66   -118  #8 #9    u=6     $ water
35    5  -7.84    118:-129:65:-66                 u=6     $ Steel
36    4  -1.     129   -64    67   -118           u=6     $ Water
c
37    5  -7.84    25   -64    30    -31           u=6     $ Steel
38    4  -1.      26   -25    30    -31           u=6     $ Water
39    7  -2.7     27   -26    30    -31           u=6     $ Al clad
```

```
40    6  -2.66     28    -27     30    -31            u=6     $ Boral
41    7  -2.7      29    -28     30    -31            u=6     $ Al clad
42    4  -1.      129    -29     30    -31            u=6     $ water
43    4  -1.      129    -64     33    -67            u=6     $ Water
44    5  -7.84    129    -64     32    -30            u=6     $ Steel ends
45    5  -7.84    129    -64     31    -33            u=6     $ Steel ends
46    4  -1.      129    -64     66    -32            u=6     $ Water
c
c    Type B box -  Boral on Top only
c
47    0  -10   11  -12   13          u=7 fill=1 (0.8814  0.8814  0)
48    3  -6.55     60    -61     62    -63  #8        u=7     $ Zr flow channel
49    4  -1.       64    -65     66    -67  #8 #9     u=7     $ water
50    5  -7.84     20    -23     67    -14            u=7     $ 0.075" STEEL
51    4  -1.       20    -23     14    -15            u=7     $ WATER POCKET
52    7  -2.7      20    -23     15    -16            u=7     $ Al CLAD
53    6  -2.66     20    -23     16    -17            u=7     $ BORAL Absorber
54    7  -2.7      20    -23     17    -18            u=7     $ water
55    4  -1.       20    -23     18   -118            u=7     $ Water
56    5  -7.84     118:-129:65:-66                    u=7     $ Steel
57    4  -1.       64    -21     67    -118           u=7     $ Water
58    4  -1.       24    -65     67    -118           u=7     $ water
59    5  -7.84     21    -20     67    -118           u=7     $ Steel
60    5  -7.84     23    -24     67    -118           u=7     $ Steel
61    4  -1.      129    -64     66    -118           u=7     $ Water
c
c    Type E box  - No Boral Panels
c
62    0  -10   11  -12   13          u=8 fill=1 (0.8814  0.8814  0)
63    3  -6.55     60    -61     62    -63  #8        u=8     $ Zr flow channel
64    4  -1.      129    -65     66  -118  #8 #9      u=8     $ water
65    5  -7.84     118:-129:65:-66                    u=8     $ Steel
c
c    Type F box  - No Boral Panels or fuel
c
66    4  -1.      129    -65     66  -118             u=9     $ water
67    5  -7.84     118:-129:65:-66                    u=9     $ Steel
c
68    4  -1.0    -34  35  -36  37  u=5  lat=1  fill=-7:6  -7:6  0:0
                5 5 5 5 5 5 5 5 5 5 5 5 5 5
                5 9 9 9 9 9 9 9 9 9 9 9 9 5
                5 9 9 9 9 9 7 4 9 9 9 9 9 5
                5 9 9 9 7 4 4 4 4 4 9 9 9 5
                5 9 9 7 4 4 4 4 4 4 4 9 9 5
                5 9 9 7 4 4 4 4 4 4 4 9 9 5
                5 9 7 4 4 4 4 4 4 4 4 4 9 5
                5 9 8 4 4 4 4 4 4 4 4 6 9 5
                5 9 9 7 4 4 4 4 4 4 4 9 9 5
                5 9 9 8 4 4 4 4 4 4 6 9 9 5
                5 9 9 9 8 4 4 4 6 6 9 9 9 5
                5 9 9 9 9 9 8 6 9 9 9 9 9 5
                5 9 9 9 9 9 9 9 9 9 9 9 9 5
                5 5 5 5 5 5 5 5 5 5 5 5 5 5
69    0           -41                  50  -49  fill=5 (8.1661  8.1661  0)
70    4  -1.0    -41        43  -50                 $ Water below Fuel
71    4  -1.0    -41        49  -44                 $ Water above Fuel
72    5  -7.84   -42        68  -43                 $ Steel below Fuel
73    5  -7.84   -42        44  -69                 $ Steel above Fuel
74    5  -7.84    41  -42   43  -44                 $ Radial Steel
75    0            42 :-68:  69                     $ outside world
```

```
1      cz          0.6274       $ Fuel OD
2      cz          0.6280       $ Clad ID
3      cz          0.7169       $ Clad OD
4      cz          0.6280       $ Thimble ID
5      cz          0.7169       $ Thimble OD
6      px          0.8814       $ Pin Pitch
7      px         -0.8814
8      py          0.8814
9      py         -0.8814
10     px          5.4483       $ Channel ID
11     px         -5.4483
12     py          5.4483
13     py         -5.4483
14     py          7.8016
15     py          7.8155
16     py          7.8410
17     py          8.0467
18     py          8.0721
118    py          8.0861
20     px         -6.0325
21     px         -6.2230
23     px          6.0325
24     px          6.2230
25     px         -7.8016
26     px         -7.8155
27     px         -7.8410
28     px         -8.0467
29     px         -8.0721
129    px         -8.0861
30     py         -6.0325
31     py          6.0325
32     py         -6.2230
33     py          6.2230
34     px          7.6111
35     px         -8.7211
36     py          8.7211
37     py         -7.6111
41     cz          85.57
42     cz          108.43
43     pz          11.46
44     pz          331.0
49     pz          309.4         $ Top of Active F
50     pz           30.          $ Start of Active
60     px          -5.6007       $ Channel OD
61     px           5.6007
62     py          -5.6007
63     py           5.6007
64     px          -7.6111       $ Cell Box ID
65     px           7.6111
66     py          -7.6111
67     py           7.6111
68     pz         -10.13
69     pz           370.36

imp:n      1 73r 0
kcode    10000  0.94   20  120
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1 -2 1.2895
c
```

```
si3  h 30. 309.
sp3  0 1
c
c
si4  s              15 16
              13 14 15 16 17 18
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
        11 12 13 14 15 16 17 18 19 20
        11 12 13 14 15 16 17 18 19 20
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
              13 14 15 16 17 18
                    15 16
sp4  1 67r
c
ds5  s              30 30
              29 29 29 29 29 29
           28 28 28 28 28 28 28 28
           27 27 27 27 27 27 27 27
        26 26 26 26 26 26 26 26 26 26
        25 25 25 25 25 25 25 25 25 25
           24 24 24 24 24 24 24 24
           23 23 23 23 23 23 23 23
              22 22 22 22 22 22
                    21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
si15  -14.7447 -1.7399
si16   1.7399   14.7447
si17   18.2245  31.2293
si18   34.7091  47.7139
si19   51.1937  64.1985
si20   67.6783  80.6831
c
si21  -80.6831 -67.6783
si22  -64.1985 -51.1937
si23  -47.7139 -34.7091
si24  -31.2293 -18.2245
si25  -14.7447 -1.7399
si26   1.7399   14.7447
si27   18.2245  31.2293
si28   34.7091  47.7139
si29   51.1937  64.1985
si30   67.6783  80.6831
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp17  0 1
sp18  0 1
sp19  0 1
sp20  0 1
sp21  0 1
sp22  0 1
sp23  0 1
```

```
sp24   0 1
sp25   0 1
sp26   0 1
sp27   0 1
sp28   0 1
sp29   0 1
sp30   0 1
c
m1            92235.50c    -0.02644       $ 3.00% E Fuel
              92238.50c    -0.85504
              8016.50c     -0.11852
m3            40000.56c    1.            $ Zr Clad
m4            1001.50c     0.6667        $ Water
              8016.50c     0.3333
m5            24000.50c    0.01761       $ Steel
              25055.50c    0.001761
              26000.55c    0.05977
              28000.50c    0.008239
m6            5010.50c  1.9592E-03        $ Boral 0.0067 gm/cm2
              5011.50c  8.1175E-03
              6000.50c  2.5176E-03
              13027.50c 5.4933E-02
m7            13027.50c    1.             $ Al Clad
mt4          lwtr.01t
prdmp    j   -120   j   2
fm4      1000   1   -6
f4:n   1
sd4      1000
e4     1.000E-11   1.000E-10   5.000E-10   7.500E-10   1.000E-09   1.200E-09
       1.500E-09   2.000E-09   2.500E-09   3.000E-09
       4.700E-09   5.000E-09   7.500E-09   1.000E-08   2.530E-08
       3.000E-08   4.000E-08   5.000E-08   6.000E-08   7.000E-08
       8.000E-08   9.000E-08   1.000E-07   1.250E-07   1.500E-07
       1.750E-07   2.000E-07   2.250E-07   2.500E-07   2.750E-07
       3.000E-07   3.250E-07   3.500E-07   3.750E-07   4.000E-07
       4.500E-07   5.000E-07   5.500E-07   6.000E-07   6.250E-07
       6.500E-07   7.000E-07   7.500E-07   8.000E-07   8.500E-07
       9.000E-07   9.250E-07   9.500E-07   9.750E-07   1.000E-06
       1.010E-06   1.020E-06   1.030E-06   1.040E-06   1.050E-06
       1.060E-06   1.070E-06   1.080E-06   1.090E-06   1.100E-06
       1.110E-06   1.120E-06   1.130E-06   1.140E-06   1.150E-06
       1.175E-06   1.200E-06   1.225E-06   1.250E-06   1.300E-06
       1.350E-06   1.400E-06   1.450E-06   1.500E-06   1.590E-06
       1.680E-06   1.770E-06   1.860E-06   1.940E-06   2.000E-06
       2.120E-06   2.210E-06   2.300E-06   2.380E-06   2.470E-06
       2.570E-06   2.670E-06   2.770E-06   2.870E-06   2.970E-06
       3.000E-06   3.050E-06   3.150E-06   3.500E-06   3.730E-06
       4.000E-06   4.750E-06   5.000E-06   5.400E-06   6.000E-06
       6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
       8.100E-06   9.100E-06   1.000E-05   1.150E-05   1.190E-05
       1.290E-05   1.375E-05   1.440E-05   1.510E-05   1.600E-05
       1.700E-05   1.850E-05   1.900E-05   2.000E-05   2.100E-05
       2.250E-05   2.500E-05   2.750E-05   3.000E-05   3.125E-05
       3.175E-05   3.325E-05   3.375E-05   3.460E-05   3.550E-05
       3.700E-05   3.800E-05   3.910E-05   3.960E-05   4.100E-05
       4.240E-05   4.400E-05   4.520E-05   4.700E-05   4.830E-05
       4.920E-05   5.060E-05   5.200E-05   5.340E-05   5.900E-05
       6.100E-05   6.500E-05   6.750E-05   7.200E-05   7.600E-05
       8.000E-05   8.200E-05   9.000E-05   1.000E-04   1.080E-04
       1.150E-04   1.190E-04   1.220E-04   1.860E-04   1.925E-04
       2.075E-04   2.100E-04   2.400E-04   2.850E-04   3.050E-04
```

5.500E-04	6.700E-04	6.830E-04	9.500E-04	1.150E-03
1.500E-03	1.550E-03	1.800E-03	2.200E-03	2.290E-03
2.580E-03	3.000E-03	3.740E-03	3.900E-03	6.000E-03
8.030E-03	9.500E-03	1.300E-02	1.700E-02	2.500E-02
3.000E-02	4.500E-02	5.000E-02	5.200E-02	6.000E-02
7.300E-02	7.500E-02	8.200E-02	8.500E-02	1.000E-01
1.283E-01	1.500E-01	2.000E-01	2.700E-01	3.300E-01
4.000E-01	4.200E-01	4.400E-01	4.700E-01	4.995E-01
5.500E-01	5.730E-01	6.000E-01	6.700E-01	6.790E-01
7.500E-01	8.200E-01	8.611E-01	8.750E-01	9.000E-01
9.200E-01	1.010E+00	1.100E+00	1.200E+00	1.250E+00
1.317E+00	1.356E+00	1.400E+00	1.500E+00	1.850E+00
2.354E+00	2.479E+00	3.000E+00	4.304E+00	4.800E+00
6.434E+00	8.187E+00	1.000E+01	1.284E+01	1.384E+01
1.455E+01	1.568E+01	1.733E+01	2.000E+01	

```
HI-STAR containing MPC68F, 06x06 in DFC with 08 missing rods
c     3.00 % uniform enrichment, unreflected cask, 0.0067 g/cmsq B-10 in Boral
c
c
1     1 -10.522      -1   u=2       $ fuel
2     4 -1.0      1   -2   u=2       $ gap
3     3 -6.55     2   -3   u=2       $ Zr Clad
4     4 -1.0           3   u=2       $ water in fuel region
5     4 -1.0     -4:5      u=3       $ water in guide tubes
6     3 -6.55     4 -5     u=3       $ guide tubes
7     4 -1.0     -6    +7    -8    +9    u=1  lat=1
      fill= -4:3     -4:3    0:0
      1  1 1 1 1 1 1  1
      1  2 2 2 2 2 2  1
      1  2 1 2 1 2 2  1
      1  2 2 1 2 1 2  1
      1  2 1 2 1 2 2  1
      1  2 2 1 2 1 2  1
      1  2 2 2 2 2 2  1
      1  1 1 1 1 1 1  1
c
C  BOX TYPE R
c
8     0  -10    11   -12    13          u=4 fill=1 (0.8814   0.8814  0)
9     3  -6.55    60    -61    62    -63   #8        u=4      $ Zr flow channel
100   5  -7.84   74 -75 76 -77 (-70:71:-72:73)  u=4      $ DFC
10    4  -1.      64    -65    66    -67   #8 #9 #100  u=4 $ water
11    5  -7.84    20    -23    67    -14            u=4      $ 0.075" STEEL
12    4  -1.      20    -23    14    -15            u=4      $ WATER POCKET
13    7  -2.7     20    -23    15    -16            u=4      $ Al CLAD
14    6  -2.66    20    -23    16    -17            u=4      $ BORAL Absorber
15    7  -2.7     20    -23    17    -18            u=4      $ Al Clad
16    4  -1.      20    -23    18   -118            u=4      $ Water
17    5  -7.84    118:-129:65:-66                   u=4      $ Steel
18    4  -1.      64    -21    67    -118           u=4      $ Water
19    4  -1.      24    -65    67    -118           u=4      $ water
20    5  -7.84    21    -20    67    -118           u=4      $ Steel
21    5  -7.84    23    -24    67    -118           u=4      $ Steel
22    4  -1.     129    -64    33    -118           u=4      $ Water
c
23    5  -7.84    25    -64    30    -31            u=4      $ Steel
24    4  -1.      26    -25    30    -31            u=4      $ Water
25    7  -2.7     27    -26    30    -31            u=4      $ Al clad
26    6  -2.66    28    -27    30    -31            u=4      $ Boral
27    7  -2.7     29    -28    30    -31            u=4      $ Al clad
28    4  -1.     129    -29    30    -31            u=4      $ water
29    5  -7.84   129    -64    32    -30            u=4      $ Steel ends
30    5  -7.84   129    -64    31    -33            u=4      $ Steel ends
31    4  -1.     129    -64    66    -32            u=4      $ Water
c
c    Type A box - Boral only on left side
c
32    0  -10    11   -12    13          u=6 fill=1 (0.8814   0.8814  0)
33    3  -6.55    60    -61    62    -63   #8        u=6      $ Zr flow channel
101   5  -7.84   74 -75 76 -77 (-70:71:-72:73)  u=6      $ DFC
34    4  -1.      64    -65    66   -118   #8 #9 #101 u=6  $ water
35    5  -7.84    118:-129:65:-66                   u=6      $ Steel
36    4  -1.     129    -64    67    -118           u=6      $ Water
c
37    5  -7.84    25    -64    30    -31            u=6      $ Steel
38    4  -1.      26    -25    30    -31            u=6      $ Water
```

```
39    7  -2.7      27    -26    30    -31            u=6     $ Al clad
40    6  -2.66     28    -27    30    -31            u=6     $ Boral
41    7  -2.7      29    -28    30    -31            u=6     $ Al clad
42    4  -1.      129    -29    30    -31            u=6     $ water
43    4  -1.      129    -64    33    -67            u=6     $ Water
44    5  -7.84    129    -64    32    -30            u=6     $ Steel ends
45    5  -7.84    129    -64    31    -33            u=6     $ Steel ends
46    4  -1.      129    -64    66    -32            u=6     $ Water
c
c    Type B box -  Boral on Top only
c
47    0  -10   11  -12   13          u=7 fill=1 (0.8814  0.8814  0)
48    3  -6.55     60    -61    62    -63  #8        u=7     $ Zr flow channel
102   5  -7.84    74 -75 76 -77 (-70:71:-72:73)  u=7     $ DFC
49    4  -1.       64    -65    66    -67  #8 #9 #102 u=7  $ water
50    5  -7.84     20    -23    67    -14            u=7     $ 0.075" STEEL
51    4  -1.       20    -23    14    -15            u=7     $ WATER POCKET
52    7  -2.7      20    -23    15    -16            u=7     $ Al CLAD
53    6  -2.66     20    -23    16    -17            u=7     $ BORAL Absorber
54    7  -2.7      20    -23    17    -18            u=7     $ water
55    4  -1.       20    -23    18   -118            u=7     $ Water
56    5  -7.84     118:-129:65:-66                   u=7     $ Steel
57    4  -1.       64    -21    67    -118           u=7     $ Water
58    4  -1.       24    -65    67    -118           u=7     $ water
59    5  -7.84     21    -20    67    -118           u=7     $ Steel
60    5  -7.84     23    -24    67    -118           u=7     $ Steel
61    4  -1.      129    -64    66    -118           u=7     $ Water
c
c    Type E box  - No Boral Panels
c
62    0  -10   11  -12   13          u=8 fill=1 (0.8814  0.8814  0)
63    3  -6.55     60    -61    62    -63  #8        u=8     $ Zr flow channel
103   5  -7.84    74 -75 76 -77 (-70:71:-72:73)  u=8     $ DFC
64    4  -1.      129    -65    66   -118  #8 #9 #103 u=8  $ water
65    5  -7.84     118:-129:65:-66                   u=8     $ Steel
c
c    Type F box  - No Boral Panels or fuel
c
66    4  -1.      129    -65    66   -118            u=9     $ water
67    5  -7.84     118:-129:65:-66                   u=9     $ Steel
c
68    4  -1.0     -34  35  -36  37  u=5  lat=1  fill=-7:6  -7:6  0:0
               5 5 5 5 5 5 5 5 5 5 5 5 5 5
               5 9 9 9 9 9 9 9 9 9 9 9 9 5
               5 9 9 9 9 9 7 4 9 9 9 9 9 5
               5 9 9 9 7 4 4 4 4 4 9 9 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 7 4 4 4 4 4 4 4 4 4 9 5
               5 9 8 4 4 4 4 4 4 4 4 6 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 9 8 4 4 4 4 4 4 6 9 9 5
               5 9 9 9 8 4 4 4 6 6 9 9 9 5
               5 9 9 9 9 9 8 6 9 9 9 9 9 5
               5 9 9 9 9 9 9 9 9 9 9 9 9 5
               5 5 5 5 5 5 5 5 5 5 5 5 5 5
69    0            -41                 50  -49  fill=5 (8.1661  8.1661  0)
70    4  -1.0     -41          43  -50           $ Water below Fuel
71    4  -1.0     -41          49  -44           $ Water above Fuel
72    5  -7.84    -42          68  -43           $ Steel below Fuel
73    5  -7.84    -42          44  -69           $ Steel above Fuel
```

```
74     5  -7.84     41  -42  43  -44              $ Radial Steel
75     0              42 :-68:  69                $ outside world

1      cz          0.6274      $ Fuel OD
2      cz          0.6280      $ Clad ID
3      cz          0.7169      $ Clad OD
4      cz          0.6280      $ Thimble ID
5      cz          0.7169      $ Thimble OD
6      px          0.8814      $ Pin Pitch
7      px         -0.8814
8      py          0.8814
9      py         -0.8814
10     px          5.4483      $ Channel ID
11     px         -5.4483
12     py          5.4483
13     py         -5.4483
14     py          7.8016
15     py          7.8155
16     py          7.8410
17     py          8.0467
18     py          8.0721
118    py          8.0861
20     px         -6.0325
21     px         -6.2230
23     px          6.0325
24     px          6.2230
25     px         -7.8016
26     px         -7.8155
27     px         -7.8410
28     px         -8.0467
29     px         -8.0721
129    px         -8.0861
30     py         -6.0325
31     py          6.0325
32     py         -6.2230
33     py          6.2230
34     px          7.6111
35     px         -8.7211
36     py          8.7211
37     py         -7.6111
41     cz          85.57
42     cz          108.43
43     pz          11.46
44     pz          331.0
49     pz          309.4        $ Top of Active F
50     pz           30.         $ Start of Active
60     px          -5.6007      $ Channel OD
61     px           5.6007
62     py          -5.6007
63     py           5.6007
64     px          -7.6111      $ Cell Box ID
65     px           7.6111
66     py          -7.6111
67     py           7.6111
68     pz          -10.13
69     pz           370.36
70     px          -6.2611      $ DFC ID
71     px           6.2611
72     py          -6.2611
73     py           6.2611
74     px          -6.5659      $ DFC OD
```

```
75    px          6.5659
76    py         -6.5659
77    py          6.5659

imp:n     1 77r 0
kcode    10000  0.94   20  120
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1 -2 1.2895
c
si3  h 30. 309.
sp3  0 1
c
c
si4  s             15 16
              13 14 15 16 17 18
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
        11 12 13 14 15 16 17 18 19 20
        11 12 13 14 15 16 17 18 19 20
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
              13 14 15 16 17 18
                    15 16
sp4  1 67r
c
ds5  s             30 30
              29 29 29 29 29 29
           28 28 28 28 28 28 28 28
           27 27 27 27 27 27 27 27
        26 26 26 26 26 26 26 26 26 26
        25 25 25 25 25 25 25 25 25 25
           24 24 24 24 24 24 24 24
           23 23 23 23 23 23 23 23
              22 22 22 22 22 22
                    21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
si15  -14.7447 -1.7399
si16   1.7399   14.7447
si17   18.2245  31.2293
si18   34.7091  47.7139
si19   51.1937  64.1985
si20   67.6783  80.6831
c
si21  -80.6831 -67.6783
si22  -64.1985 -51.1937
si23  -47.7139 -34.7091
si24  -31.2293 -18.2245
si25  -14.7447 -1.7399
si26   1.7399   14.7447
si27   18.2245  31.2293
si28   34.7091  47.7139
si29   51.1937  64.1985
si30   67.6783  80.6831
sp11  0 1
sp12  0 1
```

```
sp13   0 1
sp14   0 1
sp15   0 1
sp16   0 1
sp17   0 1
sp18   0 1
sp19   0 1
sp20   0 1
sp21   0 1
sp22   0 1
sp23   0 1
sp24   0 1
sp25   0 1
sp26   0 1
sp27   0 1
sp28   0 1
sp29   0 1
sp30   0 1
c
m1             92235.50c   -0.02644      $ 3.00% E Fuel
               92238.50c   -0.85504
               8016.50c    -0.11852
m3             40000.56c   1.           $ Zr Clad
m4             1001.50c    0.6667       $ Water
               8016.50c    0.3333
m5             24000.50c   0.01761      $ Steel
               25055.50c   0.001761
               26000.55c   0.05977
               28000.50c   0.008239
m6             5010.50c  1.9592E-03      $ Boral 0.0067 gm/cm2
               5011.50c  8.1175E-03
               6000.50c  2.5176E-03
               13027.50c 5.4933E-02
m7             13027.50c    1.           $ Al Clad
mt4           lwtr.01t
prdmp     j   -120    j   2
fm4       1000    1    -6
f4:n    1
sd4       1000
e4      1.000E-11   1.000E-10   5.000E-10   7.500E-10   1.000E-09   1.200E-09
        1.500E-09   2.000E-09   2.500E-09   3.000E-09
        4.700E-09   5.000E-09   7.500E-09   1.000E-08   2.530E-08
        3.000E-08   4.000E-08   5.000E-08   6.000E-08   7.000E-08
        8.000E-08   9.000E-08   1.000E-07   1.250E-07   1.500E-07
        1.750E-07   2.000E-07   2.250E-07   2.500E-07   2.750E-07
        3.000E-07   3.250E-07   3.500E-07   3.750E-07   4.000E-07
        4.500E-07   5.000E-07   5.500E-07   6.000E-07   6.250E-07
        6.500E-07   7.000E-07   7.500E-07   8.000E-07   8.500E-07
        9.000E-07   9.250E-07   9.500E-07   9.750E-07   1.000E-06
        1.010E-06   1.020E-06   1.030E-06   1.040E-06   1.050E-06
        1.060E-06   1.070E-06   1.080E-06   1.090E-06   1.100E-06
        1.110E-06   1.120E-06   1.130E-06   1.140E-06   1.150E-06
        1.175E-06   1.200E-06   1.225E-06   1.250E-06   1.300E-06
        1.350E-06   1.400E-06   1.450E-06   1.500E-06   1.590E-06
        1.680E-06   1.770E-06   1.860E-06   1.940E-06   2.000E-06
        2.120E-06   2.210E-06   2.300E-06   2.380E-06   2.470E-06
        2.570E-06   2.670E-06   2.770E-06   2.870E-06   2.970E-06
        3.000E-06   3.050E-06   3.150E-06   3.500E-06   3.730E-06
        4.000E-06   4.750E-06   5.000E-06   5.400E-06   6.000E-06
        6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
        8.100E-06   9.100E-06   1.000E-05   1.150E-05   1.190E-05
```

1.290E-05	1.375E-05	1.440E-05	1.510E-05	1.600E-05
1.700E-05	1.850E-05	1.900E-05	2.000E-05	2.100E-05
2.250E-05	2.500E-05	2.750E-05	3.000E-05	3.125E-05
3.175E-05	3.325E-05	3.375E-05	3.460E-05	3.550E-05
3.700E-05	3.800E-05	3.910E-05	3.960E-05	4.100E-05
4.240E-05	4.400E-05	4.520E-05	4.700E-05	4.830E-05
4.920E-05	5.060E-05	5.200E-05	5.340E-05	5.900E-05
6.100E-05	6.500E-05	6.750E-05	7.200E-05	7.600E-05
8.000E-05	8.200E-05	9.000E-05	1.000E-04	1.080E-04
1.150E-04	1.190E-04	1.220E-04	1.860E-04	1.925E-04
2.075E-04	2.100E-04	2.400E-04	2.850E-04	3.050E-04
5.500E-04	6.700E-04	6.830E-04	9.500E-04	1.150E-03
1.500E-03	1.550E-03	1.800E-03	2.200E-03	2.290E-03
2.580E-03	3.000E-03	3.740E-03	3.900E-03	6.000E-03
8.030E-03	9.500E-03	1.300E-02	1.700E-02	2.500E-02
3.000E-02	4.500E-02	5.000E-02	5.200E-02	6.000E-02
7.300E-02	7.500E-02	8.200E-02	8.500E-02	1.000E-01
1.283E-01	1.500E-01	2.000E-01	2.700E-01	3.300E-01
4.000E-01	4.200E-01	4.400E-01	4.700E-01	4.995E-01
5.500E-01	5.730E-01	6.000E-01	6.700E-01	6.790E-01
7.500E-01	8.200E-01	8.611E-01	8.750E-01	9.000E-01
9.200E-01	1.010E+00	1.100E+00	1.200E+00	1.250E+00
1.317E+00	1.356E+00	1.400E+00	1.500E+00	1.850E+00
2.354E+00	2.479E+00	3.000E+00	4.304E+00	4.800E+00
6.434E+00	8.187E+00	1.000E+01	1.284E+01	1.384E+01
1.455E+01	1.568E+01	1.733E+01	2.000E+01	

```
HI-STAR containing MPC68F, 07x07 in DFC with 13 missing rods
c     3.00 % uniform enrichment, unreflected cask, 0.0067 g/cmsq B-10 in Boral
c
c
1     1 -10.522     -1   u=2       $ fuel
2     4 -1.0      1  -2   u=2       $ gap
3     3 -6.55    2  -3   u=2       $ Zr Clad
4     4 -1.0         3   u=2       $ water in fuel region
5     4 -1.0    -4:5     u=3       $ water in guide tubes
6     3 -6.55   4 -5     u=3       $ guide tubes
7     4 -1.0    -6   +7   -8   +9   u=1  lat=1
      fill= -4:4    -4:4   0:0
      1  1 1 1 1 1 1 1  1
      1  2 2 2 2 2 2 2  1
      1  2 1 2 1 2 1 2  1
      1  2 2 1 2 1 2 2  1
      1  2 1 2 1 2 1 2  1
      1  2 2 1 2 1 2 2  1
      1  2 1 2 1 2 1 2  1
      1  2 2 2 2 2 2 2  1
      1  1 1 1 1 1 1 1  1
c
C  BOX TYPE R
c
8     0  -10   11  -12   13          u=4 fill=1
9     3  -6.55    60   -61    62   -63  #8          u=4     $ Zr flow channel
100   5  -7.84   74 -75 76 -77 (-70:71:-72:73)  u=4     $ DFC
10    4  -1.      64   -65    66   -67  #8 #9 #100 u=4  $ water
11    5  -7.84    20   -23    67   -14            u=4     $ 0.075" STEEL
12    4  -1.      20   -23    14   -15            u=4     $ WATER POCKET
13    7  -2.7     20   -23    15   -16            u=4     $ Al CLAD
14    6  -2.66    20   -23    16   -17            u=4     $ BORAL Absorber
15    7  -2.7     20   -23    17   -18            u=4     $ Al Clad
16    4  -1.      20   -23    18  -118            u=4     $ Water
17    5  -7.84    118:-129:65:-66                 u=4     $ Steel
18    4  -1.      64   -21    67   -118           u=4     $ Water
19    4  -1.      24   -65    67   -118           u=4     $ water
20    5  -7.84    21   -20    67   -118           u=4     $ Steel
21    5  -7.84    23   -24    67   -118           u=4     $ Steel
22    4  -1.     129   -64    33   -118           u=4     $ Water
c
23    5  -7.84    25   -64    30   -31            u=4     $ Steel
24    4  -1.      26   -25    30   -31            u=4     $ Water
25    7  -2.7     27   -26    30   -31            u=4     $ Al clad
26    6  -2.66    28   -27    30   -31            u=4     $ Boral
27    7  -2.7     29   -28    30   -31            u=4     $ Al clad
28    4  -1.     129   -29    30   -31            u=4     $ water
29    5  -7.84   129   -64    32   -30            u=4     $ Steel ends
30    5  -7.84   129   -64    31   -33            u=4     $ Steel ends
31    4  -1.     129   -64    66   -32            u=4     $ Water
c
c    Type A box - Boral only on left side
c
32    0  -10   11  -12   13          u=6 fill=1
33    3  -6.55    60   -61    62   -63  #8          u=6     $ Zr flow channel
101   5  -7.84   74 -75 76 -77 (-70:71:-72:73)  u=6     $ DFC
34    4  -1.      64   -65    66   -118 #8 #9 #101 u=6  $ water
35    5  -7.84    118:-129:65:-66                 u=6     $ Steel
36    4  -1.     129   -64    67   -118           u=6     $ Water
c
37    5  -7.84    25   -64    30   -31            u=6     $ Steel
```

```
38    4  -1.       26   -25    30   -31            u=6     $ Water
39    7  -2.7      27   -26    30   -31            u=6     $ Al clad
40    6  -2.66     28   -27    30   -31            u=6     $ Boral
41    7  -2.7      29   -28    30   -31            u=6     $ Al clad
42    4  -1.      129   -29    30   -31            u=6     $ water
43    4  -1.      129   -64    33   -67            u=6     $ Water
44    5  -7.84    129   -64    32   -30            u=6     $ Steel ends
45    5  -7.84    129   -64    31   -33            u=6     $ Steel ends
46    4  -1.      129   -64    66   -32            u=6     $ Water
c
c    Type B box -  Boral on Top only
c
47    0  -10   11  -12   13          u=7 fill=1
48    3  -6.55     60   -61    62   -63  #8        u=7     $ Zr flow channel
102   5  -7.84    74 -75 76 -77 (-70:71:-72:73)  u=7     $ DFC
49    4  -1.       64   -65    66   -67  #8 #9 #102 u=7  $ water
50    5  -7.84     20   -23    67   -14            u=7     $ 0.075" STEEL
51    4  -1.       20   -23    14   -15            u=7     $ WATER POCKET
52    7  -2.7      20   -23    15   -16            u=7     $ Al CLAD
53    6  -2.66     20   -23    16   -17            u=7     $ BORAL Absorber
54    7  -2.7      20   -23    17   -18            u=7     $ water
55    4  -1.       20   -23    18  -118            u=7     $ Water
56    5  -7.84     118:-129:65:-66                 u=7     $ Steel
57    4  -1.       64   -21    67   -118           u=7     $ Water
58    4  -1.       24   -65    67   -118           u=7     $ water
59    5  -7.84     21   -20    67   -118           u=7     $ Steel
60    5  -7.84     23   -24    67   -118           u=7     $ Steel
61    4  -1.      129   -64    66   -118           u=7     $ Water
c
c    Type E box  - No Boral Panels
c
62    0  -10   11  -12   13          u=8 fill=1
63    3  -6.55     60   -61    62   -63  #8        u=8     $ Zr flow channel
103   5  -7.84    74 -75 76 -77 (-70:71:-72:73)  u=8     $ DFC
64    4  -1.      129   -65    66  -118  #8 #9 #103 u=8  $ water
65    5  -7.84     118:-129:65:-66                 u=8     $ Steel
c
c    Type F box  - No Boral Panels or fuel
c
66    4  -1.      129   -65    66  -118            u=9     $ water
67    5  -7.84     118:-129:65:-66                 u=9     $ Steel
c
68    4  -1.0     -34  35   -36  37  u=5  lat=1  fill=-7:6  -7:6  0:0
               5 5 5 5 5 5 5 5 5 5 5 5 5 5
               5 9 9 9 9 9 9 9 9 9 9 9 9 5
               5 9 9 9 9 9 7 4 9 9 9 9 9 5
               5 9 9 9 7 4 4 4 4 4 9 9 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 7 4 4 4 4 4 4 4 4 4 9 5
               5 9 8 4 4 4 4 4 4 4 4 6 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 9 8 4 4 4 4 4 4 6 9 9 5
               5 9 9 9 8 4 4 4 6 6 9 9 9 5
               5 9 9 9 9 9 8 6 9 9 9 9 9 5
               5 9 9 9 9 9 9 9 9 9 9 9 9 5
               5 5 5 5 5 5 5 5 5 5 5 5 5 5
69    0           -41                 50  -49  fill=5 (8.1661  8.1661  0)
70    4  -1.0     -41        43  -50            $ Water below Fuel
71    4  -1.0     -41        49  -44            $ Water above Fuel
72    5  -7.84    -42        68  -43            $ Steel below Fuel
```

```
73     5   -7.84    -42        44  -69              $ Steel above Fuel
74     5   -7.84     41   -42  43  -44              $ Radial Steel
75     0              42 :-68:  69                  $ outside world

1      cz           0.5220     $ Fuel OD
2      cz           0.5334     $ Clad ID
3      cz           0.6172     $ Clad OD
4      cz           0.5398     $ Thimble ID
5      cz           0.6261     $ Thimble OD
6      px           0.8014     $ Pin Pitch
7      px          -0.8014
8      py           0.8014
9      py          -0.8014
10     px           5.7684     $ Channel ID
11     px          -5.7684
12     py           5.7684
13     py          -5.7684
14     py           7.8016
15     py           7.8155
16     py           7.8410
17     py           8.0467
18     py           8.0721
118    py           8.0861
20     px          -6.0325
21     px          -6.2230
23     px           6.0325
24     px           6.2230
25     px          -7.8016
26     px          -7.8155
27     px          -7.8410
28     px          -8.0467
29     px          -8.0721
129    px          -8.0861
30     py          -6.0325
31     py           6.0325
32     py          -6.2230
33     py           6.2230
34     px           7.6111
35     px          -8.7211
36     py           8.7211
37     py          -7.6111
41     cz           85.57
42     cz           108.43
43     pz           11.46
44     pz           252.15
49     pz           230.66      $ Top of Active Fuel
50     pz           30.         $ Start of Active Fuel
60     px           -5.9207     $ Channel OD
61     px            5.9207
62     py           -5.9207
63     py            5.9207
64     px           -7.6111     $ Cell Box ID
65     px            7.6111
66     py           -7.6111
67     py            7.6111
68     pz           -10.13
69     pz            291.52
70     px           -6.2611       $ DFC ID
71     px            6.2611
72     py           -6.2611
73     py            6.2611
```

```
74    px         -6.5659        $ DFC OD
75    px          6.5659
76    py         -6.5659
77    py          6.5659

imp:n     1 77r 0
kcode   10000  0.94   20  120
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1 -2 1.2895
c
si3  h 30. 230.66
sp3  0 1
c
c
si4  s              15 16
              13 14 15 16 17 18
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
        11 12 13 14 15 16 17 18 19 20
        11 12 13 14 15 16 17 18 19 20
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
              13 14 15 16 17 18
                    15 16
sp4  1 67r
c
ds5  s              30 30
              29 29 29 29 29 29
           28 28 28 28 28 28 28 28
           27 27 27 27 27 27 27 27
        26 26 26 26 26 26 26 26 26 26
        25 25 25 25 25 25 25 25 25 25
           24 24 24 24 24 24 24 24
           23 23 23 23 23 23 23 23
              22 22 22 22 22 22
                    21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
si15  -14.7447 -1.7399
si16   1.7399   14.7447
si17   18.2245  31.2293
si18   34.7091  47.7139
si19   51.1937  64.1985
si20   67.6783  80.6831
c
si21  -80.6831 -67.6783
si22  -64.1985 -51.1937
si23  -47.7139 -34.7091
si24  -31.2293 -18.2245
si25  -14.7447 -1.7399
si26   1.7399   14.7447
si27   18.2245  31.2293
si28   34.7091  47.7139
si29   51.1937  64.1985
si30   67.6783  80.6831
sp11  0 1
```

```
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp17  0 1
sp18  0 1
sp19  0 1
sp20  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
sp27  0 1
sp28  0 1
sp29  0 1
sp30  0 1
c
m1            92235.50c   -0.02644      $ 3.00% E Fuel
              92238.50c   -0.85504
              8016.50c    -0.11852
m3            40000.56c   1.           $ Zr Clad
m4            1001.50c    0.6667       $ Water
              8016.50c    0.3333
m5            24000.50c   0.01761      $ Steel
              25055.50c   0.001761
              26000.55c   0.05977
              28000.50c   0.008239
m6            5010.50c  1.9592E-03      $ Boral 0.0067 gm/cm2
              5011.50c  8.1175E-03
              6000.50c  2.5176E-03
              13027.50c 5.4933E-02
m7            13027.50c    1.           $ Al Clad
mt4          lwtr.01t
prdmp     j   -120    j   2
fm4       1000   1    -6
f4:n    1
sd4       1000
e4    1.000E-11   1.000E-10   5.000E-10   7.500E-10   1.000E-09   1.200E-09
      1.500E-09   2.000E-09   2.500E-09   3.000E-09
      4.700E-09   5.000E-09   7.500E-09   1.000E-08   2.530E-08
      3.000E-08   4.000E-08   5.000E-08   6.000E-08   7.000E-08
      8.000E-08   9.000E-08   1.000E-07   1.250E-07   1.500E-07
      1.750E-07   2.000E-07   2.250E-07   2.500E-07   2.750E-07
      3.000E-07   3.250E-07   3.500E-07   3.750E-07   4.000E-07
      4.500E-07   5.000E-07   5.500E-07   6.000E-07   6.250E-07
      6.500E-07   7.000E-07   7.500E-07   8.000E-07   8.500E-07
      9.000E-07   9.250E-07   9.500E-07   9.750E-07   1.000E-06
      1.010E-06   1.020E-06   1.030E-06   1.040E-06   1.050E-06
      1.060E-06   1.070E-06   1.080E-06   1.090E-06   1.100E-06
      1.110E-06   1.120E-06   1.130E-06   1.140E-06   1.150E-06
      1.175E-06   1.200E-06   1.225E-06   1.250E-06   1.300E-06
      1.350E-06   1.400E-06   1.450E-06   1.500E-06   1.590E-06
      1.680E-06   1.770E-06   1.860E-06   1.940E-06   2.000E-06
      2.120E-06   2.210E-06   2.300E-06   2.380E-06   2.470E-06
      2.570E-06   2.670E-06   2.770E-06   2.870E-06   2.970E-06
      3.000E-06   3.050E-06   3.150E-06   3.500E-06   3.730E-06
      4.000E-06   4.750E-06   5.000E-06   5.400E-06   6.000E-06
      6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
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8.100E-06	9.100E-06	1.000E-05	1.150E-05	1.190E-05
1.290E-05	1.375E-05	1.440E-05	1.510E-05	1.600E-05
1.700E-05	1.850E-05	1.900E-05	2.000E-05	2.100E-05
2.250E-05	2.500E-05	2.750E-05	3.000E-05	3.125E-05
3.175E-05	3.325E-05	3.375E-05	3.460E-05	3.550E-05
3.700E-05	3.800E-05	3.910E-05	3.960E-05	4.100E-05
4.240E-05	4.400E-05	4.520E-05	4.700E-05	4.830E-05
4.920E-05	5.060E-05	5.200E-05	5.340E-05	5.900E-05
6.100E-05	6.500E-05	6.750E-05	7.200E-05	7.600E-05
8.000E-05	8.200E-05	9.000E-05	1.000E-04	1.080E-04
1.150E-04	1.190E-04	1.220E-04	1.860E-04	1.925E-04
2.075E-04	2.100E-04	2.400E-04	2.850E-04	3.050E-04
5.500E-04	6.700E-04	6.830E-04	9.500E-04	1.150E-03
1.500E-03	1.550E-03	1.800E-03	2.200E-03	2.290E-03
2.580E-03	3.000E-03	3.740E-03	3.900E-03	6.000E-03
8.030E-03	9.500E-03	1.300E-02	1.700E-02	2.500E-02
3.000E-02	4.500E-02	5.000E-02	5.200E-02	6.000E-02
7.300E-02	7.500E-02	8.200E-02	8.500E-02	1.000E-01
1.283E-01	1.500E-01	2.000E-01	2.700E-01	3.300E-01
4.000E-01	4.200E-01	4.400E-01	4.700E-01	4.995E-01
5.500E-01	5.730E-01	6.000E-01	6.700E-01	6.790E-01
7.500E-01	8.200E-01	8.611E-01	8.750E-01	9.000E-01
9.200E-01	1.010E+00	1.100E+00	1.200E+00	1.250E+00
1.317E+00	1.356E+00	1.400E+00	1.500E+00	1.850E+00
2.354E+00	2.479E+00	3.000E+00	4.304E+00	4.800E+00
6.434E+00	8.187E+00	1.000E+01	1.284E+01	1.384E+01
1.455E+01	1.568E+01	1.733E+01	2.000E+01	

```
=NITAWL
' k4rf5f45, HI-STAR containing MPC24, 15x15 assembly a17 @ 4.1% E
0$$ 84 E
1$$ 0 13  0  4R0  1  E T
2$$ 92235    92238
    40000     1001      8016      5010       5011       6012
    13027    24000     25055      26000      28000
3** 92238 294.6    2    .4752     .1928      0.        0.02251      1
   16.0    7.8209   1    235.04  0.5154     1       1.0              T
END
=KENO5A
k4rf5f45, HI-STAR containing MPC24, 15x15 assembly a17 @ 4.1% E
READ PARAM TME=10000 GEN=300 NPG=10000 NSK=50 LIB=4 TBA=5
END PARAM
READ MIXT SCT=2  EPS=1.0
MIX=1    92235  9.7463E-04
         92238  0.02251
         8016   0.04694
MIX=2    40000  0.04323
MIX=3    1001   0.06688
         8016   0.03344
MIX=4    24000  0.01761
         25055  0.001761
         26000  0.05977
         28000  0.008239
MIX=5    5010   8.7066E-03
         5011   3.5116E-02
         6012   1.0948E-02
         13027  3.6936E-02
MIX=6    1001   0.06688
         8016   0.03344
MIX=7    13027  0.06026
END MIXT
'
' cell-id       8.98
' cell-pitch    10.906
' wall-thkns    5/16
' angle-thkns   5/16
' boral-gap     0.0035
' boral-pocket  0.082
' boral-thkns   0.075
' boral-clad    0.01
' boral-core    0.055
' sheathing     0.0235
' boral-wide    7.500
' boral-narrow  6.250
'
' gap size      1.09
'
READ GEOM
UNIT           1
COM="FUEL ROD"
CYLINDER        1  1  0.4752                                       381.0   0.
CYLINDER        3  1  0.4851                                       381.0   0.
CYLINDER        2  1  0.5436                                       381.0   0.
CUBOID          3  1  0.7214   -0.7214    0.7214    -0.7214        381.0   0.
UNIT           2
COM="GUIDE  TUBE CELL"
CYLINDER        3  1  0.6350                                       381.0   0.
CYLINDER        2  1  0.6706                                       381.0   0.
CUBOID          3  1  0.7214   -0.7214    0.7214    -0.7214        381.0   0.
```

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UNIT          4
COM="LONG HORIZONTAL BORAL PANEL - NORTH"
CUBOID          5  1  9.525  -9.525   0.06985    -0.06985     381.0   0.
CUBOID          7  1  9.525  -9.525   0.09525    -0.09525     381.0   0.
CUBOID          3  1  9.525  -9.525   0.10414    -0.10414     381.0   0.
CUBOID          4  1  9.58469  -9.58469   0.16383      -0.10414     381.0   0.
UNIT          5
COM="LONG VERTICAL BORAL PANEL - EAST"
CUBOID          5  1  0.06985    -0.06985    9.525  -9.525    381.0   0.
CUBOID          7  1  0.09525    -0.09525    9.525  -9.525    381.0   0.
CUBOID          3  1  0.10414    -0.10414    9.525  -9.525    381.0   0.
CUBOID          4  1  0.16383      -0.10414    9.58469  -9.58469    381.0   0.
UNIT          6
COM="LONG HORIZONTAL BORAL PANEL - SOUTH"
CUBOID          5  1  9.525  -9.525    0.06985   -0.06985     381.0   0.
CUBOID          7  1  9.525  -9.525    0.09525   -0.09525     381.0   0.
CUBOID          3  1  9.525  -9.525    0.10414   -0.10414     381.0   0.
CUBOID          4  1  9.58469  -9.58469    0.10414   -0.16383       381.0   0.
UNIT          7
COM="LONG VERTICAL BORAL PANEL - WEST"
CUBOID          5  1  0.06985    -0.06985    9.525  -9.525    381.0   0.
CUBOID          7  1  0.09525    -0.09525    9.525  -9.525    381.0   0.
CUBOID          3  1  0.10414    -0.10414    9.525  -9.525    381.0   0.
CUBOID          4  1  0.10414    -0.16383      9.58469  -9.58469    381.0   0.
UNIT          8  ARRAY 1  -10.8204    -10.8204       0.
COM="CENTRAL FUEL ASSEMBLIES - 4 BORAL PANELS"
CUBOID          3  1  11.4046  -11.4046  11.4046  -11.4046     381.0   0.
CUBOID          4  1  12.1984  -12.1984  12.1984  -12.1984     381.0   0.
CUBOID          3  1  12.4673  -12.4673  12.4673  -12.4673     381.0   0.
HOLE            4    0.          12.3026     0.
HOLE            5   12.3026        0.        0.
HOLE            6  0.          -12.3026    0.
HOLE            7  -12.3026       0.        0.
UNIT         21  ARRAY 1  -10.8204    -10.8204       0.
COM="CENTRAL FUEL ASSEMBLIES - 4 BORAL PANELS, W/O EAST WALL"
CUBOID          3  1  11.4046  -11.4046  11.4046  -11.4046     381.0   0.
CUBOID          4  1  11.4046  -12.1984  12.1984  -12.1984     381.0   0.
CUBOID          3  1  11.4046  -12.4673  12.4673  -12.4673     381.0   0.
HOLE            4    0.          12.3026     0.
HOLE            6  0.          -12.3026    0.
HOLE            7  -12.3026       0.        0.
UNIT         22  ARRAY 1  -10.8204    -10.8204       0.
COM="CENTRAL FUEL ASSEMBLIES - 4 BORAL PANELS, W/O WEST WALL"
CUBOID          3  1  11.4046  -11.4046  11.4046  -11.4046     381.0   0.
CUBOID          4  1  12.1984  -11.4046  12.1984  -12.1984     381.0   0.
CUBOID          3  1  12.4673  -11.4046  12.4673  -12.4673     381.0   0.
HOLE            4    0.          12.3026     0.
HOLE            5   12.3026        0.        0.
HOLE            6  0.          -12.3026    0.
UNIT         23
COM="CELL WALL BETWEEN UNITS 21 AND 22"
CUBOID          4  1  0.396775  -0.396775   23.9998  -23.9998     381.0   0.
UNIT          9
COM="SHORT HORIZONTAL BORAL PANEL - NORTH"
CUBOID          5  1  7.9375  -7.9375   0.06985    -0.06985     381.0   0.
CUBOID          7  1  7.9375  -7.9375   0.09525    -0.09525     381.0   0.
CUBOID          3  1  7.9375  -7.9375   0.10414    -0.10414     381.0   0.
CUBOID          4  1  7.99719  -7.99719   0.16383      -0.10414     381.0   0.
UNIT         10
COM="SHORT VERTICAL BORAL PANEL - EAST"
CUBOID          5  1  0.06985    -0.06985    7.9375  -7.9375    381.0   0.
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CUBOID         7  1  0.09525    -0.09525    7.9375  -7.9375    381.0   0.
CUBOID         3  1  0.10414    -0.10414    7.9375  -7.9375    381.0   0.
CUBOID         4  1  0.16383      -0.10414    7.99719  -7.99719    381.0   0.
UNIT          11
COM="SHORT HORIZONTAL BORAL PANEL - SOUTH"
CUBOID         5  1  7.9375  -7.9375    0.06985   -0.06985    381.0   0.
CUBOID         7  1  7.9375  -7.9375    0.09525   -0.09525    381.0   0.
CUBOID         3  1  7.9375  -7.9375    0.10414   -0.10414    381.0   0.
CUBOID         4  1  7.99719  -7.99719    0.10414   -0.16383      381.0   0.
UNIT          12
COM="SHORT VERTICAL BORAL PANEL - WEST"
CUBOID         5  1  0.06985    -0.06985    7.9375  -7.9375    381.0   0.
CUBOID         7  1  0.09525    -0.09525    7.9375  -7.9375    381.0   0.
CUBOID         3  1  0.10414    -0.10414    7.9375  -7.9375    381.0   0.
CUBOID         4  1  0.10414    -0.16383     7.99719  -7.99719    381.0   0.
UNIT          13  ARRAY 1  -10.8204    -10.8204      0.
COM="Array B short Boral N & E "
CUBOID         3  1  11.4046  -11.4046   11.4046  -11.4046    381.0   0.
CUBOID         4  1  12.1984  -12.1984   12.1984  -12.1984    381.0   0.
CUBOID         3  1  12.4673  -12.4673   12.4673  -12.4673    381.0   0.
HOLE           9    0.         12.3026     0.
HOLE          10   12.3026       0.        0.
HOLE           6  0.          -12.3026    0.
HOLE           7  -12.3026      0.        0.
UNIT          14  ARRAY 1  -10.8204    -10.8204      0.
COM="Array C short Boral E & S "
CUBOID         3  1  11.4046  -11.4046   11.4046  -11.4046    381.0   0.
CUBOID         4  1  12.1984  -12.1984   12.1984  -12.1984    381.0   0.
CUBOID         3  1  12.4673  -12.4673   12.4673  -12.4673    381.0   0.
HOLE           4    0.         12.3026     0.
HOLE          10   12.3026       0.        0.
HOLE          11  0.          -12.3026    0.
HOLE           7  -12.3026      0.        0.
UNIT          15  ARRAY 1  -10.8204    -10.8204      0.
COM="Array D short Boral S & W "
CUBOID         3  1  11.4046  -11.4046   11.4046  -11.4046    381.0   0.
CUBOID         4  1  12.1984  -12.1984   12.1984  -12.1984    381.0   0.
CUBOID         3  1  12.4673  -12.4673   12.4673  -12.4673    381.0   0.
HOLE           4    0.         12.3026     0.
HOLE           5   12.3026       0.        0.
HOLE          11  0.          -12.3026    0.
HOLE          12  -12.3026      0.        0.
UNIT          16  ARRAY 1  -10.8204    -10.8204      0.
COM="Array E short Boral N & W "
CUBOID         3  1  11.4046  -11.4046   11.4046  -11.4046    381.0   0.
CUBOID         4  1  12.1984  -12.1984   12.1984  -12.1984    381.0   0.
CUBOID         3  1  12.4673  -12.4673   12.4673  -12.4673    381.0   0.
HOLE           9    0.         12.3026     0.
HOLE           5   12.3026       0.        0.
HOLE           6  0.          -12.3026    0.
HOLE          12  -12.3026      0.        0.
UNIT          17
CUBOID         4  1  0.7938   -0.        1.60      -0.        381.0   0.
UNIT          18
CUBOID         4  1  1.60     -0.        0.7938    -0.        381.0   0.
UNIT          30
CUBOID         4  1  1.37332  -1.37332   3.4925  -3.4925    381.0   0.
UNIT          31
CUBOID         4  1  1.05959  -1.05959   1.37332  -1.37332    381.0   0.
UNIT          41
CUBOID         3  1  14.6768  -14.6768   1.65227  -1.65227    381.0   0.
```

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CUBOID          4  1  14.6768  -14.6768   2.44602  -2.44602     381.0   0.
UNIT           42
CUBOID          3  1  1.65227  -1.65227   14.6768  -14.6768     381.0   0.
CUBOID          4  1  2.44602  -2.44602   14.6768  -14.6768     381.0   0.
GLOBAL
UNIT           19
COM="ASSEMBLY ARRAY + X DIRECTION"
CYLINDER        3  1  86.57                                  396.24  -10.16
HOLE            8   13.8506    13.8506    0.
HOLE            8   13.8506   -13.8506    0.
HOLE           21   17.949    41.5519    0.
HOLE           21   17.949   -41.5519    0.
HOLE           13   13.8506    69.2531    0.
HOLE           14   13.8506   -69.2531    0.
HOLE           22   41.5519    17.949    0.
HOLE           22   41.5519   -17.949    0.
HOLE           13   45.6502    45.6502    0.
HOLE           14   45.6502   -45.6502    0.
HOLE           13   69.2531    13.8506    0.
HOLE           14   69.2531   -13.8506    0.
HOLE            8  -13.8506    13.8506    0.
HOLE            8  -13.8506   -13.8506    0.
HOLE           22  -17.949    41.5519    0.
HOLE           22  -17.949   -41.5519    0.
HOLE           16  -13.8506    69.2531    0.
HOLE           15  -13.8506   -69.2531    0.
HOLE           21  -41.5519    17.949    0.
HOLE           21  -41.5519   -17.949    0.
HOLE           16  -45.6502    45.6502    0.
HOLE           15  -45.6502   -45.6502    0.
HOLE           16  -69.2531    13.8506    0.
HOLE           15  -69.2531   -13.8506    0.
HOLE           23   29.7505    29.7505    0.
HOLE           23  -29.7505    29.7505    0.
HOLE           23   29.7505   -29.7505    0.
HOLE           23  -29.7505   -29.7505    0.
HOLE            5   30.2516    41.5519    0.
HOLE            5   30.2516   -41.5519    0.
HOLE            7  -30.2516    41.5519    0.
HOLE            7  -30.2516   -41.5519    0.
HOLE            7   29.2494    17.949    0.
HOLE            7   29.2494   -17.949    0.
HOLE            5  -29.2494    17.949    0.
HOLE            5  -29.2494   -17.949    0.
HOLE           30      0.        0.    0.
HOLE           31   2.43291      0.    0.
HOLE           31  -2.43291      0.    0.
HOLE           41   41.5519      0.    0.
HOLE           41  -41.5519      0.    0.
HOLE           42      0.    41.5519    0.
HOLE           42      0.   -41.5519    0.
CYLINDER        4  1  108.43                               435.61  -31.75
CUBOID          3  1  139   -139    139   -139    435.61   -31.75
END GEOM
READ ARRAY
ARA=1  NUX=15  NUY=15  NUZ=1
COM="15 X 15 FUEL ASSEMBLY"
FILL
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1
```

```
      1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 2 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
END FILL
END ARRAY
END DATA
END
```

```
=NITAWL
' HI-STAR containing MPC68, 08x08 @ 4.2% E
0$$ 84 E
1$$ 0 13  0  4R0  1  E T
2$$ 92235    92238
    40000    1001     8016     5010     5011     6012
    13027    24000    25055    26000    28000
3** 92238 294.6   2   .5207   .1623    0.      0.02248     1
   16.0   7.8330  1   235.04  0.5662 . 1      1.0          T
END
=KENO5A
HI-STAR containing MPC68, 08x08 @ 4.2% E
'  GE 8X8R FUEL 2 WATER HOLES
READ PARAM TME=10000 GEN=1100 NPG=5000 NSK=100
     LIB=4 TBA=5  LNG=400000   NB8=900
END PARAM
READ MIXT SCT=2  EPS=1.
MIX=1   92235  9.983E-04
        92238  0.02248
        8016   0.04697
MIX=2   40000  0.04323
MIX=3   1001   0.06688
        8016   0.03344
MIX=4   24000  0.01761
        25055  0.001761
        26000  0.05977
        28000  0.008239
MIX=5   5010   8.071E-03
        5011   3.255E-02
        6012   1.015E-02
        13027  3.305E-02
MIX=6   13027  0.06026
END MIXT
READ GEOM
UNIT           1
COM=           "FUEL ROD"
CYLINDER        1  1  0.5207                                   381.0   0.
CYLINDER        3  1  0.5321                                   381.0   0.
CYLINDER        2  1  0.6134                                   381.0   0.
CUBOID          3  1  0.8128   -0.8128   0.8128   -0.8128      381.0   0.
UNIT           2
COM=           "GUIDE  TUBE CELL"
CYLINDER        3  1  0.6744                                   381.0   0.
CYLINDER        2  1  0.7506                                   381.0   0.
CUBOID          3  1  0.8128   -0.8128   0.8128   -0.8128      381.0   0.
UNIT           4
COM=           "HORIZONTAL BORAL PANEL"
CUBOID          5  1  6.0325   -6.0325   0.1027   -0.1027      381.0   0.
CUBOID          6  1  6.0325   -6.0325   0.1283   -0.1283      381.0   0.
CUBOID          3  1  6.0325   -6.0325   0.1422   -0.1422      381.0   0.
CUBOID          4  1  6.4611   -6.4611   0.1422   -0.3327      381.0   0.
UNIT           5
COM=           "VERTICAL BORAL PANEL"
CUBOID          5  1  0.1027   -0.1027    6.0325   -6.0325   381.0   0.
CUBOID          6  1  0.1283   -0.1283    6.0325   -6.0325   381.0   0.
CUBOID          3  1  0.1422   -0.1422    6.0325   -6.0325   381.0   0.
CUBOID          4  1  0.3327   -0.1422    6.4611   -6.4611   381.0   0.
UNIT           8  ARRAY 1  -6.5024     -6.5024      0.
COM=           "FUEL ASSEMBLIES - 2 BORAL PANELS"
CUBOID          3  1  6.7031   -6.7031   6.7031   -6.7031        381.0   0.
CUBOID          2  1  6.9571   -6.9571   6.9571   -6.9571        381.0   0.
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CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            4    0.          7.9438    0.
HOLE            5  -7.9438        0.        0.
CUBOID          4  1  7.6111   -8.7211    8.7211   -7.6111          381.0   0.
UNIT           9  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - Type A"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            5  -7.9438        0.        0.
CUBOID          4  1  8.2461   -8.7211    8.7211   -7.6111          381.0   0.
UNIT          10  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - Type B"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            5  -7.9438        0.        0.
CUBOID          4  1  7.6111   -8.7211    8.7211   -7.6111          381.0   0.
UNIT          11  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - Type C"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            4    0.          7.9438    0.
HOLE            5  -7.9438        0.        0.
CUBOID          4  1  8.2461   -8.7211    8.7211   -7.6111          381.0   0.
UNIT          12  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - Type D"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            4    0.          7.9438    0.
HOLE            5  -7.9438        0.        0.
CUBOID          4  1  8.2461   -8.7211    8.7211   -8.2461          381.0   0.
UNIT          13  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - Type E"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            4    0.          7.9438    0.
HOLE            5  -7.9438        0.        0.
CUBOID          4  1  7.6111   -8.7211    8.7211   -8.2461          381.0   0.
UNIT          14  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - Type F"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            4    0.          7.9438    0.
CUBOID          4  1  7.6111   -8.7211    8.7211   -8.2461          381.0   0.
UNIT          15  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - TYPE G"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
HOLE            4    0.          7.9438    0.
CUBOID          4  1  7.6111   -8.7211    8.7211   -7.6111          381.0   0.
UNIT          16  ARRAY 1  -6.5024     -6.5024        0.
COM=           "FUEL ASSEMBLIES - TYPE H"
CUBOID          3  1  6.7031   -6.7031    6.7031   -6.7031          381.0   0.
CUBOID          2  1  6.9571   -6.9571    6.9571   -6.9571          381.0   0.
CUBOID          3  1  7.6111   -8.0861    8.0861   -7.6111          381.0   0.
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CUBOID          4  1  7.6111    -8.7211    8.7211    -7.6111          381.0    0.
UNIT           17  ARRAY 2     -48.9966  -48.9966          0
UNIT           18  ARRAY 3     -16.3322   -7.6111          0.
UNIT           19  ARRAY 4     -48.9966   -7.6111          0.
UNIT           20  ARRAY 5      -8.7211  -16.3322          0.
UNIT           21  ARRAY 6      -8.7211  -50.1068          0.
UNIT           22  ARRAY 7      -8.7211  -16.3322          0.
UNIT           23  ARRAY 8      -8.7211  -16.3322          0.
UNIT           24  ARRAY 9      -8.7211  -16.3322          0.
UNIT           25  ARRAY 10     -8.7211  -16.3322          0.
UNIT           26  ARRAY 11    -16.3322   -8.7213          0.
UNIT           27  ARRAY 12    -16.3322   -7.6111          0.
UNIT           28  ARRAY 13    -16.3322   -8.7213          0.
UNIT           29  ARRAY 14    -16.3322   -8.7213          0.
GLOBAL
UNIT           30
CYLINDER        3  1   85.57                                        402.5   -18.54.
HOLE           17       0.0         0.0       0.
HOLE           18       0.0        73.4949    0.
HOLE           19       0.0        57.1627    0.
HOLE           20     -73.4949      0.0       0.
HOLE           21     -56.6077      0.0       0.
HOLE           22      57.7177     32.6644    0.
HOLE           23      57.7177      0.0       0.
HOLE           24      74.052       0.0       0.
HOLE           25      57.7177    -32.6644    0.
HOLE           26      32.6644    -57.7177    0.
HOLE           27       0.0       -57.7177    0.
HOLE           28     -32.6644    -57.7177    0.
HOLE           29       0.0       -74.052     0.
CYLINDER        4   1   108.43                               441.35  -40.13
CUBOID          3   1   109.      -109.      109.     -109.  442     -40.2
END GEOM
READ ARRAY
ARA=1  NUX=8   NUY=8   NUZ=1
COM=   "8 X 8 FUEL ASSEMBLY"
FILL
 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1
 1 1 1 2 1 1 1 1
 1 1 1 1 2 1 1 1
 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1
END FILL
ARA=2  NUX=6   NUY=6   NUZ=1
COM=   "6 X 6 CENTRAL ARRAY OF FUEL ASSEMBLIES"
FILL
  8 8 8 8 8 8
  8 8 8 8 8 8
  8 8 8 8 8 8
  8 8 8 8 8 8
  8 8 8 8 8 8
  8 8 8 8 8 8
END FILL
ARA=3  NUX=2   NUY=1   NUZ=1
COM=   "2 X 1  ARRAY OF FUEL ASSEMBLIES - TOP ROW"
FILL
 16  9
END FILL
```

```
ARA=4  NUX=6   NUY=1   NUZ=1
COM=   "6 X 1  ARRAY OF FUEL ASSEMBLIES - 2ND ROW"
FILL
  16  10  8  8  10  9
END FILL
ARA=5  NUX=1   NUY=2   NUZ=1
COM=   "2 X 1  ARRAY OF FUEL ASSEMBLIES - OUTER LEFT"
FILL
  14
  16
END FILL
ARA=6  NUX=1   NUY=6   NUZ=1
COM=   "1 X 6  ARRAY OF FUEL ASSEMBLIES - 2ND ROW LEFT"
FILL
  14  15  8  8  15  16
END FILL
ARA=7  NUX=1   NUY=2   NUZ=1
COM=   "1 X 2  ARRAY OF FUEL ASSEMBLIES - UPPER RIGHT"
FILL
  11
   9
END FILL
ARA=8  NUX=1   NUY=2   NUZ=1
COM=   "1 X 2  ARRAY OF FUEL ASSEMBLIES - MIDDLE RIGHT"
FILL
   8
   8
END FILL
ARA=9  NUX=1   NUY=2   NUZ=1
COM=   "1 X 2  ARRAY OF FUEL ASSEMBLIES - MIDDLE RIGHT"
FILL
   11
    9
END FILL
ARA=10  NUX=1   NUY=2   NUZ=1
COM=   "1 X 2  ARRAY OF FUEL ASSEMBLIES - LOWER RIGHT"
FILL
  11
  11
END FILL
ARA=11  NUX=2   NUY=1   NUZ=1
COM=   "2 X 1  ARRAY OF FUEL ASSEMBLIES - 2ND BOTTOM ROW"
FILL
  13  13
END FILL
ARA=12  NUX=2   NUY=1   NUZ=1
COM=   "2 X 1  ARRAY OF FUEL ASSEMBLIES - BOTTOM ROW"
FILL
  8  8
END FILL
ARA=13  NUX=2   NUY=1   NUZ=1
COM=   "2 X 1  ARRAY OF FUEL ASSEMBLIES - BOTTOM ROW"
FILL
  14  13
END FILL
ARA=14  NUX=2   NUY=1   NUZ=1
COM=   "2 X 1  ARRAY OF FUEL ASSEMBLIES - BOTTOM ROW"
FILL
  14 13
END FILL
END ARRAY
```

```
END DATA
END
```

CHAPTER 7: CONFINEMENT

7.0 INTRODUCTION

Confinement of all radioactive materials in the HI-STAR 100 System is provided by the MPC. The design of the HI-STAR 100 confinement boundary assures that there are no credible design basis events that would result in a radiological release to the environment. The HI-STAR 100 Overpack is designed to provide physical protection for an MPC during normal, off-normal, and postulated accident conditions to assure that the integrity of the MPC confinement boundary is maintained. The inert atmosphere in the MPC and the passive heat removal capabilities of the HI-STAR 100 also assure that the SNF assemblies remain protected from degradation, which might otherwise lead to gross cladding ruptures during dry storage.

The HI-STAR 100 System is classified as important to safety. Therefore, the individual structures, systems, and components (SSC's) that make up the HI-STAR 100 System shall be designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with a quality program commensurate with the particular SSC's graded quality category. Tables 2.2.6 and 8.1.4 provide the quality category for each major item or component of the HI-STAR 100 System and required ancillary equipment and systems.

A detailed description of the confinement structures, systems, and components important to safety is provided in Chapter 2. The structural adequacy of the MPC is demonstrated by the analyses documented in Chapter 3. The physical protection of the MPC provided by the overpack for normal conditions of storage is demonstrated by the structural analyses documented in Chapter 3 and for off-normal and postulated accident conditions in Chapter 11. The heat removal capabilities of the HI-STAR 100 System are demonstrated by the thermal analyses documented in Chapter 4.

This chapter describes the HI-STAR 100 confinement boundary design and describes how the design satisfies the confinement requirements of 10CFR72 [7.0.1]. It also provides an evaluation of postulated radiological releases to the environment under normal, off-normal, and accident conditions of storage to ensure compliance with the limits established by the regulations.

This chapter is in compliance with NUREG-1536 except as noted in Table 1.0.3.

7.1 CONFINEMENT BOUNDARY

The primary confinement boundary against the release of radionuclides is the cladding of the individual fuel rods. The spent fuel rods are protected from degradation by maintaining an inert gas atmosphere (helium) inside the MPC and keeping the fuel cladding temperatures below the design basis values specified in Chapter 2.

The HI-STAR 100 confinement boundary consists of any one of the two fully-welded MPC designs described in Chapter 1. Each MPC is identical from a confinement perspective so the following discussion applies to all MPCs. The confinement boundary of the MPC consists of:

- MPC shell
- Bottom baseplate
- MPC lid (including the vent and drain port cover plates)
- MPC closure ring
- Associated welds

The above items form a totally seal-welded vessel for the storage of design basis spent fuel assemblies.

The MPC requires no valves, gaskets or mechanical seals for confinement. Figure 7.1.1 shows an elevation cross-section of the MPC confinement boundary. All components of the confinement boundary are Important to Safety, Category A, as specified in Table 2.2.6. The MPC confinement boundary is designed and fabricated in accordance with the ASME Code, Section III, Subsection NB [7.1.1] to the maximum extent practicable. Chapter 2 provides design criteria for the confinement design. Section 2.2.4 and Table 2.2.7 provide applicable Code requirements. Exceptions to specific Code requirements with complete justifications are presented in Table 2.2.15.

No additional credit is required or taken for confinement of the radionuclides by the overpack. The overpack helium retention boundary (containment boundary), which surrounds the MPC confinement boundary consists of the following (see Figure 7.1.2):

- inner shell, top flange, and bottom plate welded together with full penetration radiographed welds.
- a bolted closure plate with two concentric metallic seals to form a closure between the top flange surface and the closure plate, and redundant sealing of the inner metallic seal with a threaded test port plug containing a metallic seal which is compressed between the underside of the threaded plug head and the recessed seating surface on the closure plate.

- vent and drain ports with threaded plugs containing a metallic seal which is compressed between the underside of the threaded plug head and the overpack body.

- redundant sealing of the vent and drain ports by a bolted cover plate with a metallic seal which is compressed between the cover plate and the the overpack body

Table 7.1.1 provides design operating limits for the seals described above.

The HI-STAR helium retention boundary described above is identical to the HI-STAR 100 containment boundary defined and analyzed in the HI-STAR Safety Analysis Report submitted for transport certification [7.1.2].

7.1.1 Confinement Vessel

The HI-STAR 100 confinement vessel is the MPC. The MPC is designed to provide confinement of all radionuclides under normal, off-normal and accident conditions. The MPC is designed, fabricated, and tested in accordance with the applicable requirements of ASME, Section III, Subsection NB [7.1.1] to the maximum extent practicable. The MPC shell and baseplate assembly and basket structure are delivered to the loading facility as one complete component. The MPC lid, vent and drain port cover plates, and closure ring are supplied separately and are installed following fuel loading. The MPC lid (with the vent and drain port cover plates welded to the MPC lid) and closure ring are welded to the upper part of the MPC shell at the loading site to provide redundant sealing of the confinement boundary. The vent and drain port cover plates are welded to the MPC lid after the lid is welded to the MPC. Confinement boundary welds are described in detail in the drawing(s) in Section 1.5.

The MPC lid is made intentionally thick to minimize radiation exposure to workers during MPC closure operations, and is welded to the MPC shell. The vent and drain port cover plates are welded to the MPC lid following completion of MPC draining, vacuum drying, and helium backfill activities to close the MPC vent and drain openings. The MPC lid has a stepped recess around the perimeter for accommodating the closure ring. The MPC closure ring is welded to the MPC lid on the inner diameter of the ring and to the MPC shell on the outer diameter. The combination of the welded MPC lid and closure ring form the redundant closure of the MPC.

Table 7.1.1 provides a summary of the design ratings for normal, off-normal and accident conditions for the MPC confinement vessel. Tables 1.2.2, 2.2.1, and 2.2.3 provide additional design basis information.

The MPC shell and baseplate are helium leakage tested during fabrication in accordance with the requirements defined in Chapter 9. Following fuel loading and MPC lid welding, the MPC lid-to-shell weld is examined by liquid penetrant method (root and final), volumetrically examined (if volumetric examination is not performed, multi-layer liquid penetrant examination must be performed), helium leakage tested, and hydrostatically tested. If the MPC lid weld is acceptable, the vent and drain port cover plates are welded in place, examined by the liquid penetrant method (root and final), and a leakage rate test is performed. Finally, the MPC closure ring is

installed, welded and inspected by the liquid penetrant method (root and final), volumetrically examined (if volumentric examination is not performed, multi-layer liquid penetrant examination must be performed), helium leakage tested, and hydrostatically tested. If the MPC lid weld is acceptable, the vent and drain port cover plates are welded in place, examined by liquid penetrant method (root and final), and a leakage rate test is performed. Finally, the MPC closure ring is installed, welded and inspected by the liquid penetrant method (root, if multiple pass, and final). Chapters 8, 9, and the Certificate of Compliance provide procedural guidance, acceptance criteria, and Technical Specifications, respectively, for performance and acceptance of liquid penetrant examinations, volumetric examination, hydrostatic testing, and leakage rate testing of the field welds on the MPC.

After final vacuum drying, the MPC cavity is backfilled with helium. The helium backfill provides an inert atmosphere within the MPC cavity that precludes oxidation and hydride attack of the SNF cladding. Use of a helium atmosphere within the MPC contributes to the long-term integrity of the fuel cladding, reducing the potential for release of fission gas or other radioactive products to the MPC cavity. Helium also aids in heat transfer within the MPC and reduces the maximum fuel cladding temperatures. MPC inerting, in conjunction with the thermal design features of the MPC and storage cask, assures that the fuel assemblies are sufficiently protected against degradation, which might otherwise lead to gross cladding ruptures during long-term storage.

7.1.2 Confinement Penetrations

The MPC penetrations are designed to prevent the release of radionuclides under all normal, off-normal and accident conditions of storage. Two penetrations (the MPC vent and drain ports) are provided in the MPC lid for MPC draining, vacuum drying and backfilling during MPC loading operations, and for fuel cool-down and MPC flooding during unloading operations. No other confinement penetrations exist in the MPC. The MPC vent and drain ports are equipped with metal-to-metal seals to minimize leakage and withstand the long-term effects of temperature and radiation. The vent and drain connectors allow the vent and drain ports to be operated like valves and prevent the need to hot tap into the penetrations during unloading operations. The MPC vent and drain ports are sealed by cover plates which are seal welded to the MPC lid. No credit is taken for the seal provided by the vent and drain ports. The MPC closure ring covers the vent and drain port cover plate welds and the MPC lid-to-shell weld providing the redundant closure of the MPC vessel. The redundant closures of the MPC satisfy the requirements of 10CFR72.236(e) [7.0.1].

The MPC has no bolted closures or mechanical seals. The confinement boundary contains no external penetrations for pressure monitoring or overpressure protection.

7.1.3 Seals and Welds

The MPC is designed, fabricated, and tested in accordance with the applicable requirements of ASME, Section III, Subsection NB [7.1.1] to the maximum extent practicable. The MPC has no bolted closures or mechanical seals. Section 7.1.1 describes the design of the confinement vessel welds. The welds forming the confinement boundary are summarized in Table 7.1.2.

Confinement boundary welds are performed, inspected, and tested in accordance with the applicable requirements of ASME Section III, Subsection NB [7.1.1] to the maximum extent practicable. The use of multi-pass welds, root pass for multiple pass welds and final surface liquid penetrant inspection, and volumetric examination (if volumetric examination is not performed, multi-layer liquid penetrant examination must be performed) essentially eliminates the chance of a pinhole leak through the weld. Welds are also helium leak tested, providing added assurance of weld integrity. Additionally, a hydrostatic test is performed on the MPC lid-to-shell weld to confirm the weld's structural integrity. Fit-up of all field-welded components performed at the licensee's facility will result in a uniform root opening of the minimum size and will eliminate the need for backing that could restrain the weld joint and induce residual weld stresses. The ductile stainless steel material used for the MPC confinement boundary is not susceptible to delamination or hydrogen-induced weld degradation. The closure weld redundancy assures that failure of any single MPC confinement boundary closure weld does not result in release of radioactive material to the environment. Table 7.1.3 provides a summary of the closure weld examinations and tests.

7.1.4 Closure

The MPC is a totally seal-welded pressure vessel. The MPC has no bolted closure or mechanical seals. The MPC's redundant closures are designed to maintain confinement integrity during normal conditions of storage, and off-normal and postulated accident conditions. There are no unique or special closure devices. Primary closure welds are examined and leakage tested to ensure their integrity. A description of the MPC weld examinations is provided in Chapter 9.

Since the MPC uses an entirely welded redundant closure system, no direct monitoring of the closure is required. Section 11.2.1.4 describes requirements for verifying the continued confinement capabilities of the MPC in the event of off-normal or accident conditions. As discussed in Section 2.3.3.2, no instrumentation is required or provided for HI-STAR 100 storage operations, other than normal security service instruments and TLDs.

7.1.5 Damaged Fuel Container

The MPC is designed to allow for the storage of specified damaged fuel assemblies and fuel debris in a specially designed damaged fuel container (DFC). Fuel assemblies classified as damaged fuel or fuel debris (assembly array/class 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A) as specified in the Technical Specifications have been evaluated.

To aid in loading and unloading, damaged fuel assemblies and fuel debris will be loaded into stainless steel DFCs prior to placement in the HI-STAR 100 System. Up to 68 damaged fuel assemblies in DFC's may be stored in an MPC-68 or MPC-68F. The DFC is shown in Figure 2.1.1 and detailed in the drawings in Section 1.5. The DFC is designed to provide SNF loose component retention and handling capabilities. The DFC consists of a smooth-walled, welded stainless steel container with a removable lid. The canister lid provides the means of DFC closure and handling. The DFC is provided with stainless steel wire mesh screens in the top and bottom for draining, vacuum drying and helium backfill operations. The screens are specified as a 250-by-250-mesh with an effective opening of 0.0024 inches. There are no other openings in the DFC. The Technical Specifications specify the fuel assembly characteristics for damaged

fuel acceptable for loading in the MPC-68 or MPC-68F and for fuel debris acceptable for loading in the MPC-68F.

Since the DFC has screens on the top and bottom, the DFC provides no pressure retention function. The confinement function of the DFC is limited to minimizing the release of loose particulates within the sealed MPC. The storage design basis leakage rates are not altered by the presence of the DFCs. The radioactive material available for release from the specified fuel assemblies are bounded by the design basis fuel assemblies analyzed herein.

Table 7.1.1

SUMMARY OF CONFINEMENT AND HELIUM RETENTION BOUNDARY DESIGN SPECIFICATIONS

Design Attribute	**Design Rating**
Internal Design Pressure (normal)	100 psig
Design Temperature (normal)	550°F (MPC lid)
Internal Design Pressure (off-normal)	100 psig
Design Temperature (off-normal)	775°F (MPC lid)
Internal Design Pressure (accident)	125 psig
Design Temperature (accident)	950°F (MPC basket)
Design Basis Leakage Rate	5×10^{-6} atm cm^3/sec (helium)
Closure Plate Mechanical Seal†,††	
Design Temperature	1200°F
Pressure Limits	1000 psig
Design Leakage Rate	1×10^{-6} cm^3/sec, Helium
Overpack Vent and Drain Port Cover Plate Mechanical Seals†,††	
Design Temperature	1200 °F
Pressure Limits	1000 psig
Design Leakage Rate	1×10^{-6} cm^3/sec, Helium
Overpack Vent and Drain Port Plug Mechanical Seals†,††	
Design Temperature	1200 °F
Pressure Limits	1000 psig
Design Leakage Rate	1×10^{-6} cm^3/sec, Helium

† For overpack helium retention only. No confinement credit is taken for the overpack mechanical seals.

†† Per Manufacturer's recommended operating limits.

Table 7.1.2

MPC CONFINEMENT BOUNDARY WELDS

Confinement Boundary Welds		
MPC Weld Location	**Weld Type**[†]	**ASME Code Category (Section III, Subsection NB)**
Shell longitudinal seam	Full Penetration Groove (shop weld)	A
Shell circumferential seam	Full Penetration Groove (shop weld)	B
Baseplate to shell	Full Penetration Groove (shop weld)	C
MPC lid to shell	Partial Penetration Groove (field weld)	C
MPC closure ring to shell	Fillet (field weld)	††
Vent and drain port cover plates to MPC lid	Partial Penetration Groove (field weld)	D
MPC closure ring to closure ring radial	Partial Penetration Groove (field weld)	††
MPC closure ring to MPC lid	Partial Penetration Groove (field weld)	C

† The tests and inspections for the confinement boundary welds are listed in Section 9.1.1.

†† This joint is covered by NB-5271 (liquid penetrant examination).

Table 7.1.3

CLOSURE WELD EXAMINATIONS AND TESTS

Closure Weld Description	Inspections/Tests	ASME Acceptance Criteria
MPC Lid-to-Shell	VT on Tack Welds PT Root Pass PT Final Pass VT Final Pass Volumetric Examination of Weld (UT) or multi-layer PT Hydrostatic Test Post Hydrostatic Test - PT Helium Leakage Test	NF-5360 NB-5350 NB-5350 NF-5360 NB-5332 NB-6000 NB-5350 Sect. V and ANSI N14.5
Vent/Drain Cover Plate to MPC Lid	VT on Tack Welds PT Root Pass PT Final Pass VT Final Pass Helium Leakage Test	NF-5360 NB-5350 NB-5350 NF-5360 Sect. V and ANSI N14.5
Closure Ring Radial Welds	VT on Tack Welds PT Root Pass (if multiple pass) PT Final Pass VT Final Pass	NF-5360 NB-5350 NB-5350 NF-5360
Closure Ring-to-MPC Shell	VT on Tack Welds PT Root Pass (if multiple pass) PT Final Pass VT Final Pass	NF-5360 NB-5350 NB-5350 NF-5360
Closure Ring-to-MPC Lid	VT on Tack Welds PT Root Pass PT Final Pass VT Final Pass	NF-5360 NB-5350 NB-5350 NF-5360

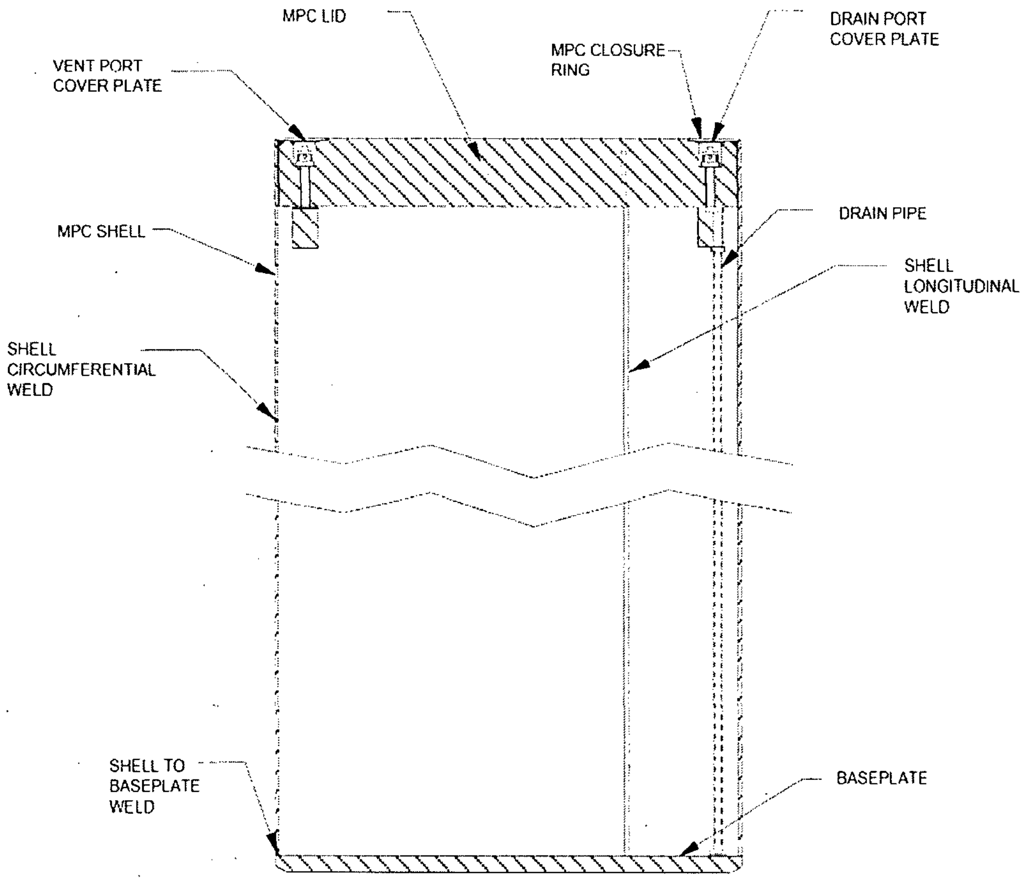

Figure 7.1.1; HI-STAR 100 System Confinement Boundary

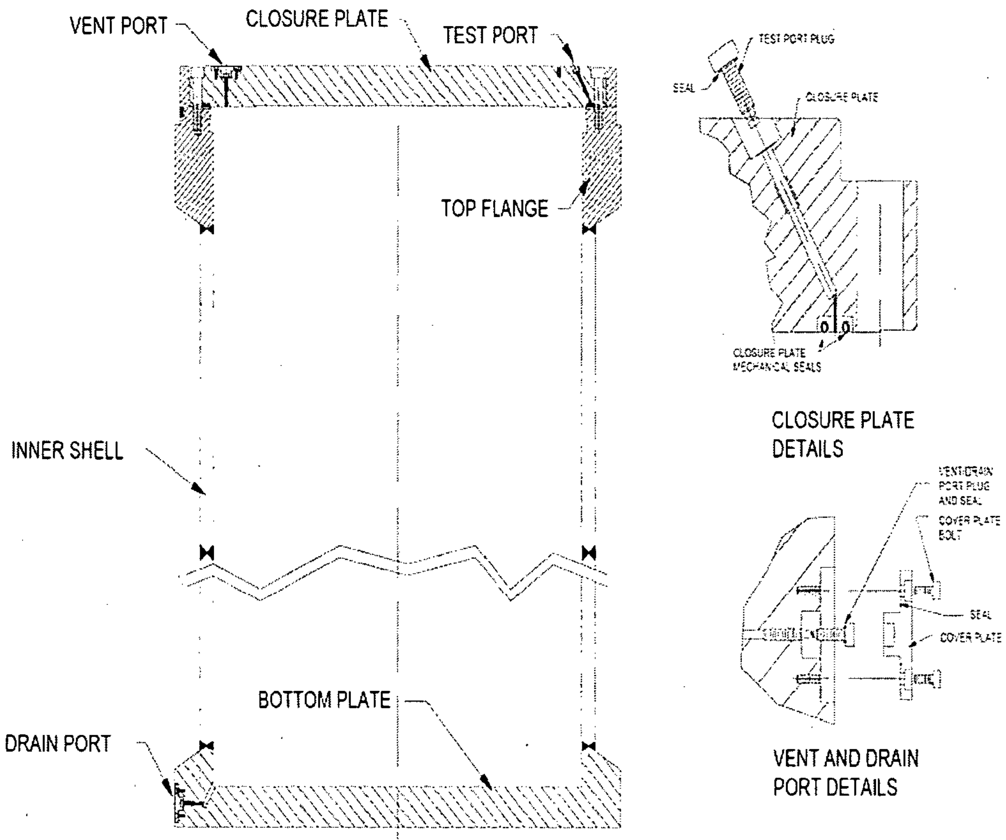

Figure 7.1.2; HI-STAR 100 System Containment Boundary

FIGURE 7.1.3

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7.2 REQUIREMENTS FOR NORMAL AND OFF-NORMAL CONDITIONS OF STORAGE

The MPC uses multiple confinement barriers provided by the fuel cladding and the MPC enclosure vessel to assure that there is no release of radioactive material to the environment. Chapter 3 shows that all confinement boundary components are maintained within their Code-allowable stress limits during normal storage conditions. Chapter 4 shows that the peak confinement boundary component temperatures and pressures are within the design basis limits for all normal conditions of storage. Since the MPC confinement vessel remains intact, and the design bases temperatures and pressure are not exceeded, the design basis leakage rate is not exceeded during normal conditions of storage.

7.2.1 Release of Radioactive Material

The MPC is closed by the MPC lid, the vent and drain port cover plates, and the MPC closure ring. Weld examinations, including multiple surface examinations, volumetric examination, hydrostatic testing, and leakage rate testing on the MPC lid weld, and multiple surface examinations and leakage rate testing of the vent and drain port cover plate welds, assure the integrity of the MPC closure. The MPC is a seal-welded pressure vessel designed to meet the stress criteria of the ASME Code, Section III, Subsection NB [7.1.1]. The all-welded construction of the MPC with redundant closure provided by the fully welded MPC closure ring, and extensive inspections and testing ensures that no release of fission gas or crud for normal storage and transfer conditions will occur. The above discussion notwithstanding, an analysis is performed in Section 7.2.7 to calculate the annual dose at 100 meters based on an assumed leakage rate of 5×10^{-6} atm-cm^3/sec plus the minimum test sensitivity of 2.5×10^{-6} atm-cm^3/sec under normal and off-normal conditions of storage.

7.2.2 Pressurization of the Confinement Vessel

The loaded and sealed MPC is drained, vacuum dried, and backfilled with helium gas. This process provides a chemically non-reactive environment for storage of spent fuel assemblies. First, air in the MPC is displaced with water and then the water is displaced by helium or nitrogen gas during MPC blowdown. The MPC is then vacuum dried, and backfilled with a predetermined mass of helium as specified in the Technical Specifications. Chapter 8 describes the steps of these processes and the Technical Specifications provide the acceptance criteria. This drying and backfilling process ensures that the resulting inventory of oxidizing gases in the MPC remains below 0.25% by volume, and that the MPC pressure is maintained within the design limitations. In addition, the MPC basket fluid contact areas are stainless steel alloy material or aluminum of extremely high corrosion and erosion resistance. The aluminum oxide layer on the aluminum components (e.g., heat conduction elements and Boral neutron absorption plates) ensures that there is a minimal amount of reaction during the short duration of exposure to the fuel pool water (see Section 3.4.1 for discussion of combustible gas control during lid welding). Carbon steels are not employed in the construction of the MPCs. Therefore, no protective coatings which could interact with borated spent fuel pool water are used.

The only means of pressure increase in the MPC is from the temperature rise to normal heat-up

to normal operating temperatures and the release of backfill and fission gas contents from fuel rods into the MPC cavity. Under the most adverse conditions of normal ambient temperature, full insolation, and design basis decay heat, the calculated pressure increase assuming 1% fuel rod failure is well below the system design pressure as shown in Chapter 4. The heavy HI-STAR 100 overpack provides protection from ambient day-night temperature swings thereby providing a relatively stable thermal environment for fuel storage. For off-normal conditions of storage, failure of up to 10% of the fuel rods has been analyzed and would result in an MPC internal pressure below the value specified as the normal design pressure.

7.2.3 Confinement Integrity During Dry Storage

There is no credible mechanism or event that results in a release of radioactive material from the MPC under normal conditions. Since the MPC remains structurally intact and provides redundant welded closures as discussed above, the postulated leakage of radioactive material from the MPC will be limited to a leakage rate equivalent to the acceptance test criteria specified for the MPC helium leak tests. Leakage from the MPC during normal conditions of storage could result in the release of gaseous fission products, fines, volatiles and airborne crud particulates as discussed in Section 7.3.1. The conservative assumption is made that 1% of the fuel inventory is available for release under normal conditions of storage and 10% of the fuel inventory is available for release under off-normal conditions of storage. The maximum cavity internal operating pressure with 10% fuel rod failure reported in Chapter 4 is bounded by the use of an internal cavity pressure of 58.7 psia (4.99 ATM), which is assumed as an initial condition for this evaluation.

The following doses to an individual at the site boundary (100 meters) as a result of an assumed effluent release under normal and off-normal conditions of storage were determined; the inhaled committed dose equivalent for critical organs and tissues (gonad, breast, lung, red marrow, bone surface, thyroid, skin, lens of the eye), the effective dose from external submersion in the plume, and the resulting Total Effective Dose Equivalent (TEDE). These doses were determined for each type of MPC. The ISFSI controlled area boundary must be at least 100 meters from the nearest loaded HI-STAR 100 System in accordance with 10CFR72.106(b) [7.0.1]. The doses are compared to the regulatory limits specified in 10CFR72.104 [7.0.1].

Confinement boundary welds performed at the fabricator's facility are inspected by volumetric and liquid penetrant examination methods as detailed in Section 9.1. Field welds are performed on the MPC lid, the MPC vent and drain port covers, and MPC closure ring. The weld of the MPC lid-to-shell is liquid penetrant examined on the root and final pass, volumetrically (or multilayer liquid penetrant) examined, hydrostatically tested, and leak rate tested. The vent and drain port cover plates are liquid penetrant examined on the root and final pass and leak rate tested. The MPC closure ring welds are inspected by the liquid penetrant examination method on the root pass, if multiple pass, and final pass. In Chapter 11, the MPC lid-to-shell weld is postulated to fail to confirm the safety of the HI-STAR 100 confinement boundary. The failure of the MPC lid weld is equivalent to the MPC drain or vent port cover weld failing. The MPC lid weld failure affects the MPC confinement boundary; however, no leakage will occur due to redundant sealing provided by the MPC closure ring.

7.2.4 Control of Radioactive Material During Fuel Loading Operations

The procedures for closure of the MPC, described in Section 8.1, are intended to assure that there is no unintended release of gas, liquid, or solid materials from the MPC during dry storage. During MPC closure operations, the lines used for venting or draining are routed to the plant's spent fuel pool or radioactive waste processing systems. MPC closure operations are performed inside the plant's fuel building in a controlled and monitored environment.

Radioactive effluent handling during fuel loading and MPC draining, vacuum drying, helium backfilling, and sealing operations is in accordance with the plant's 10CFR50 license and radioactive waste management system.

7.2.5 External Contamination Control

The external surface of the MPC is protected from contamination by preventing it from coming in contact with the spent fuel pool water. Prior to submergence in the spent fuel pool, an inflatable seal is installed at the top of the annulus formed between the MPC shell and the HI-TRAC transfer cask cavity. This annulus is filled with clean demineralized water and the seal is inflated. The inflated seal, backed by the demineralized water maintained at a slight positive pressure, is sufficient to preclude the entry of contaminated water into the annulus. These steps assure that the MPC surface is free of contamination that could become airborne during storage.

Additionally, following fuel loading operations and removal from the spent fuel pool, the upper end of the MPC shell is surveyed for loose surface contamination in accordance with the Technical Specifications.

7.2.6 Confinement Vessel Releasable Source Term

As discussed in Section 7.3.1, the source term used to evaluate the annual dose at the minimum controlled area boundary of 100 meters due to leakage from the MPC confinement boundary consists of gaseous fission products, fines, volatiles and airborne crud particulates. For this evaluation, it is conservatively assumed that 1% of the fuel inventory is available for release under normal conditions of storage and 10% of the fuel inventory is available for release under off-normal conditions of storage. A summary of the isotopes available for release is provided in Table 7.3.1.

7.2.7 Release of Contents Under Normal and Off-Normal Storage Conditions

7.2.7.1 Seal Leakage Rate

The methodology presented in Section 7.3.3.1 was used to determine the leakage rate at the upstream conditions. Using the capillary diameter determined in Section 7.3.3.1, and the parameters for normal and off-normal conditions provided in Table 7.3.6, Equation 7-3 was solved for the leakage rate at the upstream conditions. The resultant normal and off-normal condition leakage rate, 8.8×10^{-6} cm^3/s (at 499.2 K, 4.99 ATM) was calculated.

7.2.7.2 Fraction of Volume Released

The minimum free volume of each MPC design is presented in Tables 4.4.13 and 4.4.14 Using conservatively reduced values of these volumes and the upstream normal and off-normal condition leakage rate of 8.8×10^{-6} cm^3/s, the fraction of the volume released per second is calculated.

7.2.7.3 Release Fraction

The release fraction is that portion of the total radionuclide inventory that is released from the confinement boundary to the atmosphere (i.e., outside the MPC). The release fractions provided in NUREG/CR-6487 [7.3.2] are used. A summary of the release fractions is provided in Table 7.3.1.

7.2.7.4 Radionuclide Release Rate

The radionuclide release rate is the product of the quantity of isotopes available for release, the number of assemblies, the fraction of volume released, and the release fraction.

7.2.7.5 Atmospheric Dispersion Factor

For the evaluation of the dose at the controlled area boundary, the instantaneous χ/Q calculated for accident conditions (8.0×10^{-3} sec/m^3) was reduced to 1.6×10^{-4} sec/m^3 based on the long term nature of the release (1 year); the height of the release being essentially a ground level release ($h_e = 0$); all 16 compass directions (22.5 degree sectors) will be similarly affected due to the long term nature of the continuous release (over one year); the increase in average wind speeds (>1 m/s); and the additional effects of a reduction in atmospheric stability. Therefore, the χ/Q reduction factor of 50 used to correct the short term accident release χ/Q is conservative.

7.2.7.6 Dose Conversion Factors

Dose Conversion Factors (DCF) from EPA Federal Guidance Report No. 11, Table 2.1 [7.3.5] and EPA Federal Guidance Report No. 12, Table III.1 [7.3.6] were used for the analysis. The DCFs are provided on the spread sheets included as Appendix 7.A.

7.2.7.7 Occupancy Time

An occupancy time of 8,760 hours is used for the analysis [7.0.2]. This conservatively assumes that the individual is exposed 24 hours per day for 365 days at the minimum controlled area boundary of 100 meters.

7.2.7.8 Breathing Rate

A breathing rate of 3.3×10^{-4} m^3/sec for a worker is used for the analysis. This assumption is in accordance with the guidance provided in NUREG-1536 [7.0.2] for a worker.

7.2.8 Postulated Doses Under Normal and Off-Normal Conditions of Storage

The following doses to an individual at the site boundary (100 meters) as a result of an assumed effluent release under normal and off-normal conditions of storage were determined; the inhaled committed dose equivalent for critical organs and tissues (gonad, breast, lung, red marrow, bone surface, thyroid, skin, lens of the eye), the effective dose from external submersion in the plume, and the resulting Total Effective Dose Equivalent (TEDE). These doses are determined for each type of MPC and for each condition of storage (i.e., normal and off-normal). The postulated doses as a result of exposure to soil with ground surface contamination and soil contaminated to a depth of 15 cm were also determined. The resultant doses were negligible compared to the those resulting from submersion in the plume and are therefore not reported.

The doses were determined using spreadsheet software. The resultant doses are summarized for each MPC type in Tables 7.3.2, 7.3.3, and 7.3.4. Example spread sheets used for the dose estimates are presented in Appendix 7.A.

7.2.8.1 Whole Body Dose (Total Effective Dose Equivalent)

The whole body dose is the sum of the inhaled committed effective dose equivalent (CEDE) and the external exposure from submersion in the plume. The postulated doses were determined using spreadsheet software. Example spread sheets are provided in Appendix 7.A.

The CEDE is the product of radionuclide release rate, the atmospheric dispersion factor, the occupancy time, the breathing rate, and the effective dose conversion factor.

External exposure from submersion is the product of the nuclide release rate, the atmospheric dispersion factor, the occupancy time, and the effective dose conversion factor.

7.2.8.2 Critical Organ Dose

The dose to the critical organ (or tissue) is the sum of the committed dose equivalent to the critical organ or tissue from inhalation and the dose equivalent to the organ or tissue from submersion in the plume. The postulated doses as a result of exposure to soil with ground surface contamination and soil contaminated to a depth of 15 cm were also determined. The resultant doses were negligible compared to the those resulting from submersion in the plume and are therefore not reported.

The committed dose equivalent to the organ or tissue from inhalation is the product of radionuclide release rate, the atmospheric dispersion factor, the occupancy time, the breathing rate, and the organ/tissue dose conversion factor. The dose equivalent to the organ or tissue from submersion in the plume is the product of the nuclide release rate, the atmospheric dispersion factor, the occupancy time, and the organ/tissue dose conversion factor.

The doses for tissues and organs other than lens of the eye were determined using spreadsheet software. The dose to the lens of the eye as a result of submersion in the plume was estimated using guidance from Dr. James Turner in his book, Atoms, Radiation, and Radiation Protection

[7.3.10]]. Dr. Turner states that alpha particles and low-energy beta particles, such as those from tritium, cannot penetrate to the lens of the eye (at a depth of 3 mm). The discussion continues that many noble gases emit photons and energetic beta particles, which in turn must be considered in the dose estimate. Dr. Turner states that the dose-equivalent rate to tissues near the surface of the body (e.g., lens of the eye) is more than 130 times the dose-equivalent rate in the lung from gases contained in the lung. The estimated dose to the lens of the eye is greatest using the accident condition of storage for the MPC-68. Section 7.3.4.2 presents the detailed discussion of the dose to the lens of the eye.

7.2.9 Site Boundary

The estimated annual dose at the controlled area boundary is highest due to anticipated occurrences (off-normal) using the MPC-68. The estimated TEDE (0.87 mrem/yr) is a small fraction of the annual 25 mrem whole body limit imposed by 10 CFR 72.104(a). The estimated thyroid dose (0.10 mrem/yr) is a small fraction of the annual 75 mrem thyroid limit imposed by 10 CFR 72.104(a). Additionally, the dose estimates to other critical organs are small fractions of the annual 25 mrem critical organ limit imposed by 10 CFR 72.104(a). The highest of the "other critical organs" is 8.01 mrem to the bone surface.

7.2.10 Assumptions

The following presents a summary of assumptions for the normal and off-normal condition confinement analysis of the HI-STAR 100 System.

- The distance from the cask to the site boundary is 100 meters.
- Under normal conditions of storage, 1% of the fuel rods have ruptured. This assumption is in accordance with NUREG-1536 for normal storage conditions.
- Under off-normal conditions of storage, 10% of the fuel rods have ruptured. This assumption is in accordance with ISG-5 and NUREG-1536 for off-normal storage conditions.
- Unchoked flow correlations were used as the unchoked flow correlations better approximate the true measured flow rate for the leakage rates associated with transportation packages.
- The capillary length required for Equation 7-3 was chosen to be the smaller of the MPC lid closure weld sizes (MPC 24 and MPC-68, a=1.9cm and MPC-68F, a=3.2), which is 1.9 cm. The shorter leak path assumptions conservatively over estimates the leak rate in the thicker (MPC-68F) weld.
- For conservatism, the upstream pressure at test conditions (inside of the MPC) is assumed to be 2 ATM and the down stream pressure (outside of the MPC) is assumed to be 1 ATM.

- The temperature at test conditions is assumed to be equal to a temperature, 212° F based on the maximum temperature achievable by the water in the MPC during performance of the leak test. This is conservative because the leak hole diameter computed from test conditions is larger.

- The majority of the activity associated with crud is due to ^{60}Co. This assumption follows from the discussion provided in NUREG/CR-6487 [7.3.2].

- The normal and off-normal condition leakage rate persists for one year without a decrease in the rate or nuclide concentration.

- The individual at the site boundary is exposed for 8,760 hours [7.0.2]. This conservatively assumes that the individual is exposed 24 hours per day for 365 days.

- In accordance with the International Commission on Radiological Protection (ICRP) Publication 30 [7.3.7 *"for exposure in radioisotopes of the noble gases, external irradiation will be of such overriding importance that it alone need be considered."* Therefore, the contribution to the committed effective dose equivalent from ^{85}Kr is neglected.

- A breathing rate of 3.3×10^{-4} m^3/sec for a worker is used for the analysis [7.0.2]. This assumption is in accordance with the guidance provided in NUREG-1536 for a worker.

- All fuel stored in the MPC is of the design basis type with a bounding burnup and cooling time.

- Exposure to dose conversion factors for inhalation reported in EPA Federal Guidance Report No. 11, Table 2.1 [7.3.5] were selected by lung clearance class which reports the most conservative values.

7.3 CONFINEMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The MPC uses redundant confinement closures to assure that there is no release of radioactive materials, including fission gases, volatiles, fuel fines or crud, for postulated storage accident conditions. The analyses presented in Chapters 3 and 11 demonstrate that the MPC remains intact during all normal, off-normal and postulated accident conditions, including the associated increased internal pressure due to decay heat generated by the stored fuel. The MPC is designed, fabricated, and tested in accordance with the applicable requirements of ASME, Section III, Subsection NB [7.1.1] to the maximum extent practicable. In summary, there is no mechanistic failure that results in a breach of the MPC confinement boundary.

The above discussion notwithstanding, this section evaluates the consequences of a non-mechanistic postulated ground level breach of the MPC confinement boundary. This breach could result in the release of gaseous fission products, fines, volatiles and airborne crud particulates. The internal accident pressure of 125 psig, as specified in Table 7.1.1, is assumed as an initial condition for this evaluation. The following doses to an individual at the site boundary (100 meters) as a result of an assumed effluent release under accident conditions of storage were determined; the inhaled committed dose equivalent for critical organs and tissues (gonad, breast, lung, red marrow, bone surface, thyroid, skin, lens of the eye), the effective dose from external submersion in the plume, and the resulting Total Effective Dose Equivalent (TEDE). These doses were determined for each type of MPC. The ISFSI controlled area boundary must be at least 100 meters from the nearest loaded HI-STAR 100 System in accordance with 10CFR72.106(b) [7.0.1]. The doses are compared to the regulatory limits specified in 10CFR72.106(b) [7.0.1].

7.3.1 Confinement Vessel Releasable Source Term

In accordance with NUREG/CR-6487 [7.3.2], the following contributions are considered in determining the releasable source term for packages designed to transport irradiated fuel rods: (1) the radionuclides comprising the fuel rods, (2) the radionuclides on the surface of the fuel rods, and (3) the residual contamination on the inside surfaces of the vessel. NUREG/CR-6487 goes on to state that a radioactive aerosol can be generated inside a vessel when radioactive material from the fuel rods or from the inside surfaces of the container become airborne. The sources for the airborne material are (1) residual activity on the cask interior, (2) fission and activation-product activity associated with corrosion-deposited material (crud) on the fuel assembly surface, and (3) the radionuclides within the individual fuel rods. In accordance with NUREG/CR-6487, contamination due to residual activity on the cask interior surfaces is negligible as compared to crud deposits on the fuel rods themselves and therefore may be neglected. The source term considered for this calculation results from the spallation of crud from the fuel rods and from the fines, gases and volatiles which result from cladding breaches. The methodology of NUREG/CR-6487 is conservatively applied to the storage confinement accident analysis as dry storage conditions are less severe than transport conditions.

The inventory for isotopes other than ^{60}Co is calculated with the SAS2H and ORIGEN-S modules of the SCALE 4.3 system as described in Section 5.2. The inventory for the MPC-24 was conservatively based on the B&W 15x15 fuel assembly with a burnup of 40,000 MWD/MTU, 5 years of cooling time, and an enrichment of 3.4%. The inventory for the MPC-68 was based the GE

7x7 fuel assembly with a burnup of 40,000 MWD/MTU, 5 years of cooling time, and 3.0% enrichment. The Technical Specifications limit the fuel assembly burnup well below 40,000 MWD/MTU for both BWR and PWR fuel at 5 years of cooling time. This ensures that the inventory used in this calculation exceeds that of the fuel authorized for storage in accordance with the Technical Specifications. The inventory for the MPC-68F was based on the GE 6x6 fuel assembly with a burnup of 30,000 MWD/MTU, 18 years of cooling time, and 2.24% enrichment. The Technical Specifications limit the burnup and cooling time of fuel debris in an MPC-68F to a maximum of 30,000 MWD/MTU at a minimum of 18 years cooling time. Additionally, an MPC-68F was analyzed containing 67 GE 6x6 assemblies and a DFC containing 18 thorium rods. Finally, an Sb-Be source stored in one fuel rod in one assembly with 67 GE 6x6 assemblies was analyzed. The isotopes which contribute greater than 0.1% to the total curie inventory for the fuel assembly are considered in the evaluation as fines. The analysis also includes actinides as the dose conversion factors for these isotopes are in general, orders of magnitude greater than other isotopes (e.g., isotopes of plutonium, americium, curium, and neptunium were included regardless of their contribution to the inventory). A summary of the isotopes available for release is provided in Table 7.3.1.

7.3.2 Crud Radionuclides

The majority of the activity associated with crud is due to ^{60}Co [7.3.2]. The inventory for ^{60}Co was determined by using the crud surface activity for PWR rods (140×10^{-6} Ci/cm^2) and for BWR rods (1254×10^{-6} Ci/cm^2) provided in NUREG/CR-6487 [7.3.2] multiplied by the surface area per assembly (3×10^5 cm^2 and 1×10^5 cm^2 for PWR and BWR, respectively, also provided in NUREG/CR-6487). The source terms were then decay corrected (5 years for the MPC-24 and MPC-68; 18 years for the MPC-68F) using the basic radioactive decay equation:

Equation 7-1

$$A(t) = A_0 e^{-\lambda t}$$

where:

- $A(t)$ is activity at time t [Ci]
- A_0 is the initial activity [Ci]
- λ is the $\ln 2/t_{1/2}$ (where $t_{1/2} = 5.272$ years for ^{60}Co)
- t is the time in years (5 years for the MPC-24 and MPC-68; 18 years for the MPC-68F)

Total ^{60}Co crud is 140 μCi/cm^2 for PWR and 1254 μCi/cm^2 for BWR [7.3.2].

PWR	BWR
Surface area per Assy = 3.0E+05 cm^2	Surface area per Assy = 1.0E+05 cm^2

$140\ \mu Ci/cm^2 \times 3.0E+05\ cm^2 = 42.0\ Ci$ $1254\ \mu Ci/cm^2 \times 1.0E+05\ cm^2 = 125.4\ Ci$

$^{60}Co(t) = {}^{60}Co_0\ e^{-(\lambda t)}$, where $\lambda = \ln 2/t_{1/2}$, t = 5 years (for the MPC-24 and MPC-68), t = 18 years (MPC-68F), $t_{1/2}$ = 5.272 years for ^{60}Co [7.3.3]

MPC-24

$^{60}Co(5) = 42.0\ Ci\ e^{-(\ln 2/5.272)(5)}$
$^{60}Co(5) = 21.77\ Ci$

MPC-68

$^{60}Co(5) = 125.4\ Ci\ e^{-(\ln 2/5.272)(5)}$
$^{60}Co(5) = 64.98\ Ci$

MPC-68F

$^{60}Co(18) = 125.4\ Ci\ e^{-(\ln 2/5.272)(18)}$
$^{60}Co(18) = 11.76\ Ci$

A summary of the ^{60}Co inventory available for release is provided in Table 7.3.1.

7.3.3 Release of Contents Under Non-Mechanistic Accident Conditions of Storage

7.3.3.1 Seal Leakage Rate

The helium leak rate testing performed on the MPC confinement boundary verifies the helium leak rate to be less than or equal to 5×10^{-6} atm-cm^3/s[1] as required by the Technical Specifications with a minimum sensitivity of 2.5×10^{-6} atm-cm^3/s. As demonstrated by analysis, the MPC confinement boundary is not compromised as a result of normal, off-normal, and accident conditions. Based on the robust nature of the MPC confinement boundary, the NDE inspection of the welds, and the measurement of the helium leakage rate, there is essentially no leakage. However, it is conservatively assumed that the maximum possible leakage rate from the confinement vessel is the maximum leakage rate acceptance criteria plus the sensitivity. This yields an assumed helium leakage rate of 7.5×10^{-6} atm-cm^3/s.

Equation B-1 of ANSI N14.5 (1997) [7.3.8] is used to express this mass-like helium flow rate (Q_u) measured in atm-cm^3/s as a function of the upstream volumetric leakage rate (L_u) as follows:

Equation 7-2

[1] According to ANSI N14.5 (1997), the mass-like leakage rate specified herein is often used in leakage testing. This is defined as the rate of change of the pressure-volume product of the leaking fluid at test conditions.

$$Q_u = L_u * P_u \quad \text{atm-cm}^3\text{/sec (Equation B-1 from ANSI N14.5(1997))}$$

$$L_u = Q_u/P_u \quad \text{cm}^3\text{/sec}$$

where:

L_u is the upstream volumetric leakage rate [cm^3/s],
Q_u is the mass-like helium leak rate [atm cm^3/s], and
P_u is the upstream pressure [ATM]

The corresponding leakage rate at accident conditions is determined using the following methodology. For conservatism, unchoked flow correlations were used as the unchoked flow correlations better approximate the true measured flowrate for the leakage rates.

For conservatism, the upstream pressure at test conditions (inside of the MPC) is assumed to be 2 ATM (minimum) and the down stream pressure (outside of the MPC) is assumed to be 1 ATM (at 298 K), therefore, the average pressure is 1.5 ATM. The evaluation was performed using the helium gas temperature at test conditions of both 70°F and 212°F. These temperatures are representative of the possible temperature of the helium gas in the confinement vessel during the helium leak test. The 212°F helium temperature is the upper bound because the water inside the MPC is shown not to boil in Chapter 4 as long as the "time-to-boil" time limit is not exceeded. From the two calculations using the two temperatures, it was determined that the higher temperature (212°F) results in a greater capillary diameter.

Using the equations for molecular and continuum flow, Equation B-5 provided in ANSI N14.5-1997 [7.3.8], the corresponding capillary diameter, D, was calculated. The capillary length required for Equation 7-3 was conservatively chosen to be the minimum MPC lid closure weld which is 1.9 cm. Table 7.3.6 provides a summary of the parameters used in the calculation.

Equation 7-3

$$L_u = \left[\frac{2.49 x 10^6 D^4}{a u} + \frac{3.81 x 10^3 D^3 \sqrt{\frac{T}{M}}}{a P_a}\right]\left[P_u - P_d\right]\left[\frac{P_a}{P_u}\right]$$

where:

L_u is the allowable leakage rate at the upstream pressure [cm^3/s],
a is the capillary length [cm],
T is the temperature [°K],
M is the gas molecular weight [g/mole] from ANSI N14.5, Table B1 [7.3.8],
u is the fluid viscosity for helium [cP] from Rosenhow and Hartnett [7.3.9]
P_u is the upstream pressure [ATM],
P_d is the downstream pressure [ATM], and
P_a is the average pressure; $P_a = (P_u + P_d)/2$ [ATM].

D is the capillary diameter [cm].

The capillary diameter (D) computed from the above equation is equal to 4.96×10^{-4} cm.

Using the capillary diameter determined above, and the parameters for accident conditions provided in Table 7.3.6, Equation 7-3 was solved for the leakage rate at the upstream conditions. The resultant hypothetical accident leakage rate, 1.25×10^{-5} cm^3/s (at 843 K, 9.5 ATM) was calculated.

7.3.3.2 Fraction of Volume Released

The minimum free volume of each MPC design is presented in Tables 4.4.13 and 4.4.14. Using conservatively reduced values of these volumes and the upstream hypothetical accident leakage rate of 1.25×10^{-5} cm^3/s, the fraction of the volume released per second is calculated.

7.3.3.3 Release Fraction

The release fraction is that portion of the total radionuclide inventory that is released from the confinement boundary to the atmosphere (i.e., outside the MPC). The release fractions provided in NUREG/CR-6487 [7.3.2] are used. A summary of the release fractions is provided in Table 7.3.1.

7.3.3.4 Radionuclide Release Rate

The radionuclide release rate is the product of the quantity of isotopes available for release, the number of assemblies, the fraction of volume released, and the release fraction.

7.3.3.5 Atmospheric Dispersion Factor

The short-term accident condition atmospheric dispersion factor at 100 meters was determined using Regulatory Guide 1.145 [7.3.4]. In accordance with NUREG-1536 [7.0.2], the dispersion factor was determined on the basis of F-stability diffusion, a wind speed of 1 m/s, and plume meandering.

Reg Guide 1.145 [7.3.4] specifies that χ/Q be calculated using the following three equations. The values determined using Equations 7-4 and 7-5 should be compared and the higher value selected. This value should be compared with the value determined using Equation 7-6, and the lower value of these two should be selected as the appropriate χ/Q value. This methodology was used to determine the value for χ/Q.

Equation 7-4

$$\frac{\chi}{Q} = \frac{1}{U(\pi \sigma_y \sigma_z + A/2)}$$

Equation 7-5
Equation 7-6

$$\frac{\chi}{Q} = \frac{1}{U(3\pi\,\sigma_y\,\sigma_z)}$$

$$\frac{\chi}{Q} = \frac{1}{U\,\pi\,\Sigma_y\,\sigma_z}$$

where:

χ/Q is relative concentration, in sec/m^3,

π is 3.14159,

U is windspeed at 10 meters above plant grade, in m/sec,

σ_y is lateral plume spread, in meters, a function of atmospheric stability and distance (Figure 1, Reg Guide 1.145 [7.3.4]),

σ_z is vertical plume spread, in meters, a function of atmospheric stability and distance (Figure 2, Reg Guide 1.145 [7.3.4]),

Σ_y is lateral plume spread with meander and building wake effects, in m, = M σ_y, where M is determined from Figure 3, Reg Guide 1.145 [7.3.4], and

A is the smallest vertical-plane cross-sectional area of the structure (cross section of the MPC), m^2.

Equations 7-4 through 7-6 were solved using the parameters presented in Table 7.3.5. The atmospheric dispersion factor, χ/Q, at 100 meters was selected in accordance with the methodology described above. The χ/Q value used to determine the dose is 8.0 x 10^{-3} sec/m^3. This short term accident condition χ/Q is deemed conservative for an accident evaluation period of 30 days.

7.3.3.6 Dose Conversion Factors

Dose Conversion Factors (DCF) from EPA Federal Guidance Report No. 11, Table 2.1 [7.3.5] and EPA Federal Guidance Report No. 12, Table III.1 [7.3.6] were used for the analysis. The DCFs are provided on the spread sheets included as Appendix 7.A.

7.3.3.7 Occupancy Time

An occupancy time of 720 hours (30 days) is used for the analysis [7.0.2]. This conservatively assumes that the individual is exposed 24 hours per day for 30 days at the minimum controlled area boundary of 100 meters. The accident event duration is considered conservative as any accident condition of storage resulting in the failure of 100% of the stored fuel rods would be detected by the routine security and surveillance inspections and corrective actions would be completed prior to the end of this 30-day period.

7.3.3.8 Breathing Rate

A breathing rate of 3.3 x 10^{-4} m^3/sec for a worker is used for the analysis. This assumption is in

accordance with the guidance provided in NUREG-1536 [7.0.2] for a worker.

7.3.4 Postulated Accident Doses

The following doses to an individual at the site boundary (100 meters) as a result of an assumed effluent release under accident conditions of storage were determined; the inhaled committed dose equivalent for critical organs and tissues (gonad, breast, lung, red marrow, bone surface, thyroid, skin, lens of the eye), the effective dose from external submersion in the plume, and the resulting Total Effective Dose Equivalent (TEDE). These doses are determined for each type of MPC. The postulated doses as a result of exposure to soil with ground surface contamination and soil contaminated to a depth of 15 cm were also determined. The resultant doses were negligible compared to the those resulting from submersion in the plume and are therefore not reported.

The doses were determined using spreadsheet software. The resultant doses are summarized for each MPC type in Tables 7.3.2, 7.3.3, and 7.3.4 of the HI-STAR FSAR. Example spread sheets used for the dose estimates are presented in Appendix 7.A.

7.3.4.1 Whole Body Dose (Total Effective Dose Equivalent)

The whole body dose is the sum of the inhaled committed effective dose equivalent (CEDE) and the external exposure from submersion in the plume. The postulated doses were determined using spreadsheet software. Example spread sheets are provided in Appendix 7.A.

The CEDE is the product of radionuclide release rate, the atmospheric dispersion factor, the occupancy time, the breathing rate, and the effective dose conversion factor.

External exposure from submersion is the product of the nuclide release rate, the atmospheric dispersion factor, the occupancy time, and the effective dose conversion factor.

7.3.4.2 Critical Organ Dose

The dose to the critical organ (or tissue) is the sum of the committed dose equivalent to the critical organ or tissue from inhalation and the dose equivalent to the organ or tissue from submersion in the plume. The postulated doses as a result of exposure to soil with ground surface contamination and soil contaminated to a depth of 15 cm were also determined. The resultant doses were negligible compared to the those resulting from submersion in the plume and are therefore not reported.

The committed dose equivalent to the organ or tissue from inhalation is the product of radionuclide release rate, the atmospheric dispersion factor, the occupancy time, the breathing rate, and the organ/tissue dose conversion factor. The dose equivalent to the organ or tissue from submersion in the plume is the product of the nuclide release rate, the atmospheric dispersion factor, the occupancy time, and the organ/tissue dose conversion factor.

The dose to the lens of the eye as a result of submersion in the plume was estimated using guidance from Dr. James Turner in his book, Atoms, Radiation, and Radiation Protection [7.3.10]. Dr. Turner states that alpha particles and low-energy beta particles, such as those from tritium, cannot penetrate to the lens of the eye (at a depth of 3 mm). The discussion continues that many noble gases emit

photons and energetic beta particles, which in turn must be considered in the dose estimate. Dr. Turner states that the dose-equivalent rate to tissues near the surface of the body (e.g., lens of the eye) is more than 130 times the dose-equivalent rate in the lung from gases contained in the lung. Using the accident condition of storage for the MPC-68 (which is the highest dose to the lung), the estimated dose to the lung from gases in the lung is 5.34×10^{-4} mrem. Conservatively multiplying this value by 150, the estimated dose to the lens of the eye is 8.01×10^{-2} mrem. This estimated dose to the lens of the eye, 8.01×10^{-2} mrem, is a small fraction of the 15 rem limit imposed by 10 CFR 72.106(b).

7.3.5 Site Boundary

The estimated accident doses at the controlled area boundary are highest for the accident condition of storage for the MPC-68. The estimated TEDE (44.1 mrem) is a small fraction of the 5 rem whole body limit imposed by 10 CFR 72.106(b). The estimated bone surface dose which is the highest critical organ dose (468 mrem) is a small fraction of the 50 rem critical organ limit imposed by 10 CFR 72.106(b). Additionally, the shallow dose estimate to skin (0.17 mrem) is a small fraction of the 50 rem shallow dose equivalent to skin or other extremity limit imposed by 10 CFR 72.106(b).

7.3.6 Assumptions

The following presents a summary of assumptions for the accident condition confinement analysis of the HI-STAR 100 System.

- The distance from the cask to the site boundary is 100 meters.
- 100% of the fuel rods have ruptured. This assumption is conservative because it results in the greatest potential release of radioactive material.
- Unchoked flow correlations were used as the unchoked flow correlations better approximate the true measured flowrate for the leakage rates associated with transportation packages.
- For conservatism, the upstream pressure at test conditions (inside of the MPC) is assumed to be 2 atm and the down stream pressure (outside of the MPC) is assumed to be 1 atm.
- The temperature at test conditions is assumed to be equal to an ambient reference temperature, 212° F based on the maximum temperature achievable by the water in the MPC during performance of the leak test. This is conservative because the leak hole diameter computed from test conditions is larger.
- Bounding accident conditions (i.e., MPC cavity at design pressure (125 psig) at peak cladding temperature limit (570° C)) are postulated for this analysis.
- The capillary length required for Equation 2-3 was conservatively chosen to be smaller ofthe MPC lid closure weld sizes (MPC-24 and MPC-68, a=1.9 cm and MPC-68, a=3.2 cm) which is 1.9 cm. The shorter leak path assumption conservatively over estimates the leak rate in the thicker (MPC-68F) weld.

- The majority of the activity associated with crud is due to ^{60}Co. This assumption follows from the discussion provided in NUREG/CR-6487 [7.3.2].

- The accident condition leakage rate persists for 30 days without a decrease in the rate or nuclide concentration.

- The individual at the site boundary is exposed for 720 hours (30 days). This conservatively assumes that the individual is exposed 24 hours per day for 30 days.

- A breathing rate of 3.3×10^{-4} m^3/sec for a worker is used for the analysis [7.0.2]. This assumption is in accordance with the guidance provided in NUREG-1536 for a worker.

- All fuel stored in the MPC is of the design basis type with a bounding burnup and cooling time.

- In accordance with the International Commission on Radiological Protection (ICRP) Publication 30 [7.3.7 *"for exposure in radioisotopes of the noble gases, external irraditaion will be of such overridding importance that it alone need be considered."* Therefore, the contribution to the committed effective dose equivalent from ^{85}Kr is neglected.

- Exposure to dose conversion factors for inhalation reported in EPA Federal Guidance Report No. 11, Table 2.1 [7.3.5] were selected by lung clearance class which reports the most conservative values.

Table 7.3.1

Isotope Inventory and Release Fraction

Nuclide	MPC-24 Ci/Assembly	MPC-68 Ci/Assembly	MPC-68F Ci/Assembly	Release Fraction [7.3.2]
Gases				
^{3}H	2.21E+02	8.72E+01	1.76E+01	0.30
^{129}I	1.93E-02	7.72E-03	--	0.30
^{85}Kr	3.75E+03	1.43E+03	2.54E+02	0.30
Crud				
^{60}Co	2.18E+01	6.50E+01	1.18E+01	0.15 normal/off-normal 1.0 accident
Volatiles				
^{90}Sr	3.91E+04	1.52E+04	4.64E+03	2.0E-04
^{106}Ru	1.18E+04	4.16E+03	--	2.0E-04
^{134}Cs	1.90E+04	7.20E+03	2.96E+01	2.0E-04
^{137}Cs	5.77E+04	2.29E+04	7.21E+03	2.0E-04
Fines				
^{241}Pu	6.33E+04	2.10E+04	4.99E+03	3.0 E-05
^{90}Y	3.91E+04	1.52E+04	4.64E+03	3.0 E-05
^{147}Pm	2.48E+04	8.88E+03	1.24E+02	3.0 E-05
^{144}Ce	7.97E+03	2.46E+03	--	3.0 E-05
^{144}Pr	7.97E+03	2.46E+03	--	3.0 E-05
^{154}Eu	2.89E+03	1.07E+03	1.37E+02	3.0 E-05
^{244}Cm	2.06E+03	9.30E+02	1.50E+02	3.0 E-05
^{238}Pu	1.98E+03	7.49E+02	2.41E+02	3.0 E-05
^{125}Sb	1.57E+03	6.40E+02	--	3.0 E-05
^{155}Eu	8.53E+02	3.51E+02	2.01E+01	3.0 E-05

Table 7.3.1
(continued)

Isotope Inventory and Release Fractions

Nuclide	MPC-24 Ci/Assembly	MPC-68 Ci/Assembly	MPC-68F Ci/Assembly	Release Fraction [7.3.2]
^{241}Am	6.46E+02	2.20E+02	2.45E+02	3.0 E-05
^{125m}Te	3.84E+02	1.56E+02	--	3.0 E-05
^{240}Pu	3.06E+02	1.26E+02	6.42E+01	3.0 E-05
^{151}Sm	2.37E+02	--	2.67E+01	3.0 E-05
^{239}Pu	1.86E+02	6.16E+01	3.05E+01	3.0 E-05
^{137m}Ba	5.44E+04	2.16E+04	6.81E+03	3.0 E-05
^{106}Rh	1.18E+04	4.16E+03	--	3.0 E-05
^{144m}Pr	1.12E+02	--	--	3.0 E-05
^{243}Am	1.73E+01	7.39E+00	2.55E+00	3.0 E-05
^{242}Cm	1.54E+01	6.10E+00	7.91E-01	3.0 E-05
^{243}Cm	1.14E+01	4.81E+00	1.30E+00	3.0 E-05
^{239}Np	1.73E+01	7.39E+00	--	3.0 E-05
^{237}Np	2.02E-01	7.05E-02	2.72E-02	3.0 E-05
^{242}Pu	1.38E+00	5.95E-01	2.51E-01	3.0 E-05
^{242}Am	4.69E+00	1.69E+00	9.55E-01	3.0 E-05
^{242m}Am	4.72E+00	1.70E+00	9.59E-01	3.0 E-05

Note: The isotopes which contribute greater than 0.1% to the total curie inventory for the fuel assembly are considered in the evaluation as fines. The analysis also includes actinides as the dose conversion factors for these isotopes are in general, orders of magnitude greater than other isotopes (e.g., isotopes of plutonium, americium, curium, and neptunium were included regardless of their contribution to the inventory).

Table 7.3.2

MPC-24
Postulated Doses
To An Individual at the Controlled Area Boundary (100 meters)
As a Result of an Assumed Effluent Release

	Normal Conditions of Storage			Off-Normal Conditions of Storage			Accident Conditions of Storage		
Organ or Tissue	Dose from Inhalation [mrem/yr]	Dose from Submersion [mrem/yr]	Total [mrem/yr]	Dose from Inhalation [mrem/yr]	Dose from Submersion [mrem/yr]	Total [mrem/yr]	Dose from Inhalation [mrem*]	Dose from Submersion [mrem*]	Total [mrem*]
Gonad	1.35E-02	2.45E-04	1.37E-02	1.07E-01	2.71E-04	1.07E-01	6.22E+00	1.11E-02	6.23E+00
Breast	1.22E-02	2.77E-04	1.25E-02	1.48E-02	3.06E-04	1.51E-02	6.32E-01	1.26E-02	6.45E-01
Lung	2.80E-01	2.47E-04	2.80E-01	7.82E-01	2.72E-04	7.82E-01	4.15E+01	1.12E-02	4.15E+01
Red Marrow	6.62E-02	2.45E-04	6.64E-02	5.62E-01	2.69E-04	5.62E-01	3.27E+01	1.11E-02	3.27E+01
Bone Surface	6.87E-01	3.55E-04	6.87E-01	6.79E+00	3.99E-04	6.79E+00	3.98E+02	1.65E-02	3.98E+02
Thyroid	1.08E-02	2.53E-04	1.11E-02	1.35E-02	2.79E-04	1.38E-02	5.88E-01	1.15E-02	6.00E-01
Skin	N/A	3.80E-04	3.80E-04	N/A	1.23E-03	1.23E-03	N/A	6.62E-02	6.62E-02
Effective	8.23E-02	2.51E-04	**8.26E-02**	4.77E-01	2.77E-04	**4.77E-01**	2.72E+01	1.14E-02	**2.72E+01**

*The accident duration is 30 days.

Table 7.3.3

MPC-68
Postulated Doses
To An Individual at the Controlled Area Boundary (100 meters)
As a Result of an Assumed Effluent Release

	Normal Conditions of Storage			Off-Normal Conditions of Storage			Accident Conditions of Storage		
Organ or Tissue	Dose from Inhalation [mrem/yr]	Dose from Submersion [mrem/yr]	Total [mrem/yr]	Dose from Inhalation [mrem/yr]	Dose from Submersion [mrem/yr]	Total [mrem/yr]	Dose from Inhalation [mrem*]	Dose from Submersion [mrem*]	Total [mrem*]
Gonad	4.06E-02	2.24E-03	4.28E-02	1.50E-01	2.27E-03	1.52E-01	8.21E+00	8.92E-02	8.29E+00
Breast	1.11E-01	2.53E-03	1.14E-01	1.14E-01	2.56E-03	1.17E-01	4.51E+00	1.01E-01	4.61E+00
Lung	2.13E+00	2.26E-03	2.13E+00	2.73E+00	2.29E-03	2.73E+00	1.20E+02	8.99E-02	1.20E+02
Red Marrow	1.67E-01	2.24E-03	1.70E-01	7.47E-01	2.27E-03	7.49E-01	4.18E+01	8.91E-02	4.18E+01
Bone Surface	8.75E-01	3.24E-03	8.77E-01	8.02E+00	3.29E-03	8.02E+00	4.68E+02	1.30E-01	4.68E+02
Thyroid	9.75E-02	2.31E-03	9.98E-02	1.01E-01	2.34E-03	1.03E-01	4.01E+00	9.21E-02	4.10E+00
Skin	N/A	2.74E-03	2.74E-03	N/A	3.74E-03	3.74E-03	N/A	1.68E-01	1.68E-01
Effective	4.06E-01	2.29E-03	**4.08E-01**	8.70E-01	2.32E-03	**8.72E-01**	4.41E+01	9.14E-02	**4.41E+01**

*The accident duration is 30 days.

Table 7.3.4

MPC-68F
Postulated Doses
To An Individual at the Controlled Area Boundary (100 meters)
As a Result of an Assumed Effluent Release

	Normal Conditions of Storage			Off-Normal Conditions of Storage			Accident Conditions of Storage		
Organ or Tissue	Dose from Inhalation [mrem/yr]	Dose from Submersion [mrem/yr]	Total [mrem/yr]	Dose from Inhalation [mrem/yr]	Dose from Submersion [mrem/yr]	Total [mrem/yr]	Dose from Inhalation [mrem*]	Dose from Submersion [mrem*]	Total [mrem*]
Gonad	9.62E-03	4.06E-04	1.00E-02	4.33E-02	4.08E-04	4.37E-02	2.80E+00	1.60E-02	2.82E+00
Breast	2.01E-02	4.59E-04	2.06E-02	2.07E-02	4.62E-04	2.12E-02	8.22E-01	1.80E-02	8.40E-01
Lung	3.94E-01	4.09E-04	3.94E-01	5.65E-01	4.12E-04	5.65E-01	2.57E+01	1.61E-02	2.57E+01
Red Marrow	4.24E-02	4.06E-04	4.28E-02	2.25E-01	4.08E-04	2.25E-01	1.46E+01	1.59E-02	1.46E+01
Bone Surface	3.07E-01	5.87E-04	3.08E-01	2.56E+00	5.92E-04	2.56E+00	1.72E+02	2.31E-02	1.72E+02
Thyroid	1.77E-02	4.19E-04	1.81E-02	1.84E-02	4.22E-04	1.88E-02	7.29E-01	1.65E-02	7.45E-01
Skin	N/A	4.98E-04	4.98E-04	N/A	6.73E-04	6.73E-04	N/A	3.00E-02	3.00E-02
Effective	8.26E-02	4.16E-04	**8.30E-02**	2.26E-01	4.18E-04	**2.26E-01**	1.32E+01	1.63E-02	**1.32E+01**

*The accident duration is 30 days.

Table 7.3.5
χ/Q Parameters

Parameter	Value	Reference
U	1 m/s	NUREG-1536 [7.0.2]
σ_y	4.0 m	Figure 1, Reg Guide 1.145 [7.3.4]
σ_z	2.5 m	Figure 2, Reg Guide 1.145 [7.3.4]
$\Sigma_y = M\ \sigma_y$	16	M is determined from Figure 3, Reg Guide 1.145 [7.3.4]
A	8.41 m^2	Chapter 1, Section 1.5

Table 7.3.6

Parameters for Test and Hypothetical Accident Conditions

Parameter	Test	Normal/Off-Normal	Hypothetical Accident
P_u	2 ATM (min)	4.99 ATM	9.5 ATM
P_d	1 ATM	1 ATM	1 ATM
T	373 K	499.2 K	843 K
M	4 g/mol	4 g/mol	4 g/mol
u (helium)	0.0231 cP	0.0283 cP	0.0397 cP
a	1.9 cm	1.9 cm	1.9 cm

7.4 REGULATORY COMPLIANCE

Chapter 7 of this FSAR has been prepared to summarize the confinement features and capabilities of the HI-STAR 100 System. The confinement boundary of the HI-STAR 100 System is designed to provide confinement of radionuclides under normal, off-normal, and accident conditions. The evaluations presented in Chapter 7 provides detailed analyses of the confinement system to show that the radiological releases to the environment during normal storage conditions and from a non-mechanistic accident will be within the limits established by the regulations. The inert atmosphere in the MPC and the passive heat removal capabilities of the HI-STAR 100 assure that the SNF assemblies remain protected from degradation, which might otherwise lead to gross cladding ruptures during storage.

The confinement features and capabilities of the HI-STAR 100 System can be summarized in the following evaluation statements:

1. Section 2 of this FSAR describes confinement structures, systems, and components (SSCs) important to safety in sufficient detail to permit evaluation of their effectiveness.

2. The design of the HI-STAR 100 System adequately protects the spent fuel cladding against degradation that might otherwise lead to gross cladding ruptures. The spent fuel rods are protected from degradation by maintaining an inert gas atmosphere (helium) inside the MPC and keeping the fuel cladding temperatures below the design basis values specified in Chapter 2. Chapter 4 of the FSAR discusses the relevant temperature analyses.

3. The design of the HI-STAR 100 System provides redundant sealing of the confinement system closure joints by the combination of the welded MPC lid, vent and drain port cover plates, and MPC closure ring. The MPC lid has a recess around the perimeter for installation of the closure ring. The MPC closure ring is welded to the MPC lid on the inner diameter of the ring and to the MPC shell on the outer diameter, thereby covering the vent and drain port cover plates, and the MPC lid-to-shell weld.

4. The confinement system is not required to be monitored.

5. The quantity of radionuclides postulated to be released to the environment is discussed in Section 7.2.6, 7.3.1 and 7.3.2 and is summarized in Table 7.3.1. Chapter 7 demonstrates that the incremental dose at the minimum controlled area boundary due to an atmospheric release resulting from leakage from the confinement boundary results in a minor contribution to the annual dose limit in effluents and direct radiation during normal operations or anticipated occurrences which meets the requirements in 10CFR72.104(a) [7.0.1]. The annual dose from normal and off-normal storage operations is provided in Table 7.3.2, 7.3.3 and 7.3.4 and reported in Chapter 10. The potential dose to an individual located at the minimum controlled area boundary (100 meters) from a non-mechanistic accident event is determined for each type of MPC and is summarized in Tables 7.3.2, 7.3.3 and 7.3.4. The licensee is required to perform a site-specific dose evaluation as part of the ISFSI design as dictated in 10CFR72.212 and Chapter 12 to demonstrate compliance with 10CFR72.104. The licensee's evaluation will account for the location of the controlled area boundary, ISFSI size and

configuration, fuel assembly specifics, and the effects of radiation from other on-site operations. Chapter 11 presents the results of the evaluations performed to demonstrate that the HI-STAR 100 System can withstand the effects of all credible accident conditions and natural phenomena with minimal contribution to the site boundary dose. Chapter 5 demonstrates that the direct radiation doses that result from the loss of the neutron shield are far below the requirements of 10CFR72.106. These doses combined with the doses presented in Chapter 7, satisfy the regulatory requirement of 10CFR72.106. The licensee is responsible for demonstrating site-specific compliance with 10CFR72.106.

6. The HI-STAR 100 System confinement boundary is designed and fabricated in accordance with the ASME Code, Section III, Subsection NB to the maximum extent practicable. Chapter 2 provides design criteria for the confinement design. Table 2.2.7 provides applicable Code requirements. Exceptions to specific Code requirements with complete justifications are presented in Table 2.2.15. The structural adequacy of the MPC is demonstrated by the analyses documented in Chapter 3. The HI-STAR 100 System confinement boundary is adequately designed to maintain confinement of all radionuclides under normal, off-normal and accident conditions.

7. The design of the confinement system of the HI-STAR 100 is in compliance with 10CFR72 and the applicable design and acceptance criteria are satisfied. The evaluation of the confinement system design provides reasonable assurance that the HI-STAR 100 System will allow the long term, safe storage of spent fuel.

7.5 REFERENCES

[7.0.1] 10CFR72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste.

[7.0.2] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems", January, 1997.

[7.1.1] American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, Class 1 Components, 1995 Edition.

[7.1.2] HI-STAR 100 Safety Analysis Report, Holtec International Report No. HI-951251, most current revision.

[7.3.1] Deleted.

[7.3.2] Anderson, B.L. et al. *Containment Analysis for Type B Packages Used to Transport Various Contents*. NUREG/CR-6487, UCRL-ID-124822. Lawrence Livermore National Laboratory, November 1996.

[7.3.3] Shleien, B, *The Health Physics and Radiological Health Handbook*, Scinta, Inc. Silver Spring, MD, 1992.

[7.3.4] U.S. Nuclear Regulatory Commission, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," Regulatory Guide 1.145, November 1982.

[7.3.5] U.S. EPA, Federal Guidance Report No. 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, DE89-011065, 1988.

[7.3.6] U.S. EPA, Federal Guidance Report No. 12, *External Exposure to Radionuclides in Air, Water, and Soil*, EPA 402-R-93-081, 1993.

[7.3.7] International Commission on Radiological Protection, Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Part 1; Pergamon Press; Oxford; 1978.

[7.3.8] ANSI N14.5-1997. "American National Standard for Radioactive Material Leakage Tests on Packages for Shipment."

[7.3.9] Rosenhow, W.M.. and Hartnett, J.P., *Handbook of Heat Transfer*, McGraw Hill Book Company, New York, 1973.

[7.3.10] Turner, James E. *Atoms, Radiation , and Radiation Protection*, McGraw Hill Book Company, New York, 1992.

APPENDIX 7.A

EXAMPLE DOSE CALCULATIONS FOR NORMAL, OFF-NORMAL, AND ACCIDENT CONDITIONS OF STORAGE

MPC-68, Normal Conditions of Storage, Dose from Inhalation: 7 pages
MPC-68, Off-Normal Conditions of Storage, Dose from Inhalation: 7 pages
MPC-68, Accident Conditions of Storage, Dose from Inhalation: 7 pages

MPC-68, Normal Conditions of Storage, Dose from Submersion: 8 pages
MPC-68, Off-Normal Conditions of Storage, Dose from Submersion: 8 pages
MPC-68, Accident Conditions of Storage, Dose from Submersion: 8 pages

MPC-68 Normal Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	8.69E-11	3.22E-01	3.15E+07	1.24E-09
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	4.76E-09	1.76E+01	3.15E+07	2.85E-02
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	2.69E-10	9.95E-01	3.15E+07	5.03E-06
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.30E-09	4.81E+00	3.15E+07	6.65E-06
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.30E-08	4.81E+01	3.15E+07	1.15E-04
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	8.76E-09	3.24E+01	3.15E+07	2.47E-04
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	6.82E-07	2.52E+03	3.15E+07	2.64E-03
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	9.52E-12	3.52E-02	3.15E+07	2.67E-08
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	8.25E-15	3.05E-05	3.15E+07	1.35E-11
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.93E-09	7.14E+00	3.15E+07	8.76E-07
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	2.41E-15	8.92E-06	3.15E+07	1.09E-12
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	1.17E-08	4.33E+01	3.15E+07	2.31E-06
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	1.59E-05	5.88E+04	3.15E+07	2.73E-03
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	2.80E-05	1.04E+05	3.15E+07	3.87E-03
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	3.60E-10	1.33E+00	3.15E+07	4.25E-08
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	3.56E-10	1.32E+00	3.15E+07	2.30E-08
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	3.25E-05	1.20E+05	3.15E+07	1.32E-03
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	1.24E-10	4.59E-01	3.15E+07	3.57E-09
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	3.18E-05	1.18E+05	3.15E+07	7.39E-04
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	4.03E-14	1.49E-04	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	3.18E-05	1.18E+05	3.15E+07	3.61E-04
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	3.26E-05	1.21E+05	3.15E+07	4.44E-05
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	5.70E-07	2.11E+03	3.15E+07	6.41E-07
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	2.07E-05	7.66E+04	3.15E+07	1.84E-05
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	7.45E-11	2.76E-01	3.15E+07	1.02E-10
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	2.96E-05	1.10E+05	3.15E+07	3.85E-07
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	3.02E-05	1.12E+05	3.15E+07	3.31E-06
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	1.94E-09	7.18E+00	3.15E+07	6.05E-10
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	3.21E-05	1.19E+05	3.15E+07	1.01E-05
													Total	4.06E-02

MPC-68 Normal Conditions Commilted Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	2.09E-10	7.73E-01	3.15E+07	2.98E-09
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.84E-08	6.81E+01	3.15E+07	1.10E-01
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	2.69E-10	9.95E-01	3.15E+07	5.03E-06
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.78E-09	6.59E+00	3.15E+07	9.10E-06
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.08E-08	4.00E+01	3.15E+07	9.56E-05
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	7.84E-09	2.90E+01	3.15E+07	2.21E-04
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	3.06E-11	1.13E-01	3.15E+07	1.19E-07
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	9.52E-12	3.52E-02	3.15E+07	2.67E-08
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	3.60E-14	1.33E-04	3.15E+07	5.90E-11
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.97E-09	7.29E+00	3.15E+07	8.94E-07
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.05E-14	3.89E-05	3.15E+07	4.76E-12
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	1.55E-08	5.74E+01	3.15E+07	3.06E-06
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	1.04E-09	3.85E+00	3.15E+07	1.78E-07
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	1.00E-09	3.70E+00	3.15E+07	1.38E-07
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	4.16E-10	1.54E+00	3.15E+07	4.91E-08
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	6.14E-10	2.27E+00	3.15E+07	3.97E-08
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	2.67E-09	9.88E+00	3.15E+07	1.08E-07
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	1.07E-10	3.96E-01	3.15E+07	3.08E-09
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	9.51E-10	3.52E+00	3.15E+07	2.21E-08
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.49E-13	5.51E-04	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	9.22E-10	3.41E+00	3.15E+07	1.05E-08
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	1.52E-08	5.62E+01	3.15E+07	2.07E-08
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	9.44E-10	3.49E+00	3.15E+07	1.06E-09
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	6.29E-09	2.33E+01	3.15E+07	5.58E-09
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	1.63E-11	6.03E-02	3.15E+07	2.22E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	1.69E-08	6.25E+01	3.15E+07	2.20E-10
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	9.45E-10	3.50E+00	3.15E+07	1.04E-10
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	2.49E-12	9.21E-03	3.15E+07	7.76E-13
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	1.38E-09	5.11E+00	3.15E+07	4.33E-10
													Total	1.11E-01

MPC-68														
Normal Conditions														
Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	3.14E-10	1.16E+00	3.15E+07	4.47E-09
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	3.45E-07	1.28E+03	3.15E+07	2.07E+00
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	2.86E-06	1.06E+04	3.15E+07	5.35E-02
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.04E-06	3.85E+03	3.15E+07	5.32E-03
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.18E-08	4.37E+01	3.15E+07	1.04E-04
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	8.82E-09	3.26E+01	3.15E+07	2.48E-04
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	7.42E-09	2.75E+01	3.15E+07	2.87E-05
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	8.89E-09	3.29E+01	3.15E+07	2.49E-05
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	7.74E-08	2.86E+02	3.15E+07	1.27E-04
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.83E-07	6.77E+02	3.15E+07	8.30E-05
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	9.40E-11	3.48E-01	3.15E+07	4.26E-08
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	7.92E-08	2.93E+02	3.15E+07	1.56E-05
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	1.93E-05	7.14E+04	3.15E+07	3.31E-03
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	1.84E-05	6.81E+04	3.15E+07	2.54E-03
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	2.17E-08	8.03E+01	3.15E+07	2.56E-06
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	1.19E-08	4.40E+01	3.15E+07	7.70E-07
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	1.84E-05	6.81E+04	3.15E+07	7.47E-04
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	4.66E-10	1.72E+00	3.15E+07	1.34E-08
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	1.73E-05	6.40E+04	3.15E+07	4.02E-04
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	3.26E-09	1.21E+01	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	1.73E-05	6.40E+04	3.15E+07	1.97E-04
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	1.78E-05	6.59E+04	3.15E+07	2.43E-05
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	1.55E-05	5.74E+04	3.15E+07	1.74E-05
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	1.94E-05	7.18E+04	3.15E+07	1.72E-05
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	2.36E-09	8.73E+00	3.15E+07	3.22E-09
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	1.61E-05	5.96E+04	3.15E+07	2.09E-07
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	1.64E-05	6.07E+04	3.15E+07	1.80E-06
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	5.20E-08	1.92E+02	3.15E+07	1.62E-08
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	4.20E-06	1.55E+04	3.15E+07	1.32E-06
													Total	2.13E+00

MPC-68 Normal Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	1.40E-10	5.18E-01	3.15E+07	1.99E-09
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.72E-08	6.36E+01	3.15E+07	1.03E-01
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	3.28E-08	1.21E+02	3.15E+07	6.13E-04
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.76E-09	6.51E+00	3.15E+07	9.00E-06
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.18E-08	4.37E+01	3.15E+07	1.04E-04
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	8.30E-09	3.07E+01	3.15E+07	2.34E-04
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	3.36E-06	1.24E+04	3.15E+07	1.30E-02
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	2.79E-10	1.03E+00	3.15E+07	7.82E-07
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	1.61E-09	5.96E+00	3.15E+07	2.64E-06
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	2.67E-08	9.88E+01	3.15E+07	1.21E-05
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.38E-14	5.11E-05	3.15E+07	6.26E-12
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	1.06E-07	3.92E+02	3.15E+07	2.09E-05
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	9.38E-05	3.47E+05	3.15E+07	1.61E-02
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	1.52E-04	5.62E+05	3.15E+07	2.10E-02
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	5.35E-10	1.98E+00	3.15E+07	6.31E-08
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	1.43E-08	5.29E+01	3.15E+07	9.26E-07
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	1.74E-04	6.44E+05	3.15E+07	7.06E-03
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	3.01E-09	1.11E+01	3.15E+07	8.66E-08
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	1.69E-04	6.25E+05	3.15E+07	3.93E-03
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.10E-08	4.07E+01	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	1.69E-04	6.25E+05	3.15E+07	1.92E-03
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	1.73E-04	6.40E+05	3.15E+07	2.36E-04
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	3.90E-06	1.44E+04	3.15E+07	4.39E-06
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	1.18E-04	4.37E+05	3.15E+07	1.05E-04
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	2.08E-10	7.70E-01	3.15E+07	2.83E-10
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	2.62E-04	9.69E+05	3.15E+07	3.41E-06
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	1.61E-04	5.96E+05	3.15E+07	1.77E-05
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	1.32E-08	4.88E+01	3.15E+07	4.11E-09
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	1.69E-04	6.25E+05	3.15E+07	5.30E-05
													Total	1.68E-01

68-B Surface

MPC-68 Normal Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	1.38E-10	5.11E-01	3.15E+07	1.96E-09
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.35E-08	5.00E+01	3.15E+07	8.09E-02
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	7.09E-08	2.62E+02	3.15E+07	1.33E-03
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.61E-09	5.96E+00	3.15E+07	8.23E-06
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.10E-08	4.07E+01	3.15E+07	9.74E-05
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	7.94E-09	2.94E+01	3.15E+07	2.24E-04
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	4.20E-05	1.55E+05	3.15E+07	1.63E-01
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	2.78E-10	1.03E+00	3.15E+07	7.79E-07
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	2.01E-08	7.44E+01	3.15E+07	3.29E-05
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	4.54E-08	1.68E+02	3.15E+07	2.06E-05
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.47E-14	5.44E-05	3.15E+07	6.67E-12
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	5.23E-07	1.94E+03	3.15E+07	1.03E-04
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	1.17E-03	4.33E+06	3.15E+07	2.01E-01
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	1.90E-03	7.03E+06	3.15E+07	2.62E-01
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	9.78E-10	3.62E+00	3.15E+07	1.15E-07
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	1.52E-07	5.62E+02	3.15E+07	9.84E-06
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	2.17E-03	8.03E+06	3.15E+07	8.80E-02
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	3.21E-08	1.19E+02	3.15E+07	9.24E-07
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	2.11E-03	7.81E+06	3.15E+07	4.90E-02
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.38E-07	5.11E+02	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	2.11E-03	7.81E+06	3.15E+07	2.40E-02
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	2.17E-03	8.03E+06	3.15E+07	2.96E-03
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	4.87E-05	1.80E+05	3.15E+07	5.48E-05
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	1.47E-03	5.44E+06	3.15E+07	1.30E-03
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	2.03E-09	7.51E+00	3.15E+07	2.77E-09
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	3.27E-03	1.21E+07	3.15E+07	4.25E-05
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	2.01E-03	7.44E+06	3.15E+07	2.21E-04
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	1.65E-07	6.11E+02	3.15E+07	5.14E-08
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	2.12E-03	7.84E+06	3.15E+07	6.65E-04
													Total	8.75E-01

MPC-68														
Normal Conditions														
Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	1.56E-06	5.77E+03	3.15E+07	2.22E-05
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.62E-08	5.99E+01	3.15E+07	9.71E-02
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	2.69E-10	9.95E-01	3.15E+07	5.03E-06
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.72E-09	6.36E+00	3.15E+07	8.80E-06
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.11E-08	4.11E+01	3.15E+07	9.83E-05
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	7.93E-09	2.93E+01	3.15E+07	2.23E-04
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	1.24E-11	4.59E-02	3.15E+07	4.80E-08
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	9.52E-12	3.52E-02	3.15E+07	2.67E-08
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	1.98E-14	7.33E-05	3.15E+07	3.24E-11
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.88E-09	6.96E+00	3.15E+07	8.53E-07
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	8.47E-15	3.13E-05	3.15E+07	3.84E-12
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	7.14E-09	2.64E+01	3.15E+07	1.41E-06
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	1.01E-09	3.74E+00	3.15E+07	1.73E-07
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	9.62E-10	3.56E+00	3.15E+07	1.33E-07
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	3.24E-10	1.20E+00	3.15E+07	3.82E-08
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	2.40E-10	8.88E-01	3.15E+07	1.55E-08
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	1.60E-09	5.92E+00	3.15E+07	6.49E-08
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	9.93E-11	3.67E-01	3.15E+07	2.86E-09
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	9.05E-10	3.35E+00	3.15E+07	2.10E-08
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.32E-14	4.88E-05	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	9.03E-10	3.34E+00	3.15E+07	1.03E-08
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	8.29E-09	3.07E+01	3.15E+07	1.13E-08
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	9.41E-10	3.48E+00	3.15E+07	1.06E-09
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	3.83E-09	1.42E+01	3.15E+07	3.40E-09
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	7.62E-12	2.82E-02	3.15E+07	1.04E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	1.34E-08	4.96E+01	3.15E+07	1.74E-10
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	8.79E-10	3.25E+00	3.15E+07	9.65E-11
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	2.52E-12	9.32E-03	3.15E+07	7.85E-13
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	5.64E-10	2.09E+00	3.15E+07	1.77E-10
													Total	9.75E-02

MPC-68 Normal Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-06
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.30E-04	4.69E-08	1.74E+02	3.15E+07	6.68E-07
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud		3.30E-04				
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	5.91E-08	2.19E+02	3.15E+07	3.54E-01
								Volatiles		3.30E-04				
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	3.30E-04	3.51E-07	1.30E+03	3.15E+07	6.56E-03
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	3.30E-04	1.29E-07	4.77E+02	3.15E+07	6.60E-04
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	3.30E-04	1.25E-08	4.63E+01	3.15E+07	1.11E-04
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	3.30E-04	8.63E-09	3.19E+01	3.15E+07	2.43E-04
								Fines		3.30E-04				
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	3.30E-04	2.23E-06	8.25E+03	3.15E+07	8.64E-03
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	3.30E-04	2.13E-09	7.88E+00	3.15E+07	5.97E-06
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	3.30E-04	1.06E-08	3.92E+01	3.15E+07	1.74E-05
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	5.84E-08	2.16E+02	3.15E+07	2.65E-05
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	3.30E-04	1.17E-11	4.33E-02	3.15E+07	5.31E-09
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	3.30E-04	7.73E-08	2.86E+02	3.15E+07	1.53E-05
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.30E-04	6.70E-05	2.48E+05	3.15E+07	1.15E-02
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	3.30E-04	1.06E-04	3.92E+05	3.15E+07	1.46E-02
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.30E-04	3.30E-09	1.22E+01	3.15E+07	3.90E-07
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.30E-04	1.12E-08	4.14E+01	3.15E+07	7.25E-07
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	3.30E-04	1.20E-04	4.44E+05	3.15E+07	4.87E-03
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	3.30E-04	1.52E-09	5.62E+00	3.15E+07	4.37E-08
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.30E-04	1.16E-04	4.29E+05	3.15E+07	2.70E-03
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	8.10E-09	3.00E+01	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.30E-04	1.16E-04	4.29E+05	3.15E+07	1.32E-03
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	1.19E-04	4.40E+05	3.15E+07	1.62E-04
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	3.30E-04	4.67E-06	1.73E+04	3.15E+07	5.25E-06
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	3.30E-04	8.30E-05	3.07E+05	3.15E+07	7.36E-05
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	3.30E-04	6.78E-10	2.51E+00	3.15E+07	9.24E-10
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.30E-04	1.46E-04	5.40E+05	3.15E+07	1.90E-06
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.30E-04	1.11E-04	4.11E+05	3.15E+07	1.22E-05
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	3.30E-04	1.58E-08	5.85E+01	3.15E+07	4.92E-09
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.30E-04	1.15E-04	4.26E+05	3.15E+07	3.61E-05
													Total	4.06E-01

MPC-68 Off-Normal Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off-normal storage	No. Assy	MPC Vol (cm3)	$L_{off\,nor}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	8.69E-11	3.22E-01	3.15E+07	1.24E-08
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	4.76E-09	1.76E+01	3.15E+07	2.85E-02
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	2.69E-10	9.95E-01	3.15E+07	5.03E-05
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.30E-09	4.81E+00	3.15E+07	6.65E-05
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.30E-08	4.81E+01	3.15E+07	1.15E-03
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	8.76E-09	3.24E+01	3.15E+07	2.47E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	6.82E-07	2.52E+03	3.15E+07	2.64E-02
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	9.52E-12	3.52E-02	3.15E+07	2.67E-07
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	8.25E-15	3.05E-05	3.15E+07	1.35E-10
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.93E-09	7.14E+00	3.15E+07	8.76E-06
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	2.41E-15	8.92E-06	3.15E+07	1.09E-11
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	1.17E-08	4.33E+01	3.15E+07	2.31E-05
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	1.59E-05	5.88E+04	3.15E+07	2.73E-02
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	2.80E-05	1.04E+05	3.15E+07	3.87E-02
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	3.60E-10	1.33E+00	3.15E+07	4.25E-07
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	3.56E-10	1.32E+00	3.15E+07	2.30E-07
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	3.25E-05	1.20E+05	3.15E+07	1.32E-02
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	1.24E-10	4.59E-01	3.15E+07	3.57E-08
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	3.18E-05	1.18E+05	3.15E+07	7.39E-03
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	4.03E-14	1.49E-04	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	3.18E-05	1.18E+05	3.15E+07	3.61E-03
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	3.26E-05	1.21E+05	3.15E+07	4.44E-04
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	5.70E-07	2.11E+03	3.15E+07	6.41E-06
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	2.07E-05	7.66E+04	3.15E+07	1.84E-04
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	7.45E-11	2.76E-01	3.15E+07	1.02E-09
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	2.96E-05	1.10E+05	3.15E+07	3.85E-06
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	3.02E-05	1.12E+05	3.15E+07	3.31E-05
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	1.94E-09	7.18E+00	3.15E+07	6.05E-09
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	3.21E-05	1.19E+05	3.15E+07	1.01E-04
													Total	1.50E-01

MPC-68 Off-Normal Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off-normal storage	No. Assy	MPC Vol (cm3)	$L_{off\,norm}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	2.09E-10	7.73E-01	3.15E+07	2.98E-08
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.84E-08	6.81E+01	3.15E+07	1.10E-01
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	2.69E-10	9.95E-01	3.15E+07	5.03E-05
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.78E-09	6.59E+00	3.15E+07	9.10E-05
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.08E-08	4.00E+01	3.15E+07	9.56E-04
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	7.84E-09	2.90E+01	3.15E+07	2.21E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	3.06E-11	1.13E-01	3.15E+07	1.19E-06
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	9.52E-12	3.52E-02	3.15E+07	2.67E-07
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	3.60E-14	1.33E-04	3.15E+07	5.90E-10
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.97E-09	7.29E+00	3.15E+07	8.94E-06
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.05E-14	3.89E-05	3.15E+07	4.76E-11
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	1.55E-08	5.74E+01	3.15E+07	3.06E-05
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	1.04E-09	3.85E+00	3.15E+07	1.78E-06
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	1.00E-09	3.70E+00	3.15E+07	1.38E-06
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	4.16E-10	1.54E+00	3.15E+07	4.91E-07
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	6.14E-10	2.27E+00	3.15E+07	3.97E-07
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	2.67E-09	9.88E+00	3.15E+07	1.08E-06
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	1.07E-10	3.96E-01	3.15E+07	3.08E-08
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	9.51E-10	3.52E+00	3.15E+07	2.21E-07
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.49E-13	5.51E-04	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	9.22E-10	3.41E+00	3.15E+07	1.05E-07
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	1.52E-08	5.62E+01	3.15E+07	2.07E-07
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	9.44E-10	3.49E+00	3.15E+07	1.06E-08
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	6.29E-09	2.33E+01	3.15E+07	5.58E-08
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	1.63E-11	6.03E-02	3.15E+07	2.22E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	1.69E-08	6.25E+01	3.15E+07	2.20E-09
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	9.45E-10	3.50E+00	3.15E+07	1.04E-09
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	2.49E-12	9.21E-03	3.15E+07	7.76E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	1.38E-09	5.11E+00	3.15E+07	4.33E-09
													Total	1.14E-01

MPC-68 Off-Normal Conditions Commited Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off-normal storage	No. Assy	MPC Vol (cm3)	$L_{off\ nor}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	3.14E-10	1.16E+00	3.15E+07	4.47E-08
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	3.45E-07	1.28E+03	3.15E+07	2.07E+00
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	2.86E-06	1.06E+04	3.15E+07	5.35E-01
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.04E-06	3.85E+03	3.15E+07	5.32E-02
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.18E-08	4.37E+01	3.15E+07	1.04E-03
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	8.82E-09	3.26E+01	3.15E+07	2.48E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	7.42E-09	2.75E+01	3.15E+07	2.87E-04
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	8.89E-09	3.29E+01	3.15E+07	2.49E-04
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	7.74E-08	2.86E+02	3.15E+07	1.27E-03
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.83E-07	6.77E+02	3.15E+07	8.30E-04
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	9.40E-11	3.48E-01	3.15E+07	4.26E-07
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	7.92E-08	2.93E+02	3.15E+07	1.56E-04
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	1.93E-05	7.14E+04	3.15E+07	3.31E-02
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	1.84E-05	6.81E+04	3.15E+07	2.54E-02
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	2.17E-08	8.03E+01	3.15E+07	2.56E-05
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	1.19E-08	4.40E+01	3.15E+07	7.70E-06
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	1.84E-05	6.81E+04	3.15E+07	7.47E-03
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	4.66E-10	1.72E+00	3.15E+07	1.34E-07
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	1.73E-05	6.40E+04	3.15E+07	4.02E-03
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	3.26E-09	1.21E+01	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	1.73E-05	6.40E+04	3.15E+07	1.97E-03
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	1.78E-05	6.59E+04	3.15E+07	2.43E-04
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	1.55E-05	5.74E+04	3.15E+07	1.74E-04
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	1.94E-05	7.18E+04	3.15E+07	1.72E-04
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	2.36E-09	8.73E+00	3.15E+07	3.22E-08
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	1.61E-05	5.96E+04	3.15E+07	2.09E-06
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	1.64E-05	6.07E+04	3.15E+07	1.80E-05
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	5.20E-08	1.92E+02	3.15E+07	1.62E-07
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	4.20E-06	1.55E+04	3.15E+07	1.32E-05
													Total	2.73E+00

MPC-68														
Off-Normal Conditions														
Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	$L_{off\ nor}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	1.40E-10	5.18E-01	3.15E+07	1.99E-08
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.72E-08	6.36E+01	3.15E+07	1.03E-01
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	3.28E-08	1.21E+02	3.15E+07	6.13E-03
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.76E-09	6.51E+00	3.15E+07	9.00E-05
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.18E-08	4.37E+01	3.15E+07	1.04E-03
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	8.30E-09	3.07E+01	3.15E+07	2.34E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	3.36E-06	1.24E+04	3.15E+07	1.30E-01
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	2.79E-10	1.03E+00	3.15E+07	7.82E-06
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	1.61E-09	5.96E+00	3.15E+07	2.64E-05
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	2.67E-08	9.88E+01	3.15E+07	1.21E-04
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.38E-14	5.11E-05	3.15E+07	6.26E-11
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	1.06E-07	3.92E+02	3.15E+07	2.09E-04
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	9.38E-05	3.47E+05	3.15E+07	1.61E-01
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	1.52E-04	5.62E+05	3.15E+07	2.10E-01
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	5.35E-10	1.98E+00	3.15E+07	6.31E-07
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	1.43E-08	5.29E+01	3.15E+07	9.26E-06
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	1.74E-04	6.44E+05	3.15E+07	7.06E-02
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	3.01E-09	1.11E+01	3.15E+07	8.66E-07
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	1.69E-04	6.25E+05	3.15E+07	3.93E-02
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.10E-08	4.07E+01	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	1.69E-04	6.25E+05	3.15E+07	1.92E-02
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	1.73E-04	6.40E+05	3.15E+07	2.36E-03
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	3.90E-06	1.44E+04	3.15E+07	4.39E-05
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	1.18E-04	4.37E+05	3.15E+07	1.05E-03
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	2.08E-10	7.70E-01	3.15E+07	2.83E-09
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	2.62E-04	9.69E+05	3.15E+07	3.41E-05
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	1.61E-04	5.96E+05	3.15E+07	1.77E-04
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	1.32E-08	4.88E+01	3.15E+07	4.11E-08
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	1.69E-04	6.25E+05	3.15E+07	5.30E-04
													Total	7.47E-01

68-B Surface

MPC-68														
Off-Normal Conditions														
Commiited Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	$L_{off\ nor}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	1.38E-10	5.11E-01	3.15E+07	1.96E-08
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.35E-08	5.00E+01	3.15E+07	8.09E-02
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	7.09E-08	2.62E+02	3.15E+07	1.33E-02
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.61E-09	5.96E+00	3.15E+07	8.23E-05
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.10E-08	4.07E+01	3.15E+07	9.74E-04
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	7.94E-09	2.94E+01	3.15E+07	2.24E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	4.20E-05	1.55E+05	3.15E+07	1.63E+00
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	2.78E-10	1.03E+00	3.15E+07	7.79E-06
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	2.01E-08	7.44E+01	3.15E+07	3.29E-04
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	4.54E-08	1.68E+02	3.15E+07	2.06E-04
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.47E-14	5.44E-05	3.15E+07	6.67E-11
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	5.23E-07	1.94E+03	3.15E+07	1.03E-03
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	1.17E-03	4.33E+06	3.15E+07	2.01E+00
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	1.90E-03	7.03E+06	3.15E+07	2.62E+00
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	9.78E-10	3.62E+00	3.15E+07	1.15E-06
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	1.52E-07	5.62E+02	3.15E+07	9.84E-05
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	2.17E-03	8.03E+06	3.15E+07	8.80E-01
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	3.21E-08	1.19E+02	3.15E+07	9.24E-06
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	2.11E-03	7.81E+06	3.15E+07	4.90E-01
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.38E-07	5.11E+02	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	2.11E-03	7.81E+06	3.15E+07	2.40E-01
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	2.17E-03	8.03E+06	3.15E+07	2.96E-02
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	4.87E-05	1.80E+05	3.15E+07	5.48E-04
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	1.47E-03	5.44E+06	3.15E+07	1.30E-02
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	2.03E-09	7.51E+00	3.15E+07	2.77E-08
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	3.27E-03	1.21E+07	3.15E+07	4.25E-04
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	2.01E-03	7.44E+06	3.15E+07	2.21E-03
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	1.65E-07	6.11E+02	3.15E+07	5.14E-07
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	2.12E-03	7.84E+06	3.15E+07	6.65E-03
													Total	8.02E+00

MPC-68														
Off-Normal Conditions														
Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	$L_{off nor}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	1.56E-06	5.77E+03	3.15E+07	2.22E-04
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	1.62E-08	5.99E+01	3.15E+07	9.71E-02
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	2.69E-10	9.95E-01	3.15E+07	5.03E-05
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.72E-09	6.36E+00	3.15E+07	8.80E-05
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.11E-08	4.11E+01	3.15E+07	9.83E-04
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	7.93E-09	2.93E+01	3.15E+07	2.23E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	1.24E-11	4.59E-02	3.15E+07	4.80E-07
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	9.52E-12	3.52E-02	3.15E+07	2.67E-07
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	1.98E-14	7.33E-05	3.15E+07	3.24E-10
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.88E-09	6.96E+00	3.15E+07	8.53E-06
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	8.47E-15	3.13E-05	3.15E+07	3.84E-11
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	7.14E-09	2.64E+01	3.15E+07	1.41E-05
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	1.01E-09	3.74E+00	3.15E+07	1.73E-06
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	9.62E-10	3.56E+00	3.15E+07	1.33E-06
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	3.24E-10	1.20E+00	3.15E+07	3.82E-07
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	2.40E-10	8.88E-01	3.15E+07	1.55E-07
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	1.60E-09	5.92E+00	3.15E+07	6.49E-07
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	9.93E-11	3.67E-01	3.15E+07	2.86E-08
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	9.05E-10	3.35E+00	3.15E+07	2.10E-07
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	1.32E-14	4.88E-05	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	9.03E-10	3.34E+00	3.15E+07	1.03E-07
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	8.29E-09	3.07E+01	3.15E+07	1.13E-07
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	9.41E-10	3.48E+00	3.15E+07	1.06E-08
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	3.83E-09	1.42E+01	3.15E+07	3.40E-08
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	7.62E-12	2.82E-02	3.15E+07	1.04E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	1.34E-08	4.96E+01	3.15E+07	1.74E-09
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	8.79E-10	3.25E+00	3.15E+07	9.65E-10
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	2.52E-12	9.32E-03	3.15E+07	7.85E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	5.64E-10	2.09E+00	3.15E+07	1.77E-09
													Total	1.01E-01

68-Effective

MPC-68 Off-Normal Conditions Commited Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	10% for off-normal storage	No. Assy	MPC Vol (cm3)	$L_{off nor}$ Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
								Gases						
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.30E-04	1.73E-11	6.40E-02	3.15E+07	2.78E-05
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.30E-04	4.69E-08	1.74E+02	3.15E+07	6.68E-06
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	3.30E-04	5.91E-08	2.19E+02	3.15E+07	3.54E-01
								Volatiles						
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	3.30E-04	3.51E-07	1.30E+03	3.15E+07	6.56E-02
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	3.30E-04	1.29E-07	4.77E+02	3.15E+07	6.60E-03
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	3.30E-04	1.25E-08	4.63E+01	3.15E+07	1.11E-03
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	3.30E-04	8.63E-09	3.19E+01	3.15E+07	2.43E-03
								Fines						
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	3.30E-04	2.23E-06	8.25E+03	3.15E+07	8.64E-02
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	3.30E-04	2.13E-09	7.88E+00	3.15E+07	5.97E-05
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	3.30E-04	1.06E-08	3.92E+01	3.15E+07	1.74E-04
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	5.84E-08	2.16E+02	3.15E+07	2.65E-04
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	3.30E-04	1.17E-11	4.33E-02	3.15E+07	5.31E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	3.30E-04	7.73E-08	2.86E+02	3.15E+07	1.53E-04
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.30E-04	6.70E-05	2.48E+05	3.15E+07	1.15E-01
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	3.30E-04	1.06E-04	3.92E+05	3.15E+07	1.46E-01
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.30E-04	3.30E-09	1.22E+01	3.15E+07	3.90E-06
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.30E-04	1.12E-08	4.14E+01	3.15E+07	7.25E-06
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	3.30E-04	1.20E-04	4.44E+05	3.15E+07	4.87E-02
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	3.30E-04	1.52E-09	5.62E+00	3.15E+07	4.37E-07
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.30E-04	1.16E-04	4.29E+05	3.15E+07	2.70E-02
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	8.10E-09	3.00E+01	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.30E-04	1.16E-04	4.29E+05	3.15E+07	1.32E-02
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.30E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	1.19E-04	4.40E+05	3.15E+07	1.62E-03
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	3.30E-04	4.67E-06	1.73E+04	3.15E+07	5.25E-05
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	3.30E-04	8.30E-05	3.07E+05	3.15E+07	7.36E-04
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	3.30E-04	6.78E-10	2.51E+00	3.15E+07	9.24E-09
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.30E-04	1.46E-04	5.40E+05	3.15E+07	1.90E-05
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.30E-04	1.11E-04	4.11E+05	3.15E+07	1.22E-04
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	3.30E-04	1.58E-08	5.85E+01	3.15E+07	4.92E-08
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.30E-04	1.15E-04	4.26E+05	3.15E+07	3.61E-04
													Total	8.70E-01

MPC-68 Accident Conditions Committed Effective Dose Equivalent From Inhalation													
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	8.69E-11	3.22E-01	2.59E+06	7.25E-07
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	4.76E-09	1.76E+01	2.59E+06	1.11E+00
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	2.69E-10	9.95E-01	2.59E+06	2.95E-03
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.30E-09	4.81E+00	2.59E+06	3.90E-03
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.30E-08	4.81E+01	2.59E+06	6.74E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	8.76E-09	3.24E+01	2.59E+06	1.44E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	6.82E-07	2.52E+03	2.59E+06	1.55E+00
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	9.52E-12	3.52E-02	2.59E+06	1.56E-05
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	8.25E-15	3.05E-05	2.59E+06	7.92E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.93E-09	7.14E+00	2.59E+06	5.13E-04
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	2.41E-15	8.92E-06	2.59E+06	6.41E-10
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	1.17E-08	4.33E+01	2.59E+06	1.35E-03
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	1.59E-05	5.88E+04	2.59E+06	1.60E+00
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	2.80E-05	1.04E+05	2.59E+06	2.27E+00
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	3.60E-10	1.33E+00	2.59E+06	2.49E-05
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	3.56E-10	1.32E+00	2.59E+06	1.35E-05
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	3.25E-05	1.20E+05	2.59E+06	7.73E-01
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	1.24E-10	4.59E-01	2.59E+06	2.09E-06
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	3.18E-05	1.18E+05	2.59E+06	4.33E-01
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	4.03E-14	1.49E-04	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	3.18E-05	1.18E+05	2.59E+06	2.12E-01
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	3.26E-05	1.21E+05	2.59E+06	2.60E-02
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	5.70E-07	2.11E+03	2.59E+06	3.76E-04
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	2.07E-05	7.66E+04	2.59E+06	1.08E-02
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	7.45E-11	2.76E-01	2.59E+06	5.95E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	2.96E-05	1.10E+05	2.59E+06	2.25E-04
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	3.02E-05	1.12E+05	2.59E+06	1.94E-03
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	1.94E-09	7.18E+00	2.59E+06	3.54E-07
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	3.21E-05	1.19E+05	2.59E+06	5.90E-03
												Total	8.21E+00

MPC-68 Accident Conditions Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	2.09E-10	7.73E-01	2.59E+06	1.74E-06
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	1.84E-08	6.81E+01	2.59E+06	4.31E+00
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	2.69E-10	9.95E-01	2.59E+06	2.95E-03
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.78E-09	6.59E+00	2.59E+06	5.33E-03
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.08E-08	4.00E+01	2.59E+06	5.60E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	7.84E-09	2.90E+01	2.59E+06	1.29E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	3.06E-11	1.13E-01	2.59E+06	6.94E-05
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	9.52E-12	3.52E-02	2.59E+06	1.56E-05
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	3.60E-14	1.33E-04	2.59E+06	3.45E-08
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.97E-09	7.29E+00	2.59E+06	5.24E-04
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.05E-14	3.89E-05	2.59E+06	2.79E-09
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	1.55E-08	5.74E+01	2.59E+06	1.79E-03
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	1.04E-09	3.85E+00	2.59E+06	1.05E-04
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	1.00E-09	3.70E+00	2.59E+06	8.09E-05
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	4.16E-10	1.54E+00	2.59E+06	2.88E-05
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	6.14E-10	2.27E+00	2.59E+06	2.33E-05
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	2.67E-09	9.88E+00	2.59E+06	6.35E-05
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	1.07E-10	3.96E-01	2.59E+06	1.80E-06
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	9.51E-10	3.52E+00	2.59E+06	1.29E-05
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	1.49E-13	5.51E-04	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	9.22E-10	3.41E+00	2.59E+06	6.14E-06
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	1.52E-08	5.62E+01	2.59E+06	1.21E-05
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	9.44E-10	3.49E+00	2.59E+06	6.22E-07
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	6.29E-09	2.33E+01	2.59E+06	3.27E-06
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	1.63E-11	6.03E-02	2.59E+06	1.30E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	1.69E-08	6.25E+01	2.59E+06	1.29E-07
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	9.45E-10	3.50E+00	2.59E+06	6.08E-08
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	2.49E-12	9.21E-03	2.59E+06	4.55E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	1.38E-09	5.11E+00	2.59E+06	2.53E-07
												Total	4.51E+00

MPC-68													
Accident Conditions													
Commited Effective Dose Equivalent From Inhalation													
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	3.14E-10	1.16E+00	2.59E+06	2.62E-06
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	3.45E-07	1.28E+03	2.59E+06	8.08E+01
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	2.86E-06	1.06E+04	2.59E+06	3.13E+01
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.04E-06	3.85E+03	2.59E+06	3.12E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.18E-08	4.37E+01	2.59E+06	6.12E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	8.82E-09	3.26E+01	2.59E+06	1.45E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	7.42E-09	2.75E+01	2.59E+06	1.68E-02
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	8.89E-09	3.29E+01	2.59E+06	1.46E-02
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	7.74E-08	2.86E+02	2.59E+06	7.43E-02
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.83E-07	6.77E+02	2.59E+06	4.86E-02
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	9.40E-11	3.48E-01	2.59E+06	2.50E-05
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	7.92E-08	2.93E+02	2.59E+06	9.16E-03
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	1.93E-05	7.14E+04	2.59E+06	1.94E+00
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	1.84E-05	6.81E+04	2.59E+06	1.49E+00
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	2.17E-08	8.03E+01	2.59E+06	1.50E-03
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	1.19E-08	4.40E+01	2.59E+06	4.51E-04
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	1.84E-05	6.81E+04	2.59E+06	4.37E-01
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	4.66E-10	1.72E+00	2.59E+06	7.85E-06
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	1.73E-05	6.40E+04	2.59E+06	2.36E-01
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	3.26E-09	1.21E+01	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	1.73E-05	6.40E+04	2.59E+06	1.15E-01
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	1.78E-05	6.59E+04	2.59E+06	1.42E-02
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	1.55E-05	5.74E+04	2.59E+06	1.02E-02
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	1.94E-05	7.18E+04	2.59E+06	1.01E-02
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	2.36E-09	8.73E+00	2.59E+06	1.88E-06
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	1.61E-05	5.96E+04	2.59E+06	1.23E-04
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	1.64E-05	6.07E+04	2.59E+06	1.05E-03
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	5.20E-08	1.92E+02	2.59E+06	9.50E-06
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	4.20E-06	1.55E+04	2.59E+06	7.71E-04
												Total:	1.20E+02

MPC-68 Accident Conditions Commilted Effective Dose Equivalent From Inhalation													
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	1.40E-10	5.18E-01	2.59E+06	1.17E-06
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	1.72E-08	6.36E+01	2.59E+06	4.03E+00
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	3.28E-08	1.21E+02	2.59E+06	3.59E-01
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.76E-09	6.51E+00	2.59E+06	5.27E-03
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.18E-08	4.37E+01	2.59E+06	6.12E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	8.30E-09	3.07E+01	2.59E+06	1.37E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	3.36E-06	1.24E+04	2.59E+06	7.62E+00
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	2.79E-10	1.03E+00	2.59E+06	4.58E-04
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	1.61E-09	5.96E+00	2.59E+06	1.54E-03
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	2.67E-08	9.88E+01	2.59E+06	7.10E-03
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.38E-14	5.11E-05	2.59E+06	3.67E-09
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	1.06E-07	3.92E+02	2.59E+06	1.23E-02
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	9.38E-05	3.47E+05	2.59E+06	9.43E+00
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	1.52E-04	5.62E+05	2.59E+06	1.23E+01
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	5.35E-10	1.98E+00	2.59E+06	3.70E-05
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	1.43E-08	5.29E+01	2.59E+06	5.42E-04
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	1.74E-04	6.44E+05	2.59E+06	4.14E+00
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	3.01E-09	1.11E+01	2.59E+06	5.07E-05
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	1.69E-04	6.25E+05	2.59E+06	2.30E+00
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	1.10E-08	4.07E+01	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	1.69E-04	6.25E+05	2.59E+06	1.12E+00
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	1.73E-04	6.40E+05	2.59E+06	1.38E-01
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	3.90E-06	1.44E+04	2.59E+06	2.57E-03
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	1.18E-04	4.37E+05	2.59E+06	6.13E-02
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	2.08E-10	7.70E-01	2.59E+06	1.66E-07
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	2.62E-04	9.69E+05	2.59E+06	2.00E-03
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	1.61E-04	5.96E+05	2.59E+06	1.04E-02
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	1.32E-08	4.88E+01	2.59E+06	2.41E-06
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	1.69E-04	6.25E+05	2.59E+06	3.10E-02
												Total	4.18E+01

MPC-68 Accident Conditions Committed Effective Dose Equivalent From Inhalation													
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	1.38E-10	5.11E-01	2.59E+06	1.15E-06
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	1.35E-08	5.00E+01	2.59E+06	3.16E+00
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	7.09E-08	2.62E+02	2.59E+06	7.76E-01
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.61E-09	5.96E+00	2.59E+06	4.82E-03
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.10E-08	4.07E+01	2.59E+06	5.70E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	7.94E-09	2.94E+01	2.59E+06	1.31E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	4.20E-05	1.55E+05	2.59E+06	9.53E+01
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	2.78E-10	1.03E+00	2.59E+06	4.57E-04
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	2.01E-08	7.44E+01	2.59E+06	1.93E-02
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	4.54E-08	1.68E+02	2.59E+06	1.21E-02
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.47E-14	5.44E-05	2.59E+06	3.91E-09
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	5.23E-07	1.94E+03	2.59E+06	6.05E-02
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	1.17E-03	4.33E+06	2.59E+06	1.18E+02
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	1.90E-03	7.03E+06	2.59E+06	1.54E+02
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	9.78E-10	3.62E+00	2.59E+06	6.76E-05
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	1.52E-07	5.62E+02	2.59E+06	5.76E-03
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	2.17E-03	8.03E+06	2.59E+06	5.16E+01
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	3.21E-08	1.19E+02	2.59E+06	5.41E-04
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	2.11E-03	7.81E+06	2.59E+06	2.87E+01
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	1.38E-07	5.11E+02	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	2.11E-03	7.81E+06	2.59E+06	1.40E+01
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	2.17E-03	8.03E+06	2.59E+06	1.73E+00
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	4.87E-05	1.80E+05	2.59E+06	3.21E-02
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	1.47E-03	5.44E+06	2.59E+06	7.64E-01
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	2.03E-09	7.51E+00	2.59E+06	1.62E-06
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	3.27E-03	1.21E+07	2.59E+06	2.49E-02
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	2.01E-03	7.44E+06	2.59E+06	1.29E-01
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	1.65E-07	6.11E+02	2.59E+06	3.01E-05
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	2.12E-03	7.84E+06	2.59E+06	3.89E-01
												Total	4.68E+02

MPC-68														
Accident Conditions														
Committed Effective Dose Equivalent From Inhalation														
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	1.56E-06	5.77E+03	2.59E+06	1.30E-02
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	1.62E-08	5.99E+01	2.59E+06	3.79E+00
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	2.69E-10	9.95E-01	2.59E+06	2.95E-03
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.72E-09	6.36E+00	2.59E+06	5.15E-03
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.11E-08	4.11E+01	2.59E+06	5.76E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	7.93E-09	2.93E+01	2.59E+06	1.31E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	1.24E-11	4.59E-02	2.59E+06	2.81E-05
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	9.52E-12	3.52E-02	2.59E+06	1.56E-05
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	1.98E-14	7.33E-05	2.59E+06	1.90E-08
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.88E-09	6.96E+00	2.59E+06	5.00E-04
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	8.47E-15	3.13E-05	2.59E+06	2.25E-09
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	7.14E-09	2.64E+01	2.59E+06	8.25E-04
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	1.01E-09	3.74E+00	2.59E+06	1.01E-04
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	9.62E-10	3.56E+00	2.59E+06	7.79E-05
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	3.24E-10	1.20E+00	2.59E+06	2.24E-05
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	2.40E-10	8.88E-01	2.59E+06	9.10E-06
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	1.60E-09	5.92E+00	2.59E+06	3.80E-05
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	9.93E-11	3.67E-01	2.59E+06	1.67E-06
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	9.05E-10	3.35E+00	2.59E+06	1.23E-05
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	1.32E-14	4.88E-05	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	9.03E-10	3.34E+00	2.59E+06	6.01E-06
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	8.29E-09	3.07E+01	2.59E+06	6.62E-06
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	9.41E-10	3.48E+00	2.59E+06	6.20E-07
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	3.83E-09	1.42E+01	2.59E+06	1.99E-06
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	7.62E-12	2.82E-02	2.59E+06	6.08E-09
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	1.34E-08	4.96E+01	2.59E+06	1.02E-07
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	8.79E-10	3.25E+00	2.59E+06	5.65E-08
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	2.52E-12	9.32E-03	2.59E+06	4.60E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	5.64E-10	2.09E+00	2.59E+06	1.04E-07
												Total	4.01E+00

MPC-68 Accident Conditions Commited Effective Dose Equivalent From Inhalation													
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	Breathing Rate (m3/sec)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	CEDE (mRem)
							Gases						
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.30E-04	1.73E-11	6.40E-02	2.59E+06	1.63E-03
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.30E-04	4.69E-08	1.74E+02	2.59E+06	3.91E-04
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
							Crud						
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	3.30E-04	5.91E-08	2.19E+02	2.59E+06	1.38E+01
							Volatiles						
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	3.30E-04	3.51E-07	1.30E+03	2.59E+06	3.84E+00
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	3.30E-04	1.29E-07	4.77E+02	2.59E+06	3.87E-01
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	3.30E-04	1.25E-08	4.63E+01	2.59E+06	6.48E-02
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	3.30E-04	8.63E-09	3.19E+01	2.59E+06	1.42E-01
							Fines						
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	3.30E-04	2.23E-06	8.25E+03	2.59E+06	5.06E+00
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	3.30E-04	2.13E-09	7.88E+00	2.59E+06	3.50E-03
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	3.30E-04	1.06E-08	3.92E+01	2.59E+06	1.02E-02
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	5.84E-08	2.16E+02	2.59E+06	1.55E-02
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	3.30E-04	1.17E-11	4.33E-02	2.59E+06	3.11E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	3.30E-04	7.73E-08	2.86E+02	2.59E+06	8.94E-03
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.30E-04	6.70E-05	2.48E+05	2.59E+06	6.73E+00
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	3.30E-04	1.06E-04	3.92E+05	2.59E+06	8.58E+00
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.30E-04	3.30E-09	1.22E+01	2.59E+06	2.28E-04
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.30E-04	1.12E-08	4.14E+01	2.59E+06	4.25E-04
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	3.30E-04	1.20E-04	4.44E+05	2.59E+06	2.85E+00
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	3.30E-04	1.52E-09	5.62E+00	2.59E+06	2.56E-05
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.30E-04	1.16E-04	4.29E+05	2.59E+06	1.58E+00
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	8.10E-09	3.00E+01	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.30E-04	1.16E-04	4.29E+05	2.59E+06	7.72E-01
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.30E-04	0.00E+00	0.00E+00	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	1.19E-04	4.40E+05	2.59E+06	9.50E-02
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	3.30E-04	4.67E-06	1.73E+04	2.59E+06	3.08E-03
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	3.30E-04	8.30E-05	3.07E+05	2.59E+06	4.31E-02
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	3.30E-04	6.78E-10	2.51E+00	2.59E+06	5.41E-07
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.30E-04	1.46E-04	5.40E+05	2.59E+06	1.11E-03
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.30E-04	1.11E-04	4.11E+05	2.59E+06	7.14E-03
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	3.30E-04	1.58E-08	5.85E+01	2.59E+06	2.89E-06
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.30E-04	1.15E-04	4.26E+05	2.59E+06	2.11E-02
												Total	4.41E+01

MPC-68													
Normal Conditions													
Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	4.83E-16	1.79E-06	3.15E+07	2.08E-11
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.17E-16	4.33E-07	3.15E+07	9.35E-07
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.23E-13	4.55E-04	3.15E+07	2.23E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	7.78E-18	2.88E-08	3.15E+07	4.41E-10
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	7.40E-14	2.74E-04	3.15E+07	1.99E-06
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	7.96E-18	2.95E-08	3.15E+07	6.79E-10
								Fines					
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	7.19E-20	2.66E-10	3.15E+07	8.44E-13
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	1.89E-16	6.99E-07	3.15E+07	1.61E-09
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	7.48E-19	2.77E-09	3.15E+07	3.71E-12
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	8.53E-16	3.16E-06	3.15E+07	1.17E-09
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	1.90E-15	7.03E-06	3.15E+07	2.61E-09
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	6.00E-14	2.22E-04	3.15E+07	3.59E-08
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	6.90E-18	2.55E-08	3.15E+07	3.59E-12
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	6.56E-18	2.43E-08	3.15E+07	2.75E-12
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	1.98E-14	7.33E-05	3.15E+07	7.08E-09
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	2.49E-15	9.21E-06	3.15E+07	4.88E-10
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	8.58E-16	3.17E-06	3.15E+07	1.05E-10
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	5.96E-16	2.21E-06	3.15E+07	5.20E-11
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	6.36E-18	2.35E-08	3.15E+07	4.48E-13
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	5.20E-20	1.92E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	4.84E-18	1.79E-08	3.15E+07	1.67E-13
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	2.82E-14	1.04E-04	3.15E+07	3.40E-07
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.01E-14	3.74E-05	3.15E+07	2.35E-08
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.25E-16	1.20E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	2.19E-15	8.10E-06	3.15E+07	9.04E-12
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	7.83E-18	2.90E-08	3.15E+07	2.67E-14
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	5.77E-15	2.13E-05	3.15E+07	1.55E-11
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	7.53E-15	2.79E-05	3.15E+07	3.11E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	1.04E-15	3.85E-06	3.15E+07	4.10E-14
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	5.34E-18	1.98E-08	3.15E+07	1.78E-15
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	6.09E-16	2.25E-06	3.15E+07	5.75E-13
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.80E-17	1.41E-07	3.15E+07	3.61E-14
												Total	2.24E-03

MPC-68 Normal Conditions Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	6.66E-16	2.46E-06	3.15E+07	2.87E-11
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.34E-16	4.96E-07	3.15E+07	1.07E-06
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.39E-13	5.14E-04	3.15E+07	2.52E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	9.49E-18	3.51E-08	3.15E+07	5.37E-10
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	8.43E-14	3.12E-04	3.15E+07	2.26E-06
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	9.67E-18	3.58E-08	3.15E+07	8.25E-10
								Fines					
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	8.67E-20	3.21E-10	3.15E+07	1.02E-12
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	2.20E-16	8.14E-07	3.15E+07	1.87E-09
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	9.56E-19	3.54E-09	3.15E+07	4.74E-12
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	1.01E-15	3.74E-06	3.15E+07	1.39E-09
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	2.15E-15	7.96E-06	3.15E+07	2.96E-09
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	6.81E-14	2.52E-04	3.15E+07	4.07E-08
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	1.33E-17	4.92E-08	3.15E+07	6.91E-12
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	1.27E-17	4.70E-08	3.15E+07	5.32E-12
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	2.27E-14	8.40E-05	3.15E+07	8.12E-09
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	2.95E-15	1.09E-05	3.15E+07	5.79E-10
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	1.07E-15	3.96E-06	3.15E+07	1.32E-10
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	8.48E-16	3.14E-06	3.15E+07	7.39E-11
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	1.23E-17	4.55E-08	3.15E+07	8.66E-13
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	8.80E-20	3.26E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	7.55E-18	2.79E-08	3.15E+07	2.60E-13
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.22E-14	1.19E-04	3.15E+07	3.89E-07
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.16E-14	4.29E-05	3.15E+07	2.70E-08
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	4.20E-16	1.55E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	2.61E-15	9.66E-06	3.15E+07	1.08E-11
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	1.48E-17	5.48E-08	3.15E+07	5.05E-14
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	6.68E-15	2.47E-05	3.15E+07	1.80E-11
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	8.73E-15	3.23E-05	3.15E+07	3.61E-11
237Np	7.05E-02	1.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.13E-16	1.60E-04	1.26E-15	4.66E-06	3.15E+07	5.01E-12
242Pu	5.95E-01	2.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.58E-15	1.60E-04	1.03E-17	3.81E-08	3.15E+07	6.88E-13
242Am	1.69E+00	3.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.52E-14	1.60E-04	7.30E-16	2.70E-06	3.15E+07	2.08E-10
242mAm	1.70E+00	4.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.04E-14	1.60E-04	6.01E-17	2.22E-07	3.15E+07	2.29E-11
												Total	2.53E-03

MPC-68 Normal Conditions Effective Dose Equivalent From Submersion														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)	
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	2.75E-18	1.02E-08	3.15E+07	1.34E-09	
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	2.14E-16	7.92E-07	3.15E+07	9.23E-12	
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.14E-16	4.22E-07	3.15E+07	9.11E-07	
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.24E-13	4.59E-04	3.15E+07	2.25E-03	
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	6.44E-18	2.38E-08	3.15E+07	3.65E-10	
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00	
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	7.37E-14	2.73E-04	3.15E+07	1.98E-06	
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	6.68E-18	2.47E-08	3.15E+07	5.70E-10	
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	6.48E-20	2.40E-10	3.15E+07	7.61E-13	
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	1.77E-16	6.55E-07	3.15E+07	1.50E-09	
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	5.45E-19	2.02E-09	3.15E+07	2.70E-12	
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	7.69E-16	2.85E-06	3.15E+07	1.06E-09	
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	1.90E-15	7.03E-06	3.15E+07	2.61E-09	
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	5.99E-14	2.22E-04	3.15E+07	3.58E-08	
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	7.08E-19	2.62E-09	3.15E+07	3.68E-13	
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	1.06E-18	3.92E-09	3.15E+07	4.44E-13	
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	1.95E-14	7.22E-05	3.15E+07	6.97E-09	
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	2.22E-15	8.21E-06	3.15E+07	4.35E-10	
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	6.74E-16	2.49E-06	3.15E+07	8.29E-11	
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	2.23E-16	8.25E-07	3.15E+07	1.94E-11	
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	1.09E-18	4.03E-09	3.15E+07	7.68E-14	
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	7.08E-21	2.62E-11	3.15E+07	0.00E+00	
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	2.65E-18	9.81E-09	3.15E+07	9.12E-14	
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	2.80E-14	1.04E-04	3.15E+07	3.38E-07	
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.01E-14	3.74E-05	3.15E+07	2.35E-08	
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	2.00E-16	7.40E-07	3.15E+07	0.00E+00	
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	1.92E-15	7.10E-06	3.15E+07	7.93E-12	
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	1.13E-18	4.18E-09	3.15E+07	3.85E-15	
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	5.50E-15	2.04E-05	3.15E+07	1.48E-11	
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	7.18E-15	2.66E-05	3.15E+07	2.97E-11	
237Np	7.05E-02	1.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.13E-16	1.60E-04	9.02E-16	3.34E-06	3.15E+07	3.59E-12	
242Pu	5.95E-01	2.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.58E-15	1.60E-04	9.69E-19	3.59E-09	3.15E+07	6.48E-14	
242Am	1.69E+00	3.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.52E-14	1.60E-04	5.51E-15	2.04E-05	3.15E+07	1.57E-09	
242mAm	1.70E+00	4.01E+00	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.04E-14	1.60E-04	1.72E-17	6.36E-08	3.15E+07	6.55E-12	
												Total	2.26E-03	

MPC-68													
Normal Conditions													
Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	1.64E-16	6.07E-07	3.15E+07	7.08E-12
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.09E-16	4.03E-07	3.15E+07	8.71E-07
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.23E-13	4.55E-04	3.15E+07	2.23E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	5.44E-18	2.01E-08	3.15E+07	3.08E-10
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	7.19E-14	2.66E-04	3.15E+07	1.93E-06
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	5.70E-18	2.11E-08	3.15E+07	4.86E-10
								Fines					
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	5.63E-20	2.08E-10	3.15E+07	6.61E-13
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	1.62E-16	5.99E-07	3.15E+07	1.38E-09
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	4.46E-19	1.65E-09	3.15E+07	2.21E-12
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	6.68E-16	2.47E-06	3.15E+07	9.18E-10
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	1.87E-15	6.92E-06	3.15E+07	2.57E-09
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	5.87E-14	2.17E-04	3.15E+07	3.51E-08
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	1.46E-18	5.40E-09	3.15E+07	7.59E-13
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	1.68E-18	6.22E-09	3.15E+07	7.03E-13
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	1.87E-14	6.92E-05	3.15E+07	6.69E-09
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	1.85E-15	6.85E-06	3.15E+07	3.63E-10
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	5.21E-16	1.93E-06	3.15E+07	6.41E-11
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	1.86E-16	6.88E-07	3.15E+07	1.62E-11
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	1.65E-18	6.11E-09	3.15E+07	1.16E-13
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	1.13E-20	4.18E-11	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	2.67E-18	9.88E-09	3.15E+07	9.19E-14
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	2.73E-14	1.01E-04	3.15E+07	3.30E-07
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	9.75E-15	3.61E-05	3.15E+07	2.27E-08
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	1.56E-16	5.77E-07	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	1.55E-15	5.74E-06	3.15E+07	6.40E-12
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	1.89E-18	6.99E-09	3.15E+07	6.44E-15
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	5.00E-15	1.85E-05	3.15E+07	1.34E-11
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	6.50E-15	2.41E-05	3.15E+07	2.68E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	7.69E-16	2.85E-06	3.15E+07	3.03E-14
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	1.43E-18	5.29E-09	3.15E+07	4.76E-16
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	4.77E-16	1.76E-06	3.15E+07	4.51E-13
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	1.72E-17	6.36E-08	3.15E+07	1.63E-14
												Total:	2.24E-03

MPC-68 Normal Conditions Effective Dose Equivalent From Submersion														
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)	
								Gases						
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00	
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	1.10E-15	4.07E-06	3.15E+07	4.75E-11	
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	2.20E-16	8.14E-07	3.15E+07	1.76E-06	
								Crud						
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.78E-13	6.59E-04	3.15E+07	3.23E-03	
								Volatiles						
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	2.28E-17	8.44E-08	3.15E+07	1.29E-09	
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00	
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	1.20E-13	4.44E-04	3.15E+07	3.22E-06	
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	2.29E-17	8.47E-08	3.15E+07	1.95E-09	
								Fines						
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	2.19E-19	8.10E-10	3.15E+07	2.57E-12	
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	4.44E-16	1.64E-06	3.15E+07	3.77E-09	
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	2.18E-18	8.07E-09	3.15E+07	1.08E-11	
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	2.49E-15	9.21E-06	3.15E+07	3.42E-09	
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	2.99E-15	1.11E-05	3.15E+07	4.11E-09	
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	9.43E-14	3.49E-04	3.15E+07	5.64E-08	
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	8.82E-18	3.26E-08	3.15E+07	4.58E-12	
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	9.30E-18	3.44E-08	3.15E+07	3.89E-12	
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	3.53E-14	1.31E-04	3.15E+07	1.26E-08	
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	8.09E-15	2.99E-05	3.15E+07	1.59E-09	
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	2.87E-15	1.06E-05	3.15E+07	3.53E-10	
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	1.22E-15	4.51E-06	3.15E+07	1.06E-10	
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	9.26E-18	3.43E-08	3.15E+07	6.52E-13	
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	7.09E-20	2.62E-10	3.15E+07	0.00E+00	
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	9.47E-18	3.50E-08	3.15E+07	3.26E-13	
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	4.63E-14	1.71E-04	3.15E+07	5.59E-07	
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.72E-14	6.36E-05	3.15E+07	4.00E-08	
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	8.16E-16	3.02E-06	3.15E+07	0.00E+00	
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	7.47E-15	2.76E-05	3.15E+07	3.09E-11	
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	1.06E-17	3.92E-08	3.15E+07	3.61E-14	
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	1.50E-14	5.55E-05	3.15E+07	4.03E-11	
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	2.00E-14	7.40E-05	3.15E+07	8.26E-11	
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	3.20E-15	1.18E-05	3.15E+07	1.26E-13	
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	7.90E-18	2.92E-08	3.15E+07	2.63E-15	
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	1.88E-15	6.96E-06	3.15E+07	1.78E-12	
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	7.94E-17	2.94E-07	3.15E+07	7.54E-14	
												Total:	3.24E-03	

68-Thyroid

MPC-68 Normal Conditions Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.86E-16	1.43E-06	3.15E+07	1.67E-11
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.18E-16	4.37E-07	3.15E+07	9.43E-07
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.27E-13	4.70E-04	3.15E+07	2.31E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	7.33E-18	2.71E-08	3.15E+07	4.15E-10
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	7.57E-14	2.80E-04	3.15E+07	2.03E-06
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	7.55E-18	2.79E-08	3.15E+07	6.44E-10
								Fines					
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	6.98E-20	2.58E-10	3.15E+07	8.19E-13
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	1.87E-16	6.92E-07	3.15E+07	1.59E-09
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	6.75E-19	2.50E-09	3.15E+07	3.35E-12
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	8.33E-16	3.08E-06	3.15E+07	1.15E-09
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	1.95E-15	7.22E-06	3.15E+07	2.68E-09
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	6.15E-14	2.28E-04	3.15E+07	3.68E-08
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	4.19E-18	1.55E-08	3.15E+07	2.18E-12
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	4.01E-18	1.48E-08	3.15E+07	1.68E-12
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	2.01E-14	7.44E-05	3.15E+07	7.19E-09
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	2.41E-15	8.92E-06	3.15E+07	4.73E-10
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	7.83E-16	2.90E-06	3.15E+07	9.63E-11
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	4.64E-16	1.72E-06	3.15E+07	4.05E-11
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.92E-18	1.45E-08	3.15E+07	2.76E-13
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.58E-20	1.32E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	3.88E-18	1.44E-08	3.15E+07	1.34E-13
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	2.88E-14	1.07E-04	3.15E+07	3.48E-07
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.03E-14	3.81E-05	3.15E+07	2.39E-08
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	2.81E-16	1.04E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	2.09E-15	7.73E-06	3.15E+07	8.63E-12
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	4.91E-18	1.82E-08	3.15E+07	1.67E-14
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	5.76E-15	2.13E-05	3.15E+07	1.55E-11
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	7.52E-15	2.78E-05	3.15E+07	3.11E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	9.94E-16	3.68E-06	3.15E+07	3.92E-14
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.32E-18	1.23E-08	3.15E+07	1.10E-15
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	5.94E-16	2.20E-06	3.15E+07	5.61E-13
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	2.95E-17	1.09E-07	3.15E+07	2.80E-14
												Total	2.31E-03

MPC-68													
Normal Conditions													
Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	3.31E-19	1.22E-09	3.15E+07	1.61E-10
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	3.80E-16	1.41E-06	3.15E+07	1.64E-11
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.19E-16	4.40E-07	3.15E+07	9.51E-07
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.26E-13	4.66E-04	3.15E+07	2.29E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	7.53E-18	2.79E-08	3.15E+07	4.26E-10
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	7.57E-14	2.80E-04	3.15E+07	2.03E-06
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	7.74E-18	2.86E-08	3.15E+07	6.60E-10
								Fines					
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	7.25E-20	2.68E-10	3.15E+07	8.51E-13
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	1.90E-16	7.03E-07	3.15E+07	1.61E-09
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	6.93E-19	2.56E-09	3.15E+07	3.44E-12
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	8.53E-16	3.16E-06	3.15E+07	1.17E-09
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	1.95E-15	7.22E-06	3.15E+07	2.68E-09
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	6.14E-14	2.27E-04	3.15E+07	3.67E-08
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	4.91E-18	1.82E-08	3.15E+07	2.55E-12
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	4.88E-18	1.81E-08	3.15E+07	2.04E-12
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	2.02E-14	7.47E-05	3.15E+07	7.23E-09
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	2.49E-15	9.21E-06	3.15E+07	4.88E-10
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	8.18E-16	3.03E-06	3.15E+07	1.01E-10
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	4.53E-16	1.68E-06	3.15E+07	3.95E-11
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	4.75E-18	1.76E-08	3.15E+07	3.34E-13
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.61E-20	1.34E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	4.24E-18	1.57E-08	3.15E+07	1.46E-13
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	2.88E-14	1.07E-04	3.15E+07	3.48E-07
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.04E-14	3.85E-05	3.15E+07	2.42E-08
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	2.79E-16	1.03E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	2.18E-15	8.07E-06	3.15E+07	9.00E-12
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	5.69E-18	2.11E-08	3.15E+07	1.94E-14
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	5.88E-15	2.18E-05	3.15E+07	1.58E-11
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	7.69E-15	2.85E-05	3.15E+07	3.18E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	1.03E-15	3.81E-06	3.15E+07	4.06E-14
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	4.01E-18	1.48E-08	3.15E+07	1.33E-15
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	6.15E-16	2.28E-06	3.15E+07	5.31E-13
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	3.17E-17	1.17E-07	3.15E+07	3.01E-14
												Total	2.29E-03

MPC-68
Normal Conditions
Effective Dose Equivalent From Submersion

Nuclide	Inventory (Ci/Assy)	1% for normal storage	No. Assy	MPC Vol (cm3)	L_{nor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-11	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-15	1.60E-04	1.10E-15	4.07E-06	3.15E+07	4.75E-11
Kr-85	1.43E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-10	1.60E-04	1.32E-14	4.88E-05	3.15E+07	1.05E-04
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.45E-13	5.37E-04	3.15E+07	2.63E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-12	1.60E-04	9.20E-15	3.40E-05	3.15E+07	5.21E-07
Ru-106	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-13	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-12	1.60E-04	9.45E-14	3.50E-04	3.15E+07	2.54E-06
Cs-137	2.29E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-12	1.60E-04	8.63E-15	3.19E-05	3.15E+07	7.36E-07
								Fines					
PU241	2.10E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-13	1.60E-04	1.17E-19	4.33E-10	3.15E+07	1.37E-12
Y 90	1.52E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-13	1.60E-04	6.24E-14	2.31E-04	3.15E+07	5.30E-07
PM147	8.88E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-13	1.60E-04	8.11E-16	3.00E-06	3.15E+07	4.02E-09
CE144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	2.93E-15	1.08E-05	3.15E+07	4.03E-09
PR144	2.46E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-14	1.60E-04	8.43E-14	3.12E-04	3.15E+07	1.16E-07
EU154	1.07E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-14	1.60E-04	8.29E-14	3.07E-04	3.15E+07	4.96E-08
CM244	9.30E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-14	1.60E-04	3.91E-17	1.45E-07	3.15E+07	2.03E-11
PU238	7.49E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-14	1.60E-04	4.09E-17	1.51E-07	3.15E+07	1.71E-11
SB125	6.40E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-14	1.60E-04	2.65E-14	9.81E-05	3.15E+07	9.48E-09
EU155	3.51E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-14	1.60E-04	3.39E-15	1.25E-05	3.15E+07	6.65E-10
AM241	2.20E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-15	1.60E-04	1.28E-15	4.74E-06	3.15E+07	1.57E-10
TE125M	1.56E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-15	1.60E-04	1.94E-15	7.18E-06	3.15E+07	1.69E-10
PU240	1.26E+02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-15	1.60E-04	3.92E-17	1.45E-07	3.15E+07	2.76E-12
151Sm	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	1.90E-20	7.03E-11	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-15	1.60E-04	1.86E-17	6.88E-08	3.15E+07	6.40E-13
137mBa	2.16E+04	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-13	1.60E-04	3.73E-14	1.38E-04	3.15E+07	4.50E-07
106Rh	4.16E+03	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-13	1.60E-04	1.09E-13	4.03E-04	3.15E+07	2.53E-07
144mPr	0.00E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	5.08E-16	1.88E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	2.75E-15	1.02E-05	3.15E+07	1.14E-11
242Cm	6.10E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-16	1.60E-04	4.29E-17	1.59E-07	3.15E+07	1.46E-13
243Cm	4.81E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-16	1.60E-04	9.79E-15	3.62E-05	3.15E+07	2.63E-11
239Np	7.39E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-16	1.60E-04	1.60E-14	5.92E-05	3.15E+07	6.61E-11
237Np	7.05E-02	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-18	1.60E-04	1.54E-15	5.70E-06	3.15E+07	6.07E-14
242Pu	5.95E-01	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-17	1.60E-04	3.27E-17	1.21E-07	3.15E+07	1.09E-14
242Am	1.69E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-17	1.60E-04	8.20E-15	3.03E-05	3.15E+07	7.74E-12
242mAm	1.70E+00	1.00E-02	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-17	1.60E-04	1.36E-16	5.03E-07	3.15E+07	1.29E-13
												Total	2.74E-03

MPC-68 Off-Normal Conditions Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	4.83E-16	1.79E-06	3.15E+07	2.08E-10
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.17E-16	4.33E-07	3.15E+07	9.35E-06
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.23E-13	4.55E-04	3.15E+07	2.23E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	7.78E-18	2.88E-08	3.15E+07	4.41E-09
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	7.40E-14	2.74E-04	3.15E+07	1.99E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	7.96E-18	2.95E-08	3.15E+07	6.79E-09
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	7.19E-20	2.66E-10	3.15E+07	8.44E-12
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	1.89E-16	6.99E-07	3.15E+07	1.61E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	7.48E-19	2.77E-09	3.15E+07	3.71E-11
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	8.53E-16	3.16E-06	3.15E+07	1.17E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	1.90E-15	7.03E-06	3.15E+07	2.61E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	6.00E-14	2.22E-04	3.15E+07	3.59E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	6.90E-18	2.55E-08	3.15E+07	3.59E-11
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	6.56E-18	2.43E-08	3.15E+07	2.75E-11
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	1.98E-14	7.33E-05	3.15E+07	7.08E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	2.49E-15	9.21E-06	3.15E+07	4.88E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	8.58E-16	3.17E-06	3.15E+07	1.05E-09
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	5.96E-16	2.21E-06	3.15E+07	5.20E-10
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	6.36E-18	2.35E-08	3.15E+07	4.48E-12
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	5.20E-20	1.92E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	4.84E-18	1.79E-08	3.15E+07	1.67E-12
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	2.82E-14	1.04E-04	3.15E+07	3.40E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.01E-14	3.74E-05	3.15E+07	2.35E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.25E-16	1.20E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	2.19E-15	8.10E-06	3.15E+07	9.04E-11
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	7.83E-18	2.90E-08	3.15E+07	2.67E-13
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	5.77E-15	2.13E-05	3.15E+07	1.55E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	7.53E-15	2.79E-05	3.15E+07	3.11E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	1.04E-15	3.85E-06	3.15E+07	4.10E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	5.34E-18	1.98E-08	3.15E+07	1.78E-14
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	6.09E-16	2.25E-06	3.15E+07	5.75E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.80E-17	1.41E-07	3.15E+07	3.61E-13
												Total:	2.27E-03

Nuclide	Inventory (Ci/Assy)	10% for off-normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
MPC-68													
Off-Normal Conditions													
Effective Dose Equivalent From Submersion													
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	6.66E-16	2.46E-06	3.15E+07	2.87E-10
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.34E-16	4.96E-07	3.15E+07	1.07E-05
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.39E-13	5.14E-04	3.15E+07	2.52E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	9.49E-18	3.51E-08	3.15E+07	5.37E-09
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	8.43E-14	3.12E-04	3.15E+07	2.26E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	9.67E-18	3.58E-08	3.15E+07	8.25E-09
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	8.67E-20	3.21E-10	3.15E+07	1.02E-11
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	2.20E-16	8.14E-07	3.15E+07	1.87E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	9.56E-19	3.54E-09	3.15E+07	4.74E-11
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	1.01E-15	3.74E-06	3.15E+07	1.39E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	2.15E-15	7.96E-06	3.15E+07	2.96E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	6.81E-14	2.52E-04	3.15E+07	4.07E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	1.33E-17	4.92E-08	3.15E+07	6.91E-11
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	1.27E-17	4.70E-08	3.15E+07	5.32E-11
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	2.27E-14	8.40E-05	3.15E+07	8.12E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	2.95E-15	1.09E-05	3.15E+07	5.79E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	1.07E-15	3.96E-06	3.15E+07	1.32E-09
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	8.48E-16	3.14E-06	3.15E+07	7.39E-10
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	1.23E-17	4.55E-08	3.15E+07	8.66E-12
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	8.80E-20	3.26E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	7.55E-18	2.79E-08	3.15E+07	2.60E-12
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.22E-14	1.19E-04	3.15E+07	3.89E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.16E-14	4.29E-05	3.15E+07	2.70E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	4.20E-16	1.55E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	2.61E-15	9.66E-06	3.15E+07	1.08E-10
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	1.48E-17	5.48E-08	3.15E+07	5.05E-13
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	6.68E-15	2.47E-05	3.15E+07	1.80E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	8.73E-15	3.23E-05	3.15E+07	3.61E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	1.26E-15	4.66E-06	3.15E+07	4.96E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	1.03E-17	3.81E-08	3.15E+07	3.43E-14
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	7.30E-16	2.70E-06	3.15E+07	6.89E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	6.01E-17	2.22E-07	3.15E+07	5.71E-13
												Total	2.56E-03

MPC-68 Off-Normal Conditions Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	2.75E-18	1.02E-08	3.15E+07	1.34E-08
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	2.14E-16	7.92E-07	3.15E+07	9.23E-11
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.14E-16	4.22E-07	3.15E+07	9.11E-06
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.24E-13	4.59E-04	3.15E+07	2.25E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	6.44E-18	2.38E-08	3.15E+07	3.65E-09
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	7.37E-14	2.73E-04	3.15E+07	1.98E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	6.68E-18	2.47E-08	3.15E+07	5.70E-09
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	6.48E-20	2.40E-10	3.15E+07	7.61E-12
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	1.77E-16	6.55E-07	3.15E+07	1.50E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	5.45E-19	2.02E-09	3.15E+07	2.70E-11
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	7.69E-16	2.85E-06	3.15E+07	1.06E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	1.90E-15	7.03E-06	3.15E+07	2.61E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	5.99E-14	2.22E-04	3.15E+07	3.58E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	7.08E-19	2.62E-09	3.15E+07	3.68E-12
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	1.06E-18	3.92E-09	3.15E+07	4.44E-12
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	1.95E-14	7.22E-05	3.15E+07	6.97E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	2.22E-15	8.21E-06	3.15E+07	4.35E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	6.74E-16	2.49E-06	3.15E+07	8.29E-10
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	2.23E-16	8.25E-07	3.15E+07	1.94E-10
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	1.09E-18	4.03E-09	3.15E+07	7.68E-13
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	7.08E-21	2.62E-11	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	2.65E-18	9.81E-09	3.15E+07	9.12E-13
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	2.80E-14	1.04E-04	3.15E+07	3.38E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.01E-14	3.74E-05	3.15E+07	2.35E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	2.00E-16	7.40E-07	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	1.92E-15	7.10E-06	3.15E+07	7.93E-11
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	1.13E-18	4.18E-09	3.15E+07	3.85E-14
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	5.50E-15	2.04E-05	3.15E+07	1.48E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	7.18E-15	2.66E-05	3.15E+07	2.97E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	9.02E-16	3.34E-06	3.15E+07	3.55E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	9.69E-19	3.59E-09	3.15E+07	3.22E-15
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	5.51E-15	2.04E-05	3.15E+07	5.20E-11
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	1.72E-17	6.36E-08	3.15E+07	1.63E-13
												Total:	2.29E-03

MPC-68													
Off-Normal Conditions													
Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	1.64E-16	6.07E-07	3.15E+07	7.08E-11
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.09E-16	4.03E-07	3.15E+07	8.71E-06
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.23E-13	4.55E-04	3.15E+07	2.23E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	5.44E-18	2.01E-08	3.15E+07	3.08E-09
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	7.19E-14	2.66E-04	3.15E+07	1.93E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	5.70E-18	2.11E-08	3.15E+07	4.86E-09
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	5.63E-20	2.08E-10	3.15E+07	6.61E-12
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	1.62E-16	5.99E-07	3.15E+07	1.38E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	4.46E-19	1.65E-09	3.15E+07	2.21E-11
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	6.68E-16	2.47E-06	3.15E+07	9.18E-09
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	1.87E-15	6.92E-06	3.15E+07	2.57E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	5.87E-14	2.17E-04	3.15E+07	3.51E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	1.46E-18	5.40E-09	3.15E+07	7.59E-12
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	1.68E-18	6.22E-09	3.15E+07	7.03E-12
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	1.87E-14	6.92E-05	3.15E+07	6.69E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	1.85E-15	6.85E-06	3.15E+07	3.63E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	5.21E-16	1.93E-06	3.15E+07	6.41E-10
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	1.86E-16	6.88E-07	3.15E+07	1.62E-10
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	1.65E-18	6.11E-09	3.15E+07	1.16E-12
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	1.13E-20	4.18E-11	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	2.67E-18	9.88E-09	3.15E+07	9.19E-13
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	2.73E-14	1.01E-04	3.15E+07	3.30E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	9.75E-15	3.61E-05	3.15E+07	2.27E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	1.56E-16	5.77E-07	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	1.55E-15	5.74E-06	3.15E+07	6.40E-11
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	1.89E-18	6.99E-09	3.15E+07	6.44E-14
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	5.00E-15	1.85E-05	3.15E+07	1.34E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	6.50E-15	2.41E-05	3.15E+07	2.68E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	7.69E-16	2.85E-06	3.15E+07	3.03E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	1.43E-18	5.29E-09	3.15E+07	4.76E-15
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	4.77E-16	1.76E-06	3.15E+07	4.51E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	1.72E-17	6.36E-08	3.15E+07	1.63E-13
												Total:	2.27E-03

68-B Surface

						MPC-68							
						Off-Normal Conditions							
						Effective Dose Equivalent From Submersion							
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	1.10E-15	4.07E-06	3.15E+07	4.75E-10
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	2.20E-16	8.14E-07	3.15E+07	1.76E-05
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.78E-13	6.59E-04	3.15E+07	3.23E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	2.28E-17	8.44E-08	3.15E+07	1.29E-08
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	1.20E-13	4.44E-04	3.15E+07	3.22E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	2.29E-17	8.47E-08	3.15E+07	1.95E-08
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	2.19E-19	8.10E-10	3.15E+07	2.57E-11
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	4.44E-16	1.64E-06	3.15E+07	3.77E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	2.18E-18	8.07E-09	3.15E+07	1.08E-10
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	2.49E-15	9.21E-06	3.15E+07	3.42E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	2.99E-15	1.11E-05	3.15E+07	4.11E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	9.43E-14	3.49E-04	3.15E+07	5.64E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	8.82E-18	3.26E-08	3.15E+07	4.58E-11
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	9.30E-18	3.44E-08	3.15E+07	3.89E-11
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	3.53E-14	1.31E-04	3.15E+07	1.26E-07
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	8.09E-15	2.99E-05	3.15E+07	1.59E-08
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	2.87E-15	1.06E-05	3.15E+07	3.53E-09
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	1.22E-15	4.51E-06	3.15E+07	1.06E-09
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	9.26E-18	3.43E-08	3.15E+07	6.52E-12
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	7.09E-20	2.62E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	9.47E-18	3.50E-08	3.15E+07	3.26E-12
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	4.63E-14	1.71E-04	3.15E+07	5.59E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.72E-14	6.36E-05	3.15E+07	4.00E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	8.16E-16	3.02E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	7.47E-15	2.76E-05	3.15E+07	3.09E-10
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	1.06E-17	3.92E-08	3.15E+07	3.61E-13
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	1.50E-14	5.55E-05	3.15E+07	4.03E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	2.00E-14	7.40E-05	3.15E+07	8.26E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	3.20E-15	1.18E-05	3.15E+07	1.26E-12
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	7.90E-18	2.92E-08	3.15E+07	2.63E-14
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	1.88E-15	6.96E-06	3.15E+07	1.78E-11
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	7.94E-17	2.94E-07	3.15E+07	7.54E-13
												Total:	3.29E-03

MPC-68 Off-Normal Conditions Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.86E-16	1.43E-06	3.15E+07	1.67E-10
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.18E-16	4.37E-07	3.15E+07	9.43E-06
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.27E-13	4.70E-04	3.15E+07	2.31E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	7.33E-18	2.71E-08	3.15E+07	4.15E-09
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	7.57E-14	2.80E-04	3.15E+07	2.03E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	7.55E-18	2.79E-08	3.15E+07	6.44E-09
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	6.98E-20	2.58E-10	3.15E+07	8.19E-12
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	1.87E-16	6.92E-07	3.15E+07	1.59E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	6.75E-19	2.50E-09	3.15E+07	3.35E-11
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	8.33E-16	3.08E-06	3.15E+07	1.15E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	1.95E-15	7.22E-06	3.15E+07	2.68E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	6.15E-14	2.28E-04	3.15E+07	3.68E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	4.19E-18	1.55E-08	3.15E+07	2.18E-11
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	4.01E-18	1.48E-08	3.15E+07	1.68E-11
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	2.01E-14	7.44E-05	3.15E+07	7.19E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	2.41E-15	8.92E-06	3.15E+07	4.73E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	7.83E-16	2.90E-06	3.15E+07	9.63E-10
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	4.64E-16	1.72E-06	3.15E+07	4.05E-10
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.92E-18	1.45E-08	3.15E+07	2.76E-12
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.58E-20	1.32E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	3.88E-18	1.44E-08	3.15E+07	1.34E-12
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	2.88E-14	1.07E-04	3.15E+07	3.48E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.03E-14	3.81E-05	3.15E+07	2.39E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	2.81E-16	1.04E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	2.09E-15	7.73E-06	3.15E+07	8.63E-11
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	4.91E-18	1.82E-08	3.15E+07	1.67E-13
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	5.76E-15	2.13E-05	3.15E+07	1.55E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	7.52E-15	2.78E-05	3.15E+07	3.11E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	9.94E-16	3.68E-06	3.15E+07	3.92E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.32E-18	1.23E-08	3.15E+07	1.10E-14
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	5.94E-16	2.20E-06	3.15E+07	5.61E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	2.95E-17	1.09E-07	3.15E+07	2.80E-13
												Total:	2.34E-03

MPC-68													
Off-Normal Conditions													
Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	10% for off normal storage	No. Assy	MPC Vol (cm3)	L_{offnor} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	Effective Dose (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	3.31E-19	1.22E-09	3.15E+07	1.61E-09
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	3.80E-16	1.41E-06	3.15E+07	1.64E-10
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.19E-16	4.40E-07	3.15E+07	9.51E-06
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.26E-13	4.66E-04	3.15E+07	2.29E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	7.53E-18	2.79E-08	3.15E+07	4.26E-09
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	7.57E-14	2.80E-04	3.15E+07	2.03E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	7.74E-18	2.86E-08	3.15E+07	6.60E-09
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	7.25E-20	2.68E-10	3.15E+07	8.51E-12
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	1.90E-16	7.03E-07	3.15E+07	1.61E-08
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	6.93E-19	2.56E-09	3.15E+07	3.44E-11
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	8.53E-16	3.16E-06	3.15E+07	1.17E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	1.95E-15	7.22E-06	3.15E+07	2.68E-08
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	6.14E-14	2.27E-04	3.15E+07	3.67E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	4.91E-18	1.82E-08	3.15E+07	2.55E-11
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	4.88E-18	1.81E-08	3.15E+07	2.04E-11
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	2.02E-14	7.47E-05	3.15E+07	7.23E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	2.49E-15	9.21E-06	3.15E+07	4.88E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	8.18E-16	3.03E-06	3.15E+07	1.01E-09
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	4.53E-16	1.68E-06	3.15E+07	3.95E-10
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	4.75E-18	1.76E-08	3.15E+07	3.34E-12
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	3.61E-20	1.34E-10	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	4.24E-18	1.57E-08	3.15E+07	1.46E-12
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	2.88E-14	1.07E-04	3.15E+07	3.48E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.04E-14	3.85E-05	3.15E+07	2.42E-07
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	2.79E-16	1.03E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	2.18E-15	8.07E-06	3.15E+07	9.00E-11
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	5.69E-18	2.11E-08	3.15E+07	1.94E-13
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	5.88E-15	2.18E-05	3.15E+07	1.58E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	7.69E-15	2.85E-05	3.15E+07	3.18E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	1.03E-15	3.81E-06	3.15E+07	4.06E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	4.01E-18	1.48E-08	3.15E+07	1.33E-14
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	6.15E-16	2.28E-06	3.15E+07	5.81E-12
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	3.17E-17	1.17E-07	3.15E+07	3.01E-13
												Total:	2.32E-03

MPC-68 Off-Normal Conditions Effective Dose Equivalent From Submersion													
Nuclide	Inventory (Ci/Assy)	10% for off-normal storage	No. Assy	MPC Vol (cm3)	L_{offnor}, Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	Effective Dose (mRem)
								Gases					
H-3	8.72E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.61E-10	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
I-129	7.72E-03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	2.31E-14	1.60E-04	1.10E-15	4.07E-06	3.15E+07	4.75E-10
Kr-85	1.43E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	0.30	4.29E-09	1.60E-04	1.32E-14	4.88E-05	3.15E+07	1.05E-03
								Crud					
Co-60	6.50E+01	1.00E+00	68	5.99E+06	8.80E-06	1.47E-12	0.15	9.74E-10	1.60E-04	1.45E-13	5.37E-04	3.15E+07	2.63E-03
								Volatiles					
Sr-90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	3.04E-11	1.60E-04	9.20E-15	3.40E-05	3.15E+07	5.21E-06
Ru-106	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	8.31E-12	1.60E-04	0.00E+00	0.00E+00	3.15E+07	0.00E+00
Cs-134	7.20E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	1.44E-11	1.60E-04	9.45E-14	3.50E-04	3.15E+07	2.54E-05
Cs-137	2.29E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	2.00E-04	4.58E-11	1.60E-04	8.63E-15	3.19E-05	3.15E+07	7.36E-06
								Fines					
PU241	2.10E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.29E-12	1.60E-04	1.17E-19	4.33E-10	3.15E+07	1.37E-11
Y 90	1.52E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.56E-12	1.60E-04	6.24E-14	2.31E-04	3.15E+07	5.30E-06
PM147	8.88E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.66E-12	1.60E-04	8.11E-16	3.00E-06	3.15E+07	4.02E-08
CE144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	2.93E-15	1.08E-05	3.15E+07	4.03E-08
PR144	2.46E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	7.37E-13	1.60E-04	8.43E-14	3.12E-04	3.15E+07	1.16E-06
EU154	1.07E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.21E-13	1.60E-04	8.29E-14	3.07E-04	3.15E+07	4.96E-07
CM244	9.30E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.79E-13	1.60E-04	3.91E-17	1.45E-07	3.15E+07	2.03E-10
PU238	7.49E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.24E-13	1.60E-04	4.09E-17	1.51E-07	3.15E+07	1.71E-10
SB125	6.40E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.92E-13	1.60E-04	2.65E-14	9.81E-05	3.15E+07	9.48E-08
EU155	3.51E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.05E-13	1.60E-04	3.39E-15	1.25E-05	3.15E+07	6.65E-09
AM241	2.20E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.59E-14	1.60E-04	1.28E-15	4.74E-06	3.15E+07	1.57E-09
TE125M	1.56E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	4.68E-14	1.60E-04	1.94E-15	7.18E-06	3.15E+07	1.69E-09
PU240	1.26E+02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	3.78E-14	1.60E-04	3.92E-17	1.45E-07	3.15E+07	2.76E-11
151Sm	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	1.90E-20	7.03E-11	3.15E+07	0.00E+00
239Pu	6.16E+01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.85E-14	1.60E-04	1.86E-17	6.88E-08	3.15E+07	6.40E-12
137mBa	2.16E+04	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	6.47E-12	1.60E-04	3.73E-14	1.38E-04	3.15E+07	4.50E-06
106Rh	4.16E+03	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.25E-12	1.60E-04	1.09E-13	4.03E-04	3.15E+07	2.53E-06
144mPr	0.00E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	0.00E+00	1.60E-04	5.08E-16	1.88E-06	3.15E+07	0.00E+00
243Am	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	2.75E-15	1.02E-05	3.15E+07	1.14E-10
242Cm	6.10E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.83E-15	1.60E-04	4.29E-17	1.59E-07	3.15E+07	1.46E-12
243Cm	4.81E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.44E-15	1.60E-04	9.79E-15	3.62E-05	3.15E+07	2.63E-10
239Np	7.39E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.21E-15	1.60E-04	1.60E-14	5.92E-05	3.15E+07	6.61E-10
237Np	7.05E-02	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	2.11E-17	1.60E-04	1.54E-15	5.70E-06	3.15E+07	6.07E-13
242Pu	5.95E-01	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	1.78E-16	1.60E-04	3.27E-17	1.21E-07	3.15E+07	1.09E-13
242Am	1.69E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.06E-16	1.60E-04	8.20E-15	3.03E-05	3.15E+07	7.74E-11
242mAm	1.70E+00	1.00E-01	68	5.99E+06	8.80E-06	1.47E-12	3.00E-05	5.09E-16	1.60E-04	1.36E-16	5.03E-07	3.15E+07	1.29E-12
												Total:	3.74E-03

MPC-68												
Accident Conditions												
Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	4.83E-16	1.79E-06	2.59E+06	1.22E-08
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.17E-16	4.33E-07	2.59E+06	5.48E-04
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.23E-13	4.55E-04	2.59E+06	8.73E-02
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	7.78E-18	2.88E-08	2.59E+06	2.58E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	7.40E-14	2.74E-04	2.59E+06	1.16E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	7.96E-18	2.95E-08	2.59E+06	3.98E-07
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	7.19E-20	2.66E-10	2.59E+06	4.94E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	1.89E-16	6.99E-07	2.59E+06	9.41E-07
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	7.48E-19	2.77E-09	2.59E+06	2.17E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	8.53E-16	3.16E-06	2.59E+06	6.87E-07
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	1.90E-15	7.03E-06	2.59E+06	1.53E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	6.00E-14	2.22E-04	2.59E+06	2.10E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	6.90E-18	2.55E-08	2.59E+06	2.10E-09
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	6.56E-18	2.43E-08	2.59E+06	1.61E-09
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	1.98E-14	7.33E-05	2.59E+06	4.15E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	2.49E-15	9.21E-06	2.59E+06	2.86E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	8.58E-16	3.17E-06	2.59E+06	6.18E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	5.96E-16	2.21E-06	2.59E+06	3.04E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	6.36E-18	2.35E-08	2.59E+06	2.62E-10
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	5.20E-20	1.92E-10	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	4.84E-18	1.79E-08	2.59E+06	9.76E-11
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	2.82E-14	1.04E-04	2.59E+06	1.99E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.01E-14	3.74E-05	2.59E+06	1.38E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.25E-16	1.20E-06	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	2.19E-15	8.10E-06	2.59E+06	5.30E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	7.83E-18	2.90E-08	2.59E+06	1.56E-11
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	5.77E-15	2.13E-05	2.59E+06	9.09E-09
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	7.53E-15	2.79E-05	2.59E+06	1.82E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	1.04E-15	3.85E-06	2.59E+06	2.40E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	5.34E-18	1.98E-08	2.59E+06	1.04E-12
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	6.09E-16	2.25E-06	2.59E+06	3.37E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.80E-17	1.41E-07	2.59E+06	2.12E-11
											Total	8.92E-02

MPC-68												
Accident Conditions												
Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	6.66E-16	2.46E-06	2.59E+06	1.68E-08
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.34E-16	4.96E-07	2.59E+06	6.27E-04
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.39E-13	5.14E-04	2.59E+06	9.86E-02
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	9.49E-18	3.51E-08	2.59E+06	3.15E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	8.43E-14	3.12E-04	2.59E+06	1.32E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	9.67E-18	3.58E-08	2.59E+06	4.83E-07
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	8.67E-20	3.21E-10	2.59E+06	5.96E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	2.20E-16	8.14E-07	2.59E+06	1.09E-06
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	9.56E-19	3.54E-09	2.59E+06	2.78E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	1.01E-15	3.74E-06	2.59E+06	8.13E-07
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	2.15E-15	7.96E-06	2.59E+06	1.73E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	6.81E-14	2.52E-04	2.59E+06	2.39E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	1.33E-17	4.92E-08	2.59E+06	4.05E-09
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	1.27E-17	4.70E-08	2.59E+06	3.11E-09
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	2.27E-14	8.40E-05	2.59E+06	4.76E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	2.95E-15	1.09E-05	2.59E+06	3.39E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	1.07E-15	3.96E-06	2.59E+06	7.71E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	8.48E-16	3.14E-06	2.59E+06	4.33E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	1.23E-17	4.55E-08	2.59E+06	5.07E-10
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	8.80E-20	3.26E-10	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	7.55E-18	2.79E-08	2.59E+06	1.52E-10
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.22E-14	1.19E-04	2.59E+06	2.28E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.16E-14	4.29E-05	2.59E+06	1.58E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	4.20E-16	1.55E-06	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	2.61E-15	9.66E-06	2.59E+06	6.32E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	1.48E-17	5.48E-08	2.59E+06	2.96E-11
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	6.68E-15	2.47E-05	2.59E+06	1.05E-08
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	8.73E-15	3.23E-05	2.59E+06	2.11E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	1.26E-15	4.66E-06	2.59E+06	2.91E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	1.03E-17	3.81E-08	2.59E+06	2.01E-12
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	7.30E-16	2.70E-06	2.59E+06	4.04E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	6.01E-17	2.22E-07	2.59E+06	3.35E-11
											Total	1.01E-01

MPC-68 Accident Conditions Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	2.75E-18	1.02E-08	2.59E+06	7.85E-07
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	2.14E-16	7.92E-07	2.59E+06	5.41E-09
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.14E-16	4.22E-07	2.59E+06	5.34E-04
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.24E-13	4.59E-04	2.59E+06	8.80E-02
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	6.44E-18	2.38E-08	2.59E+06	2.14E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	7.37E-14	2.73E-04	2.59E+06	1.16E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	6.68E-18	2.47E-08	2.59E+06	3.34E-07
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	6.48E-20	2.40E-10	2.59E+06	4.46E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	1.77E-16	6.55E-07	2.59E+06	8.81E-07
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	5.45E-19	2.02E-09	2.59E+06	1.58E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	7.69E-16	2.85E-06	2.59E+06	6.19E-07
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	1.90E-15	7.03E-06	2.59E+06	1.53E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	5.99E-14	2.22E-04	2.59E+06	2.10E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	7.08E-19	2.62E-09	2.59E+06	2.16E-10
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	1.06E-18	3.92E-09	2.59E+06	2.60E-10
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	1.95E-14	7.22E-05	2.59E+06	4.09E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	2.22E-15	8.21E-06	2.59E+06	2.55E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	6.74E-16	2.49E-06	2.59E+06	4.85E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	2.23E-16	8.25E-07	2.59E+06	1.14E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	1.09E-18	4.03E-09	2.59E+06	4.50E-11
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	7.08E-21	2.62E-11	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	2.65E-18	9.81E-09	2.59E+06	5.34E-11
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	2.80E-14	1.04E-04	2.59E+06	1.98E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.01E-14	3.74E-05	2.59E+06	1.38E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	2.00E-16	7.40E-07	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	1.92E-15	7.10E-06	2.59E+06	4.65E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	1.13E-18	4.18E-09	2.59E+06	2.26E-12
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	5.50E-15	2.04E-05	2.59E+06	8.66E-09
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	7.18E-15	2.66E-05	2.59E+06	1.74E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	9.02E-16	3.34E-06	2.59E+06	2.08E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	9.69E-19	3.59E-09	2.59E+06	1.89E-13
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	5.51E-15	2.04E-05	2.59E+06	3.05E-09
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	1.72E-17	6.36E-08	2.59E+06	9.57E-12
											Total	8.99E-02

MPC-68 Accident Conditions Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	1.64E-16	6.07E-07	2.59E+06	4.15E-09
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.09E-16	4.03E-07	2.59E+06	5.10E-04
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.23E-13	4.55E-04	2.59E+06	8.73E-02
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	5.44E-18	2.01E-08	2.59E+06	1.80E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	7.19E-14	2.66E-04	2.59E+06	1.13E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	5.70E-18	2.11E-08	2.59E+06	2.85E-07
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	5.63E-20	2.08E-10	2.59E+06	3.87E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	1.62E-16	5.99E-07	2.59E+06	8.06E-07
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	4.46E-19	1.65E-09	2.59E+06	1.30E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	6.68E-16	2.47E-06	2.59E+06	5.38E-07
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	1.87E-15	6.92E-06	2.59E+06	1.51E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	5.87E-14	2.17E-04	2.59E+06	2.06E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	1.46E-18	5.40E-09	2.59E+06	4.45E-10
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	1.68E-18	6.22E-09	2.59E+06	4.12E-10
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	1.87E-14	6.92E-05	2.59E+06	3.92E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	1.85E-15	6.85E-06	2.59E+06	2.13E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	5.21E-16	1.93E-06	2.59E+06	3.75E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	1.86E-16	6.88E-07	2.59E+06	9.50E-09
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	1.65E-18	6.11E-09	2.59E+06	6.81E-11
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	1.13E-20	4.18E-11	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	2.67E-18	9.88E-09	2.59E+06	5.38E-11
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	2.73E-14	1.01E-04	2.59E+06	1.93E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	9.75E-15	3.61E-05	2.59E+06	1.33E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	1.56E-16	5.77E-07	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	1.55E-15	5.74E-06	2.59E+06	3.75E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	1.89E-18	6.99E-09	2.59E+06	3.77E-12
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	5.00E-15	1.85E-05	2.59E+06	7.87E-09
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	6.50E-15	2.41E-05	2.59E+06	1.57E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	7.69E-16	2.85E-06	2.59E+06	1.78E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	1.43E-18	5.29E-09	2.59E+06	2.79E-13
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	4.77E-16	1.76E-06	2.59E+06	2.64E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	1.72E-17	6.36E-08	2.59E+06	9.57E-12
											Total	8.91E-02

MPC-68												
Accident Conditions												
Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	1.10E-15	4.07E-06	2.59E+06	2.78E-08
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	2.20E-16	8.14E-07	2.59E+06	1.03E-03
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.78E-13	6.59E-04	2.59E+06	1.26E-01
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	2.28E-17	8.44E-08	2.59E+06	7.56E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	1.20E-13	4.44E-04	2.59E+06	1.89E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	2.29E-17	8.47E-08	2.59E+06	1.14E-06
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	2.19E-19	8.10E-10	2.59E+06	1.51E-09
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	4.44E-16	1.64E-06	2.59E+06	2.21E-06
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	2.18E-18	8.07E-09	2.59E+06	6.34E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	2.49E-15	9.21E-06	2.59E+06	2.01E-06
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	2.99E-15	1.11E-05	2.59E+06	2.41E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	9.43E-14	3.49E-04	2.59E+06	3.30E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	8.82E-18	3.26E-08	2.59E+06	2.69E-09
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	9.30E-18	3.44E-08	2.59E+06	2.28E-09
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	3.53E-14	1.31E-04	2.59E+06	7.40E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	8.09E-15	2.99E-05	2.59E+06	9.30E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	2.87E-15	1.06E-05	2.59E+06	2.07E-07
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	1.22E-15	4.51E-06	2.59E+06	6.23E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	9.26E-18	3.43E-08	2.59E+06	3.82E-10
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	7.09E-20	2.62E-10	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	9.47E-18	3.50E-08	2.59E+06	1.91E-10
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	4.63E-14	1.71E-04	2.59E+06	3.27E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.72E-14	6.36E-05	2.59E+06	2.34E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	8.16E-16	3.02E-06	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	7.47E-15	2.76E-05	2.59E+06	1.81E-08
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	1.06E-17	3.92E-08	2.59E+06	2.12E-11
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	1.50E-14	5.55E-05	2.59E+06	2.36E-08
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	2.00E-14	7.40E-05	2.59E+06	4.84E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	3.20E-15	1.18E-05	2.59E+06	7.39E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	7.90E-18	2.92E-08	2.59E+06	1.54E-12
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	1.88E-15	6.96E-06	2.59E+06	1.04E-09
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	7.94E-17	2.94E-07	2.59E+06	4.42E-11
											Total	1.30E-01

MPC-68 Accident Conditions Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.86E-16	1.43E-06	2.59E+06	9.76E-09
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.18E-16	4.37E-07	2.59E+06	5.52E-04
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.27E-13	4.70E-04	2.59E+06	9.01E-02
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	7.33E-18	2.71E-08	2.59E+06	2.43E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	7.57E-14	2.80E-04	2.59E+06	1.19E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	7.55E-18	2.79E-08	2.59E+06	3.77E-07
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	6.98E-20	2.58E-10	2.59E+06	4.80E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	1.87E-16	6.92E-07	2.59E+06	9.31E-07
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	6.75E-19	2.50E-09	2.59E+06	1.96E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	8.33E-16	3.08E-06	2.59E+06	6.71E-07
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	1.95E-15	7.22E-06	2.59E+06	1.57E-05
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	6.15E-14	2.28E-04	2.59E+06	2.15E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	4.19E-18	1.55E-08	2.59E+06	1.28E-09
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	4.01E-18	1.48E-08	2.59E+06	9.83E-10
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	2.01E-14	7.44E-05	2.59E+06	4.21E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	2.41E-15	8.92E-06	2.59E+06	2.77E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	7.83E-16	2.90E-06	2.59E+06	5.64E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	4.64E-16	1.72E-06	2.59E+06	2.37E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.92E-18	1.45E-08	2.59E+06	1.62E-10
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.58E-20	1.32E-10	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	3.88E-18	1.44E-08	2.59E+06	7.83E-11
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	2.88E-14	1.07E-04	2.59E+06	2.04E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.03E-14	3.81E-05	2.59E+06	1.40E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	2.81E-16	1.04E-06	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	2.09E-15	7.73E-06	2.59E+06	5.06E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	4.91E-18	1.82E-08	2.59E+06	9.81E-12
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	5.76E-15	2.13E-05	2.59E+06	9.07E-09
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	7.52E-15	2.78E-05	2.59E+06	1.82E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	9.94E-16	3.68E-06	2.59E+06	2.29E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.32E-18	1.23E-08	2.59E+06	6.47E-13
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	5.94E-16	2.20E-06	2.59E+06	3.29E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	2.95E-17	1.09E-07	2.59E+06	1.64E-11
											Total	9.21E-02

68-Effective

MPC-68												
Accident Conditions												
Effective Dose Equivalent From Submersion												
Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	3.31E-19	1.22E-09	2.59E+06	9.45E-08
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	3.80E-16	1.41E-06	2.59E+06	9.60E-09
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.19E-16	4.40E-07	2.59E+06	5.57E-04
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.26E-13	4.66E-04	2.59E+06	8.94E-02
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	7.53E-18	2.79E-08	2.59E+06	2.50E-07
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	7.57E-14	2.80E-04	2.59E+06	1.19E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	7.74E-18	2.86E-08	2.59E+06	3.87E-07
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	7.25E-20	2.68E-10	2.59E+06	4.98E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	1.90E-16	7.03E-07	2.59E+06	9.46E-07
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	6.93E-19	2.56E-09	2.59E+06	2.01E-09
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	8.53E-16	3.16E-06	2.59E+06	6.87E-07
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	1.95E-15	7.22E-06	2.59E+06	1.57E-06
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	6.14E-14	2.27E-04	2.59E+06	2.15E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	4.91E-18	1.82E-08	2.59E+06	1.50E-09
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	4.88E-18	1.81E-08	2.59E+06	1.20E-09
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	2.02E-14	7.47E-05	2.59E+06	4.23E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	2.49E-15	9.21E-06	2.59E+06	2.86E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	8.18E-16	3.03E-06	2.59E+06	5.89E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	4.53E-16	1.68E-06	2.59E+06	2.31E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	4.75E-18	1.76E-08	2.59E+06	1.96E-10
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	3.61E-20	1.34E-10	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	4.24E-18	1.57E-08	2.59E+06	8.55E-11
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	2.88E-14	1.07E-04	2.59E+06	2.04E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.04E-14	3.85E-05	2.59E+06	1.42E-05
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	2.79E-16	1.03E-06	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	2.18E-15	8.07E-06	2.59E+06	5.27E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	5.69E-18	2.11E-08	2.59E+06	1.14E-11
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	5.88E-15	2.18E-05	2.59E+06	9.26E-09
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	7.69E-15	2.85E-05	2.59E+06	1.86E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	1.03E-15	3.81E-06	2.59E+06	2.38E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	4.01E-18	1.48E-08	2.59E+06	7.81E-13
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	6.15E-16	2.28E-06	2.59E+06	3.40E-10
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	3.17E-17	1.17E-07	2.59E+06	1.76E-11
											Total	9.14E-02

MPC-68

Accident Conditions

Effective Dose Equivalent From Submersion

Nuclide	Inventory (Ci/Assy)	No. Assy	MPC Vol (cm3)	L_{acc} Rate at Upstream (cm3/s)	Fraction Released per sec	Release Fraction	Release Rate (Ci/sec)	X/Q (sec/m3)	DCF (Sv/Bq)	DCF (mRem/uCi)	Occ Time (sec)	EDE (mRem)
							Gases					
H-3	8.72E+01	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.72E-09	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
I-129	7.72E-03	68	5.99E+06	1.25E-05	2.09E-12	0.30	3.30E-13	8.00E-03	1.10E-15	4.07E-06	2.59E+06	2.78E-08
Kr-85	1.43E+03	68	5.99E+06	1.25E-05	2.09E-12	0.30	6.11E-08	8.00E-03	1.32E-14	4.88E-05	2.59E+06	6.18E-02
							Crud					
Co-60	6.50E+01	68	5.99E+06	1.25E-05	2.09E-12	1.00	9.25E-09	8.00E-03	1.45E-13	5.37E-04	2.59E+06	1.03E-01
							Volatiles					
Sr-90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	4.33E-10	8.00E-03	9.20E-15	3.40E-05	2.59E+06	3.05E-04
Ru-106	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	1.18E-10	8.00E-03	0.00E+00	0.00E+00	2.59E+06	0.00E+00
Cs-134	7.20E+03	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	2.05E-10	8.00E-03	9.45E-14	3.50E-04	2.59E+06	1.49E-03
Cs-137	2.29E+04	68	5.99E+06	1.25E-05	2.09E-12	2.00E-04	6.52E-10	8.00E-03	8.63E-15	3.19E-05	2.59E+06	4.31E-04
							Fines					
PU241	2.10E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	8.97E-11	8.00E-03	1.17E-19	4.33E-10	2.59E+06	8.04E-10
Y 90	1.52E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.49E-11	8.00E-03	6.24E-14	2.31E-04	2.59E+06	3.11E-04
PM147	8.88E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.79E-11	8.00E-03	8.11E-16	3.00E-06	2.59E+06	2.36E-06
CE144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	2.93E-15	1.08E-05	2.59E+06	2.36E-06
PR144	2.46E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.05E-11	8.00E-03	8.43E-14	3.12E-04	2.59E+06	6.79E-05
EU154	1.07E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	4.57E-12	8.00E-03	8.29E-14	3.07E-04	2.59E+06	2.90E-05
CM244	9.30E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.97E-12	8.00E-03	3.91E-17	1.45E-07	2.59E+06	1.19E-08
PU238	7.49E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.20E-12	8.00E-03	4.09E-17	1.51E-07	2.59E+06	1.00E-08
SB125	6.40E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.73E-12	8.00E-03	2.65E-14	9.81E-05	2.59E+06	5.55E-06
EU155	3.51E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.50E-12	8.00E-03	3.39E-15	1.25E-05	2.59E+06	3.90E-07
AM241	2.20E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.40E-13	8.00E-03	1.28E-15	4.74E-06	2.59E+06	9.22E-08
TE125M	1.56E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	6.66E-13	8.00E-03	1.94E-15	7.18E-06	2.59E+06	9.91E-08
PU240	1.26E+02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	5.38E-13	8.00E-03	3.92E-17	1.45E-07	2.59E+06	1.62E-09
151Sm	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	1.90E-20	7.03E-11	2.59E+06	0.00E+00
239Pu	6.16E+01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.63E-13	8.00E-03	1.86E-17	6.88E-08	2.59E+06	3.75E-10
137mBa	2.16E+04	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	9.22E-11	8.00E-03	3.73E-14	1.38E-04	2.59E+06	2.64E-04
106Rh	4.16E+03	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	1.78E-11	8.00E-03	1.09E-13	4.03E-04	2.59E+06	1.48E-04
144mPr	0.00E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	0.00E+00	8.00E-03	5.08E-16	1.88E-06	2.59E+06	0.00E+00
243Am	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	2.75E-15	1.02E-05	2.59E+06	6.65E-09
242Cm	6.10E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.61E-14	8.00E-03	4.29E-17	1.59E-07	2.59E+06	8.57E-11
243Cm	4.81E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.05E-14	8.00E-03	9.79E-15	3.62E-05	2.59E+06	1.54E-08
239Np	7.39E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.16E-14	8.00E-03	1.60E-14	5.92E-05	2.59E+06	3.87E-08
237Np	7.05E-02	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	3.01E-16	8.00E-03	1.54E-15	5.70E-06	2.59E+06	3.55E-11
242Pu	5.95E-01	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	2.54E-15	8.00E-03	3.27E-17	1.21E-07	2.59E+06	6.37E-12
242Am	1.69E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.22E-15	8.00E-03	8.20E-15	3.03E-05	2.59E+06	4.54E-09
242mAm	1.70E+00	68	5.99E+06	1.25E-05	2.09E-12	3.00E-05	7.26E-15	8.00E-03	1.36E-16	5.03E-07	2.59E+06	7.57E-11
											Total	1.68E-01

CHAPTER 8: OPERATING PROCEDURES

8.0 INTRODUCTION:

This chapter outlines the loading, unloading, and recovery procedures for the HI-STAR 100 System for storage operations. The procedures provided in this chapter are prescriptive to the extent that they provide the basis and general guidance for plant personnel in preparing detailed written site-specific loading, handling, storage and unloading procedures. The information provided in this chapter meets all requirements of NUREG-1536 [8.0.1].

Section 8.1 provides the procedure for loading the HI-STAR 100 System in the spent fuel pool. Section 8.2 provides guidance for ISFSI operations and general guidance for responding to abnormal events. Responses to abnormal events that may occur during normal loading operations are provided with the procedure steps. Section 8.3 provides the procedure for unloading the HI-STAR 100 System in the spent fuel pool. Section 8.4 provides the procedures for placement of the HI-STAR 100 System into storage directly from transport. Appendices A and B to the Certificate of Compliance (CoC) 1008, including the Technical Specifications provide functional and Operating Limits, Limiting Conditions for Operation (LCOs), Surveillance Requirements (SR's) and design features, as well as administrative information, such as Use and Application. FSAR Appendix 12.A includes Bases for the Functional and Operating Limits, and the LCOs. The Technical Specifications impose restrictions and requirements that must be applied throughout the loading and unloading process. Equipment specific operating details such as Vacuum Drying System valve manipulation and Transporter operation will be provided to users based on the specific equipment selected by the users and the configuration of the site.

Licensees (Users) will utilize the procedures provided in this chapter, the Technical Specifications, the conditions of the Certificate of Compliance, equipment-specific operating instructions, and plant working procedures and apply them to develop the site-specific written loading, handling, unloading and storage procedures. The procedures contained herein describe acceptable methods for performing HI-STAR 100 loading and unloading operations. Users may alter these procedures to allow operations to be performed in parallel or out of sequence as long as the general intent of the procedure is met. Users may add or delete steps in their site-specific implementation procedures provided the intent of these guidelines is met. In the figures following each section, acceptable configurations of rigging, piping, and instrumentation are shown. The equipment specified in this chapter is acceptable for use in performing the associated cask operations. Alternative equipment may be used provided the design and operation of the proposed alternate equipment is reviewed by the Certificate Holder. Any deviations to the rigging should be approved by the user's load handling authority.

The loading and unloading procedures in Section 8.1 and 8.3 can also be appropriately revised into written site-specific procedures to allow dry loading and unloading of the system in a hot cell or other remote handling facility. The Dry Transfer Facility (DTF) loading and unloading procedures are essentially the same with respect to loading, vacuum drying, inerting, and leakage testing of the MPC. The dry transfer facility shall develop the appropriate site-specific procedures as part of the DTF facility license.

Tables 8.1.1 and 8.1.2 provide the handling weights for each of the HI-STAR 100 System major components and the loads to be lifted during the operation of the HI-STAR 100 System. Table 8.1.3 provides the HI-STAR 100 System bolt torque and sequencing requirements. Table 8.1.4 provides an operational description of the HI-STAR 100 System ancillary equipment and its safety designation. Fuel assembly selection and verification shall be performed by the licensee in accordance with written, approved procedures which ensure that only SNF assemblies authorized in Appendix B to the Certificate of Compliance are loaded into the HI-STAR 100 System.

In addition to the requirements set forth in the CoC, users will be required to develop or modify existing programs and procedures to account for the operation of an ISFSI. Written procedures will be required to be developed or modified to account for such things as nondestructive examination (NDE) of the MPC welds, handling and storage of items and components identified as Important to Safety, 10CFR72.48 [8.0.2] programs, specialized instrument calibration, special nuclear material accountability at the ISFSI, security modifications, fuel handling procedures, training and emergency response, equipment and process qualifications. Users shall implement controls to ensure that the lifted weights do not exceed the HI-STAR 100 trunnion design limits. Users shall implement controls to monitor the time limit from the removal of the HI-STAR 100 from the spent fuel pool to the commencement of MPC draining to prevent boiling. Chapter 4 of the FSAR provides examples of the time limits based on representative spent fuel pool temperatures and design basis heat loads. Users shall also implement controls to ensure that the HI-STAR 100 overpack cannot be subjected to a fire in excess of design limits during both transport operations and storage operations.

Table 8.1.5 summarizes the instrumentation used to load and unload the HI-STAR 100 System. Tables 8.1.6 and 8.1.7 provide sample receipt inspection checklists for the HI-STAR 100 overpack and the MPC, respectively. Users shall develop site-specific receipt inspection checklists, as required. Fuel handling, including the handling of fuel assemblies in the Damaged Fuel Container (DFC) shall be performed in accordance with written site-specific procedures. Damaged fuel and fuel debris, as defined in the Technical Specifications appended to CoC 1008 shall be loaded in DFCs.

8.0.1 <u>Technical and Safety Basis for Loading and Unloading Procedures:</u>

The procedures herein (Sections 8.1 through 8.4) are developed for the loading, storage, handling, and unloading of spent fuel in the HI-STAR 100 System. The activities involved in loading of spent fuel in a canister system, if not carefully performed, may present personnel hazards and radiological impact. The design of the HI-STAR 100 System, including these procedures, the ancillary equipment, and the Technical Specifications, serve to minimize risks and mitigate consequences of potential events. To summarize, consideration is given in the loading and unloading systems and procedures to the potential events listed in Table 8.0.1.

The primary objective is to reduce the risk of occurrence and/or to mitigate the consequences of the event. The procedures contain Notes, Warnings, and Cautions to notify the operators of upcoming situations and provide additional information as needed. The Notes, Warnings and Cautions are purposely bolded and boxed, and immediately precede the applicable steps.

In the event of an extreme abnormal condition (e.g., cask drop or tip-over event) the user shall have appropriate procedural guidance to respond to the situation. As a minimum, the procedures shall address establishing emergency action levels, implementation of emergency action program, establishment of personnel exclusion zones, monitoring of radiological conditions, actions to mitigate or prevent the release of radioactive materials, and recovery planning and execution.

Table 8.0.1
OPERATIONAL CONSIDERATIONS

Potential Event:	Breached MPC in HI-STAR 100 overpack as it related to unloading operations
Methods Used to Address:	Procedural guidance is given to sample the HI-STAR 100 overpack annulus gas prior to opening of the HI-STAR 100 overpack penetrations.
References:	See Section 8.3.2 Step 4.
Potential Event:	Cask drop during handling operations
Methods Used to Address:	Lifting and handling equipment used to lift the cask higher than the lifting height limits is designed to ANSI N14.6 [8.0.3] and incorporates redundant drop protection features. Procedural guidance is given for cask handling, inspection of lifting equipment, and proper engagement to the trunnions. Technical Specifications provide lifting requirements.
References:	See Section 8.1.2. See LCO 2.1.3.
Potential Event:	Cask tip-over prior to welding of the MPC lid
Methods Used to Address:	The optional Lid Retention System is available to secure the MPC lid during movement between the spent fuel pool and the cask preparation area.
References:	See Section 8.1.5 Step 1. See Figure 8.1.14 and 8.1.16.
Potential Event:	Contamination of the MPC external shell
Methods Used to Address:	The annulus seal and Annulus Overpressure System minimize the potential for the MPC external shell to become contaminated from contact with the spent fuel pool water. Technical Specifications require surveys of the accessible portions of the MPC shell to monitor for removable contamination.
References:	See Figures 8.1.12 and 8.1.13. See LCO 2.2.2.
Potential Event:	Contamination spread from cask process system exhausts
Methods Used to Address:	All processing systems are equipped with exhausts that can be directed to the plant's processing systems or spent fuel pool.
References:	See Figures 8.1.19, 8.1.21, and 8.1.22.

Table 8.0.1
OPERATIONAL CONSIDERATIONS
(Continued)

Potential Event:	Damage to fuel assembly cladding from oxidation/thermal shock.
Methods Used to Address:	Fuel assemblies are never subjected to air or oxygen during loading and unloading operations. The Cool-Down System brings fuel assembly temperatures to below water boiling temperature using helium prior to reflooding with water during cask unloading operations.
References:	See Section 8.1.5 Step 24b and Section 8.3.2 Step 14.

Potential Event:	Damage to Vacuum Drying System vacuum gauges from positive pressure.
Methods Used to Address:	Vacuum Drying System is separate from pressurized gas and water systems.
References:	See Figure 8.1.22 and 8.1.23.

Potential Event:	Difficulty in installing the MPC lid.
Methods Used to Address:	The optional Lid Retention System has alignment pins to help guide the MPC lid into position during underwater installation.
References:	See Figure 8.1.14 and 8.1.16.

Potential Event:	Excess dose from grossly-damaged fuel assemblies
Methods Used to Address:	MPC gas sampling allows operators to determine the integrity of the fuel cladding prior to opening the MPC. This allows preparation and planning for handling of grossly-damaged fuel. The Removable Valve Operating Assemblies (RVOAs) allow the vent and drain ports to be operated like valves and prevent the need to hot tap into the penetrations during unloading operation.
References:	See Figure 8.1.15 and Section 8.3.2 Step 13.

Potential Event:	Excess dose to operators.
Methods Used to Address:	The procedures provide ALARA Notes and Warnings when radiological conditions may change.
References:	See ALARA Notes and Warnings throughout the procedures.

Table 8.0.1
OPERATIONAL CONSIDERATIONS
(Continued)

Potential Event:	Excess generation of radioactive waste
Methods Used to Address:	The HI-STAR 100 System uses process systems that minimize the amount of radioactive waste generated. Such features include smooth surfaces for ease of decontamination efforts, prevention of avoidable contamination, and procedural guidance to reduce decontamination requirements. Where possible, items are installed by hand and require no tools.
References:	Examples: HI-STAR 100 overpack bottom protective cover, bolt plugs in empty holes, pre-wetting of components.
Potential Event:	Ignition of combustible mixtures of gas (e.g., hydrogen) during MPC lid welding or cutting
Methods Used to Address:	Combustible gas monitoring will be performed and the space below the MPC lid will be exhausted or purged with an inert gas during welding and cutting operations.
References	See Section 8.1.5 Step 25a and Section 8.3.2 Step 14k.

8.1 PROCEDURE FOR LOADING THE HI-STAR 100 SYSTEM IN THE SPENT FUEL POOL

8.1.1 Overview of Loading Operations

The HI-STAR 100 System is used to load, unload, transfer and store spent fuel. Specific steps are performed to prepare the HI-STAR 100 System for fuel loading, to load the fuel, to prepare the system for storage and to place it in storage at an ISFSI. The HI-STAR 100 overpack may be transferred between the ISFSI and the fuel loading facility using a specially designed transporter, heavy haul transfer trailer, or any other load handling equipment designed for such applications as long as the lifting requirements described in LCO 2.1.3 are met. Users shall develop detailed written procedures to control on-site transport operations. Section 8.1.2 provides the general procedures for handling of the HI-STAR 100 overpack and MPC. Figure 8.1.1 shows a flow diagram of the HI-STAR 100 System loading operations. Figure 8.1.2 illustrates some of the major HI-STAR 100 System loading operations.

Note:
The procedures describe plant facilities, functions, and processes in general terms. Each site is different with regard to layout, organization and nomenclature. Users shall interpret the nomenclature used herein to suit their particular site, organization, and methods of operation.

Refer to the boxes of Figure 8.1.2 for the following description. At the start of loading operations, an empty MPC is upended (Box 1). The empty MPC is raised and inserted into the HI-STAR 100 overpack (Box 2). The annulus is filled with plant demineralized water and the MPC is filled with either spent fuel pool water or plant demineralized water (Box 3). An inflatable seal is installed in the annulus between the MPC and the HI-STAR 100 overpack to prevent spent fuel pool water from contaminating the exterior surface of the MPC. The HI-STAR 100 overpack and the MPC are then raised and lowered into the spent fuel pool for fuel loading using the lift yoke (Box 4). Pre-selected assemblies are loaded into the MPC and a visual verification of the assembly identification is performed (Box 5).

While still underwater, a thick, shielded lid (the MPC lid) is installed using either slings attached to the lift yoke or the Lid Retention System (Box 6). The lift yoke remotely engages to the HI-STAR 100 overpack lifting trunnions to lift the HI-STAR 100 overpack and loaded MPC close to the spent fuel pool surface (Box 7). When radiation dose rate measurements confirm that it is safe to remove the HI-STAR 100 overpack from the spent fuel pool, the cask is removed from the spent fuel pool. If the Lid Retention System is being used, the HI-STAR 100 overpack closure plate bolts are installed to secure the MPC lid for the transfer to the cask preparation area. The lift yoke and HI-STAR 100 overpack are sprayed with demineralized water to help remove contamination as they are removed from the spent fuel pool.

The HI-STAR 100 overpack is placed in the designated preparation area and the lift yoke and Lid Retention System retention disk are removed. The next phase of decontamination is then performed. The top surfaces of the MPC lid and the upper flange of the HI-STAR 100 overpack are decontaminated. The Temporary Shield Ring (if utilized) is installed and filled with water. The inflatable annulus seal is removed, and the annulus shield is installed. The Temporary Shield

Ring provides additional personnel shielding around the top of the HI-STAR 100 overpack during MPC closure operations. The annulus shield provides additional personnel shielding at the top of the annulus and also prevents small items from being dropped into the annulus. Dose rates are measured at the MPC lid and around the mid-height circumference of the HI-STAR 100 overpack to ensure that the dose rates are within expected values. The MPC water level is lowered slightly, the MPC is vented, and the MPC lid is seal welded using the Automated Welding System (Box 8). Visual examinations are performed on the tack welds. Liquid penetrant examinations are performed on the root and final passes. An ultrasonic or multi-layer PT examination is performed on the MPC Lid-to-Shell weld to ensure that the weld is satisfactory. As an alternative to volumetric examination of the MPC lid-to-shell weld, a multi-layer PT is performed including one intermediate examination after approximately every three-eighth inch of weld depth. The water level is raised to the top of the MPC and a hydrostatic test is performed on the primary MPC confinement welds to verify structural integrity. A small amount of water is displaced with helium gas for leakage testing. A helium leakage rate test is performed on the MPC lid-to-shell weld to verify weld integrity and to ensure that required leakage rates are within Technical Specification acceptance criteria (LCO 2.1.1).

The water level is raised to the top of the MPC again and then the MPC water is displaced from the MPC by blowdown of the water using pressurized helium or nitrogen gas introduced into the vent port of the MPC thus displacing the water through the drain line. The Vacuum Drying System (VDS) is connected to the MPC and is used to remove all residual liquid water from the MPC in a stepped evacuation process (Box 9). A stepped evacuation process is used to preclude the formation of ice in the MPC and Vacuum Drying System lines. The internal pressure is reduced to below 3 torr and held for 30 minutes to ensure that all liquid water is removed (LCO 2.1.1).

Following the dryness test, the VDS is disconnected, the Helium Backfill System (HBS) is connected, and the MPC is backfilled with a predetermined pressure of helium gas (LCO 2.1.1). The helium backfill ensures adequate heat transfer during storage, provides an inert atmosphere for long-term fuel integrity, and provides the means of future leakage rate testing of the MPC confinement boundary welds. Cover plates are installed and seal welded over the MPC vent and drain ports and liquid penetrant examinations are performed on the root (for multi-pass welds) and final passes (Box 10). The cover plates are helium leakage tested to confirm that they meet the established leakage rate criteria (LCO 2.1.1).

The MPC closure ring is then placed on the MPC and dose rates are measured at the MPC lid to ensure that the dose rates are within expected values. The closure ring is aligned, tacked in place and seal welded providing redundant closure of the MPC confinement boundary closure welds. Tack welds are visually examined, and the root (for multi-pass welds) and final welds are inspected using the liquid penetrant examination technique to ensure weld integrity.

The annulus shield is removed and the remaining water in the annulus is drained. The MPC lid and accessible areas at the top of the MPC shell are smeared for removable contamination and the HI-STAR 100 overpack dose rates are measured (LCO 2.2.1). The HI-STAR 100 overpack closure plate is installed (Box 11) and the bolts are torqued. The HI-STAR 100 overpack annulus

is vacuum dried and backfilled with helium gas (LCO 2.1.2). The HI-STAR 100 overpack mechanical seals are helium leakage tested to assure they will provide long-term retention of the annulus helium (LCO 2.1.2). The HI-STAR 100 overpack cover plates are installed. The Temporary Shield Ring is drained and removed. Dose rates are taken on the overpack to ensure that they are less than the Technical Specification limits (LCO 2.2.1).

The HI-STAR 100 overpack is moved to the ISFSI pad (Box 12). The HI-STAR 100 overpack may be moved using a number of methods as long as the lifting requirements of LCO 2.1.3 are met.

8.1.2 HI-STAR 100 System Receiving and Handling Operations:

> **Note:**
> The HI-STAR 100 overpack may be received and handled in several different configurations and may be transported on-site in a horizontal or vertical orientation. This section provides general guidance for the HI-STAR 100 overpack and MPC rigging and handling. Site-specific procedures shall specify the required operational sequences based on the cask handling configuration and limitations at the sites. Refer to LCO 2.1.3 for lifting requirements for a loaded overpack.

> **Note:**
> Steps 1 through 4 describe the handling operations using a lift yoke. Specialty rigging may be substituted if the lift complies with NUREG-0612 [8.0.4].

1. Vertical Handling of the HI-STAR 100 overpack:

> **Note:**
> Prior to performing any lifting operation, the removable shear ring segments under the two lifting trunnions must be removed.

a. Verify that the lift yoke load test certifications are current.

b. Visually inspect the lift yoke and the lifting trunnions for gouges, cracks, deformation or other indications of damage.

c. Engage the lift yoke to the lifting trunnions. See Figure 8.1.3.

d. Apply lifting tension to the lift yoke and verify proper engagement of the lift yoke.

> **Note:**
> Refer to the site's heavy load handling procedures for lift height, load path, floor loading and other applicable load handling requirements. Refer to LCO 2.1.3 for lifting requirements for a loaded HI-STAR 100 System.

e. Raise the HI-STAR 100 overpack and position it accordingly.

2. Upending of the HI-STAR 100 overpack in the transport frame:

Warning:
Personnel shall remain clear of the unshielded bottom of the loaded overpack. Users shall coordinate operations to keep the bottom cover installed to the maximum extent practicable whenever when the loaded overpack is downended.

a. If installed, remove the overpack bottom cover. Rigging points are provided. See Figure 8.1.4.

b. Position the HI-STAR 100 overpack under the lifting device. Refer to Step 1, above.

c. Verify that the lift yoke load test certifications are current.

d. Visually inspect the lift yoke and the lifting trunnions for gouges, cracks, deformation or other indications of damage.

e. Deleted.

f. Engage the lift yoke to the lifting trunnions. (The use of a ratchet strap or similar device to restrain the lift yoke arms is recommended during HI-STAR upending operation). See Figure 8.1.3.

g. Apply lifting tension to the lift yoke and verify proper engagement of the lift yoke.

h. Slowly rotate the HI-STAR 100 overpack to the vertical position keeping all rigging as close to vertical as practicable. See Figure 8.1.4.

i. Lift the pocket trunnions clear of the transport frame rotation trunnions.

j. Position the HI-STAR 100 overpack per site direction.

3. Downending of the HI-STAR 100 overpack in the transport frame:

a. Position the transport frame under the lifting device.

b. Verify that the lift yoke load test certifications are current.

c. Visually inspect the lift yoke and the lifting trunnions for gouges, cracks, deformation or other indications of damage.

d. Deleted.

e. Deleted.

f. Engage the lift yoke to the lifting trunnions. (The use of a ratchet strap or similar device to restrain the lift yoke arms is recommended during HI-STAR downending operation). See Figure 8.1.3.

g. Apply lifting tension to the lift yoke and verify proper lift yoke engagement.

h. Position the pocket trunnions to receive the transport frame rotation trunnions. See Figure 8.1.4.

i. Slowly rotate the HI-STAR 100 overpack to the horizontal position keeping all rigging as close to vertical as practicable.

j. Disengage the lift yoke.

Warning:
Personnel shall remain clear of the unshielded bottom of the loaded overpack. Users shall coordinate operations to keep the bottom cover installed to the maximum extent practicable whenever when the loaded overpack is downended.

k. If necessary for radiation shielding, install the overpack bottom cover. Rigging points are provided. See Figure 8.1.4.

4. Horizontal Handling of the HI-STAR 100 overpack in the transport frame:

a. Secure the transport frame for HI-STAR 100 downending.

b. Downend the HI-STAR 100 overpack on the transport frame per Step 3, if necessary.

c. Inspect the transport frame lift rigging in accordance with site approved rigging procedures.

d. Position the transport frame accordingly.

5. Empty MPC Installation in the HI-STAR 100 overpack:

Note:
To avoid side loading the MPC lift lugs, the MPC must be upended in the MPC Upending Frame (or equivalent). See Figure 8.1.5

a. If necessary, remove any MPC shipping covers and rinse off any road dirt with water. Be sure to remove any foreign objects from the MPC internals.

b. Upend the MPC as follows:

1. Visually inspect the MPC Upending Frame for gouges, cracks, deformation or other indications of damage.

2. Install the MPC on the Upending Frame. Make sure that the banding straps are secure around the MPC shell. See Figure 8.1.5.

Warning:
The Upending Frame rigging bars are equipped with cleats that prevent the slings from sliding along the bar. The slings must be placed to the outside of the cleats to prevent an out-of-balance condition. The Upending Frame rigging points are labeled.

3. Inspect the Upending Frame slings in accordance with the site's lifting equipment inspection procedures. Rig the slings around the bar in a choker configuration to the outside of the cleats. See Figure 8.1.5.

4. Attach the MPC upper end slings of the Upending Frame to the main overhead lifting device. Attach the bottom-end slings to a secondary lifting device (or a chain fall attached to the primary lifting device).

5. Raise the MPC in the Upending Frame.

Warning:
The Upending Frame corner should be kept close to the ground during the upending process.

6. Slowly lift the upper end of the Upending Frame while lowering the bottom end of the Upending Frame.

7. When the MPC approaches the vertical orientation, release the tension on the lower slings.

8. Place the MPC in a vertical orientation on a level surface.

9. Disconnect the MPC straps and disconnect the rigging.

c. Install the MPC in the HI-STAR 100 overpack as follows:

1. Install the four point lift sling to the lift lugs inside the MPC. See Figure 8.1.6.

Caution:
Be careful not to damage the seal seating surface during MPC installation.

2. Raise and place the MPC inside the HI-STAR 100 overpack.

Note:
An alignment punch mark is provided on the HI-STAR 100 overpack and the top edge of the MPC. Similar marks are provided on the MPC lid and closure ring. See Figure 8.1.7.

3. Rotate the MPC so the alignment marks agree and seat the MPC inside the HI-STAR 100 overpack. Disconnect the MPC rigging or the MPC lift rig.

8.1.3 HI-STAR 100 Overpack and MPC Receipt Inspection and Loading Preparation

ALARA Note:
A bottom protective cover may be attached to the HI-STAR 100 overpack bottom or placed in the designated preparation area and spent fuel pool. This will help prevent embedding contaminated particles in the HI-STAR 100 overpack bottom surface and ease the decontamination effort.

1. Place the HI-STAR 100 overpack in the cask receiving area. Perform appropriate contamination and security surveillances, as required.

2. If necessary, remove the HI-STAR 100 overpack closure plate by removing the closure plate bolts. See Figure 8.1.8 for rigging example.

    a. Place the closure plate on cribbing that protects the seal seating surfaces and allows access for seal replacement.

    b. Install the seal surface protector on the HI-STAR 100 overpack seal seating surface. See Figure 8.1.12.

3. Rinse off any road dirt with water. Inspect all cavity locations for foreign objects. Remove any foreign objects.

4. Disconnect the rigging.

5. Store the closure plate and bolts in a site-approved location.

6. At the site's discretion, perform an MPC receipt inspection and cleanliness inspection in accordance with a site-specific inspection checklist.

7. Install the MPC inside the HI-STAR 100 overpack and place the HI-STAR 100 overpack in the designated preparation area. See Section 8.1.2.

Note:
Fuel spacers are fuel-type specific. Not all fuel types require fuel spacers. Upper fuel spacers are threaded into the underside of the MPC lid. Fuel spacers may be loaded any time prior to insertion of the fuel assemblies in the MPC.

8. Install the upper fuel spacers in the MPC lid as follows:

Warning:
Never work under a suspended load.

    a. Position the MPC lid on supports to allow access to the underside of the MPC lid.

    b. Thread the fuel spacers into the holes provided on the underside of the MPC lid. See Figure 8.1.9 and Table 8.1.3 for torque requirements. See Figure 8.1.8.

c. Install threaded inserts in the MPC lid where and when spacers will not be installed, if necessary. See Table 8.1.3 for torque requirements.

9. Perform an MPC lid and closure ring fit test:

Note:
It will be necessary to perform the MPC installation and inspection in a location that has sufficient crane clearance to perform the operation.

a. Visually inspect the MPC lid rigging (See Figure 8.1.8).

b. Raise the MPC lid such that the drain line can be installed. Install the drain line to the underside of the MPC lid. See Figure 8.1.10.

Note:
The MPC Shell is relatively flexible compared to the MPC Lid and may create areas of local contact that impede Lid insertion in the Shell. Grinding of the MPC Lid below the minimum diameter on the drawing is permitted to alleviate interference with the MPC Shell in areas of localized contact. If the amount of material removed from the surface exceeds 1/8", the surface shall be examined by a liquid penetrant method (NB-2546). The weld prep for the Lid-to-Shell weld shall be maintained after grinding.

c. Align the MPC lid and lift yoke so the drain line will be positioned in the MPC drain location. See Figure 8.1.11. Install the MPC lid. Verify that the MPC lid fit and weld prep are in accordance with the approved design drawings.

ALARA Note:
The closure ring is installed by hand. No tools are required.

d. Install the closure ring. See Figure 8.1.7.

e. Verify that closure ring fit and weld prep are in accordance with the approved design drawings.

f. Remove the closure ring and the MPC lid. Disconnect the drain line. Store these components in an approved plant storage location.

Note:
Fuel spacers are fuel-type specific. Not all fuel types require fuel spacers. Lower fuel spacers are set in the MPC cells manually. No restraining devices are used. Fuel spacers may be loaded any time prior to insertion of the fuel assemblies in the MPC.

10. Install lower fuel spacers in the MPC (if required for the fuel type). See Figure 8.1.9.

11. Fill the MPC and annulus as follows:

Caution:
Do not use any sharp tools or instruments to install the inflatable seal. Some air in the inflatable seal helps in the installation.

a. Remove the HI-STAR 100 overpack drain port cover and port plug and install the drain connector. Store the drain port cover plate and port plug in an approved storage location.

b. Fill the annulus with plant demineralized water to just below the inflatable seal seating surface.

c. Manually insert the inflatable annulus seal around the MPC. See Figure 8.1.12.

d. Ensure that the seal is uniformly positioned in the annulus area.

e. Inflate the seal.

f. Visually inspect the seal to ensure that it is properly seated in the annulus. Deflate, adjust and inflate the seal as necessary. Replace the seal as necessary.

ALARA Note:
Waterproof tape placed over empty bolt holes, and bolt plugs may reduce the time required for decontamination.

12. At the user's discretion, install the HI-STAR 100 overpack closure plate bolt plugs and/or apply waterproof tape over any empty bolt holes.

ALARA Note:
Keeping the water level below the top of the MPC prevents splashing during handling.

13. Fill the MPC with either demineralized water or spent fuel pool water to approximately 12 inches below the top of the MPC shell.

14. Place the HI-STAR 100 overpack in the spent fuel pool as follows:

ALARA Note:
The optional Annulus Overpressure System is used to provide further protection against MPC external shell contamination during in-pool operations.

a. If used, fill the Annulus Overpressure System lines and reservoir with demineralized water and close the reservoir valve. Attach the Annulus Overpressure System to the HI-STAR 100 overpack. See Figure 8.1.13.

b. Engage the lift yoke to the HI-STAR 100 overpack lifting trunnions and position the HI-STAR 100 overpack over the cask loading area with the basket aligned to the orientation of the spent fuel racks.

ALARA Note:
Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

c. Wet the surfaces of the HI-STAR 100 overpack and lift yoke with plant demineralized water while slowly lowering the HI-STAR 100 overpack into the spent fuel pool.

d. When the top of the HI-STAR 100 overpack reaches the elevation of the reservoir, open the Annulus Overpressure System reservoir valve. Maintain the reservoir water level at approximately 3/4 full the entire time the cask is in the spent fuel pool.

e. Place the HI-STAR 100 overpack on the floor of the cask loading area and disengage the lift yoke. Visually verify that the lift yoke is fully disengaged. Remove the lift yoke from the spent fuel pool while spraying the crane cables and yoke with plant demineralized water.

8.1.4 MPC Fuel Loading

Note:
An underwater camera or other suitable viewing device may be used for monitoring underwater operations.

1. Perform a fuel assembly selection verification using plant fuel records to ensure that only fuel assemblies that meet all the conditions for loading as specified in Appendix B to Certificate of Compliance 1008 have been selected for loading into the MPC.

2. Load the pre-selected fuel assemblies into the MPC in accordance with the approved fuel loading pattern.

3. Perform a post-loading visual verification of the assembly identification to confirm that the serial numbers match the approved fuel loading pattern.

8.1.5 MPC Closure

Note:
The user may elect to use the optional Lid Retention System (See Figure 8.1.14) to assist in the installation of the MPC lid and attachment of the lift yoke, and to provide the means to secure the MPC lid in the event of a drop or tip-over accident during loaded cask handling operations outside of the spent fuel pool. The user is responsible for evaluating the additional weight imposed on the cask, lift yoke, crane and floor prior to use to ensure that its use does not exceed the crane capacity, heavy loads handling restrictions, or 250,000 pounds. See Tables 8.1.1 and 8.1.2.

1. Visually inspect the MPC lid rigging or Lid Retention System in accordance with site-approved rigging procedures. Attach the MPC lid to the lift yoke so that MPC lid, drain line and trunnions will be in relative alignment. Raise the MPC lid and adjust the rigging so the MPC lid hangs level as necessary.

2. Install the drain line to the underside of the MPC lid. See Figure 8.1.10.

3. Align the MPC lid and lift yoke so the drain line will be positioned in the MPC drain location and the cask trunnions will also engage. See Figure 8.1.11 and 8.1.16.

ALARA Note:
Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

4. Slowly lower the MPC lid into the pool and insert the drain line into the drain access location and visually verify that the drain line is correctly oriented. See Figure 8.1.11.

5. Lower the MPC lid while monitoring for any hang-up of the drain line. If the drain line becomes kinked or disfigured for any reason, remove the MPC lid and replace the drain line.

Note:
The upper surface of the MPC lid will seat approximately flush with the top edge of the MPC shell when properly installed. Once the MPC lid is installed, the HI-STAR/MPC removal from the spent fuel pool should proceed in a continuous manner to minimize the rise in MPC water temperature.

6. Seat the MPC lid in the MPC and visually verify that the lid is properly installed.

7. Engage the lift yoke to the HI-STAR 100 overpack lifting trunnions.

8. Apply a slight tension to the lift yoke and visually verify proper engagement of the lift yoke to the lifting trunnions.

ALARA Note:
Activated debris may have settled on the top face of the HI-STAR 100 overpack and MPC during fuel loading. The cask top surface should be kept under water until a preliminary dose rate scan clears the cask for removal.

9. Raise the HI-STAR 100 overpack until the MPC lid is just below the surface of the spent fuel pool. Survey the area above the cask lid to check for hot particles. Raise and flush the upper surface of the HI-STAR 100 overpack and MPC with the plant demineralized water hoses as necessary to remove any activated particles from the HI-STAR 100 overpack or the MPC lid.

10. Visually verify that the MPC lid is properly seated. Lower the HI-STAR 100 overpack, reinstall the MPC lid, and repeat Step 9, as necessary.

11. If the Lid Retention System is used, inspect the closure plate bolts for general condition. Replace worn or damaged bolts with new bolts.

12. Install the Lid Retention System bolts if the Lid Retention System is used.

Warning:
Cask removal from the spent fuel pool is the heaviest lift that occurs during HI-STAR 100 loading operations. The HI-STAR 100 trunnions must not be subjected to lifted loads in excess of 250,000 lbs. Users may elect to pump a measured quantity of water from the MPC prior to removing the HI-STAR 100 from the spent fuel pool. See Table 8.1.1 and 8.1.2 for weight information.

13. If necessary for lifted weight conditions, pump a measured amount of water from the MPC. See Figure 8.1.18 and Tables 8.1.1 and 8.1.2.

14. Continue to raise the HI-STAR 100 overpack under the direction of the plant's radiological control personnel. Continue rinsing the surfaces with demineralized water. When the top of the HI-STAR 100 overpack reaches the approximate elevation as the reservoir, close the Annulus Overpressure System reservoir valve. See Figure 8.1.13.

Caution:
Users are required to take necessary actions to prevent boiling of the water in the MPC. This may be accomplished by performing a site-specific analysis to identify a time limitation to ensure that water boiling will not occur in the MPC prior to the initiation of draining operations. Chapter 4 of the FSAR provides some sample time limits for the time to initiation of draining for various spent fuel pool water temperatures using design basis heat loads. These time limits may be adopted if the user chooses not to perform a site-specific analysis. If time limitations are imposed, users shall have appropriate procedures and equipment to take action if time limits are approached or exceeded. One course of action involves initiating an MPC water flush for a certain duration and flow rate. Any site-specific analysis shall identify the methods to respond should it become likely that the imposed time limit could be exceeded.

ALARA Note:
To reduce decontamination time, the surfaces of the HI-STAR 100 overpack and lift yoke should be kept wet until decontamination begins.

15. Remove the HI-STAR 100 overpack from the spent fuel pool while spraying the surfaces with plant demineralized water. Record the time.

ALARA Note:
Decontamination of the HI-STAR 100 overpack bottom should be performed using pole-mounted cleaning devices.

16. Decontaminate the HI-STAR 100 overpack bottom and perform a contamination survey of the HI-STAR 100 overpack bottom. Remove the bottom protective cover, if used.

17. If used, disconnect the Annulus Overpressure System from the HI-STAR 100 overpack. See Figure 8.1.13.

18. Set the HI-STAR 100 overpack in the designated cask preparation area.

19. Disconnect the lifting slings or Lid Retention System (if used) from the MPC lid and disengage the lift yoke. Decontaminate and store these items in an approved storage location.

Warning:
MPC lid dose rates are measured to ensure that dose rates are within expected values. Dose rates exceeding the 429 mrem/hour could indicate that fuel assemblies not meeting the specifications of Appendix B to CoC 1008 have been loaded.

a. Measure the dose rates at the MPC lid and verify that the combined gamma and neutron dose rate is below 429 mrem/hour.

20. Perform decontamination of the HI-STAR 100 overpack.

21. Prepare the MPC for MPC lid welding as follows:

ALARA Note:
If the Temporary Shield Ring is not used, some form of gamma shielding (e.g. lead bricks or blankets) should be placed in the areas above the HI-STAR neutron shield to eliminate the localized hot spot.

a. Decontaminate the area around the HI-STAR 100 overpack top flange and install the Temporary Shield Ring, (if used). See Figure 8.1.17.

b. Fill the Temporary Shield Ring with water (if used).

c. Carefully decontaminate the MPC lid top surface and the shell area above the inflatable annulus seal.

d. Deflate and remove the annulus seal.

ALARA Note:
The water in the HI-STAR 100 overpack-to-MPC annulus provides personnel shielding. The level should be checked periodically and refilled accordingly.

22. Attach the drain line to the HI-STAR 100 overpack drain port connector and lower the annulus water level approximately 6 inches..

ALARA Note:
The MPC exterior shell survey is performed to evaluate the performance of the inflatable annulus seal. Indications of contamination could require the MPC to be unloaded.

a. Survey the MPC lid top surfaces and the accessible areas of the top two inches of the MPC shell in accordance with the requirements of LCO 2.2.2.

ALARA Note:
The annulus shield is used to prevent objects from being dropped into the annulus and helps reduce dose rates directly above the annulus region. The annulus shield is hand installed and requires no tools.

23. Install the annulus shield. See Figure 8.1.12.

24. Prepare for MPC lid welding as follows:

> **Note:**
> The following steps use two identical Removable Valve Operating Assemblies (RVOAs) (See Figure 8.1.15) to engage the MPC vent and drain ports. The MPC vent and drain ports are equipped with metal-to-metal seals to minimize leakage during vacuum drying, and to withstand the long-term effects of temperature and radiation. The RVOAs allow the vent and drain ports to be operated like valves and prevent the need to hot tap into the penetrations during unloading operations. The RVOAs are purposely not installed until the cask is removed from the spent fuel pool to reduce the amount of decontamination.

> **Note:**
> The vent and drain ports are opened by pushing the RVOA handle down to engage the square nut on the cap and turning the handle fully in the counter-clockwise direction. The handle will not turn once the port is fully open. Similarly, the vent and drain ports are closed by turning the handle fully in the clockwise direction. The ports are closed when the handle cannot be turned further.

a. Clean the vent and drain ports to remove any dirt. Install the RVOAs (See Figure 8.1.15) to the vent and drain ports leaving caps open.

> **ALARA Warning:**
> Personnel should remain clear of the drain lines any time water is being pumped or purged from the MPC. Assembly crud, suspended in the water, may create a radiation hazard to workers. Controlling the amount of water pumped from the MPC prior to welding keeps the fuel assembly cladding covered with water yet still allows room for thermal expansion.

b. Attach the water pump to the drain port (See Figure 8.1.18) and pump between 50 and 120 gallons of MPC water to the spent fuel pool or liquid radwaste system. The water level is lowered to keep moisture away from the weld region.

c. Disconnect the water pump.

25. Weld the MPC lid as follows:

> **ALARA Warning:**
> Grinding of MPC welds may create the potential for contamination. All grinding activities shall be performed under the direction of radiation protection personnel.

> **Caution:**
> Oxidation of Boral panels contained in the MPC may create hydrogen gas while the MPC is filled with water. Appropriate monitoring for combustible gas concentrations shall be performed prior to, and during MPC lid welding operations. The space below the MPC lid shall be exhausted or purged with inert gas prior to, and during MPC lid welding operations to provide additional assurance that flammable gas concentrations will not develop in this space.

Note:
Exhausting or purging may help improve the weld quality by keeping moist air from condensing on the MPC lid weld area. The vacuum source can be supplied from a wet/dry vacuum cleaner or small vacuum pump.

a. Attach a vacuum source to the vent port or inert the gas space under the MPC lid and begin monitoring for combustible gas concentrations.

ALARA Warning:
It may be necessary to rotate or reposition the MPC lid slightly to achieve uniform weld gap and lid alignment. A punch mark is located on the outer edge of the MPC lid and shell. These marks are aligned with the alignment mark on the top edge of the HI-STAR 100 overpack (See Figure 8.1.7). If necessary, the MPC lid lift should be performed using a hand operated chain fall to closely control the lift to allow rotation and repositioning by hand. If the chain fall is hung from the crane hook, the crane should be tagged out of service to prevent inadvertent use during this operation. Continuous radiation monitoring is recommended.

b. If necessary center the lid in the MPC shell using a hand-operated chain fall.

Note:
The MPC is equipped with lid shims that serve to close the gap in the joint for MPC lid closure weld.

c. As necessary, install the MPC lid shims around the MPC lid to make the weld gap uniform.

ALARA Note:
The optional AWS Baseplate shield is used to further reduce the dose rates to the operators working around the top cask surfaces.

d. Install the Automated Welding System baseplate shield (if used). See Figure 8.1.8 for rigging.

e. Install the Automated Welding System Robot (if used). See Figure 8.1.8 for rigging.

f. Perform the MPC Lid-to-Shell weld and NDE with approved procedures. (See 9.1 and Table 2.2.15)

g. Deleted.

h. Disconnect the vacuum /purge source from the MPC and terminate combustible gas monitoring.

i. Deleted.

j. Deleted.

k. Deleted.

26. Perform hydrostatic and MPC leakage rate testing as follows:

ALARA Note:
The leakage rates are determined before the MPC is drained for ALARA reasons. A weld repair is a lower dose activity if water remains inside the MPC.

a. Attach the drain line to the vent port and route the drain line to the spent fuel pool or the plant liquid radwaste system. See Figure 8.1.19 for the hydrostatic test arrangement.

ALARA Warning:
Water flowing from the MPC may carry activated particles and fuel particles. Apply appropriate ALARA practices around the drain line.

b. Fill the MPC with either spent fuel pool water or plant demineralized water until water is observed flowing out of the vent port drain hose.

Note:
Section 9.1.2.2.2 of the FSAR provides additional details on performance of the hydrostatic test.

c. Perform a hydrostatic test of the MPC as follows:

1. Close the drain valve and pressurize the MPC to 125 +5/-0 psig.

2. Close the inlet valve and monitor the pressure for a minimum of 10 minutes.

3. Following the 10-minute hold period, visually examine the MPC lid-to-shell weld for leakage of water. The acceptance criteria is no observable water leakage.

d. Release the MPC internal pressure, disconnect the water fill line and drain line from the vent and drain port RVOAs leaving the vent and drain port caps open.

1. Perform Required NDE inspections on MPC Lid to Shell Weld.

e. Attach a regulated helium supply to the vent port and attach the drain line to the drain port as shown on Figure 8.1.21.

f. Verify the correct pressure on the helium supply and open the helium supply valve. Drain approximately 5 to 10 gallons.

g. Close the drain port valve and pressurize the MPC.

h. Close the vent port.

Note:
The leakage detector may detect residual helium in the atmosphere. If the leakage tests detects a leak, the area should be flushed with nitrogen or compressed air and the location should be retested.

i. Perform a helium sniffer probe leakage rate test of the MPC lid-to shell weld in accordance with the Mass Spectrometer Leak Detector (MSLD) manufacturer's instructions and ANSI N14.5 [8.1.2]. The MPC helium leakage rate test acceptance criteria are specified in LCO 2.1.1.

j. Repair any weld defects in accordance with the site's approved weld repair procedures. Reperform the Ultrasonic, Hydrostatic and Helium Leakage tests if weld repair is performed.

27. Drain the MPC as follows:

ALARA Warning:
Dose rates will rise as water is drained from the MPC. Continuous dose rate monitoring is recommended.

a. Attach a regulated helium or nitrogen supply to the vent port.

b. Attach a drain line to the drain port shown on Figure 8.1.21.

c. Verify the correct pressure on the gas supply.

d. Open the gas supply valve and record the time at the start of MPC draindown.

Note:
An optional warming device may be placed under the HI-STAR 100 Overpack to replace the heat lost during the evaporation process of vacuum drying. This may be used at the user's discretion for older and colder fuel assemblies to reduce vacuum drying times.

e. Start the warming device, if used.

f. Blow the water out of the MPC until water ceases to flow out of the drain line. Shut the gas supply valve.

g. Disconnect the gas supply line from the MPC.

h. Disconnect the drain line from the MPC.

28. Vacuum Dry the MPC as follows:

Note:
Vacuum drying is performed to remove moisture and oxidizing gasses from the MPC. This ensures a suitable environment for long-term storage of spent fuel assemblies and ensures that the MPC pressure remains within design limits. The vacuum drying process reduces the MPC internal pressure in stages. Dropping the internal pressure too quickly may cause the formation of ice in the fittings. Ice formation could result in incomplete removal of moisture from the MPC.

a. Attach the Vacuum Drying System (VDS) to the vent and drain port RVOAs. See Figure 8.1.22.

Note:
The Vacuum Drying System may be configured with an optional fore-line condenser

b. Deleted.

c. Deleted.

d. Deleted.

e. Deleted.

Note:
To prevent freezing of water, the MPC internal pressure should be lowered in incremental steps. The Vacuum Drying System pressure will remain at about 30 torr until most of the liquid water has been removed from the MPC.

f. Open the VDS suction valve and reduce the MPC pressure to below 3 torr.

g. Shut the VDS valves and verify a stable MPC pressure on the vacuum gage.

Note:
The MPC pressure may rise due to the presence of water in the MPC. The dryness test may need to be repeated several times until all the water has been removed. Leaks in the Vacuum Drying System, damage to the vacuum pump, and improper vacuum gauge calibration may cause repeated failure of the dryness verification test. These conditions should be checked as part of the corrective actions if repeated failure of the dryness verification test is occurring.

h. Perform the MPC dryness verification test in accordance with the acceptance criteria of LCO 2.1.1.

i. Close the vent and drain port valves.

j. Disconnect the VDS from the MPC.

k. Stop the warming device, if used.

l. Close the drain port RVOA cap and remove the drain port RVOA.

Note:
Helium backfill requires 99.995% (minimum) purity.

29. Backfill the MPC as follows:

    a. Set the helium bottle regulator pressure to the appropriate pressure.

    b. Purge the Helium Backfill System to remove oxygen from the lines.

    c. Attach the Helium Backfill System (HBS) to the vent port as shown on Figure 8.1.23 and open the vent port.

    d. Slowly open the helium supply valve while monitoring the pressure rise in the MPC.

    e. Deleted

Note:
If helium bottles need to be replaced, the bottle valve needs to be closed and the entire regulator assembly transferred to the new bottle.

    f. Carefully backfill the MPC to greater than 0 psig and less than the maximum pressure specified in LCO 2.1.1.

    g. Disconnect the HBS from the MPC.

    h. Close the vent port RVOA and disconnect the vent port RVOA.

30. Weld the vent and drain port cover plates as follows:

    a. Wipe the inside area of the vent and drain port recesses to dry and clean the surfaces.

    b. Place the cover plate over the vent port recess.

    c. Insert the nozzle of the helium supply into the vent port recess to displace the oxygen.

Note:
Helium gas is required to be injected into the port recesses to ensure that the leakage test is valid.

    d. Deleted.

    e. Weld the cover plate and perform NDE with approved procedures. (See 9.1 and Table 2.2.15)

    f. Deleted.

g. Deleted.

h. Deleted.

i. Deleted..

j. Deleted..

k. Repeat Steps 30.a through 30.j for the drain port cover plate.

31. Perform a leakage test of the MPC vent and drain port cover plates as follows:

Note:
The leakage detector may detect residual helium in the atmosphere from the helium injection process. If the leakage tests detects a leak, the area should be blown clear with compressed air or nitrogen and the location should be retested.

a. Flush the area around the vent and drain cover plates with compressed air or nitrogen to remove any residual helium gas.

b. Perform a helium leakage rate test of vent and drain cover plate welds in accordance with the Mass Spectrometer Leak Detector (MSLD) manufacturer's instructions and ANSI N14.5 [8.1.2]. The MPC helium leakage rate test acceptance criteria are specified in LCO 2.1.1.

c. Repair any weld defects in accordance with the site's approved code weld repair procedures. Reperform the leakage test as required.

32. Weld the MPC closure ring as follows:

ALARA Note:
The closure ring is installed by hand. No tools are required.

a. Install and align the closure ring. See Figure 8.1.7.

b. Weld the closure ring to the MPC shell and the MPC lid, and perform NDE with approved procedures (See 9.1 and Table 2.2.15).

c. Deleted.

d. Deleted.

e. Deleted.

f. Deleted.

g. Deleted.

h. Deleted.

i. Deleted.

j. Remove the Automated Welding System (if used).

k. If necessary, remove the AWS baseplate shield. See Figure 8.1.8 for rigging.

8.1.6 Preparation for Storage

1. Remove the annulus shield and seal surface protector and store it in an approved plant storage location

ALARA Warning:
Dose rates will rise around the top of the annulus as water is drained from the annulus. Apply appropriate ALARA practices.

2. Attach a drain line to the HI-STAR 100 overpack drain connector and drain the remaining water from the annulus to the spent fuel pool or the plant liquid radwaste system (See Figure 8.1.13).

3. Install the overpack closure plate as follows:

   a. Remove any waterproof tape or bolt plugs used for contamination mitigation.

   b. Clean the closure plate seal seating surface and the HI-STAR 100 overpack seal seating surface and install new overpack closure plate mechanical seals.

   c. Remove the test port plug and store it in a site-approved location. Discard any used metallic seals.

Note:
Care should be taken to protect the seal seating surface from scratches, nicks or dents.

   d. Install the closure plate (see Figure 8.1.8). Disconnect the closure plate lifting eyes and install the bolt hole plugs in the empty bolt holes (See Table 8.1.3 for torque requirements).

   e. Install and torque the closure plate bolts. See Table 8.1.3 for torque requirements.

   f. Remove the vent port cover plate and remove the port plug and seal. Discard any used mechanical seals.

4. Dry the overpack annulus as follows:

   a. Disconnect the drain connector from the overpack.

   b. Install the drain port plug with a new seal and torque the plug. See Table 8.1.3 for torque requirements. Discard any used metallic seals.

Note:
Preliminary annulus vacuum drying may be performed using the test cover to improve flow rates and reduce vacuum drying time. Dryness testing and helium backfill shall use the backfill tool.

c. Load the backfill tool with the HI-STAR 100 overpack vent port plug and the vent port with a new plug seal. Attach the backfill tool to the HI-STAR 100 overpack vent port with the plug removed. See Figure 8.1.24. See Table 8.1.3 for torque requirements.

d. Deleted.

e. Deleted.

f. Deleted.

g. Deleted.

Note:
To prevent freezing of water, the MPC internal pressure should be lowered in incremental steps. The Vacuum Drying System pressure will remain at about 30 torr until most of the liquid water has been removed from the overpack.

h. Deleted.

i. Open the Vacuum Drying System suction valve and reduce the HI-STAR 100 overpack pressure to below 3 torr.

Note:
The annulus pressure may rise due to the presence of water in the HI-STAR 100 overpack. The dryness test may need to be repeated several times until all the water has been removed. Leaks in the Vacuum Drying System, damage to the vacuum pump, and improper vacuum gauge calibration may cause repeated failure of the dryness verification test. These conditions should be checked as part of the corrective actions if repeated failure of the dryness verification test is occurring.

j. Perform a HI-STAR 100 overpack Annulus Dryness Verification in accordance with LCO 2.1.2.

5. Backfill, and leakage test the overpack as follows:

a. Attach the helium supply to the backfill tool.

b. Verify the correct pressure on the helium supply (pressure set to10+4/-0 psig) and open the helium supply valve.

c. Backfill the HI-STAR 100 overpack annulus in accordance with LCO 2.1.2.

d. Install the overpack vent port plug and torque. See Table 8.1.3 for torque requirements.

e. Disconnect the overpack backfill tool from the vent port.

f. Flush the overpack vent port recess with compressed air to remove any standing helium gas.

g. Install the overpack test cover to the overpack vent port as shown on Figure 8.1.25. See Table 8.1.3 for torque requirements.

h. Evacuate the test cavity per the MSLD manufacturer's instructions and isolate the vacuum pump from the overpack test cover.

i. Perform a leakage rate test of overpack vent port plug per the MSLD manufacturer's instructions and ANSI N14.5 [8.1.2]. The helium leakage rate test acceptance criterion is specified in LCO 2.1.2.

j. Remove the overpack test cover and install a new metallic seal on the overpack vent port cover plate. Discard any used metallic seals.

k. Install the vent port cover plate and torque the bolts. See Table 8.1.3 for torque requirements.

l. Repeat Steps 5.f through 5.k for the overpack drain port.

6. Leak test the overpack closure plate inner mechanical seal as follows:

a. Attach the closure plate test tool to the closure plate test port with the MSLD attached. See Figure 8.1.26. See Table 8.1.3 for torque requirements.

b. Evacuate the closure plate test port tool and closure plate inter-seal area per the MSLD manufacturer's instructions.

c. Perform a leakage rate test of overpack closure plate inner mechanical seal in accordance with the MSLD manufacturer's instructions and ANSI N14.5 [8.1.2]. The helium leakage rate test acceptance criterion is specified in LCO 2.1.2.

d. Remove the closure plate test tool from the test port and install the test port plug with a new mechanical seal. See Table 8.1.3 for torque requirements. Discard any used metallic seals.

7. Drain the Temporary Shield Ring (Figure 8.1.17), if used. Remove the ring segments and store them in an approved plant storage location.

ALARA Warning:
For ALARA reasons, decontamination of the overpack bottom shall be performed using pole-mounted cleaning tools or other remote cleaning devices.

ALARA Warning:
If the overpack is to be downended on the transport frame, the bottom shield should be installed quickly. Personnel should remain clear of the bottom of the unshielded overpack.

a. Raise the HI-STAR 100 overpack and decontaminate the overpack bottom and perform a final survey and decontamination of the overpack. The acceptance criteria are the user's site requirements for transporting items out of the radiological controlled area or the LCO 2.2.2 (whichever is more restrictive).

8. Verify that the HI-STAR 100 overpack dose rates are within the requirements of LCO 2.2.1.

8.1.7 Placement of the HI-STAR 100 Overpack into Storage

1. Secure the HI-STAR 100 overpack to the transporter as necessary. See Figure 8.1.27 for several transporter options.

2. Verify lifting requirements of LCO 2.1.3 are met.

3. Remove the transporter wheel chocks (if necessary) and transfer the HI-STAR 100 overpack to the ISFSI along the site-approved transfer route.

Note:
The HI-STAR 100 minimum pitch shall be 12 feet (nominal).

4. Transfer the HI-STAR 100 overpack to its designated storage location at the appropriate pitch. See Figure 8.1.28.

5. Install the HI-STAR 100 overpack pocket trunnion plugs and shear ring segments, if necessary. See Table 8.1.3 for torque requirements. See Figure 8.1.29.

ALARA Note:
The optional overpack bottom ring is used to reduce dose rates around the base of the HI-STAR 100 overpack. The segments are slid into place under the HI-STAR 100 overpack neutron shield.

6. If used, install the Overpack Bottom Ring (Figure 8.1.30).

Table 8.1.1

ESTIMATED HANDLING WEIGHTS OF HI-STAR 100 SYSTEM COMPONENTS††††

Component	Weight (lbs)		Case† Applicability			
	MPC-24	MPC-68	1	2	3	4
Empty HI-STAR 100 overpack (without closure plate)	145,726	145,726	1	1	1	1
HI-STAR 100 overpack lid (closure plate without rigging)	7,984	7,984		1	1	1
Empty MPC (without lid or closure ring)	29,075	28,502	1	1	1	1
MPC lid (without fuel spacers or drain line)	9677	10,194	1	1	1	1
MPC Closure Ring	145	145		1	1	1
MPC Lower Fuel Spacers (variable)††	401	258	1	1	1	1
MPC Upper Fuel Spacers (variable)††	144	315	1	1	1	1
MPC Drain Line	50	50	1	1	1	1
Fuel (design basis without non-fuel bearing components)	36,360	42,092	1	1	1	1
Damaged Fuel Container (Dresden 1)	0	150				
Damaged Fuel Container (Humboldt Bay)	0	120				
MPC water (with fuel in MPC)†††	17,630	16,957	1			
Annulus Water	280	280	1			
HI-STAR 100 overpack Lift Yoke (with slings)	3600	3600	1	1		
Annulus Seal	50	50	1			
Lid Retention System (optional)	2300	2300				
Transport Frame	6700	6700				1
Overpack Bottom Cover (optional)	6400	6400				1
Temporary Shield Ring (optional)	2500	2500				
Automated Welding System Baseplate Shield (optional)	2000	2000				
Automated Welding System Robot	1900	1900				
Pocket Trunnion Plugs (optional)	60	60			1	
Overpack Bottom Ring (optional)	1300	1300			1	

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† See Table 8.1.2.

†† The fuel spacers referenced in this table are for the heaviest fuel assembly for each MPC. This yields the maximum weight of fuel assemblies and spacers.

††† Varies by fuel type and loading configuration. Users may opt to pump some water from the MPC prior to removal from the spent fuel pool to reduce the overall lifted weight.

†††† Actual component weights are dependant upon as-built dimensions. The values provided herein are estimated. FSAR analyses use bounding values provided elsewhere. Users are responsible for ensuring lifted loads meet site capabilities and requirements.

TABLE 8.1.2
ESTIMATED HANDLING WEIGHTS
HI-STAR 100 OVERPACK†

Caution:
The maximum weight supported by the HI-STAR 100 overpack lifting trunnions (not including the lift yoke) cannot exceed 250,000 lbs. Users should determine their specific handling weights based on the MPC contents and the expected handling modes.

Note:
The weight of the fuel spacers and the damaged fuel container are less than the weight of the design basis fuel assembly for each MPC and are therefore not included in the maximum handling weight calculations.

Case No.	Load Handling Evolution	Weight (lbs)	
		MPC-24	MPC-68
1	Loaded HI-STAR 100 Overpack Removal from Spent Fuel Pool	242,993	248,024
2	Loaded HI-STAR 100 Overpack Movement to transport device	233,162	238,866
3	Loaded HI-STAR 100 Overpack in Storage	230,922	236,626
4	Loaded HI-STAR 100 on Transport Frame During On-Site Handling	242,662	248,366

† See footnote †††† with Table 8.1.1

Table 8.1.3
HI-STAR 100 SYSTEM TORQUE REQUIREMENTS

Fastener	Torque (ft-lbs)	Pattern
Overpack Closure Plate Bolts†, ††	First Pass – Hand Tight Second Pass – Wrench Tight Third Pass – 700 +50/-50 Fourth Pass – 1400 +100/-100 Final Pass – 2000 +250/-0	Figure 8.1.31
Overpack Vent and Drain Port Cover Plate Bolts††	12+2/-0	X-pattern
Overpack Vent and Drain Port Plugs	45+5/-2	None
Closure Plate Test Port Plug	45 +5/-2	None
Backfill Tool Test Cover Bolts††	16+2/-0	X-pattern
Shear Ring Segment Bolts	22+2/-0	None
Overpack Bottom Cover Bolts	200+20/-0	None
Pocket Trunnion Plugs	Hand Tight	None
Upper Fuel Spacers	Hand Tight	None
Threaded Inserts (all)	Hand Tight	None

† Detorquing shall be performed by turning the bolts counter-clockwise in 1/3 turn +/- 30 degrees increments per pass according to Figure 8.1.31 for three passes. The bolts may then be removed.

†† Bolts shall be cleaned and inspected for damage or excessive wear (replaced if necessary) and coated with a light layer of Fel-Pro Chemical Products, N-5000, Nuclear Grade Lubricant (or equivalent).

Table 8.1.4
HI-STAR 100 SYSTEM ANCILLARY EQUIPMENT OPERATIONAL DESCRIPTION

Equipment	Important To Safety Classification	Reference Figure	Description
Annulus Overpressure System (optional)	Not Important To Safety	8.1.13	The Annulus Overpressure System is used for supplemental protection against spent fuel pool water contamination of the external MPC shell and baseplate surfaces by providing a slight annulus overpressure. The Annulus Overpressure System consists of the quick disconnects water reservoir, reservoir valve and annulus connector hoses. User is responsible for supplying demineralized water to the location of the Annulus Overpressure System.
Annulus Shield (optional)	Not Important To Safety	8.1.12	A shield that is placed at the top of the annulus to provide supplemental shielding to the operators performing cask loading and closure operations. Shield segments are installed by hand, no crane or tools required.
Automated Welding System (optional)	Not Important To Safety	8.1.2b	Used for remote welding of the MPC lid, vent and drain port cover plates and the MPC closure ring. The AWS consists of the robot, wire feed system, torch system, weld power supply and gas lines.
AWS Baseplate Shield (optional)	Not Important To Safety	8.1.2b	The AWS baseplate shield provides supplemental shielding to the operators during the cask closure operations.
Backfill Tool	Not Important to Safety	8.1.24	Used to dry, backfill the HI-STAR 100 annulus and install the HI-STAR 100 overpack vent and drain port plugs. The backfill tool uses the same bolts as the HI-STAR 100 overpack vent and drain cover plates.
Blowdown Supply System	Not Important To Safety	8.1.21	Gas hose with pressure gauge, regulator used for blowdown of the MPC.
Cask Transporter	User designated	8.1.27	Used for handling of the HI-STAR 100 overpack cask around the site. The cask transporter may take the form of heavy haul transfer trailer, special transporter or other equipment specifically designed for such function.
Closure Plate Test Tool	Not Important to Safety	8.1.26	Used to helium leakage test the HI-STAR 100 overpack Closure Plate inner mechanical seal.

Table 8.1.4
HI-STAR 100 SYSTEM ANCILLARY EQUIPMENT OPERATIONAL DESCRIPTION
(continued)

Equipment	Important To Safety Classification	Reference Figure	Description
Cool-Down System	Not Important To Safety	8.3.5	The Cool-Down System is a closed-loop forced ventilation cooling system used to gas-cool the MPC fuel assemblies down to a temperature water can be introduced without the risk of thermally shocking the fuel assemblies or flashing the water, causing uncontrolled pressure transients. The Cool-Down System is attached between the MPC drain and vent ports The CDS consists of the piping, blower, heat exchanger, valves, instrumentation, and connectors. The CDS is used only for unloading operations.
Drain Connector	Not Important To Safety	8.1.13	Used for draining the annulus water following cask closure operations. The Drain Connector consists of the connector pipe valve, and quick disconnect for adapting to the Annulus Overpressure System.
Four Legged Sling and Lifting Rings	Not Important To Safety (controlled under the user's rigging equipment program)	8.1.8	Used for rigging the HI-STAR 100 overpack upper shield lid, MPC lid, AWS Baseplate shield, and Automated Welding System Baseplate Shield. Consists of a four legged sling, lifting rings, shackles and a main lift link.
Helium Backfill System	Not Important To Safety	8.1.23	Used for helium backfilling of the MPC. System consists of the gas lines, mass flow monitor, integrator, and valved quick disconnect.
Hydrostatic Test System	Not Important to Safety	8.1.19	Used to hydrostatically test the MPC primary welds. The hydrostatic test system consists of the gauges, piping, pressure protection system piping and connectors.
Inflatable Annulus Seal	Not Important To Safety	8.1.12	Used to prevent spent fuel pool water from contaminating the external MPC shell and baseplate surfaces during in-pool operations.
Lid Retention System (optional)	User designated	8.1.14	The Lid Retention System provides three functions: it guides the MPC lid into place during underwater installation, establishes lift yoke alignment with the HI-STAR 100 overpack trunnions, and locks the MPC lid in place during cask handling operations between the pool and decontamination pad. The device consists of the retention disk, alignment pins, lift yoke connector links and lift yoke attachment bolts.

Table 8.1.4
HI-STAR 100 SYSTEM ANCILLARY EQUIPMENT OPERATIONAL DESCRIPTION
(continued)

Equipment	Important To Safety Classification	Reference Figure	Description
Lift Yoke	User designated	8.1.3	Used for HI-STAR 100 overpack cask handling when used in conjunction with the overhead crane. The lift yoke consists of the lift yoke assembly and crane hook engagement pin(s). The lift yoke is a modular design that allows inspection, disassembly, maintenance and replacement of components.
MPC Upending Frame	Not Important to Safety	8.1.5	A steel frame used to evenly support the MPC during upending operations.
MSLD (Helium Leakage Detector)	Not Important To Safety	Not shown	Used for helium leakage testing of the MPC closure welds.
Overpack Bottom Cover (optional)	Not Important to Safety	Not shown	A cup-shaped shield used to reduce dose rates around the HI-STAR 100 overpack bottom end when operated in the horizontal orientation.
Overpack Bottom Ring (optional)	Not Important to Safety	Figure 8.1.30	Segmented shield ring that fits under the HI-STAR 100 overpack neutron shield. Used to reduce dose rates around the HI-STAR 100 overpack bottom end.
Overpack Test Cover	Not Important to Safety	8.1.25	Used to helium leakage test the HI-STAR 100 overpack vent and drain port plug seals.
Seal Surface Protector (optional)	Not Important to Safety	8.1.12	Used to protect the HI-STAR 100 overpack mechanical seal seating surface during loading and MPC closure operations.
Temporary Shield Ring (optional)	Not Important To Safety	8.1.17	Fits on the cask neutron shield around the upper forging and provides supplemental shielding to personnel performing cask loading and closure operations.

Table 8.1.4
HI-STAR 100 SYSTEM ANCILLARY EQUIPMENT OPERATIONAL DESCRIPTION
(continued)

Equipment	Important To Safety Classification	Reference Figure	Description
Threaded Inserts	Not Important To Safety	Not shown	Used to fill the empty threaded holes in the HI-STAR 100 overpack and MPC.
Transport Frame (optional)	Not Important To Safety	8.1.4	A frame used to support the HI-STAR 100 overpack during on-site movement and upending/downending operations. The frame consists of the rotation trunnions, main frame beams and front saddle and lift points.
Vacuum Drying System	Not Important To Safety	8.1.22	Used for removal of residual moisture from the MPC and HI-STAR 100 Overpack annulus following water draining. Used for evacuation of the MPC to support backfilling operations. Used to support test volume samples for MPC unloading operations. The VDS consists of the vacuum pump, piping, skid, gauges, valves, inlet filter, flexible hoses, connectors, control system.
Vent and Drain RVOAs	Not Important To Safety	8.1.15	Used to drain, dry, inert and fill the MPC through the vent and drain ports. The vent and drain RVOAs allow the vent and drain ports to be operated like valves and prevent the need to hot tap into the penetrations during unloading operation.
Weld Removal System	Not Important To Safety	8.3.2b	Semi-automated weld removal system used for removal of the MPC to shell weld, MPC to closure ring weld and closure ring to MPC shell weld. The WRS mechanically removes the welds using a high-speed cutter.

Table 8.1.5
HI-STAR 100 SYSTEM INSTRUMENTATION SUMMARY FOR LOADING AND UNLOADING OPERATIONS†

Note:
The following list summarizes the instruments identified in the procedures for cask loading and unloading operations. Alternate instruments are acceptable as long as they can perform appropriate measurements.

Instrument	Function
Dose Rate Monitors/Survey Equipment	Monitors dose rate and contamination levels and ensures proper function of shielding. Ensures assembly debris is not inadvertently removed from the spent fuel pool during overpack removal.
Flow Rate Monitor	Monitors the air flow rate during assembly cool-down.
Helium Mass Flow Monitor (optional)	Determines the amount of helium introduced into the MPC during backfilling operations. Includes integrator.
Helium Mass Spectrometer Leak Detector (MSLD)	Ensures leakage rates of welds are within acceptance criteria.
Helium Pressure Gauges	Ensures correct helium backfill pressure during backfilling operation.
Volumetric Testing Rig	Used to assess the integrity of the MPC lid-to-shell weld.
Pressure Gauge	Ensures correct helium pressure during fuel cool-down operations.
Hydrostatic Test Pressure Gauge	Used for hydrostatic testing of MPC lid-to-shell weld.
Temperature Gauge	Monitors the state of fuel cool-down prior to MPC flooding.
Temperature Probe	For fuel cool-down operations
Vacuum Gauges	Used for vacuum drying operations and to prepare an MPC evacuated sample bottle for MPC gas sampling for unloading operations.
Water Pressure Gauge	Used for performance of the MPC Hydrostatic Test.

† All instruments require calibration. See figures at the end of this section for additional instruments, controllers and piping diagrams.

Table 8.1.6
HI-STAR 100 OVERPACK INSPECTION CHECKLIST

Note:
This checklist provides the basis for establishing a site-specific inspection checklist for the HI-STAR 100 overpack. Specific findings shall be brought to the attention of the appropriate site organizations for assessment, evaluation and potential corrective action prior to use.

HI-STAR 100 Overpack Closure Plate:

1. Lifting rings shall be inspected for general condition and date of required load test certification.
2. The test port shall be inspected for dirt and debris, hole blockage, thread condition, presence or availability of the port plug and replacement mechanical seals.
3. The mechanical seal grooves shall be inspected for cleanliness, dents, scratches and gouges and the presence or availability of replacement mechanical seals.
4. The painted surfaces shall be inspected for corrosion and chipped, cracked or blistered paint.
5. All closure plate surfaces shall be relatively free of dents, scratches, gouges or other damage.
6. The vent port plug shall be inspected for thread condition, and sealing surface condition (scratches, gouges).
7. Overpack vent port shall be inspected for presence or availability of port plugs, hole blockage, plug seal seating surface condition.
8. Overpack vent port cover plate shall be inspected for cleanliness, scratches, dents, and gouges, availability of retention bolts, availability of replacement mechanical seals.

HI-STAR 100 Overpack Main Body:

1. The impact limiter attachment bolt holes shall be inspected for dirt and debris and thread condition.
2. The mechanical seal seating surface shall be inspected for cleanliness, scratches, and dents or gouges.
3. The drain port plug shall be inspected for thread condition, and sealing surface condition (scratches, gouges).
4. The closure plate bolt holes shall be inspected for dirt, debris and thread damage.
5. Painted surfaces shall be inspected for corrosion and chipped, cracked or blistered paint.
6. Trunnions shall be inspected for deformation, cracks, thread damage, end plate damage, corrosion, excessive galling, damage to the locking plate, presence or availability of locking plate and end plate retention bolts.

Table 8.1.6
HI-STAR 100 OVERPACK INSPECTION CHECKLIST
(continued)

7. Pocket trunnion recesses shall be inspected for indications of over stressing (i.e., cracks, deformation, excessive wear).
8. Overpack drain port cover plate shall be inspected for cleanliness, scratches, dents, and gouges, availability of retention bolts, availability of replacement mechanical seals.
9. Overpack drain port shall be inspected for presence or availability of port plug, availability of replacement mechanical seals, hole blockage, plug seal seating surface condition.
10. Annulus inflatable seal groove shall be inspected for cleanliness, scratches, dents, gouges, sharp corners, burrs or any other condition that may damage the inflatable seal.
11. The overpack rupture disks shall be inspected for presence or availability and the top surface of the disk shall be visually inspected for holes, cracks, tears or breakage.
12. The nameplate shall be inspected for presence and general condition.
13. The removable shear ring shall be inspected for fit and thread condition.

Table 8.1.7
MPC RECEIPT INSPECTION CHECKLIST

Note:
This checklist provides the basis for establishing a site-specific inspection checklist for MPC. Specific findings shall be brought to the attention of the appropriate site organizations for assessment, evaluation and potential corrective action prior to use.

MPC Lid and Closure Ring:

1. The MPC lid and closure ring surfaces shall be relatively free of dents, gouges or other shipping damage.
2. The drain line shall be inspected for straightness, thread condition, and blockage.
3. Upper fuel spacers (if used) shall be inspected for availability and general condition. Plugs shall be available for non-used spacer locations.
4. Lower fuel spacers (if used) shall be inspected for availability and general condition.
5. Drain and vent port cover plates shall be inspected for availability and general condition.
6. Serial numbers shall be inspected for readability.

MPC Main Body:

1. All visible MPC body surfaces shall be inspected for dents, gouges or other shipping damage.
2. Fuel cell openings shall be inspected for debris, dents and general condition.
3. Lift lugs shall be inspected for general condition.
4. Verify proper MPC basket type for contents.
5. Inspect drain guide tube for debris, dents and general condition.

8.2 ISFSI OPERATIONS

The HI-STAR 100 System is a totally passive system. Maintenance on the HI-STAR 100 system is typically limited to cleaning and touch-up painting of the HI-STAR 100 overpacks. In the event of significant damage to the HI-STAR 100 System, the situation may warrant removal or unloading of the MPC, and repair or replacement of the damaged HI-STAR 100 overpack. If necessary, the procedures in Section 8.1 may be used to reposition a HI-STAR 100 overpack for minor repairs and maintenance. In extreme cases, Section 8.3 may be used as guidance for unloading the MPC from the HI-STAR 100 overpack. The procedures contained in the HI-STORM FSAR [8.2.1] may be used to transfer the MPC into a HI-STORM overpack or HI-STAR 100 overpack.

8.3 PROCEDURE FOR UNLOADING THE HI-STAR 100 SYSTEM IN THE SPENT FUEL POOL

8.3.1 Overview of HI-STAR 100 System Unloading Operations

ALARA Note:
The procedure described below uses the Weld Removal System, a remotely operated system that mechanically removes the welds. Users may opt to remove some or all of the welds using hand operated equipment. The decision should be based on dose rates, accessibility, degree of weld removal, and available tooling and equipment.

The HI-STAR 100 System unloading procedures describe the general actions necessary to prepare the MPC for unloading, cool the stored fuel assemblies in the MPC, flood the MPC cavity, remove the lid welds, unload the spent fuel assemblies, and recover the HI-STAR 100 overpack and empty MPC. Special precautions are outlined to ensure personnel safety during the unloading operations, and to prevent the risk of MPC over-pressurization and thermal shock to the stored spent fuel assemblies. Figure 8.3.1 shows a flow diagram of the HI-STAR 100 overpack unloading operations. Figure 8.3.2 illustrates the major HI-STAR 100 overpack unloading operations.

Refer to the boxes of Figure 8.3.2 for the following description. The HI-STAR 100 overpack is returned to the fuel building using any of the methodologies as described in Section 8.1 (Box 1). The HI-STAR 100 overpack vent port cover plate is removed and a gas sample is drawn from the HI-STAR 100 overpack annulus to determine the condition of the MPC confinement boundary. The annulus is depressurized and the HI-STAR 100 overpack closure plate is removed (Box 2). The Temporary Shield Ring is installed on the HI-STAR 100 overpack upper section. The Temporary Shield Ring and annulus are filled with plant demineralized water. The annulus and HI-TRAC top surfaces are protected from debris which will be produced when removing the MPC Lid. The MPC closure ring weld is removed using the Weld Removal System. The closure ring above the vent and drain ports and the vent and drain port cover plates are core-drilled and removed to access the vent and drain ports. (Box 3). The design of the vent and drain ports use metal-to-metal seals that prevent rapid decompression of the MPC and subsequent spread of contamination during unloading. The vent port RVOA is attached to the vent port and an evacuated sample bottle is connected. The vent port is opened slightly to allow the sample bottle to obtain a gas sample from inside the MPC. A gas sample is performed to assess the condition of the fuel assembly cladding. The MPC is cooled using a closed-loop heat exchanger to reduce the MPC internal temperature to allow water flooding (Box 4). The cool-down process gradually reduces the cladding temperature to a point where the MPC may be flooded with water without thermally shocking the fuel assemblies or causing uncontrolled pressure transients in the MPC from the formation of steam. Following the fuel cool-down, the MPC is filled with water at a specified rate (Box 5). The Weld Removal System then removes both the closure ring-to-MPC shell weld and the MPC lid to MPC shell welds. The Weld Removal System is removed with the MPC lid left in place (Box 6).

The top surfaces of the HI-STAR 100 overpack and MPC are cleared of metal shavings. The annulus shield is removed and the inflatable annulus seal is installed and pressurized. The MPC

lid is rigged to the lift yoke or Lid Retention System and the lift yoke is engaged to the HI-STAR 100 overpack lifting trunnions. The HI-STAR 100 overpack is placed in the spent fuel pool and the MPC lid is removed (Box 7). All fuel assemblies are returned to the spent fuel storage racks (Box 8) and the MPC fuel cells are vacuumed to remove any assembly debris and crud. The HI-STAR 100 overpack and MPC are returned to the designated preparation area (Box 9) where the MPC water is pumped back into the spent fuel pool or liquid radwaste facility. The annulus water is drained and the MPC and overpack are decontaminated (Box 10 and 11).

8.3.2 HI-STAR 100 Overpack Recovery from Storage

1. Transfer the HI-STAR 100 overpack to the fuel building. The same methods may be used as was performed in the original cask placement operations. See Section 8.1.

2. Position the HI-STAR 100 overpack under the lifting device.

3. Place the HI-STAR 100 overpack in the designated preparation area.

ALARA Warning:
Gas sampling is performed to assess the condition of the MPC confinement boundary. If a leak is discovered in the MPC boundary, the user's Radiation Control organization may require special actions to vent the HI-STAR 100.

4. Perform annulus gas sampling as follows:

   a. Remove the overpack vent port cover plate and attach the backfill tool with a sample bottle attached. See Figure 8.3.3. Store the cover plate in a site-approved location.

   b. Using a vacuum pump, evacuate the sample bottle and backfill tool.

   c. Slowly open the vent port plug and gather a gas sample from the annulus. Reinstall the HI-STAR 100 overpack vent port plug.

   d. Evaluate the gas sample and determine the condition of the MPC confinement boundary.

5. If the confinement boundary is intact (i.e., no radioactive gas is measured) then vent the overpack annulus by removing the overpack vent port seal plug (using the backfill tool). Otherwise vent the annulus gas in accordance with instructions from Radiation Protection.

6. Remove the closure plate bolts. Store the closure plate bolts in a site-approved location.

7. Remove the overpack closure plate. See Figure 8.1.8 for rigging. Store the closure plate on cribbing to protect the seal seating surfaces.

8. Install the HI-STAR 100 overpack Seal Surface Protector (See Figure 8.1.12).

Warning:
Annulus fill water may flash to steam due to high MPC shell temperatures. Water addition should be performed in a slow and controlled manner.

9. Remove the HI-STAR 100 overpack drain port cover and port plug and install the drain connector. Store the drain port cover plate and port plug in an approved storage location.

10. Slowly fill the annulus area with plant demineralized water to approximately 4 inches below the top of the MPC shell and install the annulus shield. Cover annulus & HI-TRAC top surfaces to protect them from debris produced when removing the MPC Lid. See Figure 8.1.12.

11. Remove the MPC closure welds as follows:

ALARA Note:
The following procedures describe weld removal using the Weld Removal System. The Weld Removal System removes the welds with a high speed machine tool head. A vacuum head is attached to remove a majority of the metal shavings. Other methods of opening the MPC are acceptable.

ALARA Warning:
Weld removal may create an airborne radiation condition. Weld removal must be performed under the direction of the user's Radiation Protection organization.

a. Install bolt plugs and/or waterproof tape on the closure plate bolt holes.

b. Install the Weld Removal System on the MPC lid and core drill through the closure ring and vent and drain port cover plate welds.

c. Deleted

12. Access the vent and drain ports.

ALARA Note:
The MPC vent and drain ports are equipped with metal-to-metal seals to minimize leakage and withstand the long-term effects of temperature and radiation. The vent and drain port design prevents the need to hot tap into the penetrations during unloading operation and eliminate the risk of a pressurized release of gas from the MPC.

13. Take an MPC gas sample as follows:

a. Attach the RVOA to the vent port (See Figure 8.1.15).

b. Attach a sample bottle to the vent port RVOA as shown on Figure 8.3.4.

c. Using the Vacuum Drying System, evacuate the RVOA and Sample Bottle.

d. Slowly open the vent port cap using the RVOA and gather a gas sample from the MPC internal atmosphere.

e. Close the vent port cap and disconnect the sample bottle.

ALARA Note:
The gas sample analysis is performed to determine the condition of the fuel cladding in the MPC. The gas sample may indicate that fuel with damaged cladding is present in the MPC. The results of the gas sample test may affect personnel protection and how the gas is processed during MPC depressurization.

f. Turn the sample bottle over to the site's Radiation Protection or Chemistry Department for analysis.

g. Install the RVOA in the drain port.

14. Perform Fuel Assembly Cool-Down as follows:

a. Configure the Cool-Down System as shown on Figure 8.3.5.

b. Verify that the helium gas pressure regulator is set to the appropriate pressure.

c. Open the helium gas supply valve to purge the gas lines of air.

d. Deleted.

e. If necessary, slowly open the helium supply valve and increase the Cool-Down System pressure to MPC pressure. Close the helium supply valve.

f. Start the gas coolers.

g. Open the vent and drain port caps using the RVOAs.

h. Start the blower and monitor the gas exit temperature. Continue the fuel cool-down operations until the gas exit temperature meets the requirements of LCO *2.1.4*.

Note:
Water filling should commence immediately after the completion of fuel cool-down operations to minimize fuel assembly heat-up. Prepare the water fill and vent lines in advance of water filling.

i. Prepare the MPC fill and vent lines as shown on Figure 8.1.19. Route the vent port line several feet below the spent fuel pool surface or to the radwaste gas facility. Turn off the blower and disconnect the gas lines to the vent and drain port RVOAs. Attach the vent line to the MPC vent port and slowly open the vent line valve to depressurize the MPC.

j. Attach the water fill line to the MPC drain port and slowly open the water supply valve and establish a pressure less than 90 psi. Fill the MPC until bubbling from the vent line has terminated. Close the water supply valve on completion.

Caution:
Oxidation of Boral panels contained in the MPC may create hydrogen gas while the MPC is filled with water. Appropriate monitoring for combustible gas concentrations shall be performed prior to, and during MPC cutting operations. The space below the MPC lid shall be exhausted or purged with inert gas prior to, and during MPC cutting operations to provide additional assurance that flammable gas concentrations will not develop in this space.

k. Disconnect both lines from the drain and vent ports and, connect a combustible gas monitor to the MPC vent port and check for combustible gas concentrations prior to and periodically during weld removal activities. Purge or evacuate the gas space under the lid as necessary.

l. Remove the closure ring-to-MPC shell weld and the MPC lid-to-shell weld using the Weld Removal System and remove the Weld Removal System. See Figure 8.1.8 for rigging.

m. Vacuum the top surfaces of the MPC and the HI-STAR 100 overpack to remove any metal shavings.

15. Install the inflatable annulus seal as follows:

Caution:
Do not use any sharp tools or instruments to install the inflatable seal.

a. Remove the annulus shield.

b. Manually insert the inflatable seal around the MPC. See Figure 8.1.12.

c. Ensure that the seal is uniformly positioned in the annulus area.

d. Inflate the seal.

e. Visually inspect the seal to ensure that it is properly seated in the annulus. Deflate, adjust and inflate the seal as necessary.

16. Place HI-STAR 100 overpack in the spent fuel pool as follows:

a. Engage the lift yoke to the HI-STAR 100 overpack lifting trunnions, remove the MPC lid lifting threaded inserts and attach the MPC lid slings or Lid Retention System to the MPC lid.

b. If the Lid Retention System is used, inspect the lid bolts for general condition. Replace worn or damaged bolts with new bolts.

c. Install the Lid Retention System bolts if the Lid Retention System is used.

ALARA Note:
The optional Annulus Overpressure System is used to provide additional protection against MPC external shell contamination during in-pool operations.

d. If used, fill the Annulus Overpressure System lines and reservoir with demineralized water and close the reservoir valve. Attach the Annulus Overpressure System to the HI-STAR 100 overpack. See Figure 8.1.13.

Warning:
Cask placement in the spent fuel pool is the heaviest lift that occurs during the HI-STAR 100 unloading operations. The HI-STAR 100 trunnions must not be subjected to lifted loads in excess of 250,000 lbs. Users may elect to pump a measured quantity of water from the MPC prior to placement of the HI-STAR 100 in the spent fuel pool. See Table 8.1.1 and 8.1.2 for weight information.

e. Position the HI-STAR 100 overpack over the cask loading area with the basket aligned to the orientation of the spent fuel racks.

ALARA Note:
Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

f. Wet the surfaces of the HI-STAR 100 overpack and lift yoke with plant demineralized water while slowly lowering the HI-STAR 100 overpack into the spent fuel pool.

g. When the top of the HI-STAR 100 overpack reaches the approximate elevation of the reservoir, open the Annulus Overpressure System reservoir valve. Maintain the reservoir water level at approximately 3/4 full the entire time the cask is in the spent fuel pool.

h. If the Lid Retention System is used, remove the lid retention bolts when the top of the HI-STAR 100 overpack is accessible from the operating floor.

i. Place the HI-STAR 100 overpack on the floor of the cask loading area and disengage the lift yoke. Visually verify that the lift yoke is fully disengaged.

j. Apply slight tension to the lift yoke and visually verify proper disengagement of the lift yoke from the trunnions.

k. Remove the lift yoke, MPC lid and drain line from the pool in accordance with directions from the site's Radiation Protection personnel. Spray the equipment with demineralized water as they are removed from the pool.

Warning:
The MPC lid and unloaded MPC may contain residual contamination. All work done on the unloaded MPC should be carefully monitored and performed.

l. Disconnect the drain line from the MPC lid.

m. Store the MPC lid components in an approved location. Disengage the lift yoke from MPC lid. Remove any upper fuel spacers using the same process as was used in the installation.

n. Disconnect the Lid Retention System if used.

8.3.3 MPC Unloading

1. Remove the spent fuel assemblies from the MPC using applicable site procedures.

2. Vacuum the cells of the MPC to remove any debris or corrosion products.

3. Inspect the open cells for presence of any remaining items. Remove them as appropriate.

8.3.4 Post-Unloading Operations

1. Remove the HI-STAR 100 overpack and the unloaded MPC from the spent fuel pool as follows:

   a. Engage the lift yoke to the top trunnions.

   b. Apply slight tension to the lift yoke and visually verify proper engagement of the lift yoke to the trunnions.

   c. Raise the HI-STAR 100 overpack until the HI-STAR 100 overpack flange is at the surface of the spent fuel pool.

ALARA Warning:
Activated debris may have settled on the top face of the HI-STAR 100 overpack during fuel unloading.

   d. Measure the dose rates at the top of the HI-STAR 100 overpack in accordance with plant radiological procedures and flush or wash the top surfaces to remove any highly-radioactive particles.

   e. Raise the top of the HI-STAR 100 overpack and MPC to the level of the spent fuel pool deck.

   f. Close the Annulus Overpressure System reservoir valve if the Annulus Overpressure System was used.

g. Using a water pump, lower the water level in the MPC approximately 12 inches to prevent splashing during cask movement.

ALARA Note:
To reduce contamination of the HI-STAR 100 overpack, the surfaces of the HI-STAR 100 overpack and lift yoke should be kept wet until decontamination can begin.

h. Remove the HI-STAR 100 overpack from the spent fuel pool while spraying the surfaces with plant demineralized water.

i. Disconnect the Annulus Overpressure System from the HI-STAR 100 overpack via the quick disconnect. Drain the Annulus Overpressure System lines and reservoir.

j. Place the HI-STAR 100 overpack in the designated preparation area.

k. Disengage the lift yoke.

l. Perform decontamination on the HI-STAR 100 overpack and the lift yoke.

2. Carefully decontaminate the area above the inflatable seal. Deflate, remove, and store the seal in an approved plant storage location.

3. Using a water pump, pump the remaining water in the MPC to the spent fuel pool or liquid radwaste system.

4. Drain the water in the annulus.

5. Remove the MPC from the HI-STAR 100 overpack and decontaminate the MPC as necessary.

6. Decontaminate the HI-STAR 100 overpack.

7. Remove any bolt plugs, seal surface protector and/or waterproof tape from the HI-STAR 100 overpack top bolt holes.

8. Move the HI-STAR 100 overpack and MPC for further inspection, corrective actions, or disposal as necessary..

8.4 PLACEMENT OF THE HI-STAR 100 SYSTEM INTO STORAGE DIRECTLY FROM TRANSPORT

8.4.1 Overview of the HI-STAR 100 System Placement Operations Directly From Transport

The placement operations following transport of the overpack are similar to the later part of the loading operations detailed in Section 8.1. The overpack is received and surveyed for dose rates in accordance with 10CFR20 [8.4.1] and 10CFR49.173 to 177 [8.4.2]. The overpack is surveyed for removable contamination. The overpack may be transferred horizontally or vertically depending on the site specific requirements.

8.4.2 Storage Operations from Transport

1. Survey the overpack for dose rates (LCO 2.2.1).

2. Survey the overpack for removable contamination and decontaminate as necessary (LCO 2.2.2).

3. Transfer the overpack to the ISFSI.

Note:
The HI-STAR 100 minimum pitch shall be 12 feet (nominal).

4. Place the overpack at the approved storage location at the appropriate pitch.

5. Continue operations in accordance with Section 8.2.

8.5 REGULATORY ASSESSMENT

- The HI-STAR 100 System is compatible with wet and dry loading and unloading. General procedure descriptions for these operations are summarized in Sections 8.1 and 8.3 of the Topical Safety Analysis Report. Detailed procedures will need to be developed and evaluated on a site-specific basis.

- The bolted closure plate and welded MPC of the HI-STAR 100 System allow retrieval of the spent fuel for further processing or disposal as required.

- The smooth surfaces of the HI-STAR 100 System and its ancillary equipment are designed to facilitate decontamination. Only routine decontamination will be necessary after the HI-STAR 100 overpack is removed from the spent fuel pool.

- No significant radioactive effluents are produced during storage. Any radioactive effluents generated during the cask loading will be governed by the 10CFR Part 50 license conditions, if applicable.

- The general operating procedures described in the FSAR are adequate to protect health and minimize danger to life and property. Detailed procedures will need to be developed and evaluated on a site-specific basis.

- The operating procedures in the FSAR provide reasonable assurance that the HI-STAR 100 System will enable safe storage of spent fuel.

8.6 REFERENCES

[8.0.1] U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems", NUREG-1536, Final Report, January 1997.

[8.0.2] *U.S. Code of Federal Regulations,* Title 10, "Energy", Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste."

[8.0.3] American National Standard for Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 KG) or More for Nuclear Materials, ANSI N14.6, 1993.

[8.0.4] U.S. Nuclear Regulatory Commission, "Control of Heavy Loads at Nuclear Power Plants," NUREG-0612.

[8.1.2] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," ANSI N14.5-1997.

[8.2.1] Holtec International, "Topical Safety Analysis Report for the HI-STORM 100 System", Report HI-951312, latest revision.

[8.4.1] *U.S. Code of Federal Regulations,* Title 10, "Energy", Part 20, "Standards for Protection Against Radiation."

[8.4.2] *U.S. Code of Federal Regulations,* Title 49, "Transportation", Part 173, "Shippers – General Requirements for Shipments and Packages."

CHAPTER 9: ACCEPTANCE CRITERIA AND MAINTENANCE PROGRAM

This chapter identifies the fabrication, inspection, test, and maintenance programs to be conducted on the HI-STAR 100 System to verify that the structures, systems and components (SSCs) classified as important to safety have been fabricated, assembled, inspected, tested, accepted, and maintained in accordance with the requirements set forth in this FSAR, the applicable regulatory requirements, and the Certificate of Compliance.

The controls, inspections, and tests set forth in this chapter, in conjunction with the design requirements described in previous chapters, shall ensure that the HI-STAR 100 System will maintain confinement of radioactive material under normal, off-normal, and credible accident conditions; will maintain subcriticality control; will properly transfer the decay heat of the stored radioactive materials; and that radiation doses will meet regulatory requirements.

Both pre-operational and operational tests and inspections are performed throughout HI-STAR 100 loading operations to assure that the HI-STAR 100 System is functioning within its design parameters. These include receipt inspections, nondestructive weld inspections, hydrostatic tests, radiation shielding tests, thermal performance tests, dryness tests, and others. Chapter 8 identifies the sequence and conduct of the tests and inspections. "Pre-operation", as referred to in this section, defines that period of time from receipt inspection of a HI-STAR 100 System until the empty MPC is loaded into a HI-STAR overpack for fuel assembly loading.

The HI-STAR 100 System is classified as important to safety. Therefore, the individual structures, systems, and components (SSCs) that make up the HI-STAR 100 System shall be designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with a quality program commensurate with the particular SSC's graded quality category. Tables 2.2.6 and 8.1.4 provide the quality category for each major item or component of the HI-STAR 100 System and required ancillary equipment and systems.

The acceptance criteria and maintenance program described in this chapter fully comply with the requirements of 10CFR Part 72 [9.0.1] and NUREG-1536 [9.0.2], except as clarified in Table 1.0.3.

9.1 <u>ACCEPTANCE CRITERIA</u>

This section provides the workmanship inspections and acceptance tests to be performed on the HI-STAR 100 System prior to or during first loading of the system. These inspections and tests provide assurance that the HI-STAR 100 System has been fabricated, assembled, inspected, tested, and accepted for use and loading under the conditions specified in this FSAR and the Certificate of Compliance issued by the NRC in accordance with the requirements of 10CFR Part 72 [9.0.1].

These inspections and tests are also intended to demonstrate that the initial operation of the HI-STAR 100 System complies with the applicable regulatory requirements and the Technical Specifications. Noncompliances encountered during the required inspections and tests will be corrected or dispositioned to bring the item into compliance with this FSAR. Identification and resolution of noncompliances will be performed in accordance with the Holtec International Quality Assurance Program as described in Chapter 13 of this FSAR, or the licensee's NRC-approved

Quality Assurance Program. The testing and inspection acceptance criteria applicable to the MPCs and the HI-STAR overpack are listed in Tables 9.1.1 and 9.1.2, respectively, and discussed in more detail in the sections that follow, and in Chapters 8 and 12. These inspections and tests are intended to demonstrate that the HI-STAR 100 System has been fabricated, assembled, and examined in accordance with the design criteria contained in Chapter 2 of this FSAR.

This section summarizes the test program established for the HI-STAR 100 System.

9.1.1 Fabrication and Nondestructive Examination (NDE

The design, fabrication, inspection, and testing of the HI-STAR 100 System is performed in accordance with applicable codes and standards specified in Tables 2.2.6 and 2.2.7. Additional details on specific codes used are provided below.

The following fabrication controls and required inspections shall be performed on the HI-STAR 100 System, including the MPCs, in order to assure compliance to this FSAR and the Certificate of Compliance.

1. Materials of construction specified for the HI-STAR 100 System are identified in the drawing Bills-of-Material in Chapter 1 and will be procured with certification and supporting documentation as required by ASME Code [9.1.1] Section II (when applicable); the applicable subsection of ASME Code Section III (when applicable); Holtec procurement specifications; and 10CFR72, Subpart G. All materials and components will be receipt inspected for visual and dimensional acceptability, material conformance to specification requirements, and traceability markings, as applicable. Controls shall be in place to assure material traceability is maintained throughout fabrication. Materials for the confinement boundary (MPC baseplate, lid, closure ring, port cover plates and shell) and the HI-STAR 100 System helium retention boundary (bottom plate, inner shell, top flange, vent and drain port plugs, closure plate, and closure plate bolts) (equivalent to the HI-STAR 100 System containment boundary in 10CFR71 [9.1.2] transport operations) shall also be inspected per the requirements of ASME Section III, Article NB-2500.

2. The MPC confinement boundary and HI-STAR 100 System helium retention boundary shall be fabricated and inspected in accordance with ASME Code Section III, Subsection NB to the maximum extent practicable (see exceptions in Chapter 2). Other portions of the HI-STAR 100 overpack shall be fabricated and inspected in accordance with ASME Code Section III, Subsection NF (see exceptions in Chapter 2). The MPC basket, basket supports, and fuel spacers shall be fabricated and inspected in accordance with ASME Code Section III, Subsection NG (see exceptions in Chapter 2).

3. Welding shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX and the applicable ASME Section III Subsections (e.g., NB, NG, or NF, as applicable to the SSC).

4. All welds shall be visually examined in accordance with ASME Code Section V, Article 9 with acceptance criteria per ASME Code Section III, Subsection NF, Article NF-5360, except the MPC fuel basket cell plate-to-cell plate welds, fuel basket support-to-canister welds, and fuel spacer welds which shall have acceptance criteria to ASME Code Section III, Subsection NG, Article NG-5360, except as modified by the design drawings. Table 9.1.3 identifies additional nondestructive examination (NDE) requirements to be performed on specific welds, and the applicable codes and acceptance criteria to be used in order to meet the inspection requirements of the applicable ASME Code Section III. Acceptance criteria for all NDE shall be in accordance with the applicable Code for which the item was fabricated, except as modified by the design drawings. These additional NDE criteria are also specified in the design drawings for the specific welds. Weld inspections shall be detailed in a weld inspection plan which shall identify the weld and the examination requirements, the sequence of examination, and the acceptance criteria. The inspection plan shall be reviewed and approved by Holtec International in accordance with its QA program. NDE inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [9.1.3] or other site-specific, NRC-approved program for personnel qualification.

5. The MPC confinement boundary and the HI-STAR overpack helium retention boundary shall be examined and tested by a combination of methods (including helium leak test, pressure test, UT, MT and/or PT, as applicable) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce its confinement effectiveness.

6. Any welds requiring weld repair shall be repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450, NG-4450, or NF-4450, as applicable to the SSC, and examined after repair in the same manner as the original weld.

7. Any base metal repairs shall be performed and examined in accordance with the applicable fabrication Code.

8. Grinding and machining operations of the MPC confinement boundary and HI-STAR 100 helium retention boundary shall be controlled through written and approved procedures and quality assurance oversight to ensure grinding and machining operations do not reduce base metal wall thicknesses of the confinement or helium retention boundaries beyond that allowed per the design drawings. The thicknesses of base metals shall be ultrasonically tested, as necessary, in accordance with written and approved procedures to verify base metal thickness meets Design Drawing requirements. A nonconformance shall be written for areas found to be below

allowable base metal thickness and shall be evaluated and repaired as necessary per the ASME Code Section III, Subsection NB requirements.

9. Dimensional inspections of the HI-STAR 100 System shall be performed in accordance with written and approved procedures in order to verify compliance to design drawings and fit up of individual components. All dimensional inspections and functional fit-up tests shall be documented.

10. All required inspections shall be documented. The inspection documentation shall become part of the final quality documentation package.

11. The HI-STAR 100 System shall be inspected for cleanliness and proper packaging for shipping in accordance with written and approved procedures.

12. Each HI-STAR overpack will be durably marked with the appropriate model number, a unique identification number, and its empty weight per 10CFR72.236(k) at the completion of the acceptance test program.

13. Each HI-STAR overpack will be durably marked with COC identification number assigned by the NRC, radioactive trefoil symbol, gross weight, model number, and unique identification serial number in accordance with 10CFR71.85(c) at the completion of the acceptance test program performed in accordance with Chapter 8 of the HI-STAR 100 SAR (HI-951251) [9.1.4] (Reference NRC Docket No. 71-9261).

14. A completed documentation package shall be prepared and maintained during fabrication of each HI-STAR 100 System to include detailed records and evidence that the required inspections and tests have been performed. The document package will be reviewed to verify that the HI-STAR 100 System or component has been properly fabricated and inspected in accordance with the design and Code construction requirements. The documentation package shall include, but not be limited to:

- Completed Weld Records
- Inspection Records
- Nonconformance Reports
- Material Test Reports
- NDE Reports
- Dimensional Inspection Reports

9.1.1.1 MPC Lid-to-Shell Weld Volumetric Inspection

1. The MPC lid-to-shell (LTS) weld shall be volumetrically or multi-layer liquid penetrant (PT) examined following completion of welding. If volumetric examination is used, the ultrasonic testing (UT) method shall be employed. Ultrasonic techniques (including, as appropriate, Time-of-Flight

Diffraction, Focused Phased Array, and conventional pulse-echo) shall be supplemented, as necessary, to ensure substantially complete coverage of the examination volume.

2. If volumetric examination is used, then PT examinations of the root and final passes of the LTS weld shall be performed and unacceptable indications shall be documented, repaired and re-examined.

3. If volumetric examination is not used, a multi-layer PT examination shall be performed. The multi-layer PT must, at a minimum, include the root and final layers and one intermediate PT after each approximately 3/8 inch of weld depth has been completed. The 3/8 inch weld depth corresponds to the maximum allowable flaw size in the weld [9.1.10].

4. The overall minimum thickness of the LTS weld has been increased by 0.125 inch over the size credited in structural analyses, to provide additional structural capacity. A 0.625-inch J-groove weld was assumed in the structural analyses in Chapter 3.

5. For either UT or PT, the maximum undetectable flaw size must be demonstrated to be less than the critical flaw size. The critical flaw size must be determined in accordance with ASME Section XI methods. The critical flaw size shall not cause the primary stress limits of NB-3000 to be exceeded. The inspection process, including findings (indications) shall be made a permanent part of the cask user's records by video, photographic, or other means which provide an equivalent retrievable record of weld integrity. The video or photographic records should be taken during the final interpretation period described in ASME Section V, Article 6, T-676. The inspection of the weld shall be performed by qualified personnel and shall meet the acceptance requirements of ASME Section III, NB-5350 for PT and NB-5332 for UT.

6. Evaluation of any indications identified by non-destructive examination shall include consideration of any active flaw mechanisms. However, cyclic loading on the LTS weld is not significant, so fatigue will not be a factor. The LTS weld is protected from the external environment by the closure ring and the root of the LTS weld is dry and inert (He atmosphere), so stress corrosion cracking will not be a concern for the LTS weld.

7. The volumetric or multi-layer PT examination of the LTS weld, in conjunction with other examinations performed on this weld (PT of root and final layer, hydrostatic test, and a helium leakage test); the use of ASME Section III acceptance criteria, and the additional weld material added to account for potential defects in the root pass of the weld, in total, provide reasonable assurance that the LTS weld is sound and will perform its design function under all loading conditions. The volumetric (or multi-layer PT) examination and evaluation of indications will provide reasonable assurance

that leakage of the weld or structural failure under the design basis normal, off-normal, or accident storage loading conditions will not occur.

9.1.2 Structural and Pressure Tests

9.1.2.1 Lifting Trunnions

Two trunnions (located near the top of the HI-STAR overpack) are provided for vertical lifting and handling of the HI-STAR 100 System. The trunnions are designed in accordance with ANSI N14.6 [9.1.5] using a high-strength and high-ductility material (see Chapter 1). The trunnion contains no welded components. The maximum design lifting load of 250,000 pounds for the HI-STAR 100 System will occur during the removal of the HI-STAR overpack from the spent fuel pool after the MPC has been loaded, flooded with water, and the MPC lid is installed. The high material ductility, absence of materials vulnerable to brittle fracture, large stress margins, and a carefully engineered design to eliminate local stress raisers in the highly stressed regions (during the lift operation) ensure that the lifting trunnions will work reliably. However, pursuant to the defense-in-depth approach of NUREG-0612 [9.1.6], the acceptance criteria for the lifting trunnions must be established in conjunction with other considerations applicable to heavy load handling.

Section 5 of NUREG-0612 calls for measures to "provide an adequate defense-in-depth for handling of heavy loads...". The NUREG-0612 guidelines cite four major causes of load handling accidents, of which rigging failure (including trunnion failure) is one:

i. operator errors
ii. rigging failure
iii. lack of adequate inspection
iv. inadequate procedures

The cask loading and handling operations program shall ensure maximum emphasis to mitigate the potential of load drop accidents by implementing measures to eliminate shortcomings in all aspects of the operation including the four aforementioned areas.

In order to ensure that the lifting trunnions do not have any hidden material flaws, the trunnions shall be tested at 300% of the maximum design (service) lifting load. The load (750,000 lbs) shall be applied for a minimum of 10 minutes. The accessible parts of the trunnions (areas outside the HI-STAR overpack), and the local HI-STAR 100 cask areas will then be visually examined to verify no deformation, distortion, or cracking has occurred. Any evidence of deformation, distortion or cracking of the trunnion or adjacent HI-STAR 100 cask areas will require replacement of the trunnion and/or repair of the HI-STAR 100 cask. Following any replacements and/or repair, the load testing shall be reperformed and the components re-examined in accordance with the original procedure and acceptance criteria. Testing will be performed in accordance with written and approved procedures. Certified material test reports verifying trunnion material mechanical properties meet ASME Code Section II requirements will provide further verification of the trunnion load capabilities. Test results shall be documented. The documentation shall become part of the final quality documentation package.

The acceptance testing of the trunnions in the manner described above will provide adequate assurance against handling accidents.

9.1.2.2 Pressure Testing

9.1.2.2.1 HI-STAR 100 Helium Retention Boundary

The helium retention boundary of the HI-STAR overpack (e.g., the containment boundary during transportation) will be hydrostatically or pneumatically pressure tested to 150 psig +10,-0 psig, in accordance with the requirements of the ASME Code Section III, Subsection NB, Article NB-6000. The test pressure of 150 psig is 150% of the Maximum Normal Operating Pressure (established per 10CFR71.85(b) requirements). This bounds the ASME Code Section III requirement (NB-6221) for hydrostatic testing to 125% of the design pressure (100 psig). The test shall be performed in accordance with written and approved procedures. The approved test procedure shall clearly define the test equipment arrangement.

The overpack pressure test may be performed at any time during fabrication after the containment boundary is complete. Preferably, the pressure test should be performed after all overpack fabrication is complete, including attachment of the intermediate shells. The HI-STAR overpack shall be assembled for this test with the closure plate mechanical seal (only one required) or temporary test seal installed. Closure bolts shall be installed and torqued to an appropriate value less than or equal to the value specified in Chapter 8.

The calibrated test pressure gage installed on the overpack shall have an upper limit of approximately twice that of the test pressure. The test pressure shall be maintained for ten minutes. During this time period, the pressure gage shall not fall below 150 psig. At the end of ten minutes, and while the pressure is being maintained at a minimum of 150 psig, the overpack shall be observed for leakage. In particular, the closure plate-to-top forging joint (the only credible leakage point) shall be examined. If a leak is discovered, the overpack will be emptied and an evaluation to determine the cause of the leakage will be made. Repairs and retest shall be performed until the pressure test criteria are met.

> Note: If failure of the pressure retest occurs after initial repairs are completed, a nonconformance report shall be issued and root cause and corrective action shall be addressed before further repairs and retest are performed.

After completion of the pressure testing, the closure plate will be removed and the internal surfaces shall be visually examined for cracking or deformation. Any evidence of cracking or deformation shall be cause for rejection or repair and retest, as applicable. The overpack shall be required to be

pressure tested until all examinations are found to be acceptable. All test results shall be documented and shall become part of the final quality documentation package.

9.1.2.2.2 MPC Confinement Boundary

Hydrostatic testing of the MPC confinement boundary shall be performed in accordance with the

requirements of the ASME Code Section III, Subsection NB, Article NB-6000, when field welding of the MPC lid-to-shell weld is completed. The hydrostatic pressure for the test is 125 +5,-0 psig, which is 125% of the design pressure of 100 psig. The MPC vent and drain ports will be used for pressurizing the MPC cavity. The loading procedures in Chapter 8 define the test equipment arrangement. The calibrated test pressure gage installed on the MPC confinement boundary shall have an upper limit of approximately twice that of the test pressure. Following completion of the 10-minute hold period at the hydrostatic test pressure, and while maintaining a minimum test pressure of 125 psig, the surface of the MPC lid-to-shell weld will be visually examined for leakage and then re-examined by dye penetrant examination. Any evidence of cracking or deformation shall be cause for rejection, or repair and retest, as applicable. The performance and sequence of the test and the acceptance criteria are described in Section 8.1 (loading procedures).

If a leak is discovered, the test pressure shall be reduced, the MPC cavity water level lowered, the MPC cavity vented, and the weld shall be examined to determine the cause of the leakage and/or cracking. Repairs to the weld shall be performed in accordance with approved written procedures prepared in accordance with the ASME Code Section III, Subsection NB, NB-4450.

The MPC confinement boundary hydrostatic test shall be repeated until all visual and dye penetrant examinations are found to be acceptable in accordance with the acceptance criteria. All test results shall be documented and shall be maintained as part of the loaded MPC quality documentation package.

9.1.2.3 Materials Testing

The majority of material used in the HI-STAR overpack are ferritic steels. ASME Code Section III and Regulatory Guides 7.11 [9.1.7] and 7.12 [9.1.8] require that certain materials be tested in order to assure that these materials are not subject to brittle fracture failures.

Each plate or forging for the helium retention boundary (overpack inner shell, bottom plate, top flange, and closure plate) shall be required to be drop weight tested in accordance with the requirements of Regulatory Guides 7.11 and 7.12, as applicable. Additionally, per the ASME Code Section III, Subsection NB, Article NB-2300, Charpy V-notch testing shall be performed on these materials. Weld material used in welding the helium retention boundary shall be Charpy V-notch tested in accordance with ASME Section III, Subsection NB, Articles NB-2300 and NB-2430.

Non-helium retention boundary portions of the overpack, as required, shall be Charpy V-notch tested in accordance with ASME Section III, Subsection NF, Articles NF-2300, and NF-2430. The non-helium retention boundary materials to be tested include the intermediate shells, overpack port cover plates, and applicable weld materials.

Section 3.1 provides the test temperatures or T_{NDT}, and test requirements to be used when performing the testing specified above.

All test results shall be documented and shall become part of the final quality documentation package.

9.1.2.4 Pneumatic Testing of the Neutron Shield Enclosure Vessel

A pneumatic pressure test of the neutron shield enclosure vessel will be performed following final closure welding of the enclosure shell returns and enclosure panels. The pneumatic test pressure shall be 37.5+2.5,-0 psig, which is 125 percent of the rupture disc relief set pressure. The test shall be performed in accordance with approved written procedures.

During the test, the two rupture discs on the neutron shield enclosure vessel will be removed. One of the rupture disc threaded connections will be used for connection of the air pressure line and the other rupture disc connection will be used for connection of the pressure gauge.

Following introduction of pressurized air into the neutron shield enclosure vessel, a 10 minute pressure hold time will be required. If the neutron shield enclosure vessel fails to hold pressure, an approved soap bubble solution will be applied to determine the location of the leak. The leak shall be repaired using weld repair procedures in accordance with the ASME Code Section III, Subsection NF, Article NF-4450. The pneumatic pressure test shall be re-performed until no pressure loss is observed.

All test results shall be documented and shall become part of the final quality documentation package.

9.1.3 Leakage Testing

Leakage testing shall be performed in accordance with the requirements of ANSI N14.5 [9.1.9]. Testing shall be performed in accordance with written and approved procedures.

9.1.3.1 HI-STAR Overpack

A helium retention boundary weld leakage test shall be performed at any time after the containment boundary fabrication is complete. Preferably, this test should be performed at the completion of overpack fabrication, after all intermediate shells have been attached. The leakage test shall have a minimum test sensitivity of 2.15×10^{-6} std cm^3/s (helium). Helium retention welds shall have indicated leakage rates not exceeding 4.3×10^{-6} atm cm^3/s (helium). If a leakage rate exceeding the acceptance criteria is detected, the area of leakage shall be determined using the sniffer probe method or other means, and the area will be repaired per ASME Code Section III, Subsection NB, NB-4450
requirements. Following repair and appropriate NDE, the leakage testing shall be re-performed until the test criteria are satisfied.

Note: If failure of the leakage rate retest occurs after initial repairs are completed, a nonconformance report shall be issued and root cause and corrective action shall be addressed before further repairs and retest are performed.

At the completion of overpack fabrication, helium leakage through the helium retention penetrations (consisting of the inner mechanical seal between the closure plate and top flange and the vent and drain port plug seals) shall be demonstrated to not exceed the leakage rate of $4.3x10^{-6}$ atm cm^3/s (helium) at a minimum test sensitivity of $2.15x10^{-6}$ std cm^3/s (helium). This may be performed simultaneously with the boundary weld leakage test or may be performed separately using the methods described in the paragraph below.

Testing of the helium retention penetrations may be performed by evacuating and backfilling the overpack with helium gas. . A helium MSLD will be used (see Chapter 8 for details of test connections specifically designed for testing the penetration seals) to perform the test. Starting with the vent or drain port plug, the test cover is connected. The cavity on the external side of the vent port plug is evacuated and the vacuum pump is valved out. The MSLD detector measures the leakage rate of helium into the test cavity. The minimum test sensitivity shall be $2.15x10^{-6}$ std cm^3/s (helium). If the leakage rate exceeds the acceptance criteria of $4.3x10^{-6}$ atm cm^3/s (helium), the test chamber is vented and removed. The corresponding plug seal is removed, seal seating surfaces are inspected and cleaned, and the plug with a new seal is reinstalled and torqued to the required value. The test process is then repeated until the seal leakage rate is successfully achieved. The same process is repeated for the remaining overpack vent or drain port. The process is also used to test the closure plate seal except that the closure plate test tool (see Chapter 8 for details) is used in lieu of the test cover.

If the total measured leakage rate for all tested penetrations does not exceed $4.6x10^{-6}$ atm cm^3/sec, the leakage tests are successful. If the total leakage rate exceeds $4.6x10^{-6}$ atm cm^3/sec, an evaluation should be performed to determine the cause of the leakage, repairs made as necessary, and the overpack must be re-tested until the total leakage rate is within the required acceptance criterion. All leak testing results for the HI-STAR overpack shall become part of the quality record documentation package.

9.1.3.2 MPC

On completion of welding the MPC shell to the baseplate, a confinement boundary weld leakage test shall be performed using a helium mass spectrometer leak detector (MSLD) having a minimum test sensitivity of $2.5x10^{-6}$ std cm^3/s (helium). A temporary test closure lid is used in order to provide a sealed MPC. The confinement boundary welds shall have indicated leakage rates not exceeding $5x10^{-6}$ atm cm^3/s (helium). If a leakage rate exceeding the test criteria is detected, then the area of leakage shall be determined and the area repaired per ASME Code Section III, Subsection NB, NB-4450, requirements. Retesting will be performed until the leakage rate acceptance criteria is met.

Note: If failure of the leakage rate retest occurs after initial repairs are completed, a nonconformance report shall be issued and root cause and corrective action shall be addressed before further repairs and retest are performed.

Leakage testing of the MPC lid-to-shell field weld shall be performed following completion of the MPC hydrostatic test performed per Subsection 9.1.2.2.2. Leakage testing of the vent and drain port cover plate welds will be performed after field welding of the cover plates and subsequent NDE. The description and procedures for these field tests are provided in Section 8.1, and the acceptance criteria are defined in the Technical Specifications.

All leak testing results for the MPC shall be documented and shall become part of the quality record documentation package.

9.1.4 Component Tests

9.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

There are no fluid transport devices associated with the HI-STAR 100 System. The only valve-like components in the HI-STAR 100 System are the specialty designed caps installed in the MPC lid for the drain and vent ports. These caps are recessed inside the MPC lid and covered by the fully welded vent and drain port cover plates. No credit is taken for the caps' ability to confine helium or radioactivity. After completion of drying and backfill operations, the drain and vent port cover plates are welded in place on the MPC lid and are leak tested to verify the MPC confinement boundary.

There are two rupture discs installed in the upper ledge surface of the neutron shield enclosure vessel of the HI-STAR overpack. These rupture discs are provided for venting purposes under hypothetical fire accident conditions in which vapor formation from neutron shielding material degradation may occur. The rupture discs are designed to relieve at 30 psig +/- 5 psig). Each manufactured lot of rupture discs shall be sample tested to verify their point of rupture.

9.1.4.2 Seals and Gaskets

Two metallic mechanical seals are provided on the HI-STAR overpack closure plate to provide redundant sealing. Mechanical seals are also used on the overpack vent and drain port plugs of the HI-STAR overpack. Each primary seal is individually leak tested in accordance with Subsection 9.1.3.1. An independent and redundant seal is provided for each penetration (e.g., closure plate, port cover plates, and closure plate test plug). No confinement credit is taken for these redundant seals and they are not leakage tested. Details on these seals are provided in Chapter 7. Procedures for leakage testing are provided in Chapter 8.

9.1.5 Shielding Integrity

The HI-STAR 100 System has three specifically designed shields for neutron and gamma ray attenuation. For gamma shielding, there are successive carbon steel intermediate shells attached onto the outer surface of the overpack inner shell. The details of the manufacturing process are discussed in Chapter 1. Holtite-A neutron shielding is provided in the outer enclosure of the overpack. Additional neutron attenuation is provided by the encased Boral™ neutron absorber attached to the fuel basket cell surfaces inside the MPCs. Test requirements for each of the three shielding items are described below.

9.1.5.1 Fabrication Testing and Controls

Holtite-A:

Neutron shield properties of Holtite-A are provided in Chapter 1, Section 1.2.1.3.2. Each manufactured lot of neutron shield material shall be tested to verify that the material composition (aluminum and hydrogen), boron concentration, and neutron shield density (or specific gravity) meet the requirements specified in Chapter 1 and the Bill of Material sections. A manufactured lot is defined as the total amount of material used to make any number of mixed batches comprised of constituent ingredients from the same lot/batch identification numbers supplied by the constituent manufacturer. Testing will be performed in accordance with written and approved procedures and/or standards. Material composition, boron concentration, and density (or specific gravity) data for each manufactured lot of neutron shield material will become part of the quality documentation package.

The installation of the neutron shielding material shall be performed in accordance with written and qualified procedures. The procedures shall ensure that mix ratios and mixing methods are controlled in order to achieve proper material composition, boron concentration and distribution, and that pours are controlled in order to prevent gaps from occurring in the material. Samples of each manufactured lot of neutron shield material will be maintained by Holtec International as part of the quality record documentation package.

Steel:

All steel plates utilized in the construction of the HI-STAR 100 System shall be dimensionally inspected to assure compliance for minimum thickness in accordance with the Design Drawings in Section 1.5.

The total measured thickness of the inner shell plus intermediate shells shall be a minimum of 8.5 inches. The top flange, closure plate, and bottom plate of the overpack shall be measured to confirm their thicknesses meet design drawing requirements. Measurements shall be performed in accordance with written and approved procedures. The measurement locations and measurements shall be documented. Measurements shall be made through a combination of receipt inspection thickness measurements on individual plates and actual measurements taken prior to welding the overpack or intermediate shells. Any area found to be under the specified minimum thickness will be repaired in accordance with applicable ASME Code requirements.

No additional gamma shield testing of the HI-STAR 100 System is required. A gamma shielding effectiveness test per Subsection 9.1.5.2 will be performed on each fabricated HI-STAR 100 System after the first fuel loading.

General for All Shield Materials:

1. All test results shall be documented and become part of the quality documentation package.

2. Dimensional inspections of the cavities containing poured neutron shielding materials shall assure that the design required amount of shielding material is incorporated into the fabricated item.

9.1.5.2 Shielding Effectiveness Test

Following the first fuel loading of each HI-STAR 100 System, a shielding effectiveness test will be performed at the loading facility site to verify the effectiveness of the gamma and neutron shields. This test will be performed after the HI-STAR 100 System has been loaded with fuel, drained, sealed, and backfilled with helium.

The neutron and gamma shielding effectiveness tests will be performed using written and approved procedures. Calibrated neutron and gamma dose meters shall be used to measure the actual neutron and gamma dose rates at the surface of the HI-STAR overpack. Measurements will be taken at three cross sectional planes and at four points along each plane's circumference. Additionally, four measurements shall be taken at the top of the overpack closure plate. All dose rate measurements shall be documented and become part of the quality documentation package. The average results from each sectional plane shall be compared to the design basis limits for surface dose rates established in Chapter 5. The test is considered acceptable if the actual dose readings are lower or equal to the acceptance criteria in the Technical Specifications. If dose rates are higher than the Technical Specification limits, the required actions of the Technical Specifications shall be completed.

9.1.5.3 Neutron Absorber Tests

After manufacturing, a statistical sample of each lot of Boral is tested using wet chemistry and/or neutron attenuation techniques to verify a minimum ^{10}B content at the ends of the panel. Any panel in which ^{10}B loading is less than the minimum allowed will be rejected.

Tests are performed using written and approved procedures. Results shall be documented and become part of the HI-STAR 100 System quality records documentation package.

Installation of Boral panels into the fuel basket shall be performed in accordance with written and approved procedures (or shop travelers). Travelers and/or quality control procedures shall be in place to assure each required cell wall of the MPC basket contains a Boral panel in accordance with the design drawings. These quality control processes, in conjunction with Boral manufacturing testing, provide the necessary assurances that the Boral will perform its intended function. No additional testing will be required on the Boral.

9.1.6 Thermal Acceptance Test

The first fabricated HI-STAR overpack shall be tested to confirm its heat transfer capability. The test shall be conducted after the radial channels, enclosure shell panels, and neutron shield material have been installed and all inside and outside surfaces are painted per the design drawings. A test cover plate shall be used to seal the overpack cavity. Testing shall be performed in accordance with written and approved procedures.

The thermal test is performed by heating the overpack cavity with a readily measurable source of thermal energy. Prior standard practice has utilized electrical heating systems for confirming thermal performance of casks. However, as explained below, the HI-STAR 100 overpack thermal acceptance test is performed using steam as the source of thermal energy. Steam heating of the overpack cavity surfaces is the preferred method for this test instead of electric heating. There are several advantages with steam heated testing as listed below:

(i) Uniform cavity surface temperatures are readily achieved as a result of high steam condensation heat transfer coefficient (about 1,000 Btu/ft^2 hr-^{o}F compared to about 1 Btu/ft^2 hr-^{o}F for air) coupled with the steam's uniform distribution throughout the cavity.

(ii) A reliable constant temperature source (steam at atmospheric pressure condenses at 212^o F compared to variable heater surface temperatures in excess of 1,000^o F) eliminates concerns of overpack cavity surface overheating.

(iii) Interpretation of isothermal test data is not susceptible to errors associated with electric heating systems due to heat input measurement uncertainties, leakage of heat from electrical cables, thermocouple wires, overpack lid, bottom baseplate, etc.

(iv) The test setup is simple requiring only a steam inlet source and drain compared to numerous power measurement and control instruments, switchgear and safety interlocks required to operate an electric heater assembly.

Twelve (12) calibrated thermocouples shall be installed on the external walls of the overpack as shown in Figure 9.1.2. Three calibrated thermocouples shall be installed on the internal walls of the overpack in locations to be determined by procedure. Additional temperature sensors shall be used to monitor ambient temperature, steam supply temperature, and condensate drain temperature. The thermocouples shall be attached to strip chart recorders or other similar mechanism to allow for continuous monitoring and recording of temperatures during the test. Instrumentation shall be installed to monitor overpack cavity internal pressure.

After the thermocouples have been installed, dry steam will be introduced through an opening in the test cover plate previously installed on the overpack and the test initiated. Temperatures of the thermocouples, plus ambient, steam supply, and condensate drain temperature shall be recorded at hourly intervals until thermal equilibrium is reached. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of potential ambient test conditions and incorporated into the test procedure. In general, thermal equilibrium is expected approximately 12 hours after the start of steam heating. Air will be purged from the overpack cavity via venting

during the heatup cycle. During the test, the steam condensate flowing out of the overpack drain shall be collected and the mass of the condensate measured with a precision weighing instrument.

Once thermal equilibrium is established, the final ambient, steam supply, and condensate drain temperatures and temperatures at each of the thermocouples shall be recorded. The strip charts, hand-written logs, or other similar readout shall be marked to show the point when thermal equilibrium was established and final test measurements were recorded. The final test readings along with the hourly data inputs and strip charts (or other similar mechanism) shall become part of the quality records documentation package for the overpack. The heat rejection capability of the overpack at test conditions shall be computed using the following formula:

$$Q_{hm} = (h_1 B h_2)\, m_c \qquad (8\text{-}1)$$

Where: Q_{hm} = Heat rejection rate of the overpack (Btu/hr)

h_1 = Enthalpy of steam entering the overpack cavity (Btu/lbm)

h_2 = Enthalpy of condensate leaving the overpack cavity (Btu/lbm)

m_c = Average rate of condensate flow measured during thermal equilibrium conditions (lbm/hr)

Based on the HI-STAR 100 overpack thermal model, a design basis minimum heat rejection capacity (Q_{hd}) shall be computed at the measured test conditions (i.e., steam temperature in the overpack cavity and ambient air temperature). The thermal test shall be considered acceptable if the measured heat rejection capability is greater than the design basis minimum heat rejection capacity ($Q_{hm} > Q_{hd}$).

The summary of reference ambient inputs that define the thermal test environment are provided in Table 9.1.4. In Figure 9.1.3, a steady-state temperature contour plot of a steam heated overpack is provided based on the thermal analysis methodology described in SAR Chapter 3. Transient heating of the overpack is also determined to establish the time required to approach (within 2° F) the equilibrium temperatures. The surface temperature plot shown in Figure 9.1.4 demonstrates that a 12-hour steam heating time is adequate to closely approach the equilibrium condition.

If the acceptance criteria above are not met, then the HI-STAR 100 Package shall not be accepted until the root cause is determined, appropriate corrective actions are completed, and the overpack is re-tested with acceptable results.

Test results shall be documented and shall become part of the quality record documentation package.

9.1.7 Cask Identification

Each HI-STAR 100 System shall be provided with unique identification plates with appropriate markings per 10CFR72.236(k) and 10CFR71.85(c). The identification plates shall not be installed until each HI-STAR 100 System component has completed the fabrication acceptance test program and been accepted by authorized Holtec International personnel. A unique identifying serial number shall also be stamped on the MPC to provide traceability back to the MPC-specific quality records documentation package.

Table 9.1.1
MPC INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	Fabrication	Pre-operation	Maintenance and Operations
Visual Inspection and Nondestructive Examination (NDE)	a) Assembly and examination of MPC components per ASME Code Section III, Subsections NB, NF, and NG, as defined on design drawings, per NB-5300, NF-5300, and NG-5300, as applicable. b) A dimensional inspection of the internal basket assembly and canister will be performed to verify compliance with design requirements. c) A dimensional inspection of the MPC lid and MPC closure ring will be performed prior to inserting into the canister shell to verify compliance with design requirements. d) NDE of weldments will be defined on the design drawings using standard American Welding Society NDE symbols and/or notations. e) Cleanliness of the MPC will be verified upon completion of fabrication. f) The packaging of the MPC at the completion of fabrication will be verified prior to shipment.	a) The MPC will be visually inspected prior to placement in service at the licensee's facility. b) MPC protection at the licensee's facility will be verified. c) MPC cleanliness and exclusion of foreign material will be verified prior to placing in the spent fuel pool.	a) None.

Table 9.1.1 (continued) MPC INSPECTION AND TEST ACCEPTANCE CRITERIA			
Function	**Fabrication**	**Pre-operation**	**Maintenance and Operations**
Structural	a) Assembly and welding of MPC components will be performed per ASME Code, Subsections NB, NF, and NG, as applicable. b) Materials analysis (steel, Boral, etc.), will be performed and records will be kept in a manner commensurate with "important to safety" classifications.	a) None.	a) An ultrasonic (UT) examination or multi-layer liquid penetrant (PT) examination of the MPC lid-to-shell weld shall be performed per ASME Section V, Article 5 (or ASME Section V, Article 6). Acceptance criteria for the examination are defined Table 9.1.3 and in the Design Drawings. b) ASME Code NB-6000 hydrostatic test shall be performed after MPC closure welding. Acceptance criteria are defined in Section 9.1.2.2.2.
Leak Tests	a) Helium leak rate testing will be performed on all MPC pressure boundary shop welds.	a) None.	a) Helium leak rate testing will be performed on MPC lid-to-shell, and vent and drain ports-to-MPC lid field welds after closure welding. Acceptance criteria are defined in the Technical Specifications.

Table 9.1.1 (continued) MPC INSPECTION AND TEST ACCEPTANCE CRITERIA			
Function	**Fabrication**	**Pre-operation**	**Maintenance and Operations**
Criticality Safety	a) The boron content will be verified at the time of neutron absorber material manufacture. b) The installation of Boral panels into MPC basket plates will be verified by inspection.	a) None.	a) None.
Shielding Integrity	a) Material compliance will be verified through CMTRs. b) Dimensional verification of MPC lid thickness will be performed.	a) None.	a) None.
Thermal Acceptance	a) None.	a) None.	a) None.
Fit-up Tests	a) Fit-up of the following components is to be tested during fabrication. - MPC lid - vent/drain port cover plates - MPC closure ring b) A gauge test of all basket fuel compartments.	a) Fit-up of the following components is to be verified during pre-operation. - MPC lid - MPC closure ring - vent/drain cover plates	a) None.
Canister Identification Inspections	a) Verification of identification marking applied at completion of fabrication.	a) Identification marking will be checked for legibility during pre-operation.	a) None.

Table 9.1.2
HI-STAR OVERPACK
INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	Fabrication	Pre-operation	Maintenance and Operations
Visual Inspection and Nondestructive Examination (NDE)	a) Assembly and examination will be performed per ASME Code, Subsection NB, NB-5300 for helium retention boundary and Subsection NF, NF-5300 for non-helium retention boundary components. b) A dimensional inspection of the overpack internal cavity, external dimensions, and closure plate will be performed to verify compliance with design requirements. c) NDE of weldments will be defined on design drawings using standard American Welding Society NDE symbols and/or notations. d) Cleanliness of the HI-STAR overpack will be verified upon completion of fabrication. e) Packaging of the HI-STAR overpack at the completion of fabrication will be verified prior to shipment.	a) The HI-STAR overpack will be visually inspected prior to placement in service at the licensee's facility. b) HI-STAR overpack protection at the licensee's facility will be verified. c) HI-STAR overpack cleanliness and exclusion of foreign material will be verified prior to use.	a) None.

Table 9.1.2 (continued)

HI-STAR OVERPACK INSPECTION AND TEST ACCEPTANCE CRITERIA			
Function	**Fabrication**	**Pre-operation**	**Maintenance and Operations**
Structural	a) Assembly and welding of HI-STAR overpack components will be performed per ASME Code, Subsection NB and NF, as applicable. b) Verification of structural materials will be performed through receipt inspection and review of certified material test reports (CMTRs) obtained in accordance with the item's quality classification category. c) A load test of the lifting trunnions will be performed during fabrication per ANSI N14.6. d) A pressure test of the helium retention boundary in accordance with ASME Code Section III, Subsection NB-6000 will be performed. e) A pneumatic pressure test of the neutron shield enclosure will be performed during fabrication.	a) None.	a) The rupture discs on the neutron shield vessel will be replaced every 5 years.

Table 9.1.2 (continued)
HI-STAR OVERPACK
INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	Fabrication	Pre-operation	Maintenance and Operations
Leak Tests	a) Helium leakage rate testing of the HI-STAR overpack helium retention boundary welds (e.g., containment boundary) will be performed in accordance with ANSI N14.5. b) A fabrication verification helium leakage rate test shall be performed on all HI-STAR overpack mechanical seal boundaries in accordance with ANSI N14.5.	a) None.	a) Containment Fabrication Verification Leakage Tests of the HI-STAR 100 System shall be performed prior to commencement of transport operations.
Criticality Safety	a) None.	a) None.	a) None.
Shielding Integrity	a) Material verifications (Holtite-A, shell plates, etc.), will be performed in accordance with the item's quality category. The required material certifications will be obtained. b) The placement of Holtite-A will be controlled through written special process procedures.	a) None.	a) A shielding effectiveness test will be performed after the first fuel loading and re-performed every five years while in service.

Table 9.1.2 (continued) HI-STAR OVERPACK INSPECTION AND TEST ACCEPTANCE CRITERIA			
Function	**Fabrication**	**Pre-operation**	**Maintenance and Operation**
Thermal Acceptance	a) A thermal acceptance test is performed on the first system, at completion of fabrication to confirm the heat transfer capabilities of the HI-STAR overpack.	a) None.	a) A thermal performance test of the HI-STAR 100 System shall be performed prior to commencement of transport operations.
Cask Identification Inspection	a) Identification plates will be installed on the HI-STAR overpack at completion of the acceptance test program.	a) The identification plates will be checked prior to loading.	a) The identification plates will be periodically inspected per licensee procedures and will be repaired or replaced if damaged.
Functional Performance Tests	a) Fit-up tests of HI-STAR overpack components (closure plates, port plugs, cover plates) will be performed during fabrication.	a) Fit-up test of the HI-STAR overpack lifting trunnions with the lifting yoke will be performed. b) Fit-up test of the HI-STAR overpack rotation trunnions with the horizontal transfer skid (if used) will be performed. c) Fit-up test of the MPC into the HI-STAR overpack will be performed prior to loading.	a) None.

Table 9.1.3
HI-STAR 100 NDE REQUIREMENTS

MPC			
Weld Location	**NDE Requirement**	**Applicable Code**	**Acceptance Criteria (Applicable Code)**
Shell longitudinal seam	RT PT (surface)	ASME Section V, Article 2 (RT) ASME Section V, Article 6 (PT)	RT: ASME Section III, Subsection NB, Article NB-5320 PT: ASME Section III, Subsection NB, Article NB-5350
Shell circumferential seam	RT PT (surface)	ASME Section V, Article 2 (RT) ASME Section V, Article 6 (PT)	RT: ASME Section III, Subsection NB, Article NB-5320 PT: ASME Section III, Subsection NB, Article NB-5350
Baseplate-to-shell	RT or UT PT (surface)	ASME Section V, Article 2 (RT) ASME Section V, Article 5 (UT) ASME Section V, Article 6 (PT)	RT: ASME Section III, Subsection NB, Article NB-5320 UT: ASME Section III, Subsection NB, Article NB-5330 PT: ASME Section III, Subsection NB, Article NB-5350

Table 9.1.3 (continued) HI-STAR 100 NDE REQUIREMENTS			
MPC			
Weld Location	**NDE Requirement**	**Applicable Code**	**Acceptance Criteria (Applicable Code)**
Lid-to-shell	PT (root and final pass) PT (surface following hydrostatic test) UT or multi-layer PT	ASME Section V, Article 6 (PT) ASME Section V, Article 5 (UT) ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350 UT: ASME Section III, Subsection NB, Article NB-5332 PT: ASME Section III, Subsection NB, Article NB-5350
Closure ring-to-shell	PT (final pass)	ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350
Closure ring-to-lid	PT (final pass)	ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350
Closure ring radial welds	PT (final pass)	ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350
Port cover plates-to-lid	PT (root and final pass)	ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350
Lift lug and lift lug baseplate	PT (surface)	ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NG, Article NG-5350
Vent and drain port cover plate plug welds	PT (surface)	ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350

Table 9.1.3 (continued)
HI-STAR 100 NDE REQUIREMENTS

HI-STAR OVERPACK			
Weld Location	**NDE Requirement**	**Applicable Code**	**Acceptance Criteria (Applicable Code)**
Inner shell-to-top flange	RT	ASME Section V, Article 2 (RT)	RT: ASME Section III, Subsection NB, Article NB-5320
	MT or PT (surface)	ASME Section V, Article 7 (MT)	MT: ASME Section III, Subsection NB, Article NB-5340
		ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350
Inner shell-to-bottom plate	RT	ASME Section V, Article 2 (RT)	RT: ASME Section III, Subsection NB, Article NB-5320
	MT or PT (surface)	ASME Section V, Article 7 (MT)	MT: ASME Section III, Subsection NB, Article NB-5340
		ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350
Inner shell longitudinal seam	RT	ASME Section V, Article 2 (RT)	RT: ASME Section III, Subsection NB, Article NB-5320
	MT or PT (surface)	ASME Section V, Article 7 (MT)	MT: ASME Section III, Subsection NB, Article NB-5340
		ASME Section V, Article 6 (PT)	PT: ASME Section III, Subsection NB, Article NB-5350

Table 9.1.3 (continued)
HI-STAR 100 NDE REQUIREMENTS

HI-STAR OVERPACK			
Weld Location	**NDE Requirement**	**Applicable Code**	**Acceptance Criteria (Applicable Code)**
Inner shell circumferential seam	RT MT or PT (surface)	ASME Section V, Article 2 (RT) ASME Section V, Article 7 (MT) ASME Section V, Article 6 (PT)	RT: ASME Section III, Subsection NB, Article NB-5320 MT: ASME Section III, Subsection NB, Article NB-5340 PT: ASME Section III, Subsection NB, Article NB-5350
Intermediate shell welds (as noted on Design Drawings)	MT or PT (surface)	ASME Section V, Article 7 (MT) ASME Section V, Article 6 (PT)	MT: ASME Section III, Subsection NF, Article NF-5340 PT: ASME Section III, Subsection NF, Article NF-5350

Table 9.1.4

SUMMARY OF OVERPACK THERMAL ANALYSIS
AMBIENT INPUTS FOR STEAM HEATED TEST CONDITIONS

PARAMETER	VALUE
Steam Temperature	212°F
Ambient Temperature	70°F
Radiative Blocking	None
Exposed Surfaces Insolation	None

FIGURE 9.1.1

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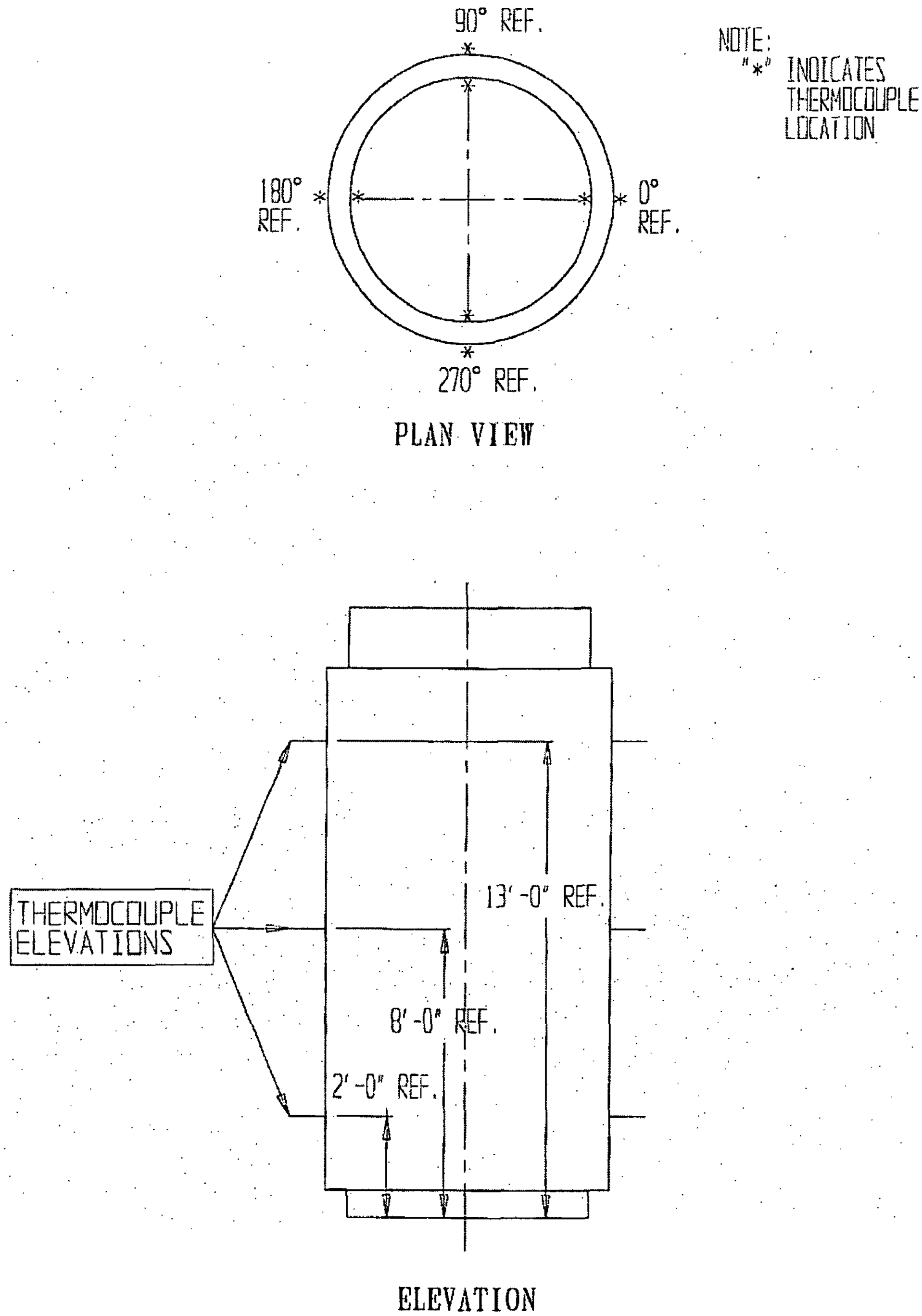


FIGURE 9.1.2; THERMOCOUPLE LOCATIONS

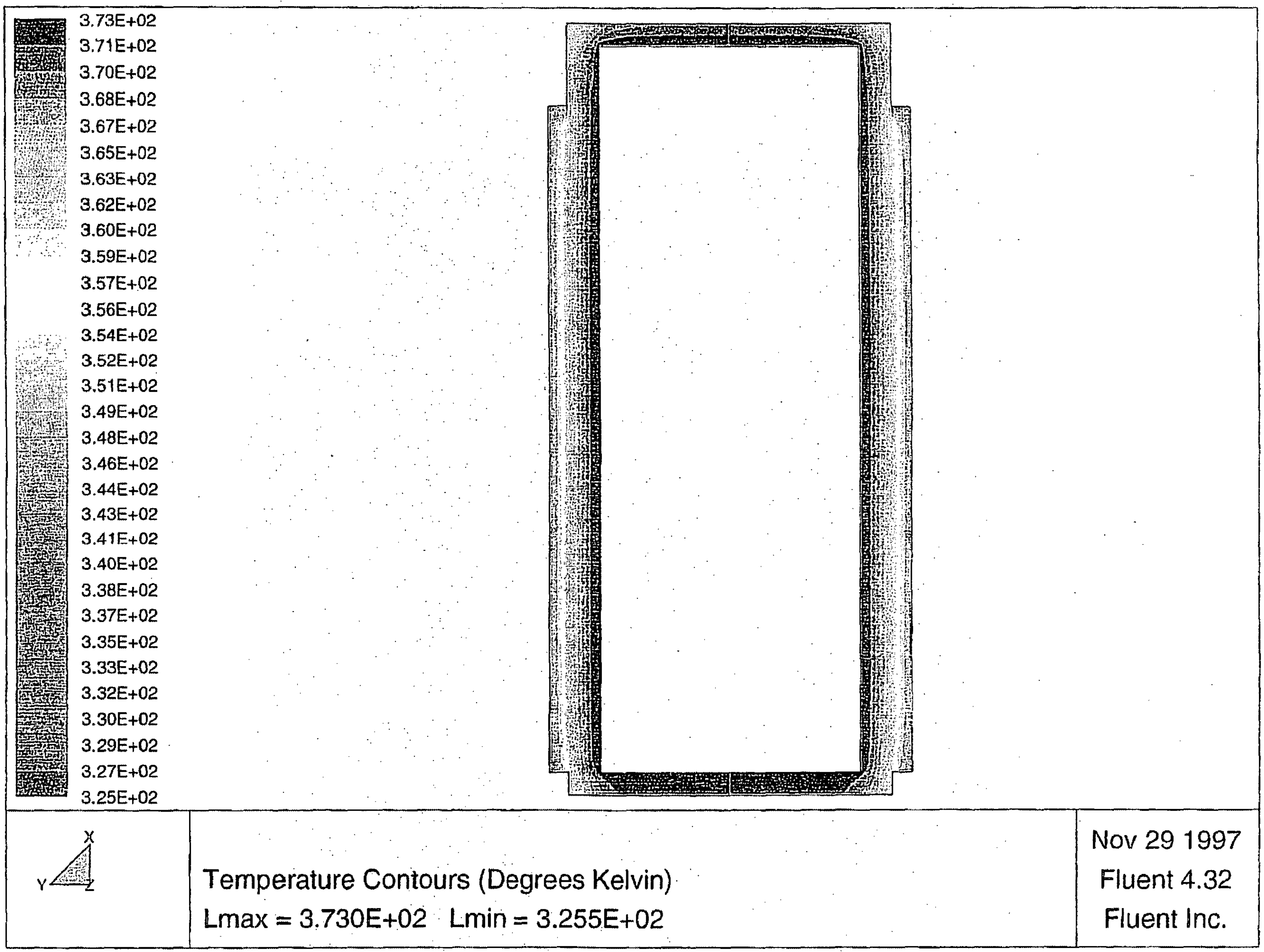


FIGURE 9.1.3: STEAM HEATED OVERPACK TEST CONDITION TEMPERATURE CONTOURS PLOT

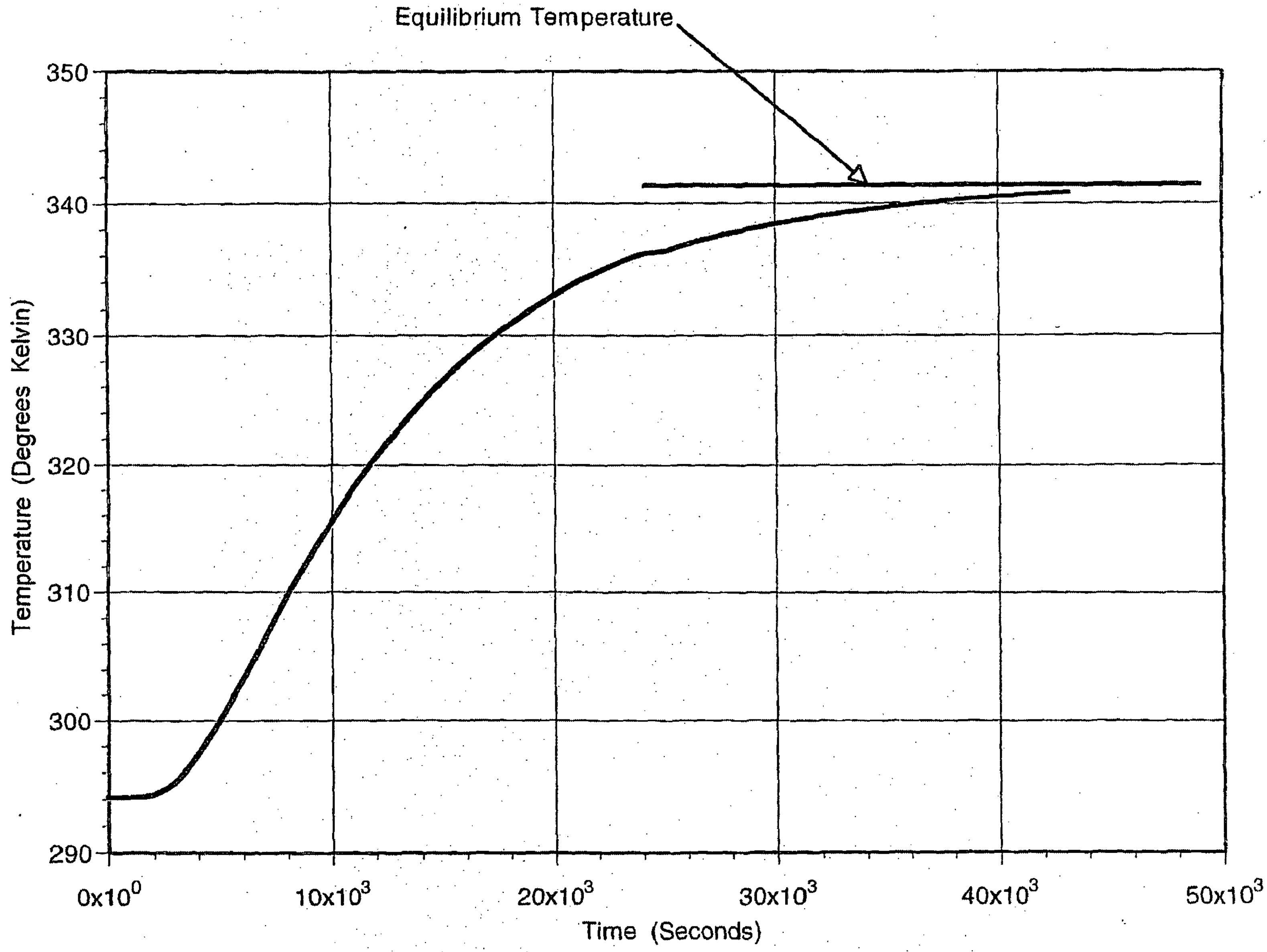


FIGURE 9.1.4: OVERPACK SURFACE TEMPERATURE HISTORY DURING A STEAM HEATED TEST

9.2 MAINTENANCE PROGRAM

An ongoing maintenance program will be defined and incorporated into the HI-STAR 100 System Operations Manual which will be prepared and issued prior to the delivery and first use of the system. This document will delineate the detailed inspections, testing, and parts replacement necessary to ensure continued radiological safety, proper handling, and confinement performance of the system in accordance with 10CFR72 [9.0.1] regulations, the conditions specified in the Certificate of Compliance, and the design requirements and criteria contained in this FSAR.

The HI-STAR 100 System is totally passive by design. There are no active components or monitoring systems required to assure the continued performance of its safety functions. As a result, only minimal maintenance will be required over the HI-STAR 100 System's lifetime, and this maintenance would primarily result from the weathering effects on the exterior coating system while in storage. Typical of such maintenance would be the reapplication of corrosion inhibiting materials on accessible external surfaces. Such maintenance requires methods and procedures no more demanding than those currently in use at licensed facilities.

The maintenance program schedule for the HI-STAR 100 System is provided in Table 9.2.1.

9.2.1 Structural and Pressure Parts

Prior to each fuel loading, a visual examination in accordance with written and approved procedures will be performed on the lifting trunnions (area outside of the overpack) and pocket trunnion recesses. The examination will inspect for indications of overstress such as cracking, deformation, or wear marks. Repairs or replacement in accordance with written and approved procedures will be required if unacceptable conditions are identified.

As described in Chapters 7 and 11, there are no credible normal, off-normal, or accident events which can cause the structural failure of the MPC or HI-STAR overpack. Therefore, periodic structural or pressure tests on the MPCs or HI-STAR overpack following the initial acceptance tests are not required as part of the storage maintenance program.

9.2.2 Leakage Tests

There are no seals or gaskets that comprise the MPC confinement boundary since the MPC lid, port cover plates, and closure ring are welded closures. Metallic seals are used on the overpack helium retention boundary to ensure the retention of the helium in the overpack. These seals are not temperature sensitive within the design temperature range, are resistant to corrosion and radiation environments, and are helium leak tested after fuel loading. There are no credible normal, off-normal, or accident events which can cause the failure of the MPC confinement boundary or overpack helium retention boundary seals or welds. No leakage tests are required as part of the storage maintenance program.

Prior to transport of the HI-STAR 100 System following completion of the storage period, a Containment Periodic Verification leakage test shall be performed in accordance with ANSI N14.5

[9.1.9] and the HI-STAR 100 Safety Analysis Report [9.1.4] to verify the continued integrity of the containment boundary metallic seals.

9.2.3 Subsystem Maintenance

The HI-STAR 100 System does not include any subsystems which provide auxiliary cooling. Normal maintenance and calibration testing will be required on the vacuum drying, helium backfill, and leakage testing systems. Rigging, remote welders, cranes, and lifting beams shall also be inspected to ensure proper maintenance and continued performance is achieved. Auxiliary shielding provided during on-site transfer operations or installed with the HI-STAR 100 at the storage pad requires no maintenance.

9.2.4 Rupture Discs

The rupture discs shall be replaced every five years with approved spares per written and approved procedures.

9.2.5 Shielding

The gamma and neutron shielding materials in the overpack and MPC degrade negligibly over time or as a result of usage. To ensure continuing compliance of the HI-STAR 100 System to the design basis dose rate values, the Shielding Effectiveness Test shall be reperformed every five years after placement into service.

Radiation monitoring of the ISFSI by the licensee provides ongoing evidence and confirmation of the shielding integrity and performance. If increased radiation doses are indicated by the facility monitoring program, additional surveys of overpacks may be performed to determine the cause of the increased dose rates.

The Boral panels installed in the MPC baskets are not expected to degrade under normal long-term dry storage conditions. The use of Boral in similar nuclear applications is discussed in Chapter 1, and the long-term performance in a dry, inert gas atmosphere is evaluated in Chapter 3. Therefore, no periodic verification testing of neutron poison material is required on the HI-STAR 100 System.

9.2.6 Thermal

There are no active cooling systems required for the long-term thermal performance of the HI-STAR 100 System. Therefore, no periodic thermal testing is required for the HI-STAR 100 System.

Table 9.2.1

HI-STAR 100 SYSTEM MAINTENANCE PROGRAM SCHEDULE

Task	Frequency
Overpack cavity visual inspection	Prior to fuel loading
Overpack bolt visual inspection	Prior to installation during each use
Overpack external surface (accessible) visual examination	Annually
HI-STAR 100 System Shield Effectiveness Test	After loading and every 5 years
Lifting trunnion and pocket trunnion recess visual inspection	Prior to next handling operation after loaded HI-STAR 100 System is placed on ISFSI pad.
Closure plate seal replacement	Following removal of closure plate bolting
Port seal replacement	Following opening of applicable port
Port cover plate seal replacement	Following removal of applicable cover plate
Replace neutron shield vessel rupture discs	Every 5 years

9.3 REGULATORY COMPLIANCE

Chapter 9 of this FSAR has been prepared to summarize the commitments of Holtec International to design, construct, and test the HI-STAR 100 System in accordance with the Codes and Standards identified in Chapter 2. Completion of the defined acceptance test program for each HI-STAR 100 System will provide assurance that the SSCs important to safety will perform their design function. The performance of the maintenance program by the licensee for each loaded HI-STAR 100 System will provide assurance for the continued safe long-term storage of the stored SNF.

The described acceptance criteria and maintenance programs can be summarized in the following evaluation statements:

1. Section 9.1 of this FSAR describes Holtec International's proposed program for preoperational testing and initial operations of the HI-STAR 100 System. Section 9.2 describes the proposed HI-STAR 100 maintenance program.

2. Structures, systems, and components (SSCs) of the HI-STAR 100 System designated as important to safety will be designed, fabricated, erected, assembled, inspected, tested, and maintained to quality standards commensurate with the importance to safety of the function they are intended to perform. Tables 2.2.6 and 8.1.4 of this FSAR identify the safety importance and quality classifications of SSCs of the HI-STAR 100 System, and Tables 2.2.6 and 2.2.7 present the applicable standards for their design, fabrication, and inspection.

3. Holtec International will examine and test the HI-STAR 100 System to ensure that it does not exhibit any defects that could significantly reduce its confinement effectiveness. Section 9.1 of this FSAR describes the MPC confinement boundary assembly, inspection, and testing.

4. Holtec International will mark the cask with a data plate indicating its model number, unique identification number, and empty weight. Holtec International Design Drawing No. 1397, Sheet 4 of 7, in Section 1.5 of this FSAR illustrates and details this data plate.

5. It can be concluded that the acceptance tests and maintenance program for the HI-STAR 100 System are in compliance with 10CFR72 [9.0.1], and that the applicable acceptance criteria have been satisfied. The acceptance tests and maintenance program will provide reasonable assurance that the HI-STAR 100 System will allow safe storage of spent fuel throughout its certified term. This can be concluded based on a review that considers the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

9.4 REFERENCES

[9.0.1] U.S. Code of Federal Regulations, Title 10, "Energy", Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste."

[9.0.2] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems", January 1997.

[9.1.1] American Society of Mechanical Engineers, " Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 1995, including Addenda through 1997.

[9.1.2] U.S. Code of Federal Regulations, Title 10, "Energy", Part 71, "Packaging and Transportation of Radioactive Material."

[9.1.3] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, December 1992.

[9.1.4] HI-STAR 100 Safety Analysis Report, Holtec Report No. HI-951251, current revision.

[9.1.5] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kilograms) or More", ANSI N14.6, September 1993.

[9.1.6] NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants", U.S. Nuclear Regulatory Commission, Washington, D.C., July 1980.

[9.1.7] U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1m)," Regulatory Guide 7.11, June 1991.

[9.1.8] U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1m) But Not Exceeding 12 Inches (0.3m)," Regulatory Guide 7.12, June 1991.

[9.1.9] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials Leakage Tests on Packages for Shipment", ANSI N14.5-1997.

[9.1.10] Holtec International Position Paper DS-213, "Acceptable Flaw Size in MPC Lid-to-Shell Welds", Revision 2.

CHAPTER 10: RADIATION PROTECTION

This chapter discusses the design considerations and operational features that are incorporated in the HI-STAR 100 System design to protect plant personnel and the public from exposure to radioactive contamination and ionizing radiation during canister loading, closure, on-site movement, and on-site dry storage. Occupational exposure estimates for typical MPC loading, closure, on-site movement operations, and ISFSI inspections are provided. An off-site dose assessment for a typical ISFSI is also discussed. Since the determination of off-site doses is necessarily site-specific, similar dose assessments are to be prepared by the licensee, as part of implementing the HI-STAR 100 System in accordance with 10CFR72.212 [10.0.1]. The information provided in this chapter is in full compliance with the requirements of NUREG-1536 [10.0.2].

10.1 ENSURING THAT OCCUPATIONAL RADIATION EXPOSURES ARE AS-LOW-AS-REASONABLY-ACHIEVABLE (ALARA)

10.1.1 Policy Considerations

The HI-STAR 100 System has been designed in accordance with 10CFR72 [10.0.1] and maintains radiation exposures ALARA consistent with 10CFR20 [10.1.1] and the guidance provided in Regulatory Guides 8.8 [10.1.2] and 8.10 [10.1.3]. Licensees using the HI-STAR 100 System will utilize and apply their existing site ALARA policies, procedures and practices for ISFSI activities to ensure that personnel exposure requirements of 10CFR20 [10.1.1] are met. Personnel performing ISFSI operations shall be trained on the operation of the HI-STAR 100 System, and be familiarized with the expected dose rates around the MPC and overpack during all phases of loading, storage, and unloading operations. Chapter 12 provides dose rate limits for the MPC lid and the overpack surfaces to ensure that the HI-STAR 100 System is operated within design basis conditions and that ALARA goals will be met. Pre-job ALARA briefings should be held with workers and radiological protection personnel prior to work on or around the system. Worker dose rate monitoring, in conjunction with trained personnel and well-planned activities, will significantly reduce the overall dose received by the workers. When preparing or making changes to site-specific procedures for ISFSI activities, users shall ensure that ALARA practices are implemented and the 10CFR20 [10.1.1] standards for radiation protection are met in accordance with the site's written commitment. Users will further reduce dose rates around the HI-STAR 100 System by preferentially loading longer-cooled and lower-burnup spent fuel assemblies in the periphery fuel storage cells of the MPC, and loading assemblies with shorter cooling times and higher burnups in the inner MPC fuel storage cell locations as specified in the Technical Specifications. Users can also further reduce the dose rates around the HI-STAR 100 System by the use of temporary shielding. Temporary shielding is discussed in Section 10.1.4.

10.1.2 Design Considerations

Consistent with the design criteria defined in Section 2.3.5, the radiological protection criteria that limit exposure to radioactive effluents and direct radiation from an ISFSI using the HI-STAR 100 System are as follows:

1. 10CFR72.104 [10.0.1] requires that for normal operation and anticipated occurrences, the annual dose equivalent to any real individual located beyond the owner-controlled area boundary must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ. This dose would be a result of planned discharges, direct radiation from the ISFSI, and any other radiation from uranium fuel cycle operations in the area. The licensee is responsible for demonstrating site-specific compliance with these requirements.

2. 10CFR72.106 [10.0.1] requires that any individual located on or beyond the nearest owner-controlled area boundary must not receive a dose greater than 5 rem to the whole body or any organ from a design basis accident. The licensee is responsible for demonstrating site-specific compliance with this requirement.

3. 10CFR20 [10.1.1], Subparts C and D, limit occupational exposure and exposure to individual members of the public. The licensee is responsible for demonstrating site-specific compliance with this requirement.

4. Regulatory Position 2 of Regulatory Guide 8.8 [10.1.2] provides guidance regarding facility and equipment design features. This guidance has been followed in the design of the HI-STAR 100 System as described below:

   - Regulatory Position 2a, regarding access control, is met by locating the ISFSI in a Protected Area in accordance with 10CFR72.212(b)(5)(ii) [10.0.1]. Unauthorized access is prevented once a loaded HI-STAR 100 System is placed in an ISFSI. Due to the nature of the system, only limited monitoring for security is required, thus reducing occupational exposure and supporting ALARA considerations. The licensee is responsible for site-specific compliance with these criteria.

   - Regulatory Position 2b, regarding radiation shielding, is met by the overpack biological shielding that minimizes personnel exposure as described in Chapter 8. Fundamental design considerations that most directly influence occupational exposures with dry storage systems in general and which have been incorporated into the HI-STAR 100 System design include:

     – system designs that reduce or minimize the number of handling and transfer operations for each spent fuel assembly;

- system designs that reduce or minimize the number of handling and transfer operations for each MPC loading;
- system designs that maximize fuel capacity, thereby taking advantage of the self-shielding characteristics of the fuel and the reduction in the number of MPCs that must be loaded and handled;
- system designs that minimize decontamination requirements at ISFSI decommissioning;
- system designs that optimize the placement of shielding with respect to anticipated worker locations and fuel placement;
- thick-walled overpacks that provide gamma and neutron shielding;
- thick MPC lid which provides effective shielding for operators during MPC loading and unloading operations;
- multiple welded barriers to confine radionuclides;
- smooth surfaces to reduce decontamination time;
- minimization of potential crud traps on the handling equipment to reduce decontamination requirements;
- capability of maintaining water in the MPC and annulus during MPC welding to reduce dose rates;
- capability of maintaining water in the annulus space to reduce dose rates during closure operations;
- MPC penetrations located and configured to reduce streaming paths;
- overpack penetrations located and oriented to reduce streaming paths;
- MPC vent and drain ports with re-sealable caps to prevent the release of radionuclides during loading and unloading operations and facilitate draining, drying, and backfill operations;
- use of an annulus seal and annulus overpressure system to prevent contamination of the MPC shell outer surfaces during in-pool activities;
- available temporary and auxiliary shielding to reduce dose rates around the overpack; and
- low-maintenance design to reduce doses during storage operation.

• Regulatory Position 2c, regarding process instrumentation and controls, is met since there are no radiation instrumentation and controls needed at the ISFSI.

- Regulatory Position 2d, regarding control of airborne contaminants, is met since the HI-STAR 100 System is designed to withstand all design basis conditions without loss of confinement function, as described in Chapter 7 of this FSAR, and no gaseous releases are anticipated. No significant surface contamination is expected since the exterior of the MPC is kept clean by using clean water in the overpack-MPC annulus and by using an inflatable annulus seal and optional annulus overpressure system.

- Regulatory Position 2e, regarding crud control, is not applicable to a HI-STAR 100 System ISFSI since there are no radioactive systems at an ISFSI that could transport crud.

- Regulatory Position 2f, regarding decontamination, is met since the exterior of the loaded overpack is decontaminated prior to being removed from the plant's fuel building. The exterior surface of the overpack is designed for ease of decontamination. In addition, an inflatable annulus seal and optional annulus overpressure system is used to prevent fuel pool water from contacting and contaminating the exterior surface of the MPC.

- Regulatory Position 2g, regarding radiation monitoring systems, is met since the HI-STAR 100 System has been designed for redundant, multi-pass welded closures on the MPC; consequently, no monitoring of the confinement boundary is necessary and no gaseous or particulate releases occur for normal, off-normal or postulated accident conditions;

- Regulatory Position 2h, regarding resin treatment systems, is not applicable to an ISFSI since there are no treatment systems containing radioactive resins.

- Regulatory Position 2i, regarding other miscellaneous ALARA items, is met since stainless steel is used in the MPC shell, the primary confinement boundary. This material is resistant to the damaging effects of radiation and is well proven in cask use. Use of this material quantitatively reduces or eliminates the need to perform maintenance (or replacement) on the primary confinement system.

10.1.3 Operational Considerations

Operational considerations that most directly influence occupational exposures with dry storage systems in general and that have been incorporated into the design of the HI-STAR 100 System include:

- totally-passive design requiring minimal maintenance and monitoring (other than security monitoring) during storage;
- remotely operated welding system, lift yoke, weld removal system and Vacuum Drying System (VDS) to reduce time operators spend in the vicinity of the loaded MPC;
- maintaining water in the MPC and the annulus region during MPC closure activities to reduce dose rates;
- descriptive operating procedures that provide guidance to reduce equipment contamination, obtain survey information, minimize dose and alert workers to possible changing radiological conditions;
- preparation and inspection of the overpack in low-dose areas;
- MPC lid fit tests and inspections prior to actual loading to ensure smooth operation during loading;
- gas sampling of the MPC and HI-STAR 100 System annulus (receiving from transport) to assess the condition of the cladding and MPC confinement boundary prior to opening;
- fuel cool-down operations developed for fuel unloading operations which minimize thermal shock to the fuel and therefore reduce the potential for fuel cladding rupture;
- wetting of component surfaces prior to placement in the spent fuel pool to reduce the need for decontamination;
- decontamination practices which consider the effects of weeping during overpack heat up and surveying of the overpack prior to removal from the fuel handling building;

- incorporation of ALARA principles in operation, surveillance, and maintenance procedures;

- a sequence of operations based on ALARA considerations; and

- use of mock-ups to prepare personnel for actual work situations.

10.1.4 Auxiliary/Temporary Shielding

To minimize occupational and site boundary doses, the HI-STAR 100 System has optional auxiliary shielding available for use during loading, storage and unloading operations. The HI-STAR 100 System auxiliary shielding consists of the Automated Welding System Baseplate, the overpack temporary shield ring, the annulus shield, the overpack bottom cover, the pocket trunnion neutron shield plugs, and the overpack bottom ring shield. Each auxiliary shield is described in Table 10.1.1, and the procedures for utilization are provided in Chapter 8. Users shall evaluate the need for auxiliary and temporary shielding based on an ALARA review of each loading operation. For fuel assemblies with lower burnups and longer cooling times, the need for auxiliary and temporary shielding is reduced.

Table 10.1.1
HI-STAR 100 System AUXILIARY AND TEMPORARY SHIELDS

Temporary Shield	Description	Utilization
Automated Welding System Baseplate - See Figure 10.1.1	Thick gamma and neutron shield circular plate that sits on the MPC lid. Plate is set directly on the MPC lid. Threaded lift holes are provided to assist in rigging.	Used during MPC closure and unloading operations in the cask preparation area to reduce the dose rates around the MPC lid. The design of the closure ring allows the baseplate shield to remain in place during the entire closure operation.
Overpack Temporary Shield Ring - See Figure 10.1.2	A shield that fits on the cask neutron shield around the upper forging and provides supplemental shielding to personnel performing cask loading and closure operations.	Used during MPC and overpack closure operations to reduce dose rates to the operators around the top flange of the overpack.
Annulus Shield - See Figure 10.1.3	A shield that is seated between the MPC shell and the overpack.	Used during MPC closure operations to reduce streaming from the annulus.
Overpack Bottom Cover - See Figure 10.1.4	A cup-shaped gamma and neutron shield cover that is attached to the overpack bottom and secured using the impact limiter bolt holes.	Used during on-site horizontal transfer of the loaded overpack to reduce dose rates from the bottom of the overpack.
Overpack Bottom Ring - See Figure 10.1.5	A series of segmented, concrete rings that are placed under the neutron shield around the base of the overpack. The ring segments when positioned, form a complete ring around the overpack base. The rings are placed in position on the ISFSI pad and are not secured.	Used during storage of the overpacks on the ISFSI pad to reduce the dose rates around the base of the overpack.
Pocket Trunnion Neutron Shield Plugs – See Figure 10.1.6	A custom-fit stainless steel clad neutron shielding material that is inserted and bolted into the pocket trunnions.	Used during storage of the overpack on the ISFSI pad. Reduces the neutron dose rate around the pocket trunnions.

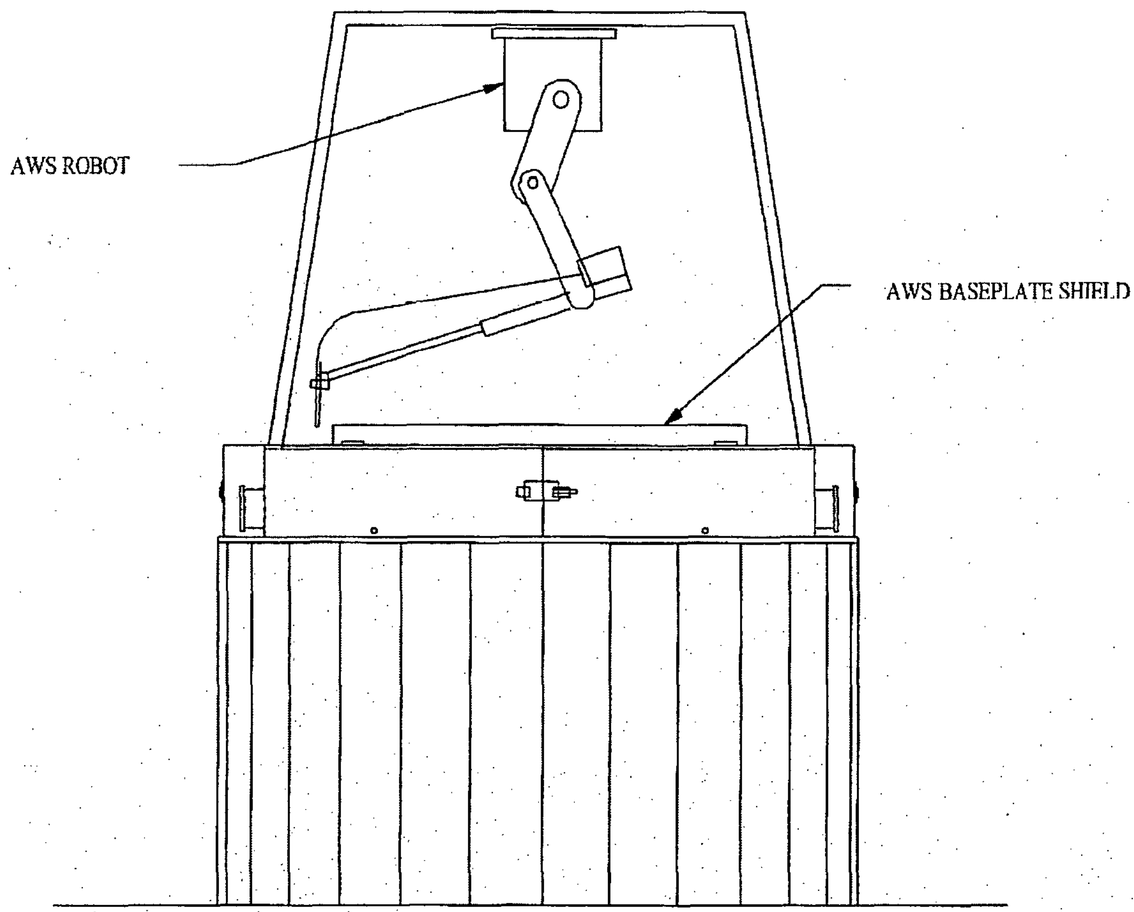


Figure 10.1.1; HI-STAR 100 Temporary Shielding – Automated Welding System Baseplate

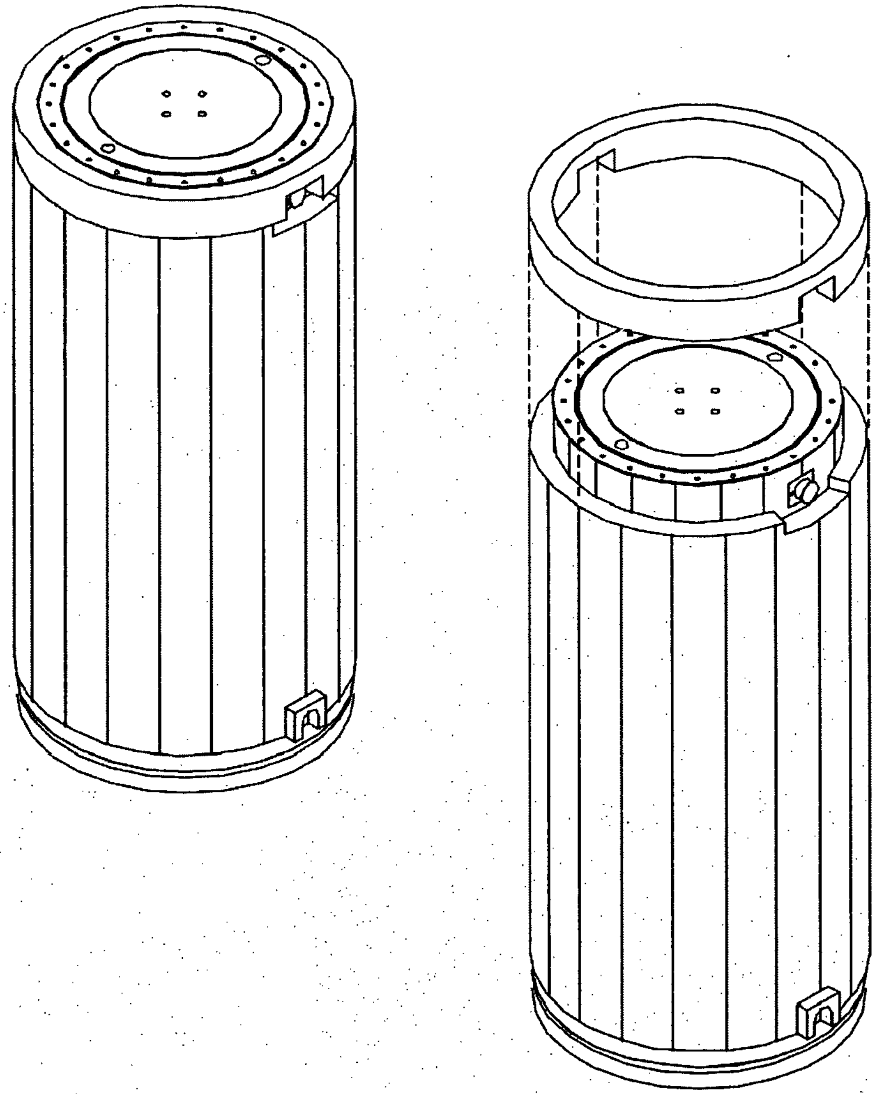


Figure 10.1.2; HI-STAR 100 Temporary Shielding - Temporary Shield Ring

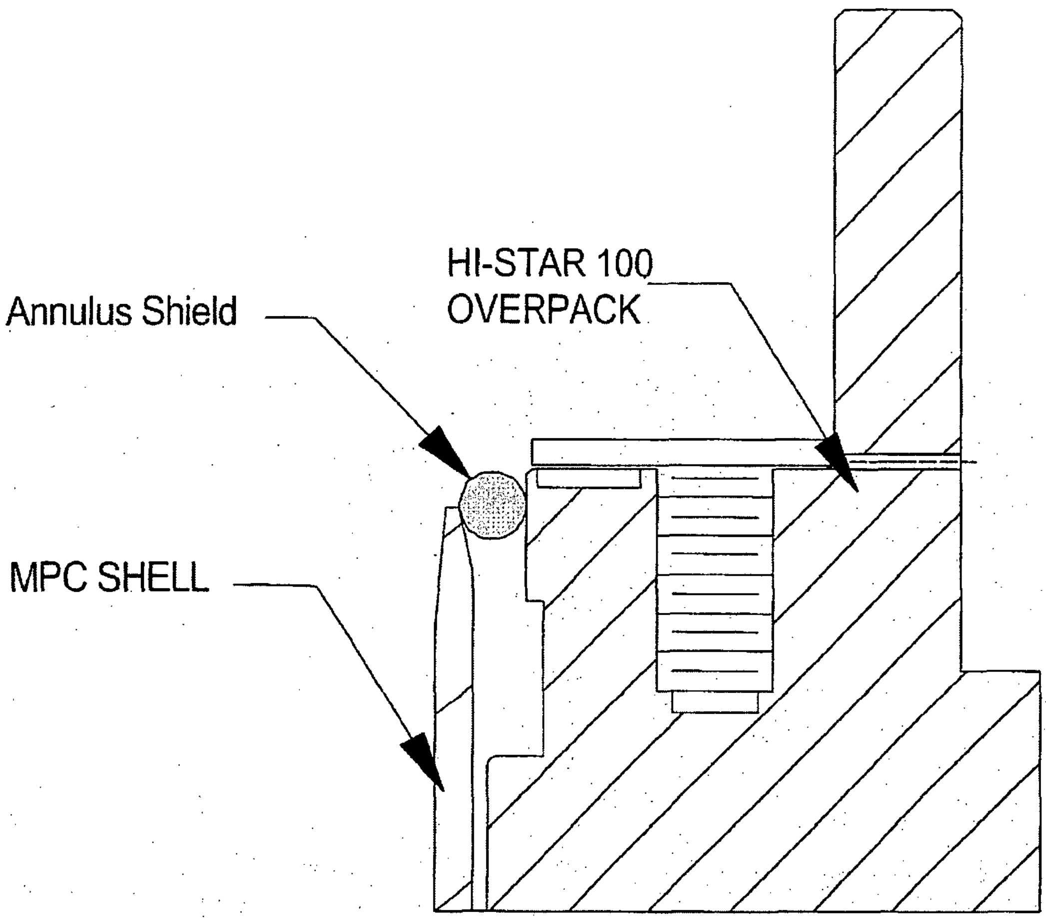


Figure 10.1.3; HI-STAR 100 Temporary Shielding – Annulus Shield

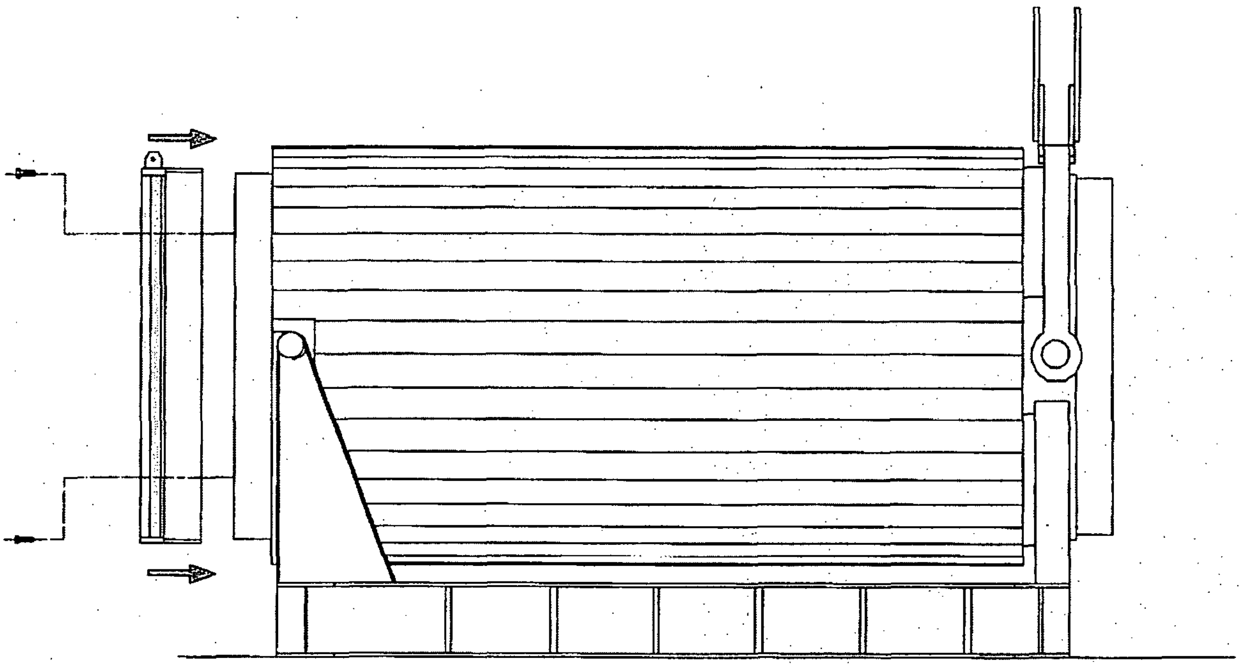


Figure 10.1.4; HI-STAR 100 Temporary Shielding – Overpack Bottom Cover

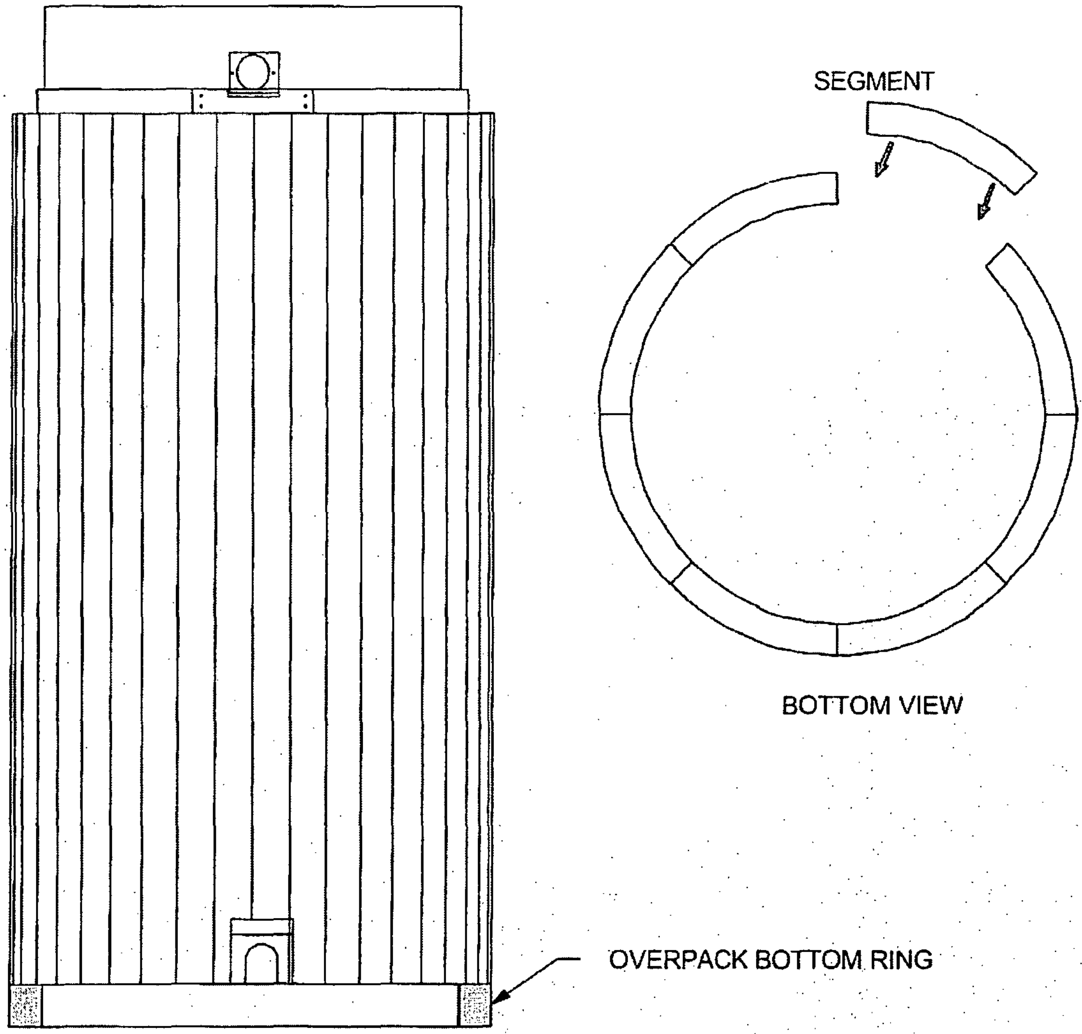


Figure 10.1.5; HI-STAR 100 Temporary Shielding – Overpack Bottom Ring

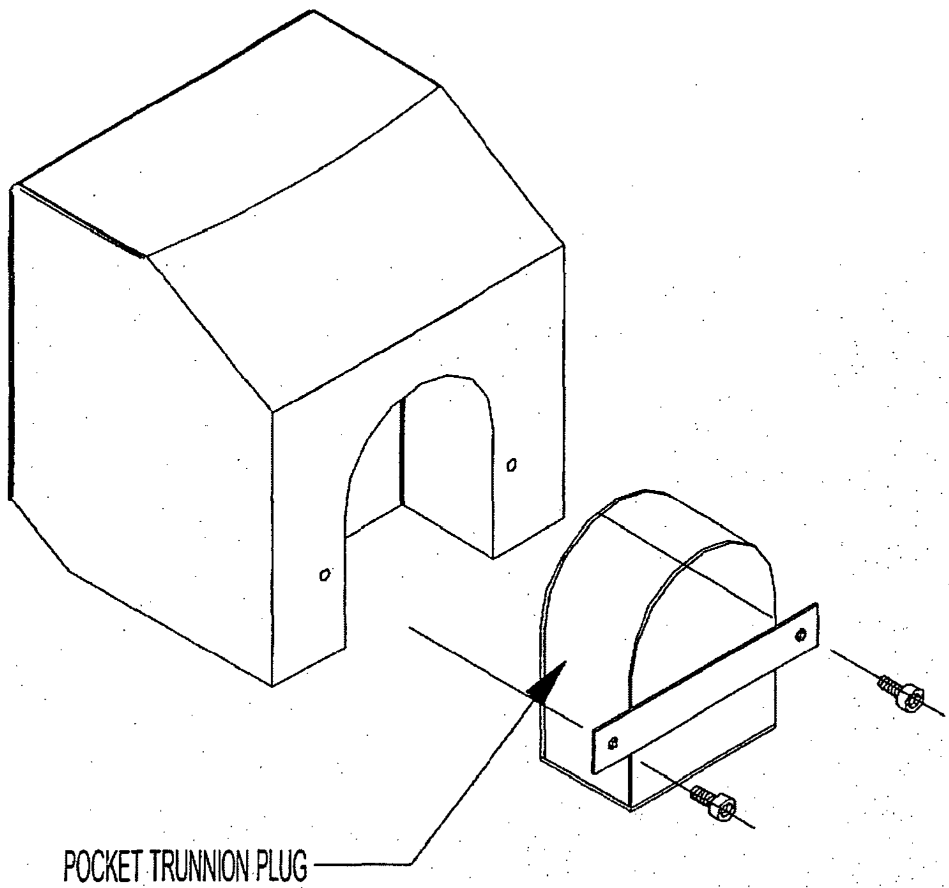


Figure 10.1.6; HI-STAR 100 Temporary Shielding – Pocket Trunnion Plugs

10.2 RADIATION PROTECTION DESIGN FEATURES

The development of the HI-STAR 100 System has focused on design provisions to address the considerations summarized in Sections 10.1.2 and 10.1.3. The following specific design features ensure a high degree of confinement integrity and radiation protection:

- HI-STAR 100 System has been designed to meet storage condition dose rates required by 10CFR72 [10.0.1] containing spent fuel assemblies cooled at least 5 years;

- HI-STAR 100 System has been designed to accommodate a maximum number of PWR or BWR fuel assemblies to minimize the number of cask systems that must be handled and stored at the storage facility and later transported off-site;

- HI-STAR 100 System is low maintenance because of the outer metal shell. The metal shell and its protective coating are extremely resistant to degradation;

- HI-STAR 100 System has been designed for redundant, multi-pass welded closures on the MPC; consequently, no monitoring of the confinement boundary is necessary and no gaseous or particulate releases occur for normal, off-normal or postulated accident conditions; and

- HI-STAR 100 System has auxiliary shielding devices which eliminate streaming paths and simplify operations.

10.3 ESTIMATED ON-SITE COLLECTIVE DOSE ASSESSMENT

This section provides the estimates of the cumulative exposure to personnel performing loading and unloading operations using the HI-STAR 100 System. This section uses the shielding analysis provided in Chapter 5 and the operations procedures provided in Chapter 8 to develop a dose rate assessment for loading and unloading operations. The dose rate assessments are provided in Table 10.3.1 and Table 10.3.2 for loading and unloading operations, respectively.

The dose rates on and around the HI-STAR 100 System overpack and MPC lid are estimated using an 18-inch, on-contact and 1-meter dose rates for the overpack during the loading and unloading operations. The dose rates around the overpack are based on 24 PWR fuel assemblies with a burnup of 40,000 MWD/MTU and cooling of 5 years. The selection of this fuel assembly type bounds all possible loading scenarios for the HI-STAR 100 System from a dose-rate perspective. No assessment is made with respect to radiation levels around the cask during operations where no fuel is in the MPC since radiation levels vary significantly by site and locations within. In addition, exposures are based on work being performed without the temporary shielding described in Section 10.1.4.

The dose rate location points around the overpack were selected to model actual worker locations. Cask operators typically work at an arms-reach distance from the cask. To account for this, either an 18-inch distance or a rough average of on-contact and 1-meter dose rates were used to roughly estimate the dose rate for the worker. This assessment takes credit for the actual number of workers directly working around the cask and the actual time spent in the vicinity of the cask. The duration times and number of workers are based on historical accounts of spent fuel canister loading operations at nuclear utilities, taking into account the proximity of controls and remote control features of the HI-STAR 100 ancillary equipment. For example, the Vacuum Drying System and Automated Welding System are remotely operated to minimize the amount of time the operators need to spend in direct contact with the cask. Typically, once the cask is configured for a specific task, the operators are free to exit the work area and continue operations from an ALARA low-dose area.

Table 10.3.1 provides a summary of the dose assessment for a HI-STAR 100 System loading operation. Table 10.3.2 provides a summary of the dose assessment for a HI-STAR 100 System unloading operation. Because of the various operational requirements for the different sites, a conservative approach on operations was used to assess the personnel exposures. The personnel requirements and anticipated duration of activities are based on previous utility canister loading experience and published data.

10.3.1 Estimated Exposures for Loading and Unloading Operations

The assumptions discussed above are conservative by design. Historically, actual occupational doses to load and place canister-based systems in storage are significantly lower than the projected values for those systems. The main factors attributed to the lower-than-projected personnel exposures are the age of the spent fuel, conservative assumptions in the dose estimates, and good ALARA practices. These same considerations are expected to factor into the actual operation of the HI-STAR 100 System. To estimate the dose received by a single worker, it should be understood that a canister-based system requires a diverse range of disciplines to perform all the necessary functions. Technical Specifications with time limits and control of utility restart conditions have prompted utilities to load canister systems in a round-the-clock mode. This results in the exposure being spread out over a team of operators and technicians with no single discipline receiving a majority of the exposure.

The dose rates provided in Tables 10.3.1 and 10.3.2 are conservatively based on fuel assemblies with 40,000 MWD/MTU and 5-year cooling which bounds the allowable burnup and cooling time combinations for the HI-STAR 100 System. The total person-rem exposure from operation of the HI-STAR 100 System is proportional to the number of systems loaded. A typical utility will load approximately four MPCs per reactor cycle to maintain the current available spent fuel pool capacity. Utilities requiring dry storage of spent fuel assemblies typically have a large inventory of spent fuel assemblies that date back to the reactor's first cycle. The older fuel assemblies will have a significantly lower dose rate than the design basis fuel assemblies. Users shall assess the cask loading for their particular fuel types (age, burnup, cooling time) to satisfy the requirements of 10CFR20 [10.1.1].

10.3.2 Estimated Exposures for Surveillance and Maintenance

Table 10.3.3 provides the maximum anticipated occupational exposure received from security surveillance and maintenance of an ISFSI. Although the HI-STAR 100 System requires minimal maintenance during storage, maintenance will be required around the ISFSI for items such as security equipment maintenance, grass cutting, snow removal, drainage system maintenance, and lighting, telephone, and intercom repair. Security surveillance time is based on a daily security patrol around the perimeter of the ISFSI security fence. Users may opt to utilize remote security viewing methods instead of performing direct visual observation of the ISFSI. Since security surveillances can be performed from outside the ISFSI, a dose rate of 4 mrem/hour is conservatively used. The estimated dose rates described below are based on a sample array of HI-STAR 100 Systems fully loaded with design basis fuel assemblies, placed at their minimum required pitch, in a 2 x 6 HI-STAR 100 System array. The maintenance worker is assumed to be at a distance of 5 meters from the center of the long edge of the array. For maintenance of the casks and the ISFSI, a dose rate of 50 mrem/hour is estimated.

Table 10.3.1
HI-STAR 100 SYSTEM LOADING OPERATIONS
ESTIMATED OPERATIONAL EXPOSURES (40,000MWD/MTU, 5-YEAR COOLED FUEL)

ACTIVITY	NUMBER OF WORKERS[†]	DURATION (HOURS)[††]	ESTIMATED DOSE RATE (MREM/HR)	OCCUPATIONAL DOSE TO INDIVIDUAL (PERSON-MREM)	ESTIMATED TOTAL DOSE FOR TASK (PERSON-MREM)
REMOVE HI-STAR CLOSURE PLATE	2	1	0	0	0
INSTALL EMPTY MPC	3	2	0	0	0
INSTALL UPPER FUEL SPACERS	3	4	0	0	0
INSTALL LOWER FUEL SPACERS	3	4	0	0	0
FILL MPC AND ANNULUS	2	4	0	0	0
INSTALL ANNULUS SEAL	1	0.3	0	0	0
PLACE HI-STAR IN SPENT FUEL POOL	3	1.2	5	6	18
LOAD FUEL ASSEMBLIES INTO MPC	3	11.3	5	56.5	170
PERFORM ASSEMBLY IDENTIFICATION VERIFICATION	3	1.5	5	7.5	22.5
INSTALL DRAIN LINE TO MPC LID	3	0.8	5	4	12
ALIGN MPC LID AND LIFT YOKE TO DRAIN LINE	2	0.2	5	1	2
INSTALL MPC LID	2	0.4	5	2	4
REMOVE HI-STAR FROM SPENT FUEL POOL	2	0.4	18.5	7.4	14.8
DECONTAMINATE HI-STAR BOTTOM	2	0.2	44	8.8	17.6
SET HI-STAR IN CASK PREPARATION AREA	2	0.5	20	10	20
MEASURE DOSE RATES AT MPC LID	1	0.2	18.5	3.7	3.7
DECONTAMINATE HI-STAR AND LIFT YOKE	3	0.7	20	14	42
INSTALL TEMPORARY SHIELD RING	2	0.3	22	6.6	13.2
REMOVE INFLATABLE ANNULUS SEAL	1	0.1	18.5	1.85	1.85

† Indicates number of workers in direct or close contact with HI-STAR 100.
†† Indicates actual duration of work in direct or close contact with HI-STAR 100.

Table 10.3.1 (Continued)
HI-STAR 100 SYSTEM LOADING OPERATIONS
ESTIMATED OPERATIONAL EXPOSURES (40,000MWD/MTU, 5-YEAR COOLED FUEL)

ACTIVITY	NUMBER OF WORKERS†	DURATION (HOURS)††	ESTIMATED DOSE RATE (MREM/HR)	OCCUPATIONAL DOSE TO INDIVIDUAL (PERSON-MREM)	ESTIMATED TOTAL DOSE FOR TASK (PERSON-MREM)
LOWER ANNULUS WATER LEVEL SLIGHTLY	1	0.2	18.5	3.7	3.7
SMEAR MPC LID TOP SURFACES	1	0.2	18.5	3.7	3.7
INSTALL ANNULUS SHIELD	1	0.1	18.5	1.85	1.85
LOWER MPC WATER LEVEL	2	0.5	18.5	9.25	18.5
WELD MPC LID & Perform NDE	2	1.2	18.5	22.2	44.4
PERFORM . VOL EXAM OF MPC WELD	2	0.3	18.5	5.55	11.1
RAISE MPC WATER LEVEL	2	0.1	18.5	1.85	3.7
PERFORM HYDRO TEST ON MPC	2	0.3	18.5	5.55	11.1
PERFORM LEAKAGE TESTING	2	0.5	18.5	9.25	18.5
DRAIN MPC	1	0.7	77	53.9	53.9
MEASURE VOLUME OF WATER DRAINED	1	0.1	77	7.7	7.7
VACUUM DRY MPC	1	0.3	77	23.1	23.1
PERFORM MPC DRYNESS VERIFICATION TEST	2	0.1	77	7.7	15.4
BACKFILL MPC	2	0.2	77	15.4	30.8
WELD VENT AND DRAIN PORT COVER PLATES	1	0.2	77	15.4	15.4
PERFORM A LIQUID PENETRANT EXAMINATION	2	0.3	77	23.1	46.2
PERFORM LEAKAGE TEST ON COVER PLATES	2	0.2	77	15.4	30.8

† Indicates number of workers in direct or close contact with HI-STAR 100.
†† Indicates actual duration of work in direct or close contact with HI-STAR 100.

Table 10.3.1 (Continued)
HI-STAR 100 SYSTEM LOADING OPERATIONS
ESTIMATED OPERATIONAL EXPOSURES (40,000MWD/MTU, 5-YEAR COOLED FUEL)

ACTIVITY	NUMBER OF WORKERS†	DURATION (HOURS)††	ESTIMATED DOSE RATE (MREM/HR)	OCCUPATIONAL DOSE TO INDIVIDUAL (PERSON-MREM)	ESTIMATED TOTAL DOSE FOR TASK (PERSON-MREM)
WELD MPC CLOSURE RING	1	0.4	77	30.8	30.8
PERFORM NDE ON CLOSURE RING WELDS	2	0.3	77	23.1	46.2
DRAIN ANNULUS	1	0.2	185	37	37
PERFORM SURVEYS ON HI-STAR	1	0.2	85	17	17
REMOVE ANNULUS SHIELD	1	0.1	77	7.7	7.7
INSTALL HI-STAR CLOSURE PLATE	3	1.5	17.6	26.4	79.2
VACUUM DRY HI-STAR ANNULUS	1	0.2	17.6	3.52	3.52
BACKFILL HI-STAR ANNULUS	1	0.2	17.6	3.52	3.52
LEAKTEST HI-STAR ANNULUS	2	0.5	73.4	36.7	73.4
REMOVE TEMPORARY SHIELD RING	2	0.2	93	18.6	37.2
PERFORM FINAL SURVEYS ON HI-STAR	1	0.2	85	17	17
PLACE HI-STAR IN STORAGE	2	1.3	85	110.5	221
INSTALL HI-STAR POCKET TRUNNION PLUGS	1	0.2	185	37	37
INSTALL BOTTOM SHIELD RING	2	0.2	185	37	74
TOTAL					1365.9

† Indicates number of workers in direct or close contact with HI-STAR 100.
†† Indicates actual duration of work in direct or close contact with HI-STAR 100.

Table 10.3.2
HI-STAR 100 SYSTEM UNLOADING OPERATIONS
ESTIMATED OPERATIONAL EXPOSURES (40,000MWD/MTU, 5-YEAR COOLED FUEL)

ACTIVITY	NUMBER OF WORKERS*	DURATION (HOURS)**	ESTIMATED DOSE RATE (MREM/HR)	OCCUPATIONAL DOSE TO INDIVIDUAL (PERSON-MREM)	ESTIMATED TOTAL DOSE FOR TASK (PERSON-MREM)
REMOVE BOTTOM SHIELD RING	2	0.2	185	37	74
REMOVE HI-STAR POCKET TRUNNION PLUGS	1	0.2	185	37	37
RECOVER HI-STAR FROM STORAGE	2	1.3	85	110.5	221
PLACE HI-STAR IN DESIGNATED PREPARATION AREA	2	0.6	85	51	102
SAMPLE ANNULUS GAS	2	0.3	18	5.4	10.8
REMOVE HI-STAR CLOSURE PLATE	2	1	77	77	154
FILL ANNULUS	1	0.2	77	15.4	15.4
INSTALL ANNULUS SHIELD	1	0.1	77	7.7	7.7
REMOVE MPC CLOSURE RING	1	0.4	77	30.8	30.8
REMOVE VENT PORT COVERPLATE WELD AND SAMPLE MPC GAS	1	0.4	77	30.8	30.8
PERFORM MPC COOL-DOWN	1	0.2	77	15.4	15.4
FILL MPC CAVITY WITH WATER	1	0.7	77	53.9	53.9
REMOVE MPC LID TO SHELL WELD	1	0.7	18	12.6	12.6
INSTALL INFLATABLE SEAL	1	0.1	18	1.8	1.8
PLACE HI-STAR IN SPENT FUEL POOL	2	0.4	20	8	16
REMOVE MPC LID	2	0.4	5	2	4
REMOVE SPENT FUEL ASSEMBLIES FROM MPC	3	11.3	5	56.5	113

* Indicates number of workers in direct or close contact with HI-STAR 100.
** Indicates actual duration of work in direct or close contact with HI-STAR 100.

Table 10.3.2 (Continued)
HI-STAR 100 SYSTEM UNLOADING OPERATIONS
ESTIMATED OPERATIONAL EXPOSURES (40,000MWD/MTU, 5-YEAR COOLED FUEL)

ACTIVITY	NUMBER OF WORKERS[†]	DURATION (HOURS)[††]	ESTIMATED DOSE RATE (MREM/HR)	OCCUPATIONAL DOSE TO INDIVIDUAL (PERSON-MREM)	ESTIMATED TOTAL DOSE FOR TASK (PERSON-MREM)
VACUUM CELLS OF MPC	2	1.5	5	7.5	15
REMOVE HI-STAR FROM SPENT FUEL POOL	3	1.2	5	6	18
LOWER WATER LEVEL IN MPC	1	0.2	5	1	1
PUMP REMAINING WATER IN MPC TO SPENT FUEL POOL	1	2	0	0	0
REMOVE MPC FROM HI-STAR	2	1	0	0	0
DECONTAMINATE MPC AND HI-STAR	3	2	0	0	0
TOTAL					934.2

† Indicates number of workers in direct or close contact with HI-STAR 100.
†† Indicates actual duration of work in direct or close contact with HI-STAR 100.

Table 10.3.3
ESTIMATED EXPOSURES FOR HI-STAR 100 SYSTEM SURVEILLANCE AND MAINTENANCE
(40,000MWD/MTU, 5-YEAR COOLED FUEL)

ACTIVITY	ESTIMATED PERSONNEL	ESTIMATED HOURS PER YEAR	ESTIMATED DOSE RATE (MREM/HR)	OCCUPATIONAL DOSE TO INDIVIDUAL (PERSON-MREM)	ESTIMATED TOTAL DOSE FOR TASK (PERSON-MREM)
SECURITY SURVEILLANCE	1	30	4	120	120
ANNUAL MAINTENANCE	2	15	50	750	1500

10.4 ESTIMATED COLLECTIVE DOSE ASSESSMENT

10.4.1 Controlled Area Boundary Dose for Normal Operations

10CFR72.104 [10.0.1] limits the annual dose to any real individual at the controlled area boundary to a maximum of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem for any other organ. This includes contributions from all uranium fuel cycle operations in the region.

It is not feasible to predict bounding controlled area boundary dose rates on a generic basis since radiation from plant and other sources; the location and the layout of an ISFSI; and the number and configuration of casks are necessarily site-specific. In order to compare the performance of the HI-STAR 100 System with the regulatory requirements, sample ISFSI arrays were analyzed in Chapter 5. These represent a full array of design basis fuel assemblies. Users are required to perform a site specific dose analysis for their particular situation in accordance with 10CFR72.212 [10.0.1]. The analysis must account for the ISFSI (size, configuration, fuel assembly specifics) and any other radiation from uranium fuel cycle operations within the region. Table 5.1.7 presents dose rates at various distance from sample ISFSI arrays for the design basis burnup and cooling time which results in the highest off-site dose for the combination of maximum burnup and minimum cooling times analyzed in Chapter 5. 10CFR72.106 [10.0.1] specifies that the minimum distance from the ISFSI to the controlled area boundary is 100 meters. Therefore this was the minimum distance analyzed in Chapter 5. As a summary of Chapter 5, Table 10.4.1 presents the annual dose results for a single cask at 100, 251, and 300 meters and a 2x5 array of HI-STAR 100 systems at 400 meters. These annual doses are based on a full array of design basis fuel with a burnup of 40,000 MWD/MTU and 5-year cooling. This burnup and cooling time combination conservatively bounds the allowable burnup and cooling times listed in the Technical Specifications. In addition, 100% occupancy (8760 hours) is conservatively assumed. In the calculation of the annual dose, a cask-to-cask pitch of 12 feet was assumed and the casks were positioned on an infinite slab of concrete to account for earth-shine effects. These results indicate that the calculated annual dose is less than the regulatory limit of 25 mrem/year at a distance of 300 meters for a single cask and at 400 meters for a 2x5 array of HI-STAR 100 Systems containing design basis fuel. The calculated annual dose is 25 mrem at 251 meters. These results are presented only as an illustration to demonstrate that the HI-STAR 100 System is in compliance with 10CFR72.104[10.0.1]. Neither the distances nor the array configurations become part of the Technical Specifications. Rather, users are required to perform a site specific analyses to demonstrate compliance with 10CFR72.104[10.0.1] contributors and 10CFR20[10.1.1]. A minor contributor to the minimum controlled area boundary is the normal storage condition leakage from the seal welded MPC. Although, leakage is not expected, Section 7.2 provides an analysis for the annual dose based on a continuous leak from the MPC equal to the tested leakage rate plus the minimum test sensitivity. The annual dose to an individual at the minimum controlled area boundary was computed to be 0.1 mrem to the whole body and less than 0.02 mrem to the thyroid for the worst case MPC. The site licensee is required to perform a site-specific dose evaluation of all dose contributors as part of the ISFSI design as dictated in Chapter 12. This evaluation will account for the location of the controlled area boundary and the effects of the radiation from uranium fuel cycle operations within the region.

10.4.2 Controlled Area Boundary Dose for Accident Conditions

10CFR72.106 [10.0.1] specifies that the maximum dose to any individual at the controlled area boundary can not exceed 5 rem to the whole body or any organ from any design basis accident. In addition, it is specified that the minimum distance from the ISFSI to the controlled area boundary be at least 100 meters.

Chapter 7 demonstrates that the resultant doses for a non-mechanistic postulated breach of the MPC confinement boundary at the regulatory minimum site boundary distance of 100 meters are less than 2.1 rem for an occupancy factor of 1 year (8760 hours). This clearly demonstrates that the HI-STAR 100 System is in full compliance with the regulatory limit of 5 rem specified in 10CFR72.106 [10.0.1] for the whole body or any organ.

Chapter 11 presents the results of the evaluations performed to demonstrate that the HI-STAR 100 System can withstand the effects of all credible accident conditions and natural phenomena without the corresponding radiation doses exceeding the requirements of 10CFR72.106 [10.0.1]. The accident events addressed in Chapter 11 include: HI-STAR 100 handling accident, tip-over, fire, tornado, flood, earthquake, 100 percent fuel rod rupture, confinement boundary leakage, explosion, lightning, burial under debris, and extreme environmental temperature. The worst-case shielding consequence of the accidents evaluated in Chapter 11 assumes that as a result of a fire, the neutron shield is completely destroyed and replaced by a void. The neutron shield is assumed to be completely lost, whereas some portion of the neutron shield would be expected to remain, as the neutron shield material is fire retardant. The shielding analysis of the HI-STAR 100 System with complete loss of the neutron shield is discussed in Section 5.1.2. The results in that section, show that the resultant dose rate at the 100-meter controlled area boundary would be less than 5 mrem/hr for a single HI-STAR 100 during the accident condition. At this level, it would take more than 1000 hours (41 days) for the dose at the controlled area boundary to reach 5 rem. This length of time greatly exceeds the time necessary to implement and complete the corrective actions outlined in Chapter 11. Therefore, the dose requirement of 10CFR72.106 [10.0.1] is satisfied.

Table 10.4.1
ANNUAL DOSE FOR ARRAYS OF HI-STAR 100
WITH DESIGN BASIS ZIRCALOY CLAD FUEL
40,000 MWD/MTU AND 5-YEAR COOLING

Array Configuration	1 Cask	1 Cask	1 Cask	2x5 Array
Annual Dose (mrem/year)†	345.00	25.00	13.55	23.06
Distance to Controlled Area Boundary (meters)††, †††	100	251	300	400

† 100% occupancy is assumed.

†† Dose location is at the center of the long side of the array.

††† Actual controlled area boundary dose rates will be lower because the maximum permissible burnup for 5-year cooling as specified in the Technical Specifications is lower than the burnup analyzed for the design basis fuel used in this table.

10.5 REGULATORY COMPLIANCE

The HI-STAR 100 System provides radiation shielding and confinement features that are sufficient to meet the requirements of 10CFR72.104 and 10CFR72.106 [10.0.1].

Occupational radiation exposures satisfy the limits of 10CFR20 [10.1.1] and meet the objective of maintaining exposures ALARA.

The design of the HI-STAR 100 System is in compliance with 10CFR72 [10.0.1] and applicable design and acceptance criteria have been satisfied. The radiation protection system design provides reasonable assurance that the HI-STAR 100 System will allow safe storage of spent fuel.

10.6 REFERENCES

[10.0.1] *U.S. Code of Federal Regulations*, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," Part 72, "*Energy*."

[10.0.2] U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems", NUREG-1536, Final Report, January 1997.

[10.1.1] *U.S. Code of Federal Regulations*, "Standards for protection Against Radiation," Part 20, "*Energy*."

[10.1.2] U.S. Nuclear Regulatory Commission "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power at Nuclear Power Stations will be As Low As Reasonably Achievable", Regulatory Guide 8.8, June 1978.

[10.1.3] U.S. Nuclear Regulatory Commission, "Operating Philosophy for Maintaining Occupational Radiation Exposures As low As is Reasonably Achievable", Regulatory Guide 8.10, Revision 1-R, May 1997.

CHAPTER 11: ACCIDENT ANALYSIS

This chapter presents the evaluation of the HI-STAR 100 System for the effects of off-normal and postulated accident conditions. The design basis off-normal and postulated accident events, including those resulting from mechanistic and non-mechanistic causes as well as those caused by natural phenomena, are identified in Sections 2.2.2 and 2.2.3. For each postulated event, the event cause, means of detection, consequences, and corrective action are discussed and evaluated. As applicable, the evaluation of consequences includes structural, thermal, shielding, criticality, confinement, and radiation protection evaluations for the effects of each design event.

The structural, thermal, shielding, criticality, and confinement features and performance of the HI-STAR 100 System are discussed in Chapters 3, 4, 5, 6, and 7, respectively. The evaluations provided in this chapter are based on the design features and evaluations described therein.

Chapter 11 is in full compliance with NUREG-1536; no exceptions are taken.

11.1 OFF-NORMAL OPERATIONS

During normal storage operations of the HI-STAR 100 System it is possible that an off-normal situation could occur. Off-normal operations, as defined in accordance with ANSI/ANS-57.9, are those conditions which, although not occurring regularly, are expected to occur no more than once a year. In this section, design events pertaining to off-normal operation for expected operational occurrences are considered.

The following off-normal operation events have been considered in the design of the HI-STAR 100, as listed in Subsection 2.2.2:

- Off-Normal Pressures
- Off-Normal Environmental Temperatures
- Leakage of One MPC Seal Weld

For each event, the postulated cause of the event, detection of the event, analysis of the event effects and consequences, corrective actions, and radiological impact from the event are presented.

The results of the evaluations performed herein demonstrate that the HI-STAR 100 System can withstand the effects of off-normal events without affecting the design function, and are in compliance with the applicable acceptance criteria. The section demonstrates that no instruments or controls are required to remain operational under all credible off-normal conditions. The following sections present the evaluation of the HI-STAR 100 System for the design basis off-normal conditions which demonstrate that the requirements of 10CFR72.122 are satisfied, and that the corresponding radiation doses satisfy the requirements of 10CFR72.106(b) and 10CFR20.

The structural load combinations evaluated for off-normal conditions are defined in Table 2.2.14. The load combinations include both normal and off-normal loads. The off-normal load combination evaluations are discussed in Section 11.1.4.

11.1.1 Off-Normal Pressures

There are three pressure regions in the HI-STAR 100 System and they are the MPC internal, the MPC external/overpack internal, and the overpack external pressure regions. Off-normal pressure at these three locations is evaluated at the point at which they act. The MPC internal pressure effects the MPC internal cavity. The MPC external/overpack internal pressure effects the MPC exterior and the overpack internal cavity. The overpack external pressure effects the exterior of the overpack.

11.1.1.1 Postulated Cause of Off-Normal Pressure

The off-normal pressure for the MPC internal cavity is a function of the initial helium fill pressure and the temperature obtained with maximum decay heat load design basis fuel. The maximum off-normal environmental temperature is 100°F with full solar insolation. The MPC internal pressure is further increased by the conservative assumption that 10% of the fuel rods rupture, 100% of the fill gas, and fission gases per NUREG-1536 are released to the cavity.

There is no cause or postulated cause for an off-normal MPC external/overpack internal pressure. There is no cause or postulated cause for off-normal overpack external pressure. Therefore, no off-normal overpack external pressure or off-normal MPC external/overpack internal pressure is evaluated.

11.1.1.2 Detection of Off-Normal Pressure

The HI-STAR 100 System is designed to withstand the MPC off-normal pressure without any effects on its ability to meet its safety requirements. There is no requirement for detection of off-normal pressure in the MPC.

11.1.1.3 Analysis of Effects and Consequences of Off-Normal Pressure

Chapter 4 calculates the MPC internal pressure with an ambient temperature of 80°F, 10% fuel rods ruptured, full insolation, and maximum decay heat and reports the maximum value of 60.2 psig in Table 4.4.15 at an average calculated MPC cavity temperature of 499.2°K. Using this pressure, the off-normal temperature of 100°F (ΔT of 20°F or 11.1°K), and the ideal gas law, the off-normal resultant pressure is calculated to be below the normal condition MPC internal design pressure, as follows:

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{(60.2\,psig + 14.7)(499.2°K + 11.1°K)}{499.2°K}$$

$$P_2 = 76.6\,psia \text{ or } 61.9\,psig$$

The normal condition MPC internal pressure of 100 psig (Table 2.2.1) has been established to bound the off-normal condition. Therefore, no additional analysis is required. The normal condition design pressure, which is equal to the off-normal design pressure, is analyzed in Chapter 3 for Load Case E1. The results in Chapter 3 show that the stress values are below the normal condition allowables.

Structural

The structural evaluation of the MPC enclosure vessel for off-normal design internal pressure conditions is equivalent to the evaluation at normal design internal pressures, since the normal design pressure was set at a value which would encompass the off-normal condition. Therefore, the resulting stresses from the off-normal design condition are equivalent to that of the normal design condition and are well within the allowable stress limits, as discussed in Section 3.4.

Thermal

The MPC internal pressure for off-normal conditions is calculated as presented above. As can be seen from the value calculated above, the 100 psig design basis internal pressure for off-normal conditions used in the structural evaluation bounds the calculated value.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the off-normal pressure does not affect the safe operation of the HI-STAR 100 System.

11.1.1.4 Corrective Action for Off-Normal Pressure

The HI-STAR 100 System is designed to withstand the off-normal pressure without any effects on its ability to maintain safe storage conditions. There is no corrective action requirement for off-normal pressure.

11.1.1.5 Radiological Impact of Off-Normal Pressure

The event of off-normal pressure has no radiological impact because the confinement barrier and shielding integrity are not affected.

11.1.2 Off-Normal Environmental Temperatures

The HI-STAR 100 System is designed for use at any site in the contiguous United States. Off-normal environmental temperature extremes of -40 and 100 degrees F have been conservatively selected to bound off-normal temperatures at these sites. The off-normal temperature range affects the entire HI-STAR 100 System and must be evaluated against the allowable component design temperatures. This off-normal event is of a short duration and therefore, the resultant temperatures are evaluated against the accident condition temperature limits as listed in Table 2.2.3.

11.1.2.1 Postulated Cause of Off-Normal Environmental Temperatures

The off-normal environmental temperature is postulated as a constant ambient temperature caused by extreme weather conditions. To determine the effects of the off-normal temperatures, it is conservatively assumed that these temperatures persist for a sufficient duration to allow the HI-STAR 100 System to achieve thermal equilibrium. Because of the large mass of the HI-STAR 100 System with its corresponding large thermal inertia and the limited duration for the off-normal temperatures, this assumption is conservative.

11.1.2.2 Detection of Off-Normal Environmental Temperatures

The HI-STAR 100 System is designed to withstand the off-normal environmental temperatures without any effects on its ability to maintain safe storage conditions. There is no requirement for detection of off-normal environmental temperatures.

11.1.2.3 Analysis of Effects and Consequences of Off-Normal Environmental Temperatures

The off-normal event considering an environmental temperature of 100°F for a duration sufficient to reach thermal equilibrium is evaluated with respect to design temperatures listed in Table 2.2.3. The evaluation is performed with design basis fuel with the maximum decay heat and the most restrictive thermal resistance. The 100°F environmental temperature is applied with full solar insolation.

The HI-STAR 100 System maximum temperatures for components close to the design basis temperatures are listed in Tables 4.4.9 through 4.4.11. These temperatures are conservatively calculated at an environmental temperature of 80°F. The maximum off-normal environmental temperature is 100°F, which is an increase of 20°F. The bounding off-normal temperatures are calculated by adding 20°F to the maximum normal temperatures from the highest component

temperature from the MPC-68 or MPC-24. Table 11.1.1 lists the maximum off-normal temperatures. As illustrated by the table, all the maximum off-normal temperatures are well below the accident condition design basis temperatures. The off-normal environmental temperature is of a short duration (several consecutive days would be highly unlikely) and, therefore, the resultant temperatures are evaluated against short-term accident condition temperature limits. Under these conditions, the HI-STAR 100 System maximum off-normal temperatures meet the design requirements specified in Table 2.2.3.

In addition, the off-normal environmental temperature generates a pressure which is evaluated in Section 11.1.1. The off-normal MPC cavity pressure is less than the design basis normal/off-normal pressures listed in Table 2.2.1.

The off-normal event considering an environmental temperature of -40°F, no decay heat, and no solar insolation for a duration sufficient to reach thermal equilibrium is evaluated with respect to material design temperatures. The HI-STAR 100 System is conservatively assumed to reach -40°F throughout the structure. All structural analysis is performed at the material design basis temperature, which is set higher than the component would experience with the design basis heat load under normal conditions. Assuming the HI-STAR 100 System is -40°F would only serve to increase the safety margins as the material strength increases with decreasing temperatures. Subsection 3.1.2.3 details the structural analysis performed to evaluate brittle fracture at the lowest service temperature. Subsection 3.4.5 provides a structural evaluation of the effects of an environmental temperature of -40°F and demonstrates that there is no reduction in the performance of the HI-STAR 100 System. Based on this evaluation, it is concluded that the off-normal environmental temperatures do not affect the safe operation of the HI-STAR 100 System.

Structural

The effect on the MPC for the maximum off-normal temperature condition is an increase in the internal pressure. As shown in Section 11.1.1.3, the resultant pressure is well below the normal/off-normal design pressure of 100 psig used in the structural analysis. The effect of the minimum off-normal temperature conditions results in an evaluation of the potential for brittle fracture which is discussed in Section 3.1.2.3.

Thermal

The resulting off-normal system and fuel assembly cladding temperatures for the hot conditions are provided in Table 11.1.1. As can be seen from this table, all temperatures for off-normal conditions are within the short-term allowable values described in Table 2.2.3.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal environmental temperatures do not affect the safe operation of the HI-STAR 100 System.

11.1.2.4 Corrective Action for Off-Normal Environmental Temperatures

The HI-STAR 100 System is designed to withstand the off-normal environmental temperatures without any effects on its ability to maintain safe storage conditions. There are no corrective actions required for off-normal environmental temperatures.

11.1.2.5 Radiological Impact of Off-Normal Environmental Temperatures

Off-normal environmental temperatures have no radiological impact as the confinement barrier and shielding integrity are not affected.

11.1.3 Leakage of One Seal

The HI-STAR 100 System has multiple boundaries to contain radioactive fission products within the confinement boundary and the helium atmosphere within the helium retention boundary (overpack internal cavity). The radioactive material confinement boundary is defined by the MPC shell, baseplate, MPC lid, and vent and drain cover plates. The closure ring provides a redundant welded closure to prevent the release of radioactive material from the MPC cavity. Confinement boundary welds, including the MPC lid-to-shell weld, are inspected by radiography or ultrasonic examination except for field welds on the closure ring and vent/drain port cover plates. The closure ring and vent/drain port cover plates are examined by the liquid penetrant method on the root (for multi-pass welds) and final pass. The welds on the MPC lid, vent and drain port covers are leakage tested. The MPC is also hydrostatically tested.

An additional redundant boundary to the release of radioactive materials is provided by the overpack helium retention boundary which is formed by the overpack bottom plate, inner shell, top flange, closure plate, closure plate bolts, inner metallic seal, and port plugs/seals. The overpack helium retention boundary welds are inspected by radiography. Vent and drain ports penetrate the helium retention boundary and are sealed by a port plug with a metallic seal. The closure plate inner seal, and the vent and drain port plug seals are helium leak tested following each loading.

The MPC lid-to-MPC shell weld is postulated to fail to confirm the safety of the HI-STAR 100 confinement boundary. The failure of the MPC lid weld is equivalent to the MPC drain or vent port cover weld failing. The MPC lid-to-shell weld has been chosen because it is the main closure weld for the MPC. It is extremely unlikely that the volumetric (or multi-layer liquid penetrant) inspection and helium leak test would fail to detect a poor welded seal. The MPC lid weld failure affects the MPC confinement boundary; however, no leakage will occur.

11.1.3.1 Postulated Cause of Leakage of One Seal in the Confinement Boundary

Failure of the MPC confinement boundary is highly unlikely. The MPC confinement boundary is shown to withstand all normal, off-normal, and accident conditions. There are no credible conditions which could damage the integrity of the MPC confinement boundary. The weld between the MPC lid and MPC shell is liquid penetrant inspected on the root and final pass, volumetrically (or multi-layer PT) examined, hydrostatically tested, and helium leak tested. The initial integrity of the closure welds will be maintained throughout the design life because the MPC is stored within an inert atmosphere within the overpack. Failure of the MPC lid weld would require all of the following:

1. Improper weld by a qualified welding machine or welder using approved welding procedures.

2. Failure to detect the unacceptable indication during the liquid penetrant inspections performed by a qualified inspector in accordance with approved procedures.

3. Failure to detect the unacceptable indication during the volumetric inspections performed by a qualified inspector in accordance with approved procedures.

4. Failure to detect the unacceptable leak during the hydrostatic test performed by qualified personnel in accordance with approved procedures.

5. Failure of the qualified leakage test equipment and personnel to detect the leak in accordance with approved procedures.

The evaluation of the failure of the MPC lid weld has been postulated to demonstrate the safety of the HI-STAR 100 confinement system and cannot be derived from a credible loading condition.

11.1.3.2 Detection of Leakage of One Seal in the Confinement Boundary

The HI-STAR 100 System is designed to withstand the leakage of any single field weld in the confinement boundary without any effects on its ability to meet its safety requirements. There is no requirement for detection of leakage of one seal and no means are provided to detect leakage.

11.1.3.3 Analysis of Effects and Consequences of Leakage of One Seal in the Confinement Boundary

If the MPC lid seal weld were to fail, the MPC closure ring would retain the design pressure. The analysis of the MPC closure ring's ability to retain the design pressure is provided in Appendix 3.E. The consequences of the MPC lid seal weld failure are that the MPC closure ring maintains the integrity of the confinement boundary.

Structural

The stress evaluation of the closure ring is discussed in Appendix 3.E. All stresses are within the allowable values.

Thermal

There is no effect on the thermal performance of the system as a result of this off-normal event.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal leakage of one seal event does not affect the safe operation of the HI-STAR 100 System.

11.1.3.4 Corrective Action for Leakage of One Seal in the Confinement Boundary

There is no corrective action required for the leakage of one seal in the confinement boundary. Leakage of one seal in the confinement boundary does not affect the HI-STAR 100 System's ability to operate safely.

11.1.3.5 Radiological Impact of Leakage of One Seal in the Confinement Boundary

The off-normal event of leakage of one seal in the confinement boundary has no radiological impact because the confinement barrier is not breached and shielding is not affected.

11.1.4 Off-normal Load Combinations

Structural load combinations for off-normal conditions are provided in Table 2.2.14. The load combinations include normal loads with the off-normal loads. The load combination results are shown in Section 3.4 to meet all allowable values.

Table 11.1.1

MAXIMUM TEMPERATURES CAUSED BY OFF-NORMAL ENVIRONMENTAL TEMPERATURES [°F]

Temperature Location	Normal	Calculated Off-Normal	Design Basis Limits (short-term)
Fuel cladding	741† (5-yr cooling)	761 (5-yr cooling)	1058 short-term
MPC basket	725†	745	950 short-term
MPC outer shell surface	332††	352	450 long-term
MPC/overpack helium gap outer surface	292†,††	312	450 long-term
Neutron shield inner surface	274††	294	300 long-term
Overpack shell outside surface	229††	249	350 long-term

† MPC-68 normal storage maximum temperatures from Table 4.4.11.

†† MPC-24 normal storage maximum temperatures from Table 4.4.10.

11.2 ACCIDENTS

Accidents, in accordance with ANSI/ANS-57.9, are either infrequent events that could reasonably be expected to occur during the lifetime of the HI-STAR 100 System or events postulated because their consequences may affect the public health and safety. Section 2.2.3 defines the design basis accidents considered. By analyzing for these design basis events, safety margins inherently provided in the HI-STAR 100 System design can be quantified.

The results of the evaluations performed herein demonstrate that the HI-STAR 100 System can withstand the effects of all credible accident conditions and natural phenomena without affecting safety function, and are in compliance with the acceptable criteria. The section demonstrates that no instruments or controls are required to remain operational under all credible accident conditions. The following sections present the evaluation of the design basis postulated accident conditions and natural phenomena which demonstrate that the requirements of 10CFR72.122 are satisfied, and that the corresponding radiation doses satisfy the requirements of 10CFR72.106(b) and 10CFR20.

The structural load combinations evaluated for postulated accident conditions are defined in Table 2.2.14. The load combinations include normal loads with the accident loads. The accident load combination evaluations are provided in Section 3.4.

11.2.1 Handling Accident

11.2.1.1 Cause of Handling Accident

During the operation of the HI-STAR 100 System, the loaded overpack is transported to the ISFSI in the vertical or horizontal position. The loaded overpack is typically transported by a heavy-haul vehicle which cradles the overpack horizontally or holds the overpack vertically. The height of the loaded overpack above the ground shall be limited to below the handling height limit specified in Table 2.2.17 to limit the inertia loading on the cask in a vertical or horizontal drop to 60g's or less. Although a handling accident is remote, a cask drop from the handling height limit is a credible accident.

11.2.1.2 Handling Accident Analysis

The handling accident analysis evaluates the effects of dropping the loaded overpack in the horizontal and vertical positions. The analysis of the handling accident is provided in Chapter 3. The analysis shows that the HI-STAR 100 System meets all structural requirements and that there is no adverse effect on the confinement, thermal or subcriticality performance of the cask. The vertical drop has no adverse consequences on the shielding analysis. Limited localized damage to the overpack outer enclosure shell and neutron shield in the area of impact may occur as a result of a side drop. Limiting the inertia loading to 60g's or less under the horizontal or vertical drop orientations ensures the fuel cladding remains intact based on dynamic impact effects on spent fuel assemblies literature [11.2.1].

Structural

Appendix 3.A calculates the maximum deceleration of the HI-STAR 100 System as a result of a free drop from the vertical and horizontal handling height limits. For both the vertical and horizontal drops of the HI-STAR 100 System onto the ISFSI pad, the analysis presented in Appendix 3.A demonstrates that the deceleration remains below 60g's. The structural analyses of the MPC and overpack under 60g vertical and radial loads are presented Section 3.4 and it is demonstrated therein that the allowable stresses are within allowable limits.

Thermal

As the structural analysis demonstrates that there is no change in the MPC or overpack except for localized damage to the radial neutron shield of the overpack, there is a negligible effect on the thermal performance of the system as a result of this event.

Shielding

Localized damage of the radial neutron shield may result from the side drop. The damage will be limited to the impacted area.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is a very localized reduction in shielding and no effect on the confinement capabilities as discussed above, there is a negligible effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the vertical and horizontal drop of the HI-STAR Overpack with the MPC inside from the handling height limits in the Technical Specifications does not affect the safe operation of the HI-STAR 100 System.

11.2.1.3 Handling Accident Dose Calculations

The side drop handling accident could cause localized damage to the neutron shield and outer enclosure shell as the neutron shield will impact upon the impact surface. If the neutron shield is damaged, the overpack surface dose rate in the affected area could increase. However, there should be no noticeable increase in the ISFSI site or controlled area boundary dose rate, because the

affected area will likely be small. Once the overpack is uprighted, some local dose increase could occur. The cask's post-accident shielding analysis analyzed in Chapter 5 assumes complete loss of the neutron shield and bounds the dose rates anticipated for the handling accident.

The maximum effect on the overpack metallic body from a handling accident would be slight denting of a localized area. This will have a negligible effect on the gamma shielding of the HI-STAR 100 System.

The analysis of the handling accident has shown that the MPC confinement barrier will not be compromised and, therefore, there will be no release of radioactivity. Any possible rupture of the fuel cladding will have no affect on the site boundary dose rates because the magnitude of the radiation source has not changed. The radiological effects of 100% fuel cladding failure are analyzed in Chapter 7.

11.2.1.4 Handling Accident Corrective Action

Following a handling accident, the ISFSI operator shall first perform a radiological and visual inspection to determine the extent of the damage to the overpack. As appropriate, place temporary shielding around the HI-STAR overpack to reduce dose rates. Special handling procedures will be developed and approved by the ISFSI operator to lift and upright the overpack. Upon uprighting, the portion of the overpack not previously accessible shall be radiologically and visually inspected. If damage to the neutron shield is limited to local penetration or crushing, local repairs can be performed to repair the outer enclosure shell and to replace the damaged neutron shield material. If damage to the neutron shield is extensive, the damage shall be repaired and retested in accordance with the shielding effectiveness test in Chapter 9.

To determine if the MPC confinement boundary has been damaged, the following procedure shall be utilized to obtain a gas sample from the overpack cavity. Based on the damage sustained by the overpack, the procedure may be performed on the overpack vent or drain port.

1. Establish a radiological boundary around the overpack port to be sampled.

2. Remove the port cover plate. Attach the backfill tool (see Chapter 8) and measure annulus gas pressure.

3. Attach an evacuated sample bottle to the backfill tool and withdraw a gas sample from the overpack annulus.

4. Using the backfill tool, re-install the port plug with a new seal.

5. If the gas sample is determined to be clean, evacuate the overpack cavity and backfill the cavity with helium to the pressure specified for the overpack cavity. Proceed to Step 7.

6. If the sample indicates the presence of radioactive gas, the MPC confinement boundary has been breached. Vent the gas through a HEPA filter. Evacuate the overpack cavity and backfill the cavity with helium to the pressure specified for the MPC cavity. The overpack cavity is now defined as the confinement boundary. Proceed to Step 7.

7. Perform a containment system periodic verification leak test on the overpack seals. After satisfactory leak testing and any required repair of the neutron shield, the HI-STAR 100 System can be returned to service.

If upon inspection of the damaged overpack, extensive structural damage of the overpack is observed, the HI-STAR 100 overpack is to be returned to the facility for fuel unloading in accordance with Chapter 8. After unloading, the structural damage of the HI-STAR 100 System shall be assessed and a determination shall be made if repairs will enable the HI-STAR 100 System to return to service. Subsequent to the repairs, the HI-STAR 100 System shall be inspected and appropriate tests shall be performed to certify the HI-STAR 100 System for service. If the HI-STAR 100 System cannot be repaired and returned to service, the HI-STAR 100 System shall be disposed of in accordance with the appropriate regulations.

11.2.2 Tip-Over

11.2.2.1 Cause of Tip-Over

The analysis of the HI-STAR 100 System has shown that the cask does not tip over as a result of the accidents (i.e., tornado missiles, flood water velocity, and seismic activity) analyzed in this section. It is highly unlikely that the cask will tip-over during on-site movement because of the low handling height limit. The tip-over accident is stipulated as a non-mechanistic accident.

11.2.2.2 Tip-Over Analysis

The tip-over accident analysis evaluates the effects of the loaded overpack tipping-over onto a reinforced concrete pad. The tip-over analysis is provided in Chapter 3. The analysis shows that the HI-STAR 100 System meets all structural requirements and there is no adverse effect on the confinement, thermal, or subcriticality performance of the cask. However, the tip-over could cause some damage to the overpack outer enclosure shell and neutron shield in the area of impact.

Structural

Appendix 3.A calculates the maximum deceleration of the HI-STAR 100 System as a result of a non-mechanistic tip-over. For tip-over analysis of the HI-STAR 100 System onto the ISFSI pad, the analysis presented in Appendix 3.A demonstrates that the deceleration of the MPC remains below 60g's. The structural analyses of the MPC and overpack under a 60g radial load are presented Section 3.4 and it is demonstrated therein that the allowable stresses are within allowable limits.

Thermal

As the structural analysis demonstrates that there is no change in the MPC or overpack except for localized neutron shield damage, there is a negligible effect on the thermal performance of the system as a result of this event.

Shielding

Localized damage of the radial neutron shield is to be expected as a result of the tip-over. The damage will be limited to the impacted area.

Criticality

As the structural analysis demonstrates that there is no change in the MPC or overpack, there is a negligible effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is a very localized reduction in shielding and no effect on the confinement capabilities as discussed above, there is a negligible effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the non-mechanistic tip-over of the HI-STAR 100 System does not affect its safe operation.

11.2.2.3 Tip-Over Dose Calculations

The tip-over accident could cause localized damage to the neutron shield and outer enclosure shell where the neutron shield impacts the ISFSI pad. The gamma shielding will not be affected. The overpack surface dose rate in the affected area could increase due to damage of the neutron shield. However, there should be no noticeable increase in the ISFSI site or controlled area boundary dose rate, because the affected areas will likely be small. Once the overpack is uprighted, some local dose increase could occur. The cask post-accident shielding analysis in Chapter 5 assumes complete loss of the neutron shield and bounds the dose rates anticipated for the tip-over accident. The analysis of the tip-over accident has shown that the MPC confinement barrier will not be compromised and, therefore, there will be no release of radioactivity.

11.2.2.4 Tip-Over Accident Corrective Action

The handling accident corrective action procedure outlined in Subsection 11.2.1.4 is applicable for the recovery of the tip-over accident.

11.2.3 Fire

11.2.3.1 Cause of Fire

Although the probability of a fire accident affecting a HI-STAR 100 System during storage operations is low due to the lack of combustible materials at the ISFSI, a fire resulting from an on-site transporter fuel tank contents is postulated and analyzed. The analysis shows that the HI-STAR 100 System continues to perform its structural, confinement, and subcriticality functions.

11.2.3.2 Fire Analysis

The thermal environment to which the HI-STAR 100 System would be exposed under a hypothetical fire accident is specified to be the same as that required in 10CFR71.73(c)(4). The overpack surfaces are therefore considered to receive an incident thermal radiation and convective heat flux from an ambient 1475°F fire condition environment. The duration of fire resulting from an on-site transporter fuel tank spill is calculated as follows:

Volume of Fuel (V) = 50 gallons (6.68 ft^3) (Specified by Subsection 2.2.3.3)

Overpack Baseplate (D_i) = 83-1/4" (6.9375 ft) (Overpack Drawing, Section 1.5)

Fuel Spill Ring Width (L) = 1 meter (IAEA Specification [11.2.6])

$$\text{Fuel Spill Diameter}\,(D_o) = 83-1/4" + 2\text{m} \times \frac{1"}{0.0254\text{m}}$$
$$= 161.99" \ (13.4991 \text{ ft})$$

$$\text{Fuel Spill Area}\,(A) = \frac{\pi}{4}(D_o^2 - D_i^2)$$
$$= 105.3 \text{ ft}^2$$

$$\text{Spill Depth}\,(d) = \frac{V}{A} = \frac{6.68}{105.3}$$
$$= 0.0634 \text{ ft } (0.761")$$

Fuel Consumption Rate (R) = 0.15 inch/min ([11.2.7])

$$\text{Fire Duration} = \frac{d}{R} = \frac{0.761}{0.15}$$
$$= 5.075 \text{ min } (305 \text{ seconds})$$

Within this time period, the cask outside surface and its contents will undergo a transient temperature rise due to the heat absorbed from the fire. Full effects of insolation before, during, and after the fire are included in the HI-STAR 100 System transient analysis. During the postulated fire event, the neutron shield material is exposed to high temperatures. Therefore, conservatively, an upper bound material thermal conductivity is assumed during the fire to maximize heat input to the cask. During the post-fire cooldown phase, no credit is taken for conduction through the neutron shield. The temperature history of a number of critical points in the HI-STAR 100 System transient fire analysis are tracked during the fire and the subsequent relaxation of temperature profiles during the post-fire cooldown phase. The impact of transient temperature excursions on HI-STAR 100 System materials is assessed in this section. During the fire, a cask surface emissivity specified in 10CFR71.73(b)(4) is applied to maximize radiant heat input. Destruction of the paint covering the external cask surfaces due to exposure to intense heat during fire is a credible possibility. Therefore, a lower emissivity of the exposed carbon steel surface is conservatively applied for post-fire cooldown analysis. This approach provides a conservatively bounding response of the HI-STAR 100 System to the fire accident condition.

Heat input from the fire to the HI-STAR 100 System is from a combination of radiation and convection heat transfer to all overpack exposed surfaces. This can be expressed by the following equation:

$$q_F = h_{fc}\left(T_F - T_S\right) + 0.1714\varepsilon\left[\left(\frac{T_F + 460}{100}\right)^4 - \left(\frac{T_S + 460}{100}\right)^4\right]$$

where:

q_F = surface heat input flux (Btu/ft^2-hr)

T_F = fire condition temperature (1475°F)

T_S = transient surface temperature (°F)

h_{fc} = forced convection heat transfer coefficient [Btu/ft^2-hr-°F]

ε = surface emissivity = 0.9 (per 10CFR71)

The forced convection heat transfer coefficient is calculated to bound the convective heat flux contribution to the exposed cask surfaces due to fire induced air flow. For the case of air flow past a heated cylinder, Jacob [11.2.3] recommends the following correlation for convective heat transfer obtained from experimental data:

$$Nu_{fc} = 0.028\,\mathrm{Re}^{0.8}\left[1 + 0.4\left(\frac{L_{st}}{L_{tot}}\right)^{2.75}\right]$$

where:

L_{tot} = length traversed by flow

L_{st} = length of unheated section

K_f = thermal conductivity of air evaluated at the average film temperature

Re = flow Reynolds Number based on L_{tot}

Nu_{fc} = Nusselt Number ($h_{fc} L_{tot}/K_f$)

A consideration of the wide range of temperatures to which the exposed surfaces are subjected during fire and the temperature dependent trend of air properties requires a careful selection of parameters to determine a conservatively large bounding value of the convective heat transfer coefficient. Table 11.2.1 provides a summary of parameter selections with justifications which provide the basis for application of this correlation to determine the forced convection heating of the HI-STAR 100 System during this short-term fire event.

After the fire event, the outside environment temperature is restored to initial ambient conditions and the HI-STAR 100 System transient analysis is continued, to evaluate temperature peaking in the interior during the post-fire cooldown phase. Heat loss from the outside exposed surfaces of the overpack is determined by the following equation:

$$q_S = 0.19(T_S - T_A)^{4/3} + 0.1714\varepsilon\left[\left(\frac{T_S + 460}{100}\right)^4 - \left(\frac{T_A + 460}{100}\right)^4\right]$$

where:

q_s= surface heat loss flux (Btu/ft^2-hr)

T_S = transient surface temperature (°F)

T_A = ambient temperature (100°F)

ε = surface emissivity of exposed carbon steel surface

The FLUENT thermal analysis model was used to perform the fire condition transient analysis. Based on this analysis, the maximum temperature attained in different portions of the cask during the fire followed by a post-fire cooldown are summarized in Table 11.2.2. From the results, it is apparent that due to the large bulk mass and long radial path lengths for flow of heat, the MPC basket centerline temperatures are relatively unaffected by this short duration fire event. However, the overpack enclosure shell and neutron shield material in its immediate vicinity experience a significant temperature increase. The short-duration temperature rise experienced by the periphery of the neutron shield may result in partial loss of its ability to shield neutrons. The neutron shields' inner surface peak transient temperature at the hottest spatial location (314°F) is slightly higher than the 300°F long-term temperature limit. This short-term elevated temperature exposure, lasting for a few hours, is not expected to significantly degrade the neutron shield materials shielding function at this location. A pressure relief system is provided on the overpack outer enclosure shell to prevent any overpressurization in the neutron shield region during the fire event. Figures 11.2.1 through 11.2.3 plot the transient temperature-time history of HI-STAR 100 components identified as

significant for fire accident performance evaluation. Figure 11.2.4 provides an axial temperature plot of the hottest rod in the post-fire cooldown.

Increased pressure of the MPC due to the temperature rise is also considered. From the maximum temperature rise of the MPC during the post-fire cooldown phase, maximum average MPC cavity temperatures are calculated by adding this temperature increment to the initial condition (before start of fire) MPC cavity average temperature for each MPC and applying the ideal gas law. The initial condition MPC cavity average temperatures and pressures have been determined by analytical methods described in Chapter 4. Maximum fire accident pressures in the MPC cavity based on a conservatively bounding 216°F (120°C) MPC cavity temperature rise are reported in Table 11.2.3. Maximum pressure calculations include a 100% fuel rod rupture condition (including hypothetical BPRA rods rupture for PWR fuel) and conservatively determined rod fill gas and fission gases release into the MPC cavity. As can be seen by Table 11.2.3, the pressure does not exceed the accident condition design basis pressure listed in Table 2.2.1.

To ensure the fuel assemblies can be retrieved by normal means and the fuel arrangement remains subcritical, the MPC fuel basket is shown to be unconstrained for thermal expansion. Table 11.2.5 provides the HI-STAR 100 component temperatures in the post-fire cooldown phase. Using these temperatures, Appendix 3.AD demonstrates that the thermal expansion of the MPC fuel basket is unconstrained.

<u>Structural</u>

As discussed above, there are no structural consequences as a result of the fire accident condition.

<u>Thermal</u>

As discussed above, the MPC internal pressure, based on a conservatively bounding fire condition temperature rise and a bounding non-mechanistic 100% fuel rod rupture accident described in Section 11.2.9, remains below accident condition design pressure. As shown in Table 11.2.2, the peak fuel cladding and material temperatures are well below short-term accident condition allowable temperatures of Table 2.2.3.

<u>Shielding</u>

The assumed complete loss of all the radial neutron shield in the shielding analysis results in an increase in the radiation dose rates at locations adjacent to the neutron shield. The shielding analysis results presented in Section 5.1.2 demonstrate that the requirements of 10CFR72.106 are not exceeded.

<u>Criticality</u>

There is no effect on the criticality control features of the system as a result of this event.

<u>Confinement</u>

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

There is no degradation in confinement capabilities of the MPC, as discussed above. There are increases in the dose rates adjacent to the neutron shield. The dose rate at 1 meter from the neutron shield after the neutron shield is replaced by a void is calculated to be less than 500 mrem/hr (Table 5.1.9). Immediately after the fire accident a radiological inspection of the HI-STAR overpack will be performed and temporary shielding installed to limit the exposure to the public. Based on a minimum distance to the controlled area boundary of 100 meters, the dose rate at the controlled area boundary will be less than 5 mrem/hr. Therefore, it is evident that the requirements of 10CFR72.106 (5 Rem) will not be exceeded.

11.2.3.3 Fire Dose Calculations

The analysis of the fire accident shows that the confinement boundary is not compromised and therefore there is no release of radioactive material. The complete loss of the overpack's radial neutron shield is assumed in the shielding analysis for the post-accident HI-STAR 100 System in Chapter 5. The HI-STAR 100 System following a fire accident meets the dose rate requirements of 10CFR72.106. The seals on the overpack will be exposed to short-term high temperature excursions which remain below the maximum design accident temperature limits listed in Table 2.2.3. However, as no radioactive materials are present in the annulus, the loss of the helium retention boundary will have no radiological impact.

11.2.3.4 Fire Accident Corrective Actions

Upon detection of a fire, the ISFSI operator shall take the appropriate immediate corrective actions necessary to extinguish the fire. Fire fighting personnel should take appropriate radiological precautions as the neutron shielding may be damaged and an increased radiation dose could result.

Following the termination of the fire, a visual and radiological inspection of the overpack shall be performed. Specific attention shall be taken during the inspection of the neutron shield. As appropriate, place temporary shielding around the HI-STAR overpack to reduce local dose rates.

If damage to the neutron shield is limited to a localized area, local repairs can be performed to replace the damaged neutron shield material. If damage to the neutron shield is widespread and/or radiological conditions require, the overpack shall be unloaded in accordance with Chapter 8, prior to repair of the neutron shield.

To verify the continued presence of the helium atmosphere within the overpack cavity, perform the procedure specified in Subsection 11.2.1.4.

Following replacement of the neutron shield material, performance of the shielding effectiveness test per Chapter 9, verification of the appropriate helium atmosphere, and leakage testing of the helium retention boundary seals, the overpack shall be certified to return the overpack to service.

11.2.4 Partial Blockage of MPC Basket Vent Holes

Each MPC basket fuel cell wall has elongated vent holes at the bottom and top. The partial blockage of the MPC basket vent holes analyzes the effects on the HI-STAR 100 System due to the restriction of the vent holes.

11.2.4.1 Cause of Partial Blockage of MPC Basket Vent Holes

After the MPC is loaded with spent nuclear fuel, the MPC cavity is drained, vacuum dried, and backfilled with helium. There are only two possible sources of material which could block the MPC basket vent holes. These are fuel cladding/fuel pellets and crud. It is not credible that the fuel cladding would rupture, and that fuel cladding and fuel pellets would fall to block the basket vent holes. Fuel assemblies classified as damaged or fuel debris will be placed in damaged fuel containers prior to placement in MPCs. The damaged fuel container will ensure that fuel cladding and fuel pellets would fall to block the basket vent holes. It is credible that a percentage of the crud deposited on the fuel rods may fall off and deposit at the bottom of the MPC.

Helium in the MPC cavity provides an inert atmosphere for storage of the fuel. The HI-STAR 100 System maintains the peak fuel cladding temperature below the specified limits. There are no credible accidents which could cause the fuel assembly to experience an inertia loading greater than 60g's. Therefore, there is no mechanism for the extensive rupture of spent fuel rod cladding and resultant loss of fuel pellets to the cavity.

Crud can be made up of two types of layers, loosely adherent and tightly adherent. The SNF movement from the fuel racks to the MPC may cause a portion of the loosely adherent crud to fall away. The tightly adherent crud will not be removed during ordinary fuel handling operations.

The amount of crud on fuel assemblies varies greatly from plant to plant and assembly type. Typically, BWR plants and fuel have more crud than PWR plants. Based on the maximum expected crud volume per fuel assembly provided in reference [11.2.2], and the area at the base of the MPC basket fuel storage cell, the maximum depth of crud at the bottom of the MPC-68 was determined. For the MPC-24, 90% of the maximum crud volume per fuel assembly was used to determine the crud depth. The maximum crud depths calculated for each of the MPCs are listed in Table 2.2.8. The maximum amount of crud was assumed to be present on all fuel assemblies within the MPC. Both the tightly and loosely adherent crud was conservatively assumed to fall off of the fuel assembly. As can be seen by the values listed in the table, the maximum amount of crud depth blocks less than 50% of the MPC basket vent hole.

11.2.4.2 Partial Blockage of MPC Basket Vent Hole Analysis

The partial blockage of the MPC basket vent holes has no affect on the structural, thermal, and confinement analysis. There is no affect on the shielding analysis other than a slight increase of the gamma radiation dose rate at the base of the MPC. As the MPC basket vent holes are not completely blocked, preferential flooding of the MPC fuel basket is not possible and, therefore, the criticality analyses are not affected.

Structural

There are no structural consequences as a result of this event.

Thermal

There is no effect on the thermal performance of the system as a result of this event.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the partial blockage of MPC vent holes does not affect the safe operation of the HI-STAR 100 System.

11.2.4.3 Partial Blockage of MPC Basket Vent Holes Dose Calculations

Partial blockage of basket vent holes will not cause loss of the confinement boundary. Therefore, there will be no effect on the controlled area boundary dose rates because the magnitude of the radiation source has not changed. There will be no radioactive release.

11.2.4.4 Partial Blockage of MPC Basket Vent Holes Corrective Action

There are no consequences which exceed normal storage conditions for this accident. No corrective action is required for the partial blockage of the MPC basket vent holes.

11.2.5 Tornado

11.2.5.1 Cause of Tornado

The HI-STAR 100 System will be stored on an unsheltered ISFSI concrete pad and subject to environmental conditions. It is possible that the HI-STAR 100 System may experience the extreme environmental conditions of a tornado.

11.2.5.2 Tornado Analysis

The tornado accident has two effects on the HI-STAR 100 System. The tornado winds or tornado missile attempts to tip-over the loaded overpack with high velocity winds exerting a pressure loading or the potential impact of large tornado missiles striking the overpack. The second effect is tornado missiles propelled by high velocity winds which attempt to penetrate the overpack helium retention boundary and damage the shielding.

Chapter 3 provides the analysis of the pressure loading which attempts to tip-over the overpack and the analysis of the effects of the different types of tornado missiles. These analyses show that the loaded overpack does not tip-over as a result of the tornado winds or tornado missiles. The analyses also show that the overpack helium retention boundary is not compromised and only minor shielding damage will be incurred as a result of the tornado missile. The tornado accident had no adverse consequences on the structural, confinement, thermal, or criticality control capabilities of the HI-STAR 100 System.

Structural

Section 3.4 and Appendix 3.C provide the analysis of the pressure loading which attempts to tip-over the storage overpack and the analysis of the effects of the different types of tornado missiles. These analyses show that the loaded storage overpack does not tip-over as a result of the tornado winds and/or tornado missiles.

Analyses provided in Section 3.4 and Appendix 3.G also show that the tornado missiles do not penetrate the overpack helium retention boundary. The result of the tornado missile impact on the overpack is limited to localized damage of the shielding.

Thermal

There is no effect on the thermal performance of the system as a result of this event.

Shielding

The shielding analysis results presented in Section 5.1.2 demonstrate that the requirements of 10CFR72.106 are not exceeded.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

There is no degradation in confinement capabilities of the MPC, since the tornado missiles do not penetrate the overpack and impact the MPC. There may be increases in the local dose rates adjacent to the impact point of the tornado missile. However, this very localized effect will have no effect on the site boundary dose rate. Therefore, it is evident that the requirements of 10CFR72.106 (5 Rem) will not be exceeded.

11.2.5.3 Tornado Dose Calculations

The tornado winds do not tip-over the loaded overpack, damage the shielding materials or the confinement boundary. There is no affect on the radiation dose as a result of the tornado winds. A tornado missile may cause a very localized reduction in the neutron shielding. However, the damage shall have a negligible effect on the controlled area boundary dose and the effects of the tornado missile damage is bounded by the post-accident dose assessment performed in Chapter 5.

11.2.5.4 Tornado Accident Corrective Action

Following exposure of the HI-STAR 100 System to a tornado, the ISFSI operator shall perform a visual and radiological inspection of the overpack. Damage sustained by the neutron shield shall be repaired in accordance with Subsection 11.2.3.4.

11.2.6 Flood

11.2.6.1 Cause of Flood

The HI-STAR 100 System will be located on an unsheltered ISFSI concrete pad. Therefore, it is possible for the storage area to be flooded. The potential sources for the flood water could be unusually high water from a river or stream, a dam break, a seismic event, or a hurricane.

11.2.6.2 Flood Analysis

The flood accident does not adversely affect the criticality, confinement, shielding, or thermal capabilities of the HI-STAR 100 System. The structural analysis shows that the overpack helium retention boundary, and consequently the MPC confinement boundary maintains full integrity. The criticality analysis for normal fuel loading operations with the cask submerged is more reactive. The flood water acts as a radiation shield and will reduce the radiation doses. The thermal consequences of the flood is an increase in the rejection of the decay heat. Since the flood water temperature will be within the off-normal temperature range specified in Table 2.2.2, the thermal transient associated with the initial contact of the flood water with the overpack exterior surface will be bounded by the off-normal operation conditions.

The flood accident affects the HI-STAR 100 System structural analysis in two ways. First, the flood water velocity acts to apply force and an overturning moment which attempts to cause sliding or tip-over of the loaded overpack. Secondly, the flood water depth applies an external pressure to the overpack. Chapter 3 provides the analysis of both of these conditions. The results of the analysis show that the overpack helium retention boundary is not affected, and that the loaded overpack does not slide or tip over if the flood velocity does not exceed the value stated in Table 2.2.8. The HI-STAR 100 design basis accident external pressure far exceeds any pressure due to an actual flood.

Structural

Section 3.4 provides the analysis of the flood water applying an overturning moment. The results of the analysis show that the loaded overpack does not tip over if the flood velocity does not exceed the value stated in Table 2.2.8.

The structural evaluation of the overpack for the accident condition external pressure (Table 2.2.1) is presented in Section 3.4 and the resulting stresses from this event are shown to be well within the allowable values.

Thermal

There is no adverse effect on the thermal performance of the system as a result of this event. The thermal consequences of the flood is an increase in the rejection of the decay heat. Since the flood water temperature will be within the off-normal temperature range specified in Table 2.2.2, the thermal transient associated with the initial contact of the flood water with the overpack exterior surface will be bounded by the off-normal operation conditions. This is due to the higher heat transfer capabilities of water compared to air.

Shielding

There is no effect on the shielding performance of the system as a result of this event. The flood water acts as a radiation shield and will reduce the radiation doses.

Criticality

There is no effect on the criticality control features of the system as a result of this event. The criticality analysis is unaffected because under the flooding condition water does not enter the MPC cavity and therefore the reactivity would be less than the loading condition in the fuel pool which is presented in Section 6.1.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the flood accident does not affect the safe operation of the HI-STAR 100 System.

11.2.6.3 Flood Dose Calculations

Since the flood accident produces no leakage of radioactive material and no reduction in shielding effectiveness, there are no adverse radiological consequences.

11.2.6.4 Flood Accident Corrective Action

As shown in the analysis of the flood accident, the HI-STAR 100 System sustains no damage as a result of the flood. At the completion of the flood, the exterior of the overpack should be inspected, cleaned, and recoated, as necessary, to maintain the proper emissivity.

11.2.7 Earthquake

11.2.7.1 Cause of Earthquake

The HI-STAR 100 System may be employed at any reactor facility or ISFSI in the contiguous United States. It is possible that during the use of the HI-STAR 100 System, the ISFSI may experience an earthquake.

11.2.7.2 Earthquake Analysis

The earthquake accident analysis evaluates the effects of a seismic event on the loaded HI-STAR 100 System. The objective is to determine the stability limits of the HI-STAR 100 System. Based on a static stability criteria, it is shown in Chapter 3 that the HI-STAR 100 System is qualified to seismic activity less than or equal to the values specified in Table 2.2.8. The analyses in Chapter 3 show that the HI-STAR 100 System will not tip over under the conditions evaluated. The seismic activity has no adverse thermal, criticality, confinement, or shielding consequences.

Structural

The sole structural effect of the earthquake is an inertial loading of less than 1g. This loading is bounded by the handling accident and tip-over analyses presented in Sections 11.2.1 and 11.2.2, which analyzes a deceleration of 60g's and demonstrates that the MPC and overpack allowable stress criteria are met.

Thermal

There is no effect on the thermal performance of the system as a result of this event.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the earthquake does not affect the safe operation of the HI-STAR 100 System.

11.2.7.3 Earthquake Dose Calculations

Structural analysis of the earthquake accident shows that the loaded overpack will not tip over as a result of seismic activity. If the overpack were to tip over, the resultant damage would be equal to that experienced by the tip-over accident analyzed in Subsection 11.2.2. Since the loaded overpack does not tip-over, there is no increase in radiation dose rates or release of radioactivity.

11.2.7.4 Earthquake Accident Corrective Action

Following the earthquake accident, the ISFSI operator shall perform a visual and radiological inspection of the overpacks in storage to determine if any of the overpacks have tipped-over due to the earthquake exceeding the maximum ZPA specified in Chapter 2. In the unlikely event of a tip-over, corrective actions shall be in accordance with Subsection 11.2.1.4.

11.2.8 100% Fuel Rod Rupture

This accident event postulates that all the fuel rod rupture and that the appropriate quantities of fission product gases and fill gas are released from the fuel rods into the MPC cavity.

11.2.8.1 Cause of 100% Fuel Rod Rupture

Through all credible accident conditions, the HI-STAR 100 System maintains the spent nuclear fuel in an inert environment while maintaining the peak fuel cladding temperature below the required short-term temperature limits. There is no credible cause for 100% fuel rod rupture. This accident is postulated to evaluate the MPC confinement barrier for the maximum possible internal pressure.

11.2.8.2 100% Fuel Rod Rupture Analysis

The 100% fuel rod rupture accident has no structural, criticality or shielding consequences. The event does not change the reactivity of the stored fuel, the magnitude of the radiation source which is being shielded, or the shielding capability of the HI-STAR 100 System. The determination of the maximum accident pressure is provided in Chapter 4. The MPC design basis accident internal pressure bounds the pressure developed assuming 100% fuel rod rupture. The structural analysis provided in Chapter 3 evaluates the MPC confinement boundary under the accident condition internal pressure.

As a result of the non-mechanistic 100% fuel rod rupture, the fuel rod fill gas and fission gases are assumed to be released into the MPC cavity. This release causes a dilution of helium by the low thermal conductivity fission gases (Kr, Xe, and Tritium). This dilution of the helium gas and subsequent reduction in the thermal conductivity is bounded by the thermal analysis performed for the vacuum condition during loading operations performed in Chapter 4. Under the vacuum conditions, there is no gas providing a pathway for the thermal conduction of the spent nuclear fuel decay heat. Under the 100% fuel rod rupture condition, the mixture of gases and their resultant lower effective thermal conductivity would provide a thermal conduction pathway. However, no credit is taken for the thermal conductivity of the gas mixture.

From Figure 4.4.19 for the MPC-24 under vacuum conditions, the maximum peak cladding temperature is 691°K and the maximum MPC shell temperature is 384°K. The ΔT between the maximum peak cladding temperature and the maximum MPC shell temperature under vacuum conditions is 307°K or 553°F. The maximum normal condition MPC shell temperature is 332°F from Table 4.4.10. Therefore, a bounding peak fuel cladding temperature for the 100% fuel rod rupture may be calculated by adding the ΔT to the maximum normal condition MPC shell temperature. This results in 332°F + 553°F = 885°F. This bounding peak fuel cladding temperature is well below the allowable fuel cladding short term temperature limit of 1058°F.

The most significant thermal consequence of a postulated 100% fuel rod rupture accident is the increase in MPC confinement boundary pressure. As demonstrated in the fire accident transient

analysis, the confinement boundary pressure design limit is not exceeded (Table 11.2.3), which includes the 100% fuel and PWR BPRA rods rupture.

Structural

The structural evaluation of the MPC for the accident condition internal pressure presented in Section 3.4 demonstrates that the MPC stresses are well within the allowable values.

Thermal

The MPC internal pressure for the 100% fuel rod rupture condition is presented in Table 4.4.15. Table 11.2.2 provides the MPC internal pressure at fire condition temperatures with 100% fuel rod rupture. As can be seen from the values in both tables, the 125 psig design basis accident condition MPC internal pressure used in the structural evaluation bounds the calculated value.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the non-mechanistic 100% fuel rod rupture accident does not affect the safe operation of the HI-STAR 100 System.

11.2.8.3 100% Fuel Rod Rupture Dose Calculations

The MPC confinement boundary maintains its integrity. There is no effect on the shielding effectiveness, and the magnitude of the radiation source is unchanged. Therefore, there is no release of radioactive material or an increase in radiation dose rates.

11.2.8.4 100% Fuel Rod Rupture Accident Corrective Action

As shown in the analysis of the 100% fuel rod rupture accident, the MPC confinement boundary is not compromised. The HI-STAR 100 System is designed to withstand this accident and continue performing the safe storage of spent nuclear fuel. No corrective actions are required.

11.2.9 Confinement Boundary Leakage

The confinement boundary leakage accident assumes complete failure of the overpack helium retention boundary, the rupture of 100% of the fuel rods and the release of the available radionuclides to the environment at a rate equal to the maximum leak test rate of the MPC confinement boundary plus the test sensitivity corrected for accident conditions.

11.2.9.1 Cause of Confinement Boundary Leakage Analysis

There is no credible cause for the confinement boundary leakage. The accidents analyzed in this chapter show that the MPC confinement boundary withstands all credible accidents. There are no man-made or natural phenomena which could cause simultaneous failure of the multiple boundaries restricting radioactive material release. The release is analyzed to demonstrate the safety of the HI-STAR 100 dry cask storage system.

11.2.9.2 Confinement Boundary Leakage

The following is the basis for the analysis of the confinement boundary leakage accident:

1. The fuel stored in the MPC has been cooled for 5 years and has a conservative burnup of 40,000 MWD/MTU. The PWR fuel type is the B&W 15x15 with 3.4% enrichment. The BWR fuel type is the GE 7x7 with 3.0% enrichment. These fuel characteristics bound the HI-STAR 100 design basis fuel.

2. One hundred percent of all the fuel rods are assumed to be ruptured.

3. The nuclides and fractions available for release are those listed in NUREG-6487 as specified in Chapter 7.

4. The leakage rate of the radionuclides to the environment is equal to the maximum leak test rate for the MPC confinement boundary plus the test sensitivity corrected for accident conditions.

5. Both the MPC confinement boundary and the overpack helium retention boundary fail simultaneously. The overpack helium retention boundary fails completely and no credit is taken for its ability to restrict the release of radionuclides.

Chapter 7 provides the analysis and assessment for the whole body and thyroid dose.

<u>Structural</u>

There are no structural consequences of the loss of confinement accident.

Thermal

Since this event is a non-mechanistic assumption, there is no realistic thermal consequences. As discussed in the technical specification, the leak test rate would result in a negligible loss of helium fill gas over the design life of the MPC and overpack, which would have an inconsequential effect on thermal performance.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

This event is based upon a non-mechanistic assumed breach of the confinement.

Radiation Protection

The postulated release will result in an increase in dose to the public. The analysis of this event is provided in Section 7.3. As shown therein, the postulated breach results in a dose to the public less than the limit established by 10CFR72.106(b) for persons located at the controlled area boundary.

11.2.9.3 Confinement Boundary Leakage Dose Calculations

10CFR72.106 requires that any individual located at or beyond the nearest controlled area boundary must not receive a dose greater than 5 Rem to the whole body or any organ from any design basis accident. The maximum whole body dose contribution as a result of the instantaneous leak accident is calculated in Chapter 7 to be less than 55 mRem. The thyroid dose as a result of the instantaneous leak accident is calculated in Chapter 7 to be less than 0.02 mRem. Both values are well below the regulatory limit of 5 Rem.

11.2.9.4 Confinement Boundary Leakage Accident Corrective Action

In the highly unlikely event that MPC confinement boundary and overpack helium retention boundary simultaneously fail and 100% of the fuel rods rupture, the analysis shows that the controlled area boundary accident dose limits are not exceeded. Following release of the radioactivity from the HI-STAR 100 System, the ISFSI operator may replace the overpack cavity inert atmosphere and seals, or unload the HI-STAR 100 System. If the HI-STAR 100 System is to be unloaded, the HI-STAR 100 System shall be placed in a pool or a dry unloading facility, and

unloaded in accordance with Chapter 8. If the overpack cavity is to be used as the confinement boundary perform the procedure below.

1. Leakage test the overpack inner closure plate seal in accordance with Chapter 8 and verify the leakage rates defined in the Technical Specifications are met. If the leakage rate is not met, remove the closure plate, replace the seal, and reperform the leakage test until the leakage rate is met.

2. Leakage test the vent port plug in accordance with Chapter 8 and verify the leakage rates defined in the Technical Specifications are met. If the leakage rate is not met, remove the vent port plug, replace the seal, and reperform the leakage test until the leakage rate is met.

3. Remove the drain port plug, evacuate the overpack cavity, and backfill the overpack cavity with helium to the pressure required for the MPC cavity.

4. Reinstall the drain port plug, leakage test the drain port plug in accordance with Chapter 8, and verify that the leakage rates defined in the Technical Specifications are met. After satisfactory leakage testing, the HI-STAR 100 System can be returned to service. The overpack is now defined as the confinement boundary.

11.2.10 Explosion

11.2.10.1 Cause of Explosion

An explosion within the bounds of an ISFSI is improbable since there are no explosive materials stored within the site boundary. An explosion as a result of combustion of the fuel contained in cask transport vehicle is possible. The fuel available for the explosion would be limited by site administrative controls and therefore, any explosion would be limited in size. Any explosion stipulated to occur beyond the site boundary would have a minimal effect on the HI-STAR 100 System.

11.2.10.2 Explosion Analysis

Any credible explosion accident is bounded by the design basis accident external pressure of 300 psig. The analysis performed in Chapter 3 shows that the HI-STAR 100 System is not adversely affected by the accident condition external pressure.

Structural

The structural evaluations for the overpack accident condition external pressure is presented in Section 3.4 and demonstrates that all stresses are within allowable values.

Thermal

There is no effect on the thermal performance of the system as a result of this event.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the explosion accident does not affect the safe operation of the HI-STAR 100 System.

11.2.10.3 Explosion Dose Calculations

The bounding external pressure load has no effect on the HI-STAR 100 overpack and therefore, no effect on the shielding, criticality, thermal or confinement capabilities of the HI-STAR 100 System.

11.2.10.4 Explosion Accident Corrective Action

The potential overpressure caused by the explosion is bounded by the design basis external pressure. The external pressure from the overpressure is shown not to damage the HI-STAR 100 System. Following an explosion, the ISFSI operator shall perform a visual and radiological inspection of the overpack. If the neutron shield is damaged as a result of explosion generated missiles, the neutron shield material may be replaced and the outer enclosure shell repaired. If damage to the neutron shield is extensive, the damage shall be repaired and retested in accordance with the shielding effectiveness test in Chapter 9.

11.2.11 Lightning

11.2.11.1 Cause of Lightning

The HI-STAR 100 System will be stored on an unsheltered ISFSI concrete pad. There is the potential for lightning to strike the overpack. This analysis evaluates the effects of lightning striking the overpack.

11.2.11.2 Lightning Analysis

The HI-STAR 100 System is a large metallic cask which can be stored in an unsheltered ISFSI. As such, it may be subject to lightning strikes. A lightning strike on the overpack may be visually detected by visible surface discoloration at the point of entry or exit of the current flow. The analysis of the consequence of a lightning strike assumes that the lightning strikes the upper surface of the top flange and proceeds through the inner shell and bottom plate to the ground. Although the total metal thickness of the HI-STAR overpack is in excess of 7 inches over most of its height, it is conservatively assumed that only the inner shell (2-1/2 inches thick) conducts the lightning energy. The electrical current flow results in current induced Joulean heating along that path. The object of the analysis is to compute the bulk heat-up of the inner shell by treating it as a laterally insulated resistor under the worst case lightning strike.

The integrated maximum current for a bounding lightning strike is a peak current of 250 kiloamps over a period of 260 microseconds, and a continuing current of up to 2 kiloamps for 2 seconds in the case of severe lightning discharges [11.2.4].

The amount of thermal energy, Q, developed by the combined currents from Joule's Law is given by:

$$Q = 9.478 \times 10^{-4}\ R\ [I_1^2\ (dt_1) + I_2^2\ (dt_2)]$$

$$Q = (22.98 \times 10^3)\ R\ \text{Btu}$$

where,

Q = thermal energy (Btu)
I_1 = peak current (amps)
I_2 = continuing current (amps)
dt_1 = duration of peak current (seconds)
dt_2 = duration of continuing current (seconds)
R = resistance (ohms)

The effective resistance, R, of the overpack top flange, inner shell, and bottom plate are calculated from:

$$R = (\rho\ l)/a$$

where,

R = resistance (ohms)
ρ = resistivity = 11.09×10^{-8} (ohm-m) for steel transformers from Table 15.1.3, Mark's Standard Handbook for Mechanical Engineers, Ninth Edition [11.2.5]
l = length of conductor path (m)
a = area of conductor (m^2) = (current penetration)(radius)(2π)

The current penetration is conservatively assumed to be 0.01 inches or 2.54×10^{-4} m.

$$R_{top\ flange} = (11.09 \times 10^{-8})(0.4572)/(2\pi)(2.54 \times 10^{-4})(0.873)$$
$$= 3.64 \times 10^{-5} \text{ ohms}$$

$$R_{inner\ shell} = (11.09 \times 10^{-8})(4.42)/(2\pi)(2.54 \times 10^{-4})(0.873)$$
$$= 3.52 \times 10^{-4} \text{ ohms}$$

$$R_{bottom\ plate} = (11.09 \times 10^{-8})(0.305)/(2\pi)(2.54 \times 10^{-4})(0.873)$$
$$= 2.43 \times 10^{-5} \text{ ohms}$$

From the resistance calculated above, it is apparent that the maximum resistance occurs at the inner shell. Therefore, we conservatively assume that all the lightning energy is transferred to the overpack inner shell.

$$Q = (22.98 \times 10^{3})\ R \text{ Btu}$$

$$Q_{inner\ shell} = (22.98 \times 10^{3})(3.52 \times 10^{-4})$$

$$= 8.09 \text{ Btu}$$

It is conservatively assumed that this thermal energy dissipation occurs in a localized volume of the inner shell. Assuming no heat loss or thermal diffusion beyond the current flow boundary, the maximum temperature increase, ΔT, is calculated as:

$$\Delta T = Q_{inner\ shell}/mc$$

where,

ΔT = temperature change (°F)
$Q_{inner\ shell}$ = thermal energy (Btu)
c = 0.113 Btu/lb°F
m = mass (lbm)

$$\Delta T = (8.09)/(0.113)m$$
$$\Delta T = 71.59/m$$

$$m = l\rho a$$
$$m = (154)(0.283)[(2\pi)(0.01)(34)]$$
$$m = 93.1 \text{ lb}$$

$$\Delta T = 0.77°F$$

From the results above, it can be seen that the temperature rise in the inner shell will be very small (less than 1°F). This increase in inner shell temperature is too minuscule to have any effect on the performance of the HI-STAR 100 System.

Structural

There is no structural consequence as a result of this event.

Thermal

There is no effect on the thermal performance of the system as a result of this event.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the lightning accident does not affect the safe operation of the HI-STAR 100 System.

11.2.11.3 Lightning Dose Calculations

An evaluation of lightning strikes demonstrates that the effect of a lightning strike has no effect on the confinement boundary or shielding materials. Therefore, no further analysis is necessary.

11.2.11.4 Lightning Accident Corrective Action

The HI-STAR 100 System will not sustain any damage from the lightning accident. There is no surveillance or corrective action required.

11.2.12 Burial Under Debris

11.2.12.1 Cause of Burial Under Debris

Burial of the HI-STAR 100 System under debris is not a credible accident. During normal storage operations at the ISFSI, there are no structures over the casks. The minimum regulatory distance of 100 meters from the ISFSI to the nearest site boundary and the controlled area around the ISFSI concrete pad precludes the close proximity of substantial amounts of vegetation.

There is no credible mechanism for the HI-STAR 100 System to become completely buried under debris. However, for conservatism, complete burial under debris is considered.

11.2.12.2 Burial Under Debris Analysis

Burial of the HI-STAR 100 System does not impose a condition that would have more severe consequences for criticality, confinement, shielding, and structural analyses than that performed for the other accidents analyzed. The debris would provide additional shielding to reduce radiation doses. The accident external pressure bounds any credible pressure loading caused by the burial under debris.

Burial under debris can affect thermal performance because the debris acts as an insulator and heat sink. This will cause the HI-STAR 100 System and fuel cladding temperatures to increase. A thermal analysis has been performed to determine the time for the fuel cladding temperatures to reach the short term accident condition temperature limits during a burial under debris accident.

To demonstrate the inherent safety of the HI-STAR 100 System, a bounding analysis which considers the debris to act as a perfect insulator is considered. Under this scenario, the contents of the HI-STAR 100 System will undergo a transient heat up under adiabatic conditions. The minimum time required for the fuel cladding to reach the short term design fuel cladding temperature limit depends on the amount of thermal inertia of the cask, the cask initial conditions, and the spent nuclear fuel decay heat generation. All three of these parameters are conservatively bounded by the values in Table 11.2.4.

Using the values stated in Table 11.2.4, the bounding cask temperature rise of less than 5°F per hour is determined. This provides in excess of 60 hours of time before the cladding temperatures exceed the short term fuel cladding temperature limit.

The MPC-68 has the highest steady-state fuel cladding temperature. If 300°F is postulated as the permissible temperature rise the resultant pressure in the MPC cavity can be calculated as a result of the burial under debris accident.

Chapter 4 calculates the MPC internal pressure with an ambient temperature of 80°F, 100% fuel rods ruptured, full insolation, and maximum decay heat, and reports the maximum value of 84.6 psig in Table 4.4.15 at an average MPC cavity temperature of 499.2°K. Using this pressure, an assumed increase in the average temperature of 300°F (499.2°K to 665.9°K), and the ideal gas law, the resultant MPC internal pressure is calculated below.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{(84.6\,psig + 14.7)(665.9°K)}{499.2°K}$$

$$P_2 = 132.5\ psia\ or\ 117.8\ psig$$

The accident MPC internal design pressure of 125 psig (Table 2.2.1) bounds the resultant pressure calculated above. Therefore, no additional analysis is required.

Structural

The structural evaluation of the MPC enclosure vessel for normal internal pressure conditions bounds the pressure calculated above. Therefore, the resulting stresses from the normal condition internal pressure bound the stresses as a result of this event and are well within the allowable values, as discussed in Section 3.4.

Thermal

The MPC internal pressure for the burial under debris accident is calculated above. As can be seen, the 100 psig design basis internal pressure for normal conditions used in the structural evaluation bounds the calculated value for this accident.

Shielding

There is no effect on the shielding performance of the system as a result of this event.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the burial under debris accident does not affect the safe operation of the HI-STAR 100 System, if the debris is removed within 60 hours of overpack burial.

11.2.12.3 Burial Under Debris Dose Calculations

As discussed in the burial under debris analysis, the shielding is enhanced while the HI-STAR 100 System is covered. As the overpack reaches elevated temperatures, the neutron shielding material will exceed its design basis temperature. This will cause some degradation of the neutron shield effectiveness. However, the loss of neutron shield effectiveness is bounded by the assumption of complete loss of the neutron shield in the shielding analysis of the post-accident HI-STAR 100 System in Chapter 5.

The elevated temperatures will not cause the breach of the confinement system and the short term fuel cladding temperature is not exceeded. Therefore, the only radiological impact is the decreased effectiveness of the overpack neutron shield, which is bounded by the analysis in Chapter 5.

11.2.12.4 Burial Under Debris Accident Corrective Action

Analysis of the burial under debris accident shows that the fuel cladding peak temperatures will not exceed the short term limit if the debris is removed within 60 hours. Upon detection of the burial under debris accident, the ISFSI operator shall assign personnel to remove the debris with mechanical and manual means as necessary. After uncovering the overpack, the cask shall be visually and radiologically inspected for any damage.

11.2.13 Extreme Environmental Temperature

11.2.13.1 Cause of Extreme Environmental Temperature

The extreme environmental temperature is postulated as a constant ambient temperature caused by extreme weather conditions. To determine the effects of the extreme temperature, it is conservatively assumed that the temperature persists for a sufficient duration to allow the HI-STAR 100 System to achieve thermal equilibrium. Because of the large mass of the HI-STAR 100 System, with its corresponding large thermal inertia and the limited duration for the extreme temperature, this assumption is conservative.

11.2.13.2 Extreme Environmental Temperature Analysis

The accident condition considering an environmental temperature of 125°F for a duration sufficient to reach thermal equilibrium is evaluated with respect to accident condition design temperatures listed in Table 2.2.3. The evaluation is performed with design basis fuel with the maximum decay heat and the most restrictive thermal resistance. The 125°F extreme environmental temperature is applied with full solar insolation.

The HI-STAR 100 System maximum temperatures for components close to the design basis temperatures are listed in Tables 4.4.10 and 4.4.11. These temperatures are conservatively calculated at the normal environmental temperature of 80°F. The extreme environmental temperature is 125°F, which is an increase of 45°F. The extreme environmental condition temperatures are calculated by adding 45°F to the maximum normal temperatures of the highest component temperature from the MPC-68 or MPC-24. Table 11.2.6 lists the component temperatures at the extreme environmental temperatures. As illustrated by the table, all the temperatures except the neutron shield are well below the accident condition design basis temperatures. The extreme environmental temperature is of a short duration (several consecutive days would be highly unlikely) and the resultant temperatures are evaluated against short-term accident condition temperature limits. Therefore, the HI-STAR 100 System will continue to operate safely under the extreme environmental temperatures.

Additionally, the extreme environmental temperature generates internal pressures which are bounded by the pressure calculated for the fire accident condition because the fire accident condition temperatures are much higher than the temperatures as a result of the extreme environmental temperature. As shown in Table 11.2.3 for the fire condition event pressures, the accident condition pressures are below the limit specified in Table 2.2.1.

Structural

The structural evaluation of the MPC enclosure vessel for accident condition internal pressure bounds the pressure resulting from this event. Therefore, the resulting stresses from this event are bounded by that of the accident condition and are well within the allowable values, as discussed in Section 3.4.

Thermal

The resulting temperatures for the system and fuel assembly cladding are provided in Table 11.2.6. As can be seen from this table, all temperatures except the neutron shield are within the short-term accident condition allowable values specified in Table 2.2.3. The neutron shield temperature does exceed the long-term normal condition temperature specified in Table 2.2.3 by 19°F.

Shielding

The peak neutron shield temperature is higher than the stipulated the long-term normal condition temperature specified in Table 2.2.3 by 19°F. This extreme ambient temperature will persist for a short duration (3-day average) and therefore the degradation in the neutron shield will be negligible.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is negligible degradation in shielding and no degradation in confinement capabilities as discussed above, there is a negligible effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the extreme environmental temperature accident does not affect the safe operation of the HI-STAR 100 System.

11.2.13.3 Extreme Environmental Temperature Dose Calculations

The extreme environmental temperature may cause very localized regions of the neutron shielding material to exceed its normal design temperature for short time durations. The bulk of the neutron shield material away from these local hot spots will remain within the stipulated normal condition temperature limits. Consequently, degradation of the neutron shield effectiveness is negligible. However, the loss of neutron shield effectiveness is bounded by the assumption of complete loss of the neutron shield in the shielding analysis of the post-accident HI-STAR 100 System in Chapter 5.

The elevated temperatures will not cause a breach of the confinement system and the short-term fuel cladding temperature is not exceeded. Therefore, the only radiological impact is the decreased effectiveness of the overpack neutron shield, which is bounded by the analysis in Chapter 5.

11.2.13.4 Extreme Environmental Temperature Corrective Action

Analysis of the extreme environmental temperature accident demonstrates that the only possible consequence is a slight loss in neutron shield effectiveness. Upon detection of an extreme environmental temperature accident, the cask shall be radiologically inspected for any damage.

Table 11.2.1

SUMMARY OF TEMPERATURE-DEPENDENT FORCED CONVECTION HEAT TRANSFER CORRELATION PARAMETERS FOR AIR

Parameter	**Trend with Increasing Temperatures**	**Criteria to Maximize h_{fc}**	**Conservative Parameter Value**	**Evaluated At**
Temperature Range	100°F-1475°F	NA	NA	NA
Density	Decreases	Reynolds Number	High	100°F
Viscosity	Increases	Reynolds Number	Low	100°F
Conductivity (K_f)	Increases	h_{fc} Proportional to K_f	High	1475°F

Table 11.2.2

MAXIMUM HI-STAR 100 SYSTEM TEMPERATURE UNDER A FIRE ACCIDENT CONDITION

Component	Initial Condition [°F]	During Fire [°F]	Post-Fire Cooldown [°F]	Short-Term Temperature Limit [°F]
Fuel Cladding	741	741	771	1058
Basket Periphery	393	393	422	950
MPC Shell	331	331	364	775
Overpack Inner Shell	292	292	328	500
Overpack Closure Plate†	155	484	484	700
Overpack Top Flange	164	524	524	700
Overpack Baseplate Periphery†	197	496	496	700
Neutron Shield Inner Surface	273	273	314	††
Neutron Shield Outer Surface	233	514	551	††
Overpack Enclosure Shell	228	854	854	1000

† Overpack closure plate, overpack port plug, and overpack port cover seals short-term temperature limits are 1200°F. The maximum fire condition seals temperature is bounded by the reported closure plate and baseplate maximum temperatures. Consequently, a large margin of safety exists to permit safe operation of seals in the overpack helium retention boundary.

†† Neutron shield integrity during fire is discussed in the text.

Table 11.2.3

MAXIMUM HI-STAR 100 SYSTEM FIRE ACCIDENT CONDITION MPC CAVITY PRESSURES†

Condition	Pressure (psig)	
	MPC-24††	MPC-68
Without fuel rod rupture	57.9	75.1
With 100% fuel rod rupture	124.2	108.8
Accident Design Pressure	125	125

† Pressure analysis is based on NUREG-1536 criteria (i.e., 100% rods fill gas and 30% of radioactive gases are available for release from a ruptured rod) and a conservatively bounding 216°F (120°C) MPC cavity temperature rise.

†† PWR fuel includes hypothetical BPRA rods rupture in the pressure calculations.

Table 11.2.4

SUMMARY OF INPUTS FOR ADIABATIC CASK HEAT-UP

Minimum Weight of HI-STAR 100 System (lb.)	200,000
Lower Heat Capacity of Carbon Steel (BTU/lb/°F)	0.1
Initial Uniform Temperature of Cask (°F)	749†
Bounding Maximum Decay Heat (kW)	20

† The cask is initially conservatively assumed to be at a uniform temperature equal to temperature limit of the fuel cladding for long-term storage (see Table 4.3.1).

Table 11.2.5

SUMMARY OF HI-STAR 100 SYSTEM MAXIMUM
POST-FIRE COOLDOWN (33 HOURS AFTER FIRE) TEMPERATURES

Location	Temperature [°F]
Hottest MPC Basket Cross Section:	
Basket center	755
Basket periphery	419
MPC shell	358
Overpack inner shell	317
Overpack enclosure shell	249
MPC Basket Bottom:	
Basket center	285
Basket periphery	238
MPC shell	231
Overpack inner shell	225
Overpack enclosure shell	188
MPC Basket Top:	
Basket center	229
Basket periphery	199
MPC shell	193
Overpack inner shell	187
Overpack outer shell	166

Table 11.2.6

MAXIMUM TEMPERATURES CAUSED BY EXTREME ENVIRONMENTAL TEMPERATURES [°F]

Temperature Location	**Normal**	**Calculated Extreme Environment**	**Accident Condition Design Temperature**
Fuel cladding	741† (5-yr cooling)	786 (5-yr cooling)	1058 short-term
MPC basket	725†	770	950 short-term
MPC outer shell surface	332††	377	775 short-term
MPC/overpack helium gap outer surface	292††	337	400 long-term
Neutron shield inner surface	274††	319	300 long-term
Overpack shell outside surface	229††	274	350 long-term

† MPC-68 normal storage maximum temperatures from Table 4.4.11.

†† MPC-24 normal storage maximum temperatures from Table 4.4.10.

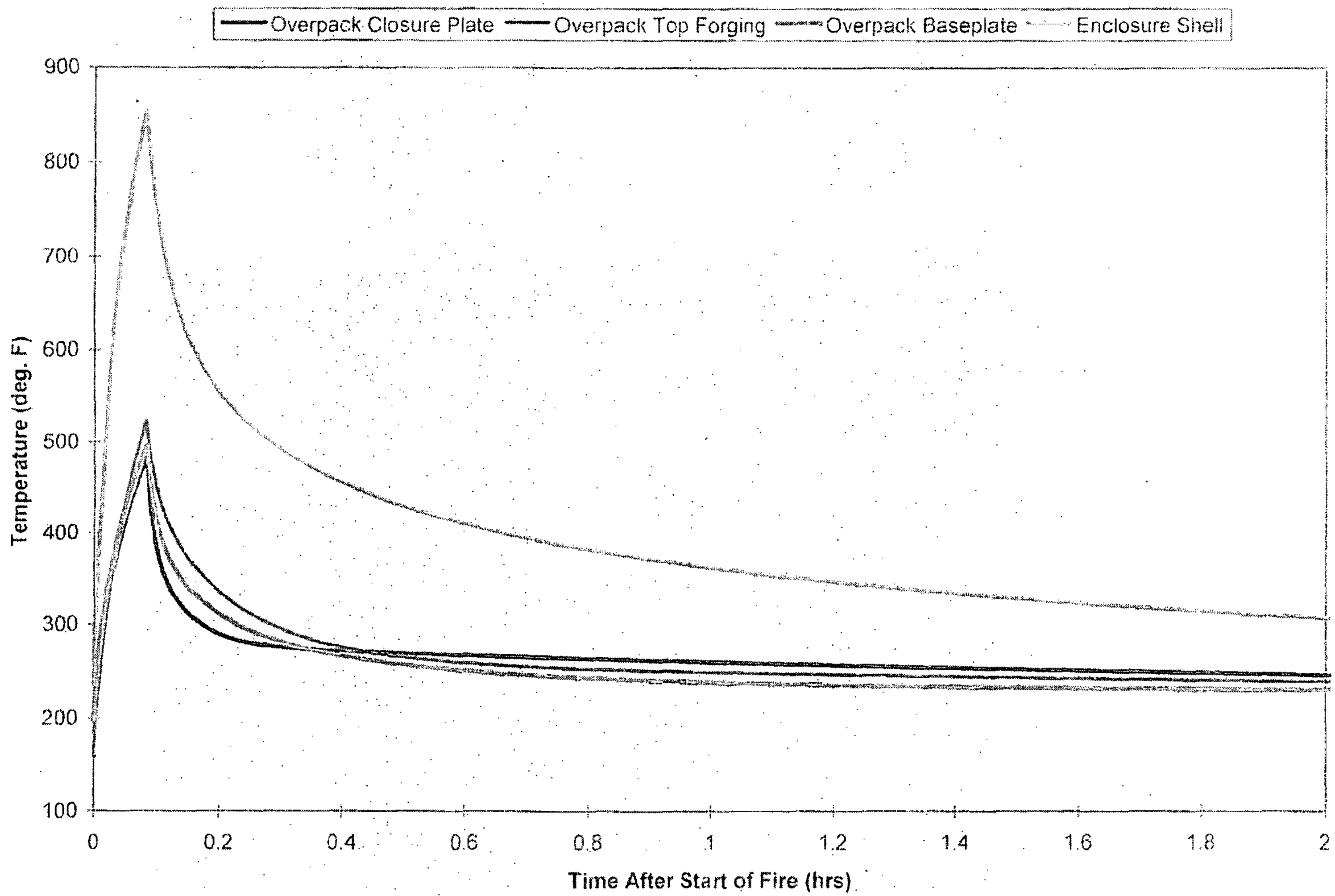


FIGURE 11.2.1; HI-STAR 100 SYSTEM EXPOSED SURFACES HYPOTHETICAL FIRE ACCIDENT TRANSIENT TEMPERATURE RESPONSE

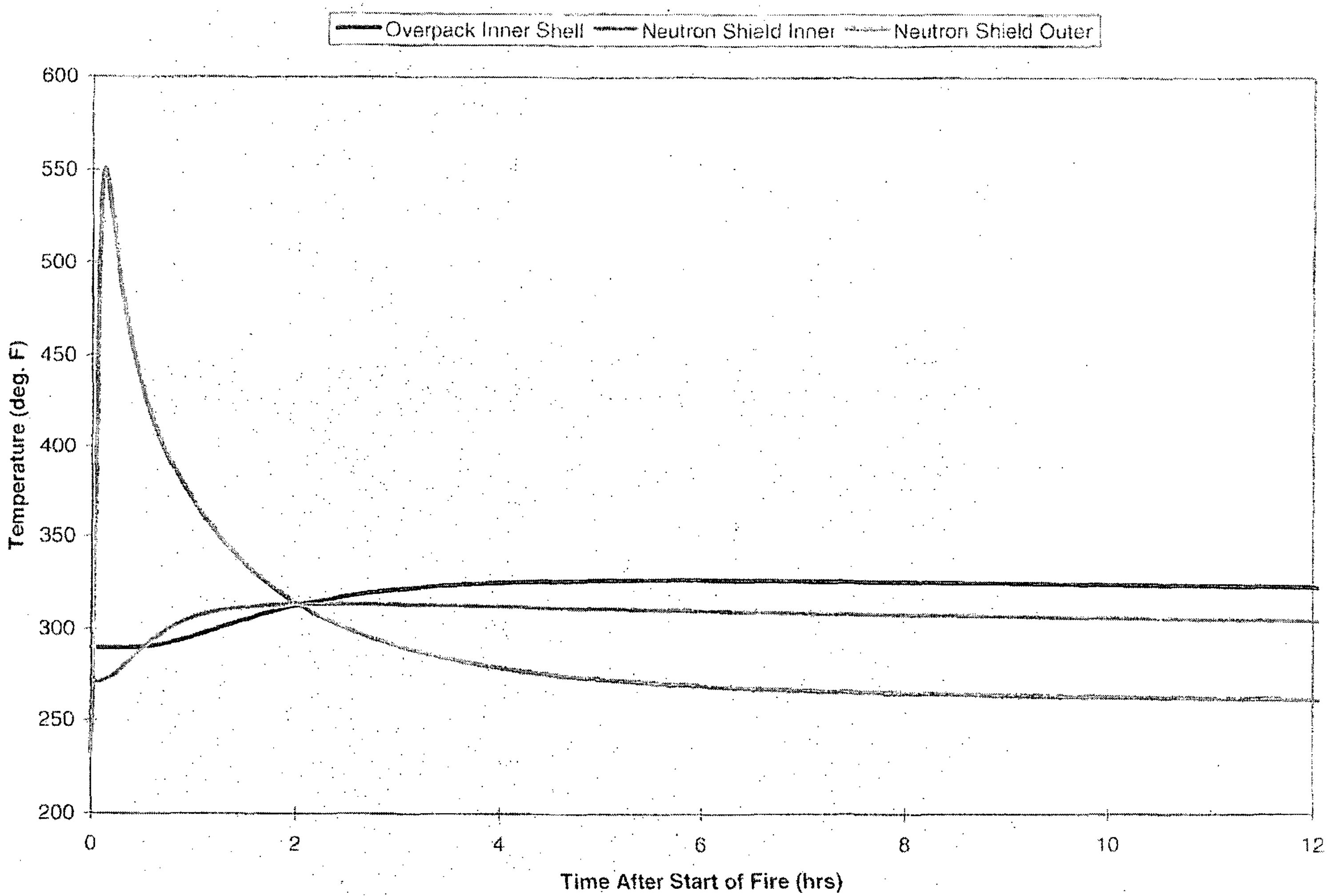


FIGURE 11.2.2; HI-STAR 100 SYSTEM NON-EXPOSED OVERPACK COMPONENTS HYPOTHETICAL FIRE ACCIDENT TRANSIENT TEMPERATURE RESPONSE

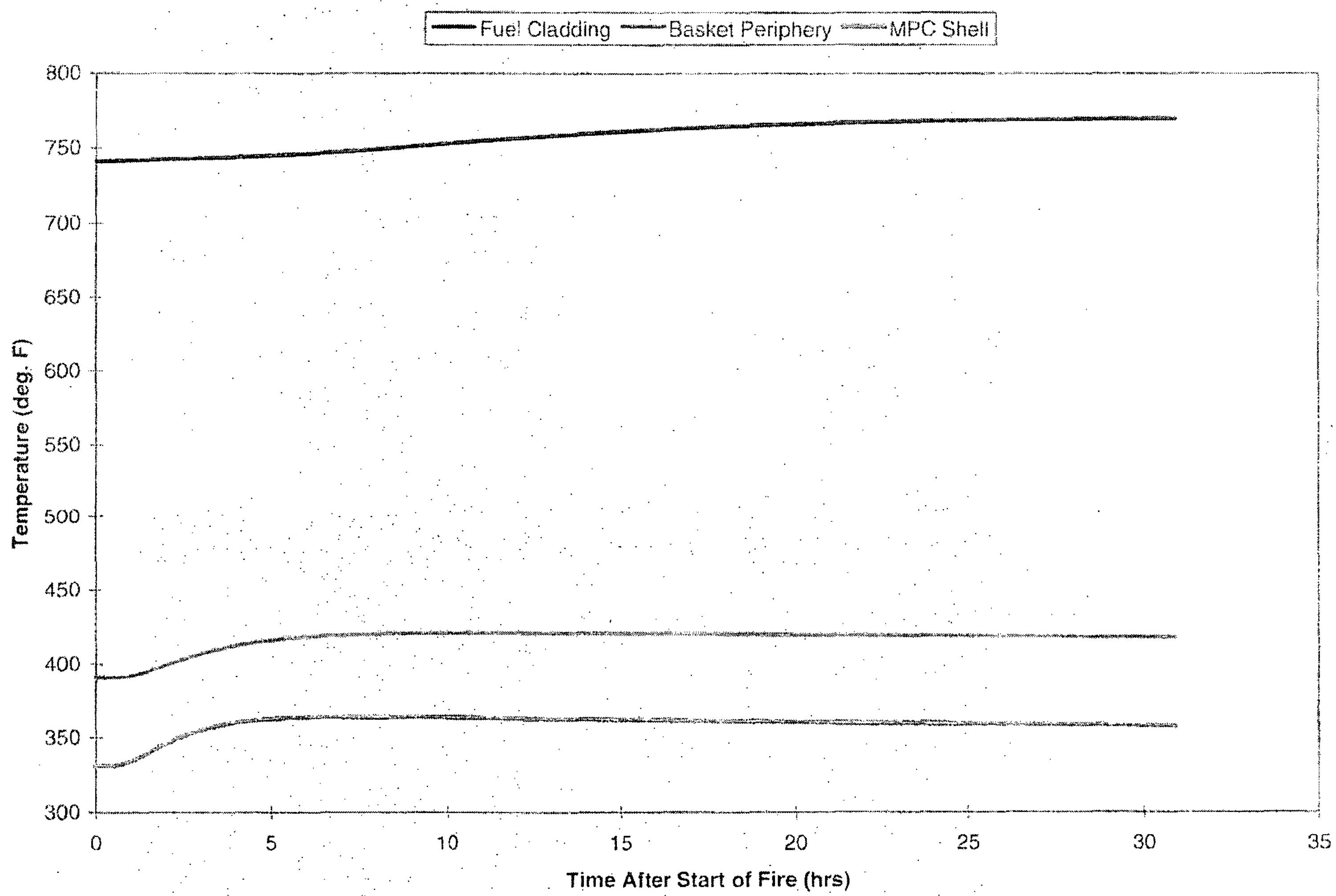
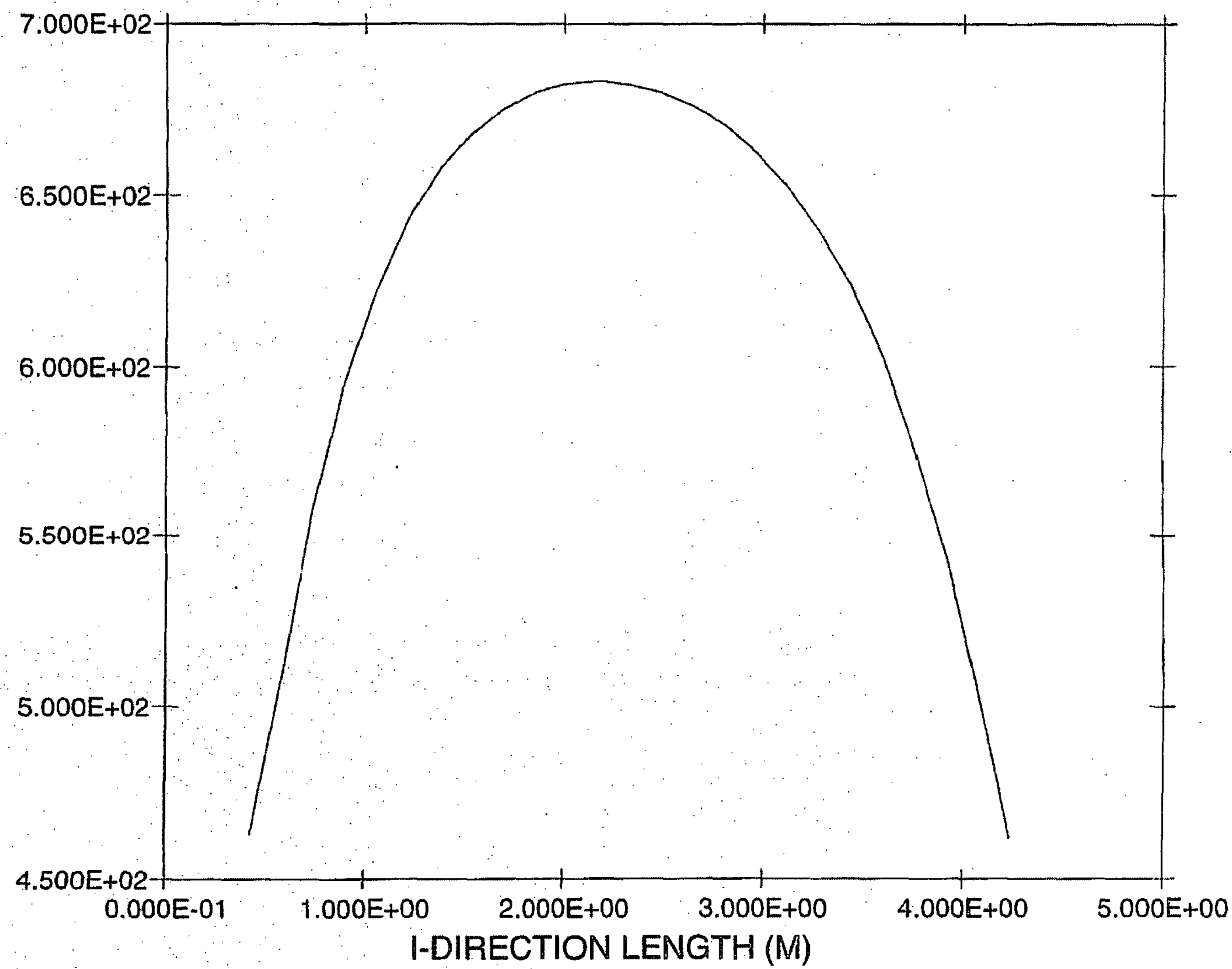


FIGURE 11.2.3; HI-STAR 100 SYSTEM MPC COMPONENTS AND FUEL CLADDING HYPOTHETICAL FIRE ACCIDENT TRANSIENT TEMPERATURE RESPONSE



Y Z X	FIGURE 11.2.4: HOTTEST ROD AXIAL TEMPERATURE PROFILE (Post Fire Cooldown at 33 Hours) Temperature (Kelvin) Vs. Axial Distance (Meters)	May 16 1998 Fluent 4.32 Fluent Inc.

11.3 Regulatory Compliance

Chapter 11 has been written to provide an identification and analysis of hazards, as well as a summary of the HI-STAR 100 System's response to both off-normal and accident or design-basis events. When evaluating each event, the cause of the event, detection of the event, summary of event consequences and regulatory compliance, and corrective course of action are provided. The information provided in Chapter 11 can be summarized as follows:

- Structures, systems, and components of the HI-STAR 100 System are adequate to prevent accidents and to mitigate the consequences of accidents and natural phenomena events that do occur.
- The spacing of the HI-STAR 100 overpacks, discussed in Section 1.4 of the FSAR, will ensure accessibility of the equipment and services required for emergency response to the events evaluated in Chapter 11.
- The Technical Specifications for the HI-STAR 100 System are provided as Appendix A to Certificate of Compliance 72-1008.
- The HI-STAR 100 System has been evaluated to demonstrate that it will maintain confinement of radioactive material under credible accident conditions.
- An accident or natural phenomena event will not preclude the ready retrieval of spent fuel for further processing or disposal.
- The spent fuel will be maintained in a subcritical condition under accident conditions.
- Neither off-normal nor accident conditions will result in a dose, to an individual outside the controlled area, that exceeds the limits of 10 CFR 72.104(a) or 72.106(b), respectively.
- No instruments or control systems are required to remain operational under accident conditions.

The accident design criteria for the HI-STAR 100 System is in compliance with 10 CFR Part 72 and the accident design and acceptance criteria have been satisfied. The accident evaluation of the HI-STAR 100 System demonstrates that it will provide for safe storage of spent fuel during credible accident situations. This is based on the analyses summarized in Chapter 11, 10 CFR Part 72, appropriate regulatory guides, applicable codes and standards, and accepted engineering practice.

11.4 REFERENCES

[11.2.1] Chun, et al., "Dynamic Impact Effects on Spent Fuel Assemblies," Lawrence Livermore National Laboratory, UCID-21246, October 1987.

[11.2.2] ESEERCO Project EP91-29 and EPRI Project 3100-02, "Debris Collection System for Boiling Water Reactor Consolidation Equipment," B&W Fuel Company, October 1995.

[11.2.3] Jacob, M., "Heat Transfer," John Wiley & Sons, Inc. page 555, (1967).

[11.2.4] Cianos, N., and Pierce, E.T., "A Ground Lightning Environment for Engineering Usage," Technical Report No. 1, SRI Project No. 1834, Standard Research Institute, Menlo Park, CA, August 1997.

[11.2.5] Avallone, E.A., and Baumeister, T., Mark's Standard Handbook for Mechanical Engineering, Ninth Edition, McGraw Hill Inc., 1987.

[11.2.6] IAEA Safety Standards, "Regulations for the Safe Transport of Radioactive Material," International Atomic Energy Agency, Vienna, 1985.

[11.2.7] "Thermal Measurements in a Series of Large Pool Fires", Sandia Report SAND85-0196.TTC-0659.UC71, August 1987.

CHAPTER 12: OPERATING CONTROLS AND LIMITS

12.1 PROPOSED OPERATING CONTROLS AND LIMITS

The HI-STAR 100 System provides passive dry storage of spent fuel assemblies in interchangeable MPCs with redundant multi-pass welded closure. The loaded MPC is enclosed in a dual-purpose metal overpack. This chapter defines the operating controls and limits (i.e., Technical Specifications) including their supporting bases for deployment and storage of a HI-STAR 100 System at an ISFSI. The information provided in this chapter is in full compliance with NUREG-1536 [12.1.1].

12.1.1 NUREG-1536 (Standard Review Plan) Acceptance Criteria

12.1.1.1 This portion of the FSAR establishes the commitments regarding the HI-STAR 100 System and its use. Other 10CFR72 [12.1.2] and 10CFR20 [12.1.3] requirements in addition to the Technical Specifications may apply. The conditions for a general license holder found in 10CFR72.212 [12.1.2] shall be met by the licensee prior to spent fuel loading into the HI-STAR 100 System. The general license conditions governed by 10CFR72 [12.1.2] are not repeated with these Technical Specifications. Licensees are required to comply with all commitments and requirements.

12.1.1.2 The Technical Specifications provided herein are primarily established to maintain subcriticality, confinement boundary integrity, shielding and radiological protection, heat removal capability, and structural integrity under normal, off-normal and accident conditions. Table 12.1.1 addresses each of these conditions respectively and identifies the appropriate Technical Specification(s) designed to control the condition. Table 12.1.2 provides the list of Technical Specifications for the HI-STAR 100 System.

Table 12.1.1

HI-STAR 100 SYSTEM CONTROLS

Condition to be Controlled	Applicable Technical Specifications
Criticality Control	Refer to Appendix B to Certificate of Compliance 72-1008 for fuel specifications and design features.
Confinement Boundary Integrity	2.1.1 Multi-Purpose Canister (MPC)
Shielding and Radiological Protection	Refer to Appendix B to Certificate of Compliance 72-1008 for fuel specifications and design features. 2.1.1 Multi-Purpose Canister (MPC) 2.1.4 Fuel Cool-Down 2.2.1 OVERPACK Average Surface Dose Rates 2.2.2 SFSC Surface Contamination
Heat Removal Capability	Refer to Appendix B to Certificate of Compliance 72-1008 for fuel specifications and design features. 2.1.1 Multi-Purpose Canister (MPC) 2.1.2 OVERPACK
Structural Integrity	2.1.2 OVERPACK 2.1.3 SFSC Lifting Requirements

Table 12.1.2

HI-STAR 100 TECHNICAL SPECIFICATIONS†

NUMBER	TECHNICAL SPECIFICATION
1.0	USE AND APPLICATION 1.1 Definitions 1.2 Logical Connectors 1.3 Completion Times 1.4 Frequency
2.0	LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY SURVEILLANCE REQUIREMENT (SR) APPLICABILITY
2.1.1	Multi-Purpose Canister (MPC)
2.1.2	OVERPACK
2.1.3	SFSC Lifting Requirements
2.1.4	Fuel Cool-Down
2.2.1	OVERPACK Average Surface Dose Rates
2.2.2	SFSC Surface Contamination
Table 2-1	MPC Model-Dependent Limits
3.0	ADMINISTRATIVE CONTROLS

† Refer to Certificate of Compliance 72-1008, Appendix A for Technical Specifications and Appendix B for fuel specifications and design features.

12.2 DEVELOPMENT OF OPERATING CONTROLS AND LIMITS

This section provides a discussion of the operating controls and limits for the HI-STAR 100 System to assure long-term performance consistent with the conditions analyzed in this FSAR. In addition to the controls and limits provided in the Technical Specifications contained in Appendix A to Certificate of Compliance (CoC) 72-1008 and the design features specified in Appendix B to CoC 72-1008, the licensee shall ensure that the following training and dry run activities are performed.

12.2.1 Training Modules

Training modules are to be developed under the licensee's training program to require a comprehensive, site-specific training, assessment, and qualification (including periodic re-qualification) program for the operation and maintenance of the HI-STAR 100 Spent Fuel Storage Cask (SFSC) System and the Independent Spent Fuel Storage Installation (ISFSI). The training modules shall include the following elements, at a minimum:

1. HI-STAR 100 System Design (overview);

2. ISFSI Facility Design (overview);

3. Systems, Structures, and Components Important to Safety (overview)

4. HI-STAR 100 System Final Safety Analysis Report (overview);

5. NRC Safety Evaluation Report (overview);

6. Certificate of Compliance conditions;

7. HI-STAR 100 Technical Specifications and other Conditions for Use;

8. HI-STAR 100 Regulatory Requirements (e.g., 10CFR72.48, 10CFR72, Subpart K, 10CFR20, 10CFR73);

9. Required instrumentation and use;

10. Inspection personnel qualifications

11. Operating Experience Reviews

12. HI-STAR 100 System and ISFSI Procedures, including

    - Procedural overview
    - Fuel qualification and loading

- MPC /overpack rigging and handling, including safe load pathways
- MPC welding operations
- Overpack closure
- Auxiliary equipment operation and maintenance (e.g., draining, vacuum drying, helium backfilling, and cooldown)
- MPC/overpack pre-operational and in-service inspections and tests
- Transfer and securing of the loaded overpack onto the transport vehicle
- Transfer and offloading of the overpack at the ISFSI
- Preparation of MPC/overpack for fuel unloading
- Unloading fuel from the MPC/overpack
- Surveillance
- Radiation protection
- Maintenance
- Security
- Off-normal and accident conditions, responses, and corrective actions

12.2.2 Dry Run Training

A dry run training exercise of the loading, closure, handling, and transfer of the HI-STAR 100 System shall be conducted by the licensee prior to the first use the system to load spent fuel assemblies. The dry run shall include, but is not limited to the following:

1. Receipt inspection of HI-STAR 100 System components.

2. Moving the HI-STAR 100 MPC/overpack into the spent fuel pool.

3. Preparation of the HI-STAR 100 System for fuel loading.

4. Selection and verification of specific fuel assemblies to ensure type conformance.

5. Locating specific assemblies and placing assemblies into the MPC (using a dummy fuel assembly), including appropriate independent verification.

6. Remote installation of the MPC lid and removal of HI-STAR 100 overpack/MPC from the spent fuel pool.

7. MPC welding, NDE inspections, hydrostatic testing, draining, vacuum drying, helium backfilling and leakage testing.

8. HI-STAR 100 overpack closure, draining, vacuum drying, helium backfilling and leakage testing.

9. HI-STAR 100 overpack upending/downending on the horizontal transfer trailer or other transfer device, as applicable to the site's cask handling arrangement.

10. Placement of the HI-STAR 100 System at the ISFSI.

12.2.3 Functional and Operating Limits, Monitoring Instruments, and Limiting Control Settings

The controls and limits apply to operating parameters and conditions which are observable, detectable, and/or measurable. The HI-STAR 100 System is completely passive during storage and requires no monitoring instruments.

12.2.4 Limiting Conditions for Operation

Limiting conditions for operation specify the minimum capability or level of performance that is required to assure that the HI-STAR 100 System can fulfill its safety functions.

12.2.4.1 Equipment

The HI-STAR 100 System and its components have been analyzed for specified normal, off-normal, and accident conditions, including extreme environmental conditions. Analysis has shown in this FSAR that no credible condition or event prevents the HI-STAR 100 System from meeting its safety function. As a result, there is no threat to public health and safety from any postulated accident condition or analyzed event. When all equipment is loaded, tested, and placed into storage in accordance with procedures developed for the ISFSI, no failure of the system to perform its safety function is expected to occur.

12.2.5 Surveillance Requirements

The analyses provided in this FSAR show that the HI-STAR 100 System fulfills its safety functions, provided that the Technical Specifications in Appendix 12.A are met. Surveillance requirements during loading, unloading, and on-site transfer operations are provided in the Technical Specifications.

12.2.6 Design Features

This section describes HI-STAR 100 System design features that are Important to Safety. These features require design controls and fabrication controls. The design features, detailed herein, are established in specifications and drawings which are controlled through the quality assurance program presented in Chapter 13. Fabrication controls and inspections to assure that the HI-STAR 100 System is fabricated in accordance with the design drawings and the requirements of this FSAR are described in Chapter 9.

12.2.6.1 <u>MPC</u>

a. Basket material composition, properties, dimensions, and tolerances for criticality control.

b. Canister material mechanical properties for structural integrity of the confinement boundary.

c. Canister and basket material thermal properties and dimensions for heat transfer control.

d. Canister and basket material composition and dimensions for dose rate control.

12.2.6.2 <u>HI-STAR 100 Overpack</u>

a. HI-STAR 100 overpack material mechanical properties and dimensions for structural integrity to provide protection of the MPC and shielding of the spent nuclear fuel assemblies during loading, unloading and handling operations.

b. HI-STAR 100 overpack material thermal properties and dimensions for heat transfer control.

c. HI-STAR 100 overpack material composition and dimensions for dose rate control.

12.3 TECHNICAL SPECIFICATIONS

Technical Specifications for the HI-STAR 100 System are provided in Appendix A to CoC 72-1008. Fuel specifications and design features are provided in Appendix B to CoC 72-1008. Bases for the Technical Specifications in CoC Appendix A are provided in FSAR Appendix 12.A. The format and content of the HI-STAR 100 System Technical Specifications and Bases are that of the Improved Standard Technical Specifications for power reactors, to the extent they apply to a dry spent fuel storage cask system. NUMARC Document 93-03, "Writer's Guide for the Restructured Technical Specifications" [12.3.9] was used as a guide in the development of the Technical Specifications and Bases.

12.4 REGULATORY EVALUATION:

Table 12.1.2 lists the Technical Specifications for HI-STAR 100 System. The Technical Specifications are detailed in Appendix A to CoC 72-1008. Fuel specifications and design features are contained in Appendix B to CoC 72-1008.

The conditions for use of HI-STAR 100 System identify necessary Technical Specifications to satisfy 10 CFR Part 72, and the applicable acceptance criteria have been satisfied. The proposed Technical Specifications, fuel specifications, and design features provide reasonable assurance that the HI-STAR 100 will allow safe storage of spent fuel and is in compliance with 10 CFR Part 72, the regulatory guides applicable codes and standards, and accepted practices.

12.5 REFERENCES

[12.1.1] U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems", NUREG-1536, Final Report, January 1997.

[12.1.2] *U.S. Code of Federal Regulations*, Title 10, "Energy", Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste."

[12.1.3] *U.S. Code of Federal Regulations*, Title 10, "Energy", Part 20, "Standards for Protection Against Radiation."

[12.3.1] R.W., Knoll, *et al.*, Pacific Northwest Laboratory, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Cask Storage of LWR Spent Fuel,"PNL-6365, DE88 003988, November 1987.

[12.3.2] American Society of Mechanical Engineers "Boiler and Pressure Vessel Code"

[12.3.3] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," ANSI N14.5-1997.

[12.3.4] *U.S. Code of Federal Regulations*, Title 10, "Energy", Part 71, "Packaging and Transport of Radioactive Materials."

[12.3.5] NUREG-0554, Single Failure Proof Cranes for Nuclear power Plants.

[12.3.6] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 KG) or More for Nuclear Materials", ANSI N14.6, 1993.

[12.3.7] Witte, M., et al., "Evaluation of Low-Velocity Impacts Tests of Solid Steel Billet onto Concrete Pads, and Application to Generic ISFSI Storage Cask for Tipover and Side Drop." Lawrence Livermore National Laboratory, UCRL-ID-126295, Livermore, California, March 1997.

[12.3.8] American Society of Nondestructive Testing – American Society for Metals, "Nondestructive Testing Handbook, Volume One, Leakage Testing", SAN 204-7586, pp 448, June 1982.

[12.3.9] Nuclear Management and Resources Council, Inc. – "Writer's Guide for the Restructured Technical Specifications" NUMARC 93-03, February 1993.

APPENDIX 12.A

TECHNICAL SPECIFICATION BASES

FOR THE HOLTEC HI-STAR 100 SPENT FUEL STORAGE CASK SYSTEM

(37 Pages Including this Page)

BASES TABLE OF CONTENTS

B 2.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES

LCOs

LCO 2.0.1, 2.0.2, 2.0.4, and 2.0.5 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.

LCO 2.0.1

LCO 2.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the facility is in the specified conditions of the Applicability statement of each Specification).

LCO 2.0.2

LCO 2.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS Condition is applicable from the point in time that an ACTIONS Condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that:

a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and

b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified.

There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. Whether stated as a Required Action or not, correction of the entered Condition is an action that may always be considered upon entering ACTIONS. The second type of Required Action specifies the

(continued)

BASES

LCO 2.0.2 (continued)

remedial measures that permit continued operation that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation.

Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications.

The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

LCO 2.0.3

This specification is not applicable to a dry storage cask system because it describes conditions under which a power reactor must be shut down when an LCO is not met and an associated ACTION is not met or provided. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 2.0.4

LCO 2.0.4 establishes limitations on changes in specified conditions in the Applicability when an LCO is not met. It precludes placing the HI-STORM 100 System in a specified condition stated in that Applicability (e.g., Applicability desired to be entered) when the following exist:

a. Facility conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and

b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in being required to

(continued)

BASES

LCO 2.0.4 (continued)

exit the Applicability desired to be entered to comply with the Required Actions.

Compliance with Required Actions that permit continuing with dry fuel storage activities for an unlimited period of time in a specified condition provides an acceptable level of safety for continued operation. This is without regard to the status of the dry storage system. Therefore, in such cases, entry into a specified condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

The provisions of LCO 2.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 2.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of an SFSC.

Exceptions to LCO 2.0.4 are stated in the individual Specifications. Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.

LCO 2.0.5

LCO 2.0.5 establishes the allowance for restoring equipment to service under administrative controls when it has been removed from service or determined to not meet the LCO to comply with the ACTIONS. The sole purpose of this Specification is to provide an exception to LCO 2.0.2 (e.g., to not comply with the applicable Required Action(s)) to allow the performance of testing to demonstrate:

a. The equipment being returned to service meets the LCO; or

b. Other equipment meets the applicable LCOs.

(continued)

BASES

LCO 2.0.5 (continued)	The administrative controls ensure the time the equipment is returned to service in conflict with the requirements of the ACTIONS is limited to the time absolutely necessary to perform the allowed testing. This Specification does not provide time to perform any other preventive or corrective maintenance.
LCO 2.0.6	This specification is not applicable to a dry storage cask system because it describes conditions under which a power reactor must be shut down when an LCO is not met and an associated ACTION is not met or provided. The placeholder is retained for consistency with the power reactor technical specifications.
LCO 2.0.7	This specification is not applicable to a dry storage cask system because it describes conditions under which a power reactor must be shut down when an LCO is not met and an associated ACTION is not met or provided. The placeholder is retained for consistency with the power reactor technical specifications.

B 2.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs

SR 2.0.1 through SR 2.0.4 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.

SR 2.0.1

SR 2.0.1 establishes the requirement that SRs must be met during the specified conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify that systems and components meet the LCO and variables are within specified limits. Failure to meet a Surveillance within the specified Frequency, in accordance with SR 2.0.2, constitutes a failure to meet an LCO.

Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when:

a. The systems or components are known to not meet the LCO, although still meeting the SRs; or

b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances.

Surveillances do not have to be performed when the HI-STORM 100 System is in a specified condition for which the requirements of the associated LCO are not applicable, unless otherwise specified.

Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment that has been determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 2.0.2, prior to returning equipment to service. Upon completion of maintenance, appropriate post-maintenance testing is required. This includes ensuring applicable Surveillances

(continued)

BASES

SR 2.0.1 (continued)

are not failed and their most recent performance is in accordance with SR 2.0.2. Post maintenance testing may not be possible in the current specified conditions in the Applicability due to the necessary dry storage cask system parameters not having been established. In these situations, the equipment may be considered to meet the LCO provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function. This will allow dry fuel storage activities to proceed to a specified condition where other necessary post maintenance tests can be completed.

SR 2.0.2

SR 2.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per..." interval.

SR 2.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers facility conditions that may not be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities).

The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 2.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications as a Note in the Frequency stating, "SR 2.0.2 is not applicable."

As stated in SR 2.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension

(continued)

SR 2.0.2 (continued)

to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the affected equipment in an alternative manner.

The provisions of SR 2.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals or periodic Completion Time intervals beyond those specified.

SR 2.0.3

SR 2.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when a Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the Surveillance has not been performed in accordance with SR 2.0.2, and not at the time that the specified Frequency was not met.

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of a Surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance.

The basis for this delay period includes consideration of HI-STORM 100 System conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements. When a Surveillance with a Frequency based not on time intervals, but upon specified facility conditions, is discovered not to have been performed when specified, SR 2.0.3 allows the full delay period of 24 hours to perform the Surveillance.

SR 2.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified conditions in the Applicability imposed by the Required Actions.

(continued)

SR 2.0.3 (continued)

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 2.0.3 is a flexibility which is not intended to be used as an operational convenience to extend Surveillance intervals.

If a Surveillance is not completed within the allowed delay period, then the equipment is considered to not meet the LCO or the variable is considered outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If a Surveillance is failed within the delay period, then the equipment does not meet the LCO, or the variable is outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance.

Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 2.0.1.

SR 2.0.4

SR 2.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry into specified conditions in the Applicability for which these systems and components ensure safe conduct of dry fuel storage activities.

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

However, in certain circumstances, failing to meet an SR will not result in SR 2.0.4 restricting a change in specified condition. When a system, subsystem, division, component, device, or variable is

(continued)

BASES

SR 2.0.4 (continued)

outside its specified limits, the associated SR(s) are not required to be performed per SR 2.0.1, which states that Surveillances do not have to be performed on equipment that has been determined to not meet the LCO. When equipment does not meet the LCO, SR 2.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the specified Frequency does not result in an SR 2.0.4 restriction to changing specified conditions of the Applicability. However, since the LCO is not met in this instance, LCO 2.0.4 will govern any restrictions that may (or may not) apply to specified condition changes.

The provisions of SR 2.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 2.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of an SFSC.

The precise requirements for performance of SRs are specified such that exceptions to SR 2.0.4 are not necessary. The specific time frames and conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite condition(s) specified in a Surveillance procedure require entry into the specified condition in the Applicability of the associated LCO prior to the performance or completion of a Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific conditions needed are met. Alternately, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further discussion of the specific formats of SRs' annotation is found in Section 1.4, Frequency.

B 2.1 SFSC Integrity

B 2.1.1 Multi-Purpose Canister (MPC)

BASES

BACKGROUND

An OVERPACK with an empty MPC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Certificate of Compliance. A lid is then placed on the MPC. The OVERPACK and MPC are raised to the top of the spent fuel pool surface. The OVERPACK and MPC are then moved into the cask preparation area where dose rates are measured and the MPC lid is welded to the MPC shell and the welds are inspected and tested. The water is drained from the MPC cavity and vacuum drying is performed. The MPC cavity is backfilled with helium and leakage tested. Additional dose rates are measured and the MPC vent and drain cover plates and closure ring are installed and welded. Inspections are performed on the welds. The OVERPACK lid is installed and secured. The annulus space between the MPC and OVERPACK is drained, vacuum dried and backfilled with helium gas. The OVERPACK seals are tested for leakage. Contamination measurements are completed prior to moving the OVERPACK and MPC to the ISFSI.

MPC cavity vacuum drying is utilized to remove residual moisture from the MPC fuel cavity after the MPC has been drained of water. Any water that has not drained from the fuel cavity evaporates from the fuel cavity due to the vacuum. This is aided by the temperature increase due to the temperature of the fuel and by the heat added to the MPC from the optional warming pad, if used.

After the completion of vacuum drying, the MPC cavity is backfilled with helium to a pressure greater than atmospheric pressure.

(continued)

BASES (continued)

BACKGROUND (continued)

Backfilling of the MPC fuel cavity with helium promotes gaseous heat dissipation and the inert atmosphere protects the fuel cladding. Providing a helium pressure greater than atmospheric pressure at room temperature (70°F), eliminates air in-leakage over the life of the MPC because the cavity pressure rises due to heat up of the confined gas by the fuel decay heat during storage. In-leakage of air could be harmful to the fuel. Prior to moving the SFSC to the storage pad, the MPC helium leak rate is determined to ensure that the fuel is confined.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in the MPC is ensured by the multiple confinement boundaries and systems. The barriers relied on are the fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the MPC in which the fuel assemblies are stored. Long-term integrity of the fuel and cladding depend on storage in an inert atmosphere. This is accomplished by removing water from the MPC and backfilling the cavity with an inert gas at a positive pressure (> 1 atm). The thermal analyses of the MPC assume that the MPC cavity is filled with dry helium.

LCO

A dry, helium filled and sealed MPC establishes an inert heat removal environment necessary to ensure the integrity of the multiple confinement boundaries. Moreover, it also ensures that there will be no air in-leakage into the MPC cavity that could damage the fuel cladding over the storage period.

APPLICABILITY

The dry, sealed and inert atmosphere is required to be in place during TRANSPORT OPERATIONS and STORAGE OPERATIONS to ensure both the confinement barriers and heat removal mechanisms are in place during these operating

(continued)

BASES

APPLICABILITY (continued)

periods. These conditions are not required during LOADING OPERATIONS or UNLOADING OPERATIONS as these conditions are being established or removed, respectively during these periods in support of other activities being performed with the stored fuel.

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each SFSC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each MPC not meeting the LCO. Subsequent SFSCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the cavity vacuum drying pressure limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the potential quantity of moisture left within the MPC cavity. Since moisture remaining in the cavity during these modes of operation may represent a long-term degradation concern, immediate action is not necessary. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

A.2

Once the quantity of moisture potentially left in the MPC cavity is determined, a corrective action plan shall be developed and implemented to the extent necessary to return the MPC to an analyzed condition. Since the quantity of moisture estimated

(continued)

BASES

ACTIONS

A.2 (continued)

under Required Action A.1 can range over a broad scale, different recovery strategies may be necessary. Since moisture remaining in the cavity during these modes of operation may represent a long-term degradation concern, immediate action is not necessary. The Completion Time is sufficient to develop and complete the corrective actions commensurate with the safety significance of the CONDITION.

B.1

If the helium backfill pressure limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the helium pressure within the MPC cavity. Since too much helium in the MPC cavity during these modes represents a potential overpressure concern, an engineering evaluation shall be performed in a timely manner. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

B.2

Once the helium pressure in the MPC cavity is determined, a corrective action plan shall be developed and initiated to the extent necessary to return the MPC to an analyzed condition. Since the helium pressure estimated under Required Action B.1 can range over a broad scale, different recovery strategies may be necessary. Since elevated helium pressures existing in the MPC cavity represent potential overpressure concerns, corrective actions should be developed and implemented in a timely manner. The Completion Time is sufficient to develop and complete the corrective actions commensurate with the safety significance of the CONDITION.

(continued)

BASES

ACTIONS (continued)

C.1

If the helium leak rate limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the potential leak rate and quantity of helium remaining within the cavity. The significance of the situation is mitigated by the existence of the OVERPACK containment boundary. Since an increased helium leak rate represents a potential challenge to MPC heat removal and the off-site doses calculated in the TSAR confinement analyses, reasonably rapid action is warranted. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

C.2

Once the cause and consequences of the elevated leak rate from the MPC are determined, a corrective action plan shall be developed and initiated to the extent necessary to return the MPC to an analyzed condition. Since the recovery mechanisms can range over a broad scale, based on the evaluation performed under Required Action C.1, different recovery strategies may be necessary. Since an elevated helium leak rate represents a challenge to heat removal rates and off-site doses, reasonably rapid action is required. The Completion Time is sufficient to develop and complete the corrective actions commensurate with the safety significance of the CONDITION.

(continued)

BASES

ACTIONS (continued)

D.1

If the MPC fuel cavity cannot be successfully returned to a safe, analyzed condition, the fuel must be placed in a safe condition in the spent fuel pool. The Completion Time is reasonable based on the time required to move the OVERPACK to the cask preparation area, perform fuel cooldown operations, re-flood the MPC, cut the MPC lid welds, move the TRANSFER CASK into the spent fuel pool, remove the MPC lid, and remove the spent fuel assemblies in an orderly manner and without challenging personnel.

SURVEILLANCE REQUIREMENTS

SR 2.1.1.1, SR 2.1.1.2, and SR 2.1.1.3

The long-term integrity of the stored fuel is dependent on storage in a dry, inert environment. Cavity dryness is demonstrated by evacuating the cavity to a very low absolute pressure and verifying that the pressure is held over a specified period of time. A low vacuum pressure is an indication that the cavity is dry. Having the proper helium backfill pressure ensures adequate heat transfer from the fuel to the fuel basket and surrounding structure of the MPC. Meeting the helium leak rate limit ensures there is adequate helium in the MPC for long term storage and the leak rate assumed in the confinement analyses remains bounding for off-site dose.

All three of these surveillances must be successfully performed during LOADING OPERATIONS to ensure that the conditions are established for TRANSPORT OPERATIONS and STORAGE OPERATIONS which preserve the analysis basis supporting the cask design.

REFERENCES

1. FSAR Sections 4.4, 7.2, 7.3 and 8.1

B 2.1 SFSC Integrity

B 2.1.2 OVERPACK

BASES

BACKGROUND

An OVERPACK with an empty MPC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Certificate of Compliance. A lid is then placed on the MPC. The OVERPACK and MPC are raised to the top of the spent fuel pool surface. The OVERPACK and MPC are then moved into the cask preparation area where dose rates are measured and the MPC lid is welded to the MPC shell and the welds are inspected and tested. The water is drained from the MPC cavity and vacuum drying is performed. The MPC cavity is backfilled with helium and leakage tested. Additional dose rates are measured and the MPC vent and drain cover plates and closure ring are installed and welded. Inspections are performed on the welds. The OVERPACK lid is installed and secured. The annulus space between the MPC and OVERPACK is drained, vacuum dried and backfilled with helium gas. The OVERPACK seals are tested for leakage. Contamination measurements are completed prior to moving the OVERPACK and MPC to the ISFSI.

Vacuum drying of the annulus between the MPC and the OVERPACK is performed to remove residual moisture from the annulus after it has been drained of water. Water that has not drained from the annulus evaporates from the annulus due to the vacuum. This is aided by the temperature increase due to the temperature of the fuel and by the heat added to the MPC from the optional warming pad, if used.

(continued)

BASES

BACKGROUND (continued)

Backfilling of the OVERPACK annulus with helium promotes heat transfer from the MPC to the OVERPACK structure. Providing a helium pressure greater than atmospheric pressure ensures that there will be no in-leakage of air over the life of the SFSC. In-leakage of air could degrade the heat transfer features of the SFSC. Prior to moving the SFSC to the storage pad, the OVERPACK annulus helium leak rate is determined to ensure that sufficient helium remains to provide adequate heat transfer.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in the MPC is ensured by the multiple confinement boundaries and systems. The barriers relied on are the fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the MPC in which the fuel assemblies are stored. No confinement credit is taken for the OVERPACK boundary. Long-term integrity of the spent fuel depends on the ability of the SFSC to reject heat to the environment. This is accomplished, in part, by retaining helium in the annulus between the MPC and the OVERPACK. By removing water from the annulus, the boiling of residual water and associated pressurization of the annulus during storage at the ISFSI is avoided. Backfilling the annulus with an inert gas optimizes the ability of the SFSC to transfer heat from the MPC to the OVERPACK. In addition, the thermal analyses assume that the annulus is filled with dry helium.

LCO

A dry, helium filled and sealed OVERPACK annulus establishes an inert cooling space necessary to ensure heat rejection to the environment. Moreover, it also ensures that there will be no air in-leakage into the annulus that could negatively affect heat transfer.

(continued)

BASES (continued)

APPLICABILITY

The dry, sealed and inert atmosphere is required to be in place during TRANSPORT OPERATIONS and STORAGE OPERATIONS to ensure a heat transfer mechanism is in place during these operating periods. These conditions are not required during LOADING OPERATIONS or UNLOADING OPERATIONS as these conditions are being established or removed, respectively during these periods in support of other activities being performed with the stored MPC.

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each SFSC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each MPC not meeting the LCO. Subsequent SFSC's that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the OVERPACK annulus vacuum drying pressure limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the potential quantity of moisture left within the annulus. Since moisture remaining in the annulus during these modes of operation may represent a long-term degradation concern, immediate action is not necessary. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

A.2

Once the quantity of moisture potentially left in the OVERPACK annulus is determined, a corrective action plan shall be developed and actions completed to return the SFSC to an analyzed condition. Since the quantity of moisture estimated under Required Action A.1 can range over a broad

(continued)

BASES

ACTIONS (continued)

A.2 (continued)

scale, different recovery strategies may be necessary. Since moisture remaining in the annulus during these modes of operation represents a long-term degradation concern, immediate action is not necessary. The Completion Time is sufficient to develop and complete the corrective actions commensurate with the safety significance of the CONDITION.

B.1

If the helium backfill pressure limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the quantity of helium within the OVERPACK annulus. Since abnormal quantities of helium in the annulus during these modes represents a minimal impact, immediate action is not necessary. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

B.2

Once the quantity of helium in the annulus is determined, a corrective action plan shall be developed and initiated to the extent necessary to return the SFSC to an analyzed condition. Since the quantity of helium estimated under Required Action B.1 can range over a broad scale, different recovery strategies may be necessary. Since abnormal quantities of helium in the annulus during these modes represents a minimal impact, immediate action is not necessary. The Completion Time is sufficient to develop and initiate the corrective actions commensurate with the safety significance of the CONDITION.

(continued)

BASES

ACTIONS (continued)

C.1

If the OVERPACK helium leak rate limit has been determined not to be met during TRANSPORT OPERATIONS or STORAGE OPERATIONS, an engineering evaluation is necessary to determine the potential leak rate and quantity of helium remaining within the annulus. The significance of the situation is mitigated by the existence of the MPC confinement boundary. Since abnormal leak rates from the annulus during these modes represents a minimal impact, immediate action is not necessary. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

C.2

Once the cause and consequences of the elevated leak rate from the OVERPACK are determined, a corrective action plan shall be developed and initiated to the extent necessary to return the MPC to an analyzed condition. Since the recovery mechanisms can range over a broad scale, based on the evaluation performed under Required Action C.1, different recovery strategies may be necessary. Since abnormal leak rates from the annulus during these modes represents a minimal impact, immediate action is not necessary. The Completion Time is sufficient to develop and initiate the corrective actions commensurate with the safety significance of the CONDITION.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS

SR 2.1.2.1, SR 2.1.2.2, and SR 2.1.2.3

The long-term integrity of the stored fuel is dependent, in part, on adequate heat transfer from the stored fuel to the environment. OVERPACK annulus dryness is demonstrated by evacuating the annulus to a very low absolute pressure and verifying that the pressure is held over a specified period of time. A low vacuum pressure is an indication that the annulus is dry. Having the proper helium backfill pressure ensures adequate heat transfer from the MPC to the OVERPACK structure. Meeting the helium leak rate limit ensures there is adequate helium in the annulus for long term storage.

All three of these surveillances must be successfully performed during LOADING OPERATIONS to ensure that the conditions are established for TRANSPORT OPERATIONS and STORAGE OPERATIONS which preserve the analysis basis supporting the cask design.

REFERENCES

1. FSAR Sections 4.4, 7.2, 7.3 and 8.1

B 2.1 SFSC INTEGRITY

B 2.1.3 SFSC Lifting Requirements

BASES

BACKGROUND

A loaded SFSC is transported between the loading facility and the ISFSI using a transporter. The SFSC may be handled in either the horizontal or vertical orientation depending on the site cask handling limitations. The height to which the SFSC is lifted is limited to ensure that the structural integrity of the SFSC is not compromised should the SFSC be dropped.

For lifting of the loaded OVERPACK using devices which are integral to a structure governed by 10CFR Part 50 regulations, 10CFR50 requirements apply.

APPLICABLE SAFETY ANALYSIS

The structural analyses of the SFSC demonstrate that the drop of a loaded SFSC from the Technical Specification height limits to a surface having the characteristics described in the Appendix B to Certificate of Compliance 72-1008 will not compromise SFSC integrity or cause physical damage to the contained fuel assemblies.

LCO

Limiting the SFSC lifting height during TRANSPORT OPERATIONS maintains the operating conditions of the SFSC within the design and analysis basis. The maximum lifting height is a function of the SFSC design and the orientation that the SFSC is carried. The lifting height requirements are specified in LCO 2.1.3.a for the vertical and horizontal orientations.

Appendix B to Certificate of Compliance 72-1008 provides the characteristics of the drop surface assumed in the analyses. As required by 10 CFR 72.212(b)(3), each licensee must "...determine whether or not the reactor site parameters...are enveloped by the cask design bases..." Therefore, licensees must evaluate the storage pad and, if applicable, the site transport route to assure that they are bounded by the features specified in the CoC.

(continued)

BASES

LCO (continued)

Alternatively, LCO 2.1.3.b allows the use of lifting devices designed in accordance with ANSI N14.6 and having redundant drop protection design features. If a suitably designed lifting device is used, dropping the SFSC is not considered credible, and the lift heights of LCO 2.1.3.a do not apply.

Alternatively, LCO 2.1.3.c allows for site-specific transport conditions which are not encompassed by those of LCO 2.1.3.a or 2.1.3.b. Under this alternative, the licensee shall evaluate the site-specific conditions to ensure that drop accident loads do not exceed 60 g's. This alternative analysis shall be commensurate with the analysis which forms the basis for LCO 2.1.3.a.

APPLICABILITY

The APPLICABILITY is modified by a note which states that the LCO is not applicable while the transporter is in the FUEL BUILDING or is being handling by a device providing support from underneath. The first part of the note is acceptable based on the relatively short duration of time TRANSPORT OPERATIONS take place in the FUEL BUILDING. This LCO does not apply if the SFSC is supported from underneath (e.g., air pads, heavy haul trailer or rail car) because the OVERPACK is not being lifted and a drop accident is not credible.

This LCO is applicable outside of the FUEL BUILDING during TRANSPORT OPERATIONS when the SFSC is being lifted or otherwise suspended above the surface below. This includes movement of the SFSC while suspended from a transporter (i.e., a vertical crawler). It is not applicable during STORAGE OPERATIONS since the SFSC is not considered lifted.

(continued)

BASES (continued)

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each SFSC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each SFSC not meeting the LCO. Subsequent SFCSs that don't meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If none of the SFSC lifting requirements are met, immediate action must be initiated and completed expeditiously to comply with one of the three lifting requirements in order to preserve the SFSC design and analysis basis.

SURVEILLANCE REQUIREMENTS

SR 2.1.3.1

The SFSC lifting requirements of LCO 2.1.3 must be verified to be met after the SFSC is suspended from, or secured in the transporter and prior to the transporter beginning to move the SFSC to or from the ISFSI. This ensures potential drop accidents during TRANSPORT OPERATIONS are bounded by the drop analyses.

For compliance with LCO 2.1.3.a, lifting heights are to be measured from the lowest surface on the OVERPACK to the potential impact surface.

REFERENCES

1. FSAR, Sections 3.4.10, 8.1, and 8.3

B 2.1 SFSC INTEGRITY

B 2.1.4 Fuel Cool-Down

BASES

BACKGROUND

In the event that an MPC must be unloaded, the OVERPACK with its enclosed MPC is returned to the cask preparation area to begin the process of fuel unloading. The MPC closure ring, and vent and drain port cover plates are removed. The MPC gas is sampled to determine the integrity of the spent fuel cladding. The MPC is attached to the Cool-Down System. The Cool-Down System is a closed-loop forced ventilation gas cooling system that cools the fuel assemblies by cooling the surrounding helium gas.

Following fuel cool-down, the MPC is then re-flooded with water and the MPC lid weld is removed leaving the MPC lid in place. The OVERPACK and MPC are placed in the spent fuel pool and the MPC lid is removed. The fuel assemblies are removed from the MPC and the MPC and transfer cask are removed from the spent fuel pool and decontaminated.

Reducing the fuel cladding temperatures significantly reduces the temperature gradients across the cladding thus minimizing thermally-induced stresses on the cladding during MPC re-flooding. Reducing the MPC internal temperatures eliminates the risk of high MPC pressure due to sudden generation of steam during re-flooding.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in the MPC is ensured by the multiple confinement boundaries and systems. The barriers relied on are the fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the MPC in which the fuel assemblies are stored. Long-term integrity of the fuel and cladding depend on minimizing thermally-induced stresses to the cladding.

(continued)

BASES

APPLICABLE SAFETY ANALYSIS (continued)	This is accomplished during the unloading operations by lowering the MPC internal temperatures prior to MPC re-flooding. The Integrity of the MPC depends on maintaining the internal cavity pressures within design limits. This is accomplished by reducing the MPC internal temperatures such that there is no sudden formation of steam during MPC re-flooding. (Ref. 1).
LCO	Monitoring the circulating MPC gas exit temperature ensures that there will be no large thermal gradient across the fuel assembly cladding during re-flooding which could be potentially harmful to the cladding. The temperature limit specified in the LCO was selected to ensure that the MPC gas exit temperature will closely match the desired fuel cladding temperature prior to re-flooding the MPC. The temperature was selected to be lower than the boiling temperature of water with an additional margin.
APPLICABILITY	The MPC helium gas exit temperature is measured during UNLOADING OPERATIONS after the OVERPACK and integral MPC are back in the FUEL BUILDING and are no longer suspended from, or secured in, the transporter. Therefore, the Fuel Cool-Down LCO does not apply during TRANSPORT OPERATIONS and STORAGE OPERATIONS. A note has been added to the APPLICABILITY for LCO 2.1.4 which states that the LCO is only applicable during wet UNLOADING OPERATIONS. This is acceptable since the intent of the LCO is to avoid uncontrolled MPC pressurization due to water flashing during re-flooding operations. This is not a concerning for dry UNLOADING OPERATIONS.
ACTIONS	A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each MPC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for

(continued)

BASES

ACTIONS (continued)

each MPC not meeting the LCO. Subsequent MPCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the MPC helium gas exit temperature limit is not met, actions must be taken to restore the parameters to within the limits before re-flooding the MPC. Failure to successfully complete fuel cool-down could have several causes, such as failure of the cool down system, inadequate cool down, or clogging of the piping lines. The Completion Time is sufficient to determine and correct most failure mechanisms and proceeding with activities to flood the MPC cavity with water are prohibited.

A.2

If the LCO is not met, in addition to performing Required Action A.1 to restore the gas temperature to within the limit, the user must ensure that the proper conditions exist for the transfer of heat from the MPC to the surrounding environs to ensure the fuel cladding remains below the short term temperature limit. If the OVERPACK is located in a relatively open area such as a typical refuel floor, no additional actions are necessary. However, if the OVERPACK is located in a structure such as a decontamination pit or fuel vault, additional actions may be necessary depending on the heat load of the stored fuel.

Three acceptable options for ensuring adequate heat transfer for a OVERPACK located in a pit or vault are provided below, based on an MPC loaded with fuel assemblies with design basis heat load in every storage location. Users may develop other alternatives on a site-specific basis, considering actual fuel loading and decay heat generation.

(continued)

BASES

ACTIONS

A.2 (continued)

1. Ensure the annulus between the MPC and the OVERPACK is filled with water. This places the system in a heat removal configuration which is bounded by the FSAR thermal evaluation of the system assuming a vacuum in the MPC. The annulus is open to the ambient environment which limits the temperature of the ultimate heat sink (the water in the annulus) and, therefore, the MPC shell to 212° F.

2. Remove the OVERPACK from the pit or vault and place it in an open area such as the refuel floor with a reasonable amount of clearance around the cask and not near a significant source of heat.

3. Supply nominally 1000 SCFM of ambient (or cooler) air to the space inside the vault at the bottom of the OVERPACK to aid the convection heat transfer process. This quantity of air is sufficient to limit the temperature rise of the air in the cask-to-vault annulus to approximately 60° F at design basis maximum heat load while providing enhanced cooling of the cask by the forced flow.

Twenty-four hours is an acceptable time frame to allow for completion of Required Action A.2 based on a thermal evaluation of a OVERPACK located in a pit or vault. Eliminating all credit for passive cooling mechanisms with the cask emplaced in the vault, the thermal inertia of the cask (in excess of 20,000 Btu/° F) will limit the rate of adiabatic temperature rise with design basis maximum heat load to less than 4° F per hour. Thus, the fuel cladding temperature rise in 24 hours will be less than 100° F. Large short term temperature margins exist to preclude any cladding integrity concerns under this temperature rise.

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 2.1.4.1

The long-term integrity of the stored fuel is dependent on the material condition of the fuel assembly cladding. By minimizing thermally-induced stresses across the cladding the integrity of the fuel assembly cladding is maintained. The integrity of the MPC is dependent on controlling the internal MPC pressure. By controlling the MPC internal temperature prior to re-flooding the MPC there is no formation of steam during MPC re-flooding.

The MPC helium exit gas temperature limit ensures that there will be no large thermal gradients across the fuel assembly cladding during MPC re-flooding and no formation of steam which could potentially overpressurize the MPC.

Fuel cool down must be performed successfully on each SFSC before the initiation of MPC re-flooding operations to ensure the design and analysis basis are preserved.

REFERENCES

1. FSAR, Sections 4.4.1, 4.5.1.1.4, and 8.3.2.

B 2.2 SFSC Radiation Protection

B 2.2.1 OVERPACK Average Surface Dose Rates

BASES

BACKGROUND	The regulations governing the operation of an ISFSI set limits on the control of occupational radiation exposure and radiation doses to the general public (Ref. 1). Occupational radiation exposure should be kept as low as reasonably achievable (ALARA) and within the limits of 10CFR Part 20. Radiation doses to the public are limited for both normal and accident conditions.
APPLICABLE SAFETY ANALYSIS	The OVERPACK average surface dose rates are not an assumption in any accident analysis, but are used to ensure compliance with regulatory limits on occupational dose and dose to the public.
LCO	The limits on OVERPACK average surface dose rates are based on the shielding analysis of the HI-STAR 100 System (Ref. 2). The limits were selected to minimize radiation exposure to the general public and maintain occupational dose ALARA to personnel working in the vicinity of the SFSCs.
APPLICABILITY	The average OVERPACK surface dose rates apply during TRANSPORT OPERATIONS and STORAGE OPERATIONS. Radiation doses during STORAGE OPERATIONS are monitored for the OVERPACK by the SFSC user in accordance with the plant-specific radiation protection program required by 10CFR72.212(b)(6).

(continued)

BASES (continued)

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each SFSC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each SFSC not meeting the LCO. Subsequent SFSCs that don't meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the OVERPACK average surface dose rates are not within limits, it could be an indication that a fuel assembly was inadvertently loaded into the MPC that did not meet the specifications in Appendix B of the Certificate of Compliance. Administrative verification of the MPC fuel loading, by means such as review of video recordings and records of the loaded fuel assembly serial numbers, can establish whether a mis-loaded fuel assembly is the cause of the out of limit condition. The Completion Time is based on the time required to perform such a verification.

A.2

If the OVERPACK average surface dose rates are not within limits, and it is determined that the MPC was loaded with the correct fuel assemblies, an analysis may be performed. This analysis will determine if the OVERPACK dose rates would result in the ISFSI offsite or occupational doses exceeding regulatory limits in 10 CFR Part 20 or 10 CFR Part 72.

B.1

If it is verified that the correct fuel was not loaded or that the ISFSI offsite radiation protection requirements of 10 CFR Part 20 or 10 CFR Part 72 will not be met with the OVERPACK average surface dose rates above the LCO limit, the fuel

(continued)

BASES

ACTIONS (continued)

assemblies must be placed in a safe condition in the spent fuel pool. The Completion Time is reasonable based on the time required to move the SFSC to the cask preparation area, perform fuel cooldown operations, re-flood the MPC, cut the MPC lid welds, move the SFSC into the spent fuel pool, remove the MPC lid, and remove the spent fuel assemblies in an orderly manner and without challenging personnel.

SURVEILLANCE REQUIREMENTS

SR 2.2.1.1

This SR is modified by two notes. The first note requires dose rate measurements to be taken after the MPC has been vacuum dried. This ensures that the dose rates measured are indicative of minimal shielding conditions with no shielding provided by the water in the MPC. The second note requires the OVERPACK average surface dose rates to be measured by performing this SR after receipt, and prior to storage if the OVERPACK was loaded at an off-site facility and transported to another facility for storage. This provides assurance that dose rates remain within the LCO limits after handling and transporting the OVERPACK between sites.

This SR ensures that the OVERPACK average surface dose rates are within the LCO limits prior to moving the SFSC to the ISFSI. Surface dose rates are measured approximately at the locations indicated on Figure 2.2.1-1 following standard industry practices for determining average dose rates for large containers. Measurements at approximate locations to those shown on Figure 2.2.1-1 are acceptable provided the radial steel channel members are avoided.

REFERENCES

1. 10 CFR Parts 20 and 72.
2. FSAR Sections 5.1 and 8.1.6.

B 2.2 SFSC Radiation Protection

B 2.2.2 SFSC Surface Contamination

BASES

BACKGROUND	An SFSC is immersed in the spent fuel pool in order to load the spent fuel assemblies. As a result, the surface of the SFSC may become contaminated with the radioactive material in the spent fuel pool water. This contamination is removed prior to moving the SFSC to the ISFSI in order to minimize the radioactive contamination to personnel or the environment. This allows dry fuel storage activities to proceed without additional radiological controls to prevent the spread of contamination and reduces personnel dose due to the spread of loose contamination or airborne contamination. This is consistent with ALARA practices.
APPLICABLE SAFETY ANALYSIS	The radiation protection measures implemented at the ISFSI are based on the assumption that the exterior surfaces of the SFSC's have been decontaminated. Failure to decontaminate the surfaces of theSFSC's could lead to higher-than-projected occupational doses and potential site contamination.
LCO	Removable surface contamination on the OVERPACK exterior surfaces and accessible surfaces of the MPC is limited to 1000 dpm/100 cm^2 from beta and gamma sources and 20 dpm/100 cm^2 from alpha sources. These limits are taken from the guidance in IE Circular 81-07 (Ref. 2) and are based on the minimum level of activity that can be routinely detected under a surface contamination control program using direct survey methods. Only loose contamination is controlled, as fixed contamination will not result from the SFSC loading process. Experience has shown that these limits are low enough to prevent the spread of contamination to clean areas and are significantly less than the levels which would cause significant personnel skin dose.

(continued)

BASES

LCO (continued)	LCO 2.2.2 requires removable contamination to be within the specified limits for the exterior surfaces of the OVERPACK and accessible portions of the MPC. The location and number of surface swipes used to determine compliance with this LCO are determined based on standard industry practice and the user's plant-specific contamination measurement program for objects of this size. Accessible portions of the MPC means the upper portion of the MPC external shell wall accessible after the inflatable annulus seal is removed and before the annulus shield ring is installed. The user shall determine a reasonable number and location of swipes for the accessible portion of the MPC. The objective is to determine a removable contamination value representative of the entire upper circumference of the MPC, while implementing sound ALARA practices.
APPLICABILITY	The requirements of this LCO must be met during TRANSPORT OPERATIONS and STORAGE OPERATIONS to minimize the potential for spreading contamination. Measurement of the OVERPACK and MPC surface contamination is unnecessary during UNLOADING OPERATIONS as surface contamination would have been measured prior to moving the subject TRANSFER CASK to the ISFSI.
ACTIONS	A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each TRANSFER CASK. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each TRANSFER CASK not meeting the LCO. Subsequent TRANSFER CASKs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

(continued)

BASES

ACTIONS (continued)

A.1

If the removable surface contamination of an SFSC that has been loaded with spent fuel is not within the LCO limits, action must be initiated to decontaminate the SFSC and bring the removable surface contamination within limits. The Completion Time of 7 days is appropriate given that surface contamination does not affect the safe storage of the spent fuel assemblies.

SURVEILLANCE REQUIREMENTS

SR 2.2.2.1

This SR is modified by a note which requires the SFSC surface contamination to be measured by performing this SR after receipt, and prior to storage if the OVERPACK was loaded at an off-site facility and transported to another facility for storage. This provides assurance that contamination levels remain within the LCO limits after handling and transporting the OVERPACK between sites.

This SR verifies that the removable surface contamination on the OVERPACK and accessible portions of the MPC is less than the limits in the LCO. The Surveillance is performed using smear surveys to detect removable surface contamination. The Frequency requires performing the verification during LOADING OPERATIONS in order to confirm that the SFSC can be moved to the ISFSI without spreading loose contamination.

REFERENCES

1. FSAR Sections 8.1.5 and 8.1.6.
2. NRC IE Circular 81-07.

APPENDIX 12.B

COMMENT RESOLUTION LETTERS

FOR THE REVIEW OF THE HI-STAR 100 SPENT FUEL STORAGE CASK SYSTEM

(95 Pages Including this Page)

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Subject: HI-STAR 100 Topical Safety Analysis Report, Revision 7 Comments Resolution

Reference: USNRC Docket No. 72-1008
Holtec Project 5014; Comment Resolution Letter No. 1

Dear Mr. Delligatti:

In accordance with the July 8, 1998 telephone conference, Holtec International herein submits the resolutions to the NRC's comments which were agreed to during the discussions. The proposed resolutions will be incorporated into the next revision of the HI-STAR 100 Topical Safety Analysis Report (TSAR) following completion of the Safety Evaluation Report (SER). As appropriate, additional materials will be submitted to the NRC to support SER preparation activities.

CRITICALITY

NRC Comment

Specify a minimum ^{10}B loading for the MPC-68 Boral.

Holtec Resolution

The appropriate Design Drawings, Bills-of-Material, criticality analyses, principal design criteria, technical specifications, and general discussions in the TSAR will be revised to specify that the minimum ^{10}B areal density for the MPC-68 fuel basket is 0.0372g/cm^2. Specifically, Figures 2.1.2, 6.2.1, and 12.3.3 will be deleted.

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NRC Comment

Revise the criticality chapter to provide greater clarity that the double contingency requirement of 10CFR72 is met.

Holtec Resolution

Holtec will revise the criticality chapter to specifically state and conclude that double contingency requirements of 10CFR72 are met.

SHIELDING

NRC Comment

The NRC requires the input files for the SAS2H runs.

Holtec Resolution

Holtec will provide the NRC with copies of the SAS2H input files on July 10, 1998.

NRC Comment

Revise shield model diagrams to provide appropriately dimensioned figures.

Holtec Resolution

Holtec will revise the MCNP figures (Figures 5.3.1 through 5.3.6) in the shielding chapter to provide the required dimensional information. Revised draft figures will be submitted to the NRC by July 22, 1998 to facilitate the final shield design review.

NRC Comment

Provide additional justification for the dose rates proposed as acceptance criteria in Technical Specification 12.3.7, and for the 20 percent margin on acceptance criteria in Technical Specification 12.3.22.

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Holtec Resolution

Technical Specifications 12.3.7 and 12.3.22 will be revised to provide justified dose rate acceptance criteria.

STRUCTURAL

NRC Issue

The NRC requested that the two outermost intermediate shells of the HI-STAR 100 overpack be fabricated with full penetration welds on all longitudinal and circumferential welds.

Holtec Resolution

Holtec will revise the HI-STAR 100 overpack Design Drawings to specify that full penetration welds will be used in the fabrication of the two outermost intermediate shells, and their assembly to the top flange and bottom plate. Revised draft Design Drawings will be submitted to the NRC by July 17, 1998, to confirm these changes.

NRC Comment

Revise the acceptance criteria for the MPC closure weld volumetric examination to specify ASME Code, Section III, Subsection NB, Article NB-5332 rather than reference the Technical Specification.

Holtec Resolution

The MPC Design Drawings will be revised to specify the volumetric examination acceptance criteria for the MPC lid-to-shell weld to be in accordance with ASME Code Section III, Subsection NB, Article NB-5332. The confinement chapter, acceptance test and maintenance program chapter, and the Technical Specifications, shall also be revised to reflect the change in the weld acceptance criteria.

The revised draft Design Drawings will be submitted to the NRC by July 17, 1998 to confirm the change.

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NRC Comment

The NRC requested that the note specifying "No ASME Stamp Required" be deleted, as it is not required to be so stated.

Holtec Resolution

The appropriate Design Drawings will be revised to delete the statement "No ASME Stamp Required". The revised Design Drawings will be submitted to the NRC by July 17, 1998 to confirm this change.

NRC Comment

The NRC requested that the MPC lid handling lifting holes be deleted to prevent the possibility of a user attempting to lift a fully loaded MPC by these holes which are not designed for the full loaded MPC.

Holtec Resolution

The lid handling lifting holes were provided for lid handling only. To ensure an inappropriate lift using these holes does not occur, the Design Drawings will be revised to remove the four 5/8" lid lifting holes. All MPC lid and loaded MPC handling will be performed using the four centrally located holes. The operations and structural chapters will also be revised to reflect this change. The revised draft Design Drawings will be submitted to the NRC by July 17, 1998 to confirm this change.

NRC Comment

The optional weld detail for outer enclosure plate welding as shown on Design Drawing No. 1399, Sheet 2, is not an acceptable weld design.

Holtec Resolution

Design Drawing No. 1399, Sheet 2, will be revised to delete the optional enclosure plate weld detail. The revised draft Design Drawings will be submitted to the NRC by July 17, 1998, to confirm the change.

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NRC Comment

The NRC advised that the acceptable weld stress for the basket plate-to-plate welds should be evaluated at $0.42S_u$ rather than $0.72\ S_u$ based on the visual examination (VT) performed to assure weld acceptability.

Holtec Resolution

The basket weld design for each MPC type will be revised to reflect an allowable weld stress based on $0.42\ S_u$. The Design Drawings will be revised to reflect the new weld dimensions. The basket analyses in the structural chapter will also be revised to reflect the modified basket weld design.

The revised draft Design Drawings will be submitted to the NRC by July 17, 1998 to confirm this change.

NRC Comment

The NRC requested clarification on the dimensions of the outer cut-out on the bottom of the HI-STAR 100 overpack closure plate.

Holtec Resolution

The Design Drawings will be revised to clarify the dimensional requirements for the closure plate cut-out. The revised draft Design Drawings will be submitted to the NRC by July 17, 1998 to confirm this change.

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THERMAL

NRC Comment

The NRC requested clarification for the term "Cryogenic Steel" in Table 4.2.2.

Holtec Resolution

The term Cryogenic Steel refers to the type of materials utilized for the HI-STAR 100 overpack inner shell, top flange, bottom plate, and closure plate. The material for the inner shell is SA203-E and for the forged components SA350-LF3. Table 4.2.2 will be revised to add "(SA203-E and SA350-LF3)" after the term "Cryogenic Steel".

NRC Comment

The NRC requested clarification on the fuel cladding temperatures in Table 4.4.11 for the MPC-68. The table currently presents that the maximum temperature exceeds the design temperature.

Holtec Resolution

Holtec confirms that the design temperature value in Table 4.4.11 should be 749°F, not 720° F as reported. The maximum calculated fuel cladding temperature of 741°F is therefore below the correct design temperature value.

Holtec will revise Table 4.4.11 to reflect the correct fuel cladding design temperature, 749°F, for BWR fuels.

NRC Comment

The NRC requested clarification of whether the maximum fuel cladding temperatures reported in Tables 4.4.9 through 4.4.11 corresponded to the applicable peak temperature curve for the hottest rod plotted in Figures 4.4.20 through 4.4.22 for each canister/fuel type.

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Holtec Resolution

Holtec confirms that the peak temperatures reported in Figures 4.4.20 through 4.4.22 are the same as those listed in Tables 4.4.9 through 4.4.11, except that the temperatures on the figures are in °K, and the tables report the temperature in °F.

The other issues and comments raised by the NRC SFPO staff during the July 8, 1998 conference will be discussed and clarified in meetings scheduled for July 10 and July 21, 1998. As further issues are resolved, Holtec International will submit future comment resolution letters.

If you have any questions or comments on the information provided, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing
Holtec Document I.D.: 5014188

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

Dr. K.P. Singh, Ph.D., PE
President and CEO

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Concurrences

Criticality:	[signature]	Dr. J. Wagner
Shielding:	[signature]	Dr. E. Redmond
Structural	[signature]	Dr. A. I. Soler
Thermal:	E Rosenbaum for I Rampall	Dr. I. Rampall

Distribution

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Mr. Rodney Pickard	American Electric Power	70851
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July 13, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: HI-STAR 100 Topical Safety Analysis Report, Revision 7 Comments Resolution

Reference: USNRC Docket No. 72-1008
Holtec Project 5014; Comment Resolution Letter No. 2

Dear Mr. Delligatti:

In accordance with the July 10, 1998 meetings at NRC headquarters on shielding and structural issues, Holtec International herein submits the resolutions to the NRC's comments which were agreed to during the discussions. The proposed resolutions will be incorporated into the next revision of the HI-STAR 100 Topical Safety Analysis Report (TSAR) following completion of the draft Safety Evaluation Report (SER). As appropriate, additional materials will be submitted to the NRC to support SER preparation activities as detailed below.

SHIELDING

NRC Comment

The NRC requested a copy of the SAS2H input files and that the files be incorporated in hard copy format in the shielding calculation package, Holtec Report HI-951322, HI-STAR 100 Shielding Design and Analysis for Transport and Storage.

Holtec Resolution

The SAS2H input files were supplied to the NRC on disk and hardcopy during the meeting held on July 10, 1998 and a hard copy of the input files will be added to the shielding calculation package, Holtec Report HI-951322. Upon completion of the comment resolution, the final shielding calculation package shall be submitted to the NRC.

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NRC Comment

The NRC requested that Tables 2.1.1 and 2.1.2 be revised or additional tables be provided to list each fuel assembly type within a fuel assembly class evaluated and authorized for storage in the HI-STAR 100 System. Also, the nomenclature used for the fuel assembly types should be consistent with the Energy Information Administration Service Report SR/CNEAF/96-01, "Spent Nuclear Fuel Discharges from U.S. Reactors".

Holtec Resolution

Tables 2.1.1 and 2.1.2 will be revised to list the fuel assembly class. Two additional tables, 2.1.12 and 2.1.13, will be provided in Section 2.1 of the TSAR to list the fuel types under each class specified. Tables 2.1.1, 2.1.2, 2.1.12, and 2.1.13 will use nomenclature consistent with the Energy Information Administration Service Report SR/CNEAF/96-01, "Spent Nuclear Fuel Discharges from U.S. Reactors". The revised and new tables will list each fuel assembly type evaluated and authorized for storage in the HI-STAR 100 System.

NRC Comment

The NRC requested that along with the total radiation source specified in Chapter 12 as the technical specification limit for gamma and neutron radiation sources, the corresponding spectrums should also be specified.

Holtec Resolution

Chapter 12 will be revised to include the corresponding spectrum for each radiation source specified as a technical specification limit. Chapter 5 will also be revised to conform with the revision to Chapter 12.

NRC Comment

The NRC requested that the discussion of the determination of the design basis fuel assembly type in Section 5.2 be expanded to provide additional information. The section should include an evaluation of each of the fuel assembly types, and the criteria used to evaluate each fuel type.

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Holtec Resolution

Section 5.2 will be revised to include a more in depth discussion of the criteria used to evaluate the different fuel assembly types and to incorporate the results of the evaluation for each fuel assembly type considered. The fuel assembly types evaluated will be consistent with the fuel assembly types listed in Tables 2.1.1, 2.1.2, 2.1.12, and 2.1.13.

NRC Comment

The NRC requested that Subsection 12.3.22 for shielding effectiveness testing be revised to add the requirement that the dose rate be equal to or less than 125 mrem/hr at the mid-point of the cask and less than or equal to 350 mrem/hr above and below the neutron shield.

Holtec Resolution

The Technical Specification in Subsection 12.3.22 will be revised to add the requirement that the dose rate be equal to or less than 125 mrem/hr at the mid-point of the cask, and less than or equal to 350 mrem/hr above and below the neutron shield.

NRC Comment

The NRC requested that the statistical error for the dose rate calculations reported in Chapter 5 be stated in Chapter 5.

Holtec Resolution

Chapter 5 will be revised to state the statistical error for the dose rate calculations.

NRC Comment

The NRC requested that the MPC lid dose rates specified in Subsection 12.3.7 be revised to correspond with the calculated dose rates provided in Chapter 5, and the shielding calculation package, Holtec Report HI-951322, HI-STAR 100 Shielding Design and Analysis for Transport and Storage.

Holtec Resolution

The MPC lid dose rates specified in Subsection 12.3.7 will be revised to correspond with the calculated dose rates provided in Chapter 5, and the shielding calculation package, HI-951322, HI-STAR 100 Shielding Design and Analysis for Transport and Storage.

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NRC Comment

The NRC requested that the neutron source calculation and its distribution should reflect the axial variation in burnup of the fuel assembly in lieu of being calculated based on the bundle average burnup and distributed based on the axial burnup profile.

Holtec Resolution

Chapter 5 will be revised to account for the effect of the axial variation in burnup on the total neutron source and its distribution.

NRC Comment

The NRC requested that the reference, [2.1.3], be revised to explicitly cite the location of the burnup profile in the referenced proceedings and that the reference, [2.1.4], be provided to the NRC.

Holtec Resolution

Reference [2.1.3] will be revised to explicitly cite the location of the burnup profile in the referenced proceedings, and reference [2.1.4] as provided in Enclosure A to this letter.

NRC Comment

The NRC requested that Subsection 5.2.4 be revised to include an example of a typical control component and the corresponding fuel assembly radiation source which is required to allow the storage of the fuel assembly with the control component.

Holtec Resolution

Subsection 5.2.4 will be revised to include an example of a typical control component and the corresponding fuel assembly radiation source which is required to allow the storage of the fuel assembly with the control component.

NRC Comment

The NRC requested that Subsection 5.4.4 be revised to provide additional discussion to support the reasoning for comparing the MOX and stainless steel clad fuel sources with the design basis fuel assembly sources based on a per inch basis (i.e., source per inch).

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Holtec Resolution

Additional information will be provided in Subsections 5.4.4 and 5.4.5 to document the reasoning for comparing the MOX and stainless steel clad fuel radiation sources with the design basis fuel assembly source based on a per inch basis (i.e., source per inch). As the MOX and stainless steel clad fuel assemblies are shorter than the design basis fuel assembly (zircaloy clad UO_2 fuel), the total radiation source for the fuel assembly may be less than the design basis fuel assembly, but the radiation source per inch may be higher - potentially causing the mid-point dose of the cask to be higher than calculated. By evaluating the fuel assembly on a source-per-inch basis the evaluation ensures that the mid-point dose rate of the cask while storing MOX or stainless steel fuel clad assemblies will not be higher than that calculated with the design basis fuel (zircaloy clad UO_2 fuel).

STRUCTURAL

NRC Comment

The NRC requested that the welds for the two outermost intermediate shells be inspected by dye penetrant (PT) or magnetic particle (MT) examination methods in addition to the currently specified visual examination (VT).

Holtec Resolution

In accordance with Holtec's Comment Resolution Letter No. 1, the two outermost intermediate shells will be fabricated and assembled to the HI-STAR 100 overpack utilizing full penetration welds. Currently, the Design Drawings specify VT for all welds, and additionally, PT or MT on the intermediate shell welds to the top flange and bottom plate forgings. The Design Drawings will be revised to specify performance of PT examinations on the remaining circumferential and longitudinal welds of the two outermost intermediate shells (Item Nos. 15 and 16 on Design Drawing No 1397, Sheet 1). The draft revised Design Drawings will be submitted to the NRC by July 17, 1998, to confirm these changes.

NRC Comment

The NRC requested clarification on the methods utilized in the TSAR to determine fabrication stresses in the HI-STAR 100 overpack weldment. Requested method be based on 1/4 symmetry rather than 1/2 symmetry as utilized in Appendix 3.L of the TSAR.

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Holtec Resolution

Following discussion by Dr. A. Soler of Holtec on the assumptions and finite element analysis methodology utilized in Appendix 3.L to calculate the residual fabrication stresses in each of the shells, the NRC advised that the method currently utilized in the TSAR by Holtec is acceptable to the NRC staff. No further action is required.

NRC Comment

The NRC advised of concerns regarding the weld design and analyses of the Damaged Fuel Container (DFC) reported in Appendix 3.B of the TSAR.

Holtec Resolution

Holtec advised the NRC staff that the weld design and analyses for the DFC in Appendix 3.B will be revised to utilize appropriate weld efficiency factors. The revised analyses will also incorporate a change in the acceptance criteria from the currently specified NUREG-0612 criteria to an acceptance criteria in accordance with Regulatory Guide 3.61 of lifting of 3X on yield and 5X on ultimate of the DFC, as the load to be lifted is not a critical lift as defined in NUREG-0612.

The revised Appendix 3.B analyses will be incorporated into the TSAR at the completion of the draft SER.

NRC Comment

The NRC requested that Holtec perform local buckling analyses for the MPC fuel baskets at 60g's in accordance with NUREG-6322 and show that the required safety factor is met.

Holtec Resolution

The current MPC fuel basket analyses in Appendices 3.N, 3.P, and 3.R of the TSAR for the three fuel basket designs includes a buckling analyses performed in accordance with the ASME Code, Section III, Subsection NG. To assist in the NRC's review, these appendices will be revised to provide an improved discussion on the description of the current global buckling analysis models, assumptions, and results. Additionally, a local buckling analysis per NUREG/CR-6322 will be performed and incorporated into the TSAR to show that the required safety factors to local basket buckling are met for the maximum design deceleration (60g's).

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The revised buckling analyses will be submitted to the NRC's staff for review by July 22, 1998 as draft TSAR Revision 8 pages to assist the NRC in final HI-STAR 100 SER preparation activities.

NRC Comment

The NRC advised of concerns regarding the safety factors for the engagement of the Lifting Trunnions to the HI-STAR 100 top flange forging. A minimum safety factor of six on yield is required to assure the requirements of NUREG-0612 are met.

Holtec Resolution

Holtec advised the NRC staff that the lifting trunnion-to-top flange forging engagement was designed to meet Reg. Guide 3.61 criteria of 3X the lifted load compared to yield, including an appropriate dynamic load factor. Based on this criteria, the current lifting trunnions have safety factors of >5X on bearing stress and >3.3X on thread shear. However, to resolve NRC concerns, Holtec will revise the design of the lifting trunnions to increase the length of trunnion thread engagement to the top flange forging, and will increase the threaded diameter of the trunnion (e.g., the change will not affect the external handling diameter of the lifting trunnion). The revised trunnion design will then be analyzed to assure that a minimum safety factor of 6 is achieved for both bearing stress and thread shear. In the analyses, the appropriate code will be utilized (e.g., ASME Code, Section III, Subsection NF). A justifiable lifting point will be utilized in the analysis.

The revised lifting trunnion design will be incorporated into the Design Drawings, and the draft revised Design Drawings will be submitted to the NRC by July 17, 1998. Additionally, the revised lifting trunnion load analyses will be submitted to the NRC as draft TSAR Revision 8 pages by July 22, 1998 to close-out this item and facilitate draft SER preparation.

NRC Comment

The NRC staff advised Holtec that Holtec Report No. HI-971779, "Benchmarking of the Holtec LS-DYNA3D Model for Cask Drop Events," September 1997, has been generally accepted by the staff for the evaluation of drop and tip-over events. The NRC staff will accept the tip-over for the HI-STAR 100 cask if a rigid body bounding case is evaluated and a filtering frequency of 350 Hz is utilized, as in the Lawrence Livermore National Laboratory (LLNL) reports. If the deceleration value exceeds the current design criteria for the HI-STAR 100 of 60g's, the higher deceleration value will be required to be evaluated in the fuel basket analyses.

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Holtec Response

Holtec advised the staff that the appropriate analyses of the HI-STAR 100 tip-over event will be performed and the decelerations will be determined using a cut-off filtering frequency of 350 Hz as used by LLNL.

Following conclusion of the meeting, Holtec identified that the requested analysis is already included in the TSAR in Appendix 3.A, Section 3.A.7, and the results are reported in Table 3.A.3 as the bounding case. These results were determined based on a filtering frequency of 350 Hz. The maximum deceleration reported for the top of the cask is 61.84 g's and for the top of the fuel basket is 56.0 g's. Therefore, the current TSAR includes the requested analyses, and the resulting maximum deceleration for the top of the basket is below the current design criteria of 60 g's utilized in the basket and cask structural analyses. Appendix 3.A shall be revised to delete the tip-over analysis performed with a filter frequency below 350 Hz.

It is requested that the NRC staff review the above proposed resolutions and advise Holtec International of any comments or questions. As new issues are identified by the NRC staff, Holtec International personnel will be available to meet or discuss the remaining issues to assure the current SER schedule is maintained.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing
Document I.D.: 5014190
Enclosure A: Commonwealth Edison Company, Letter No. NFS-BND-95-083, Chicago, Illinois

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Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

K.P. Singh, Ph.D., PE
President and CEO

Concurrences:

Shielding: John C. Wagner for E. Redmond — Dr. Everett Redmond

Structural: Gary Tjersland for — Dr. A.I. Soler

Distribution:

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Mr. Stan Miller	Vermont Yankee Corporation	

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SENT BY FedEx

July 16, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: 1. USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 3

References: 1. Holtec International Letter, B. Gilligan to M. Delligatti, USNRC, dated July 9, 1998

2. Holtec International Letter, B. Gilligan to M. Delligatti, USNRC, dated July 13, 1998

Dear Mr. Delligatti:

In accordance with the previous commitments to revise the HI-STAR 100 Design Drawings to incorporate NRC's structural comments, enclosed for your review are three (3) sets of the revised Design Drawings. The Design Drawings were revised to incorporate the specific changes as identified in the Reference 1 and 2 comment resolution letters. In addition, the drawings have also been revised to incorporate minor changes to facilitate HI-STAR 100 fabrication resulting from the continuing HI-STAR 100 Prototype Fabrication Project.

The structural analyses for the revised trunnion engagement design and the revised basket plate weld dimensions will be submitted for NRC review by July 22, 1998.

The enclosed revised Design Drawings will be incorporated into the subject HI-STAR 100 TSAR following issuance of the draft SER.

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The enclosed Design Drawings contain information which is commercially sensitive to Holtec International and is treated by us with strict confidentiality. This information is of the type described in 10CFR2.790(b)(4). The enclosed affidavit sets forth the basis for which the information is required to be withheld by the NRC from further disclosure, consistent with the considerations and pursuant to the provisions of 10CFR2.790(b)(1). It is therefore requested that the proprietary enclosures be withheld from disclosure in accordance with regulatory review requirements.

If you have any comments or questions, please do not hesitate to contact me.

Sincerely yours,

Gary T. Tjersland
Director of Licensing and Product Development

Document I.D.: 5014193

Approval:

K.P. Singh, Ph.D., PE
President and CEO

Enclosures:

Revised HI-STAR 100 Design Drawings, Three Sets, consisting of the following:

- 5014-1395 Sht. 1/4 HI-STAR 100 MPC-24 Construction, Rev. 9
- 5014-1395 Sht. 2/4 HI-STAR 100 MPC-24 Construction, Rev. 9
- 5014-1395 Sht. 3/4 HI-STAR 100 MPC-24 Construction, Rev. 9
- 5014-1396 Sht. 1/6 HI-STAR 100 MPC-24 Construction, Rev. 9
- 5014-1396 Sht. 2/6 HI-STAR 100 MPC-24 Construction, Rev. 9
- 5014-1396 Sht. 3/6 HI-STAR 100 MPC-24 Construction, Rev. 9

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Mr. Mark Delligatti
USNRC
July 16, 1998
Page 3

- 5014-1397 Sht. 1/7 — Cross Sectional View of HI-STAR 100 Overpack, Rev. 12
- 5014-1397 Sht. 2/7 — Detail of Top Flange & Bottom Plate of HI-STAR 100 Overpack, Rev. 10
- 5014-1397 Sht. 3/7 — Detail of Bolt Hole & Bolt of HI-STAR 100 Overpack, Rev. 10
- 5014-1397 Sht. 4/7 — Detail of Closure Plate Test Port and Name Plate Detail of HI-STAR 100 Overpack, Rev. 11
- 5014-1397 Sht. 5/7 — Detail of Lifting Trunnion & Locking Pad of HI-STAR 100 Overpack, Rev. 8
- 5014-1398 Sht 1/3 — HI-STAR 100 Overpack Orientation, Rev. 12
- 5014-1399 Sht. 1/3 — Section "G" - "G" of HI-STAR 100 Overpack, Rev. 8
- 5014-1399 Sht. 2/3 — Section "X"-"X" & View "Y" of HI-STAR 100 Overpack, Rev. 8
- 5014-1399 Sht. 3/3 — Detail of Trunnion Pocket Forging of HI-STAR 100 Overpack, Rev. 9
- 5014-1401 Sht. 1/4 — HI-STAR 100 MPC-68 Construction, Rev. 10
- 5014-1401 Sht. 2/4 — HI-STAR 100 MPC-68 Construction, Rev. 8
- 5014-1401 Sht. 3/4 — HI-STAR 100 MPC-68 Construction, Rev. 9
- 5014-1402 Sht. 1/6 — HI-STAR 100 MPC-68 Construction, Rev. 10
- 5014-1402 Sht. 2/6 — HI-STAR 100 MPC-68 Construction, Rev. 10
- 5014-1402 Sht. 3/6 — HI-STAR 100 MPC-68 Construction, Rev. 9
- 5014-1763 Sht 1/1 — HI-STAR 100 Assembly, Rev. 3
- BM-1476 Sht 1/2 — Bills-of-Material for HI-STAR 100 Overpack, Rev. 11
- BM-1476 Sht 2/2 — Bills-of-Material for HI-STAR 10 Overpack, Rev. 11
- BM-1478 Sht 2/2 — Bills-of-Material for 24-Assembly HI-STAR 100 PWR MPC, Rev. 10
- BM-1479 Sht. 2/2 — Bills-of-Material for 68-Assembly HI-STAR 100 BWR MPC, Rev. 10

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July 22, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 4

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with the discussions at the July 21, 1998 meeting at the NRC headquarters on shielding, criticality, structural, and confinement issues, Holtec International herein submits this resolution to the NRC's comments which were agreed to during the discussions. The proposed resolutions will be incorporated into the next revision of the HI-STAR 100 TSAR following completion of the draft SER. As appropriate, additional material will be forwarded to the NRC staff to support SER preparation activities as detailed below.

SHIELDING

NRC Comment

The NRC staff requested that the Technical Specifications for fuel selection be based on burnup and minimum cooling time curves or limits, rather than by reference to source terms. The use of source terms and enrichment should be used only in the bases of the Technical Specifications to justify the burnup and cooling times.

The NRC also requested that in developing the burnup and cooling time limits, that Holtec address conservative (low) enrichment levels for each of the fuel types (PWR and BWR) for the burnup ranges considered. The final curve also needs to include the effect of control components in the stored fuel assemblies.

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Holtec Response

Holtec will prepare final burnup and cooling times curves (and source terms in Chapter 5) using conservatively selected enrichment levels to show that the shield analyses in Chapter 5 are conservative. The final enrichment levels will be identified and justified in the revised analyses. The revised analyses will also confirm the bounding fuel assembly by comparing the source terms of the various classes of PWR assemblies (e.g., 15x15, 16x16, 17x17) and BWR assemblies (e.g., 7x7, 8x8, 9x9, etc.). The results of the revised shielding/source term analyses will be evaluated for impacts on the occupational and off-site dose assessments in Chapter 10 of the TSAR.

The revised source term and dose analyses will be submitted to the NRC (including revised SAS2H and ORIGEN-S input and output files) by end of business day on July 27, 1998.

CRITICALITY

NRC Comment

The NRC requested that Holtec revise the Technical Specifications to be explicitly consistent with the fuel parameters listed in Table 6.2.1.

Holtec Response

Due to the large number of minor variations in fuel assembly dimensions, the use of explicit dimensions in the Technical Specifications could severely limit the applicability of the HI-STAR 100 System. To resolve this limitation, Holtec committed to preparing bounding criticality analyses for each class of fuel assembly for both fuel types (PWR and BWR). The bounding criticality analyses will justify more general Technical Specifications for fuel parameters.

For each array size (e.g., 17x17, 16x16, etc.) the fuel assemblies will be subdivided into a number of classes, where a class will be defined in terms of pitch and number and locations of guide tubes (PWR) or water rods (BWR). For each assembly class, calculations will be performed for all of the dimensional variations for which we have data. These calculations will demonstrate that the maximum reactivity corresponds to:

- maximum active fuel length
- maximum fuel pellet O.D.

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- minimum cladding O.D.
- maximum cladding I.D.
- minimum guide tube/water rod thickness
- maximum channel thickness (for BWR assemblies only)

Therefore, an artificial bounding assembly will be defined based on the above characteristics and a calculation for the bounding assembly will be performed to demonstrate compliance with the regulatory requirement of keff < 0.95.

As a result of this analysis, the Technical Specifications will define acceptability in terms of these bounding parameters. The following table provides an example of the proposed Technical Specifications for one PWR assembly class (all dimensions are in inches).

Array size	17x17
Number of fuel rods	264
Number of guide tubes	25
Fuel rod pitch	0.496
Maximum pellet O.D.	0.3088
Minimum cladding O.D.	0.360
Maximum cladding I.D.	0.3150
Minimum guide tube/water rod thickness	0.0160
Cladding material	Zr
Maximum active fuel length	150
Maximum enrichment (wt% U-235)	4.0

Holtec will submit all revised criticality analyses results, and the list of fuel assemblies (and parameters) analyzed by end of business day on July 27, 1998.

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NRC Comment

The NRC requested that the Technical Specification enrichment limit for the 6x6 Dresden 1 BWR assembly be limited to the enrichment level analyzed in the TSAR.

Holtec Response

Holtec will revise the Technical Specifications to limit the 6x6 Dresden Unit 1 enrichment level to the value analyzed. In a clarification to a previous comment resolution regarding B-10 loadings, the B-10 loading for the MPC-68F will be listed as 0.0089 g/cm^2 (limited to Dresden Unit 1 and Humboldt Bay damaged fuel and fuel debris). For all other MPC-68 canisters, the B-10 loading will be set at 0.0372 g/cm^2 as currently shown on the Design Drawings and Bill-of-Material. As previously committed, the curve of minimum B-10 loading for BWR fuel assembly contents will be deleted from the TSAR.

STRUCTURAL

NRC Comment

The NRC requested the location in the TSAR of the internal MPC lifting lug (used for handling an empty MPC) load analyses.

Holtec Response

The calculation for the MPC internal lifting lug analyses is attached for your information. The analyses will be incorporated in Chapter 3 of the TSAR upon completion of the SER.

CONFINEMENT

Holtec Resolution

To clarify storage confinement requirements for damaged fuel assemblies (e.g., fuel assemblies with defects no greater than pinhole leaks or hairline cracks), and fuel debris (e.g., loose fuel pellets, and ruptured and severed rods), Holtec will revise the definitions in the TSAR. There will be no changes in the confinement analyses (Chapter 7) as a result of this change.

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To close out previous structural comments, the following revised analyses and appendices are submitted for NRC review and information:

- Section 3.4: Modification to pages 3.4-5, 3.4-8, and 3.4-24. Complete section reprinted due to page number change.
- Appendix 3A: Tipover Analyses (proprietary): revised to clarify bounding analysis with filtering at 350 Hz.
- Appendix 3.M: Revised basket weld analyses to reflect the revised weld stress allowable and to list the minimum weld size for the Design Drawings.
- Appendix 3.D: Revised lifting trunnion load analyses to meet NUREG-0612 safety factors of 6 on yield.
- Appendix 3.K: Revised MPC lid lifting analysis to reflect deletion of MPC lid lifting holes
- Appendix 3.B: Damaged Fuel Container analyses revised to analyze shear stress per NRC comment and to reflect revised lifting safety factors of 3 and 5. .
- Calculations supporting Revision 8: Revised basket buckling analyses and basket plate weld size calculations.

The enclosed Appendix 3.A contains information which is commercially sensitive to Holtec International and is treated by us with strict confidentiality. This information is of the type described in 10CFR2.790(b)(4). The enclosed affidavit sets forth the basis for which the information is required to be withheld by the NRC from further disclosure, consistent with the considerations and pursuant to the provisions of 10CFR2.790 (b)(1). It is therefore requested that the proprietary enclosure be withheld from disclosure in accordance with regulatory review requirements.

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If you have any comments or questions, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014196

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

K.P. Singh, Ph.D., PE
President and CEO

Concurrences

Dr. Everett Redmond (Shielding Analysis):

Dr. John Wagner (Criticality Analyses):

Dr. Alan Soler (Structural Analysis):

Ms. Joy Russell (Confinement Analysis):

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July 27, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 5

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with the Holtec/NRC telephone conference call of July 22, 1998, and Holtec's Comment Resolution Letter No. 4 of July 22, 1998, enclosed are the following revised analyses:

- Proposed revisions to TSAR Chapter 6 providing revised criticality results for all listed PWR and BWR fuel assemblies defined by assembly classes.
- Proposed revisions to the TSAR Chapter 5 providing revised shielding source terms and dose rates based on utilizing conservatively low fuel enrichment levels. Also included are revised SAS2H and ORIGEN-S input files for the source term analysis.
- Draft Appendix 12.A containing the revised Limiting Conditions of Operation and Technical Specifications for the HI-STAR 100 System. The draft Appendix 12.A replaces Section 12.3 of the current TSAR. These Technical Specifications have been prepared in the format of the Integrated Technical Specifications.

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Draft Revision 8 of Chapters 5, 6, and 12 will be submitted incorporating the enclosed materials by August 3, 1998, and will be incorporated into the TSAR by August 21, 1998.

In response to the NRC's request for Additional Information (RAI) on Holtec Report No. HI-971779, "Benchmarking of the Holtec LS-DYNA3D Model for Cask Drop Events", transmitted on July 24, 1998, Attachment 1 provides Holtec's detailed responses. As a result of RAIs, a minor revision to the benchmark report was completed and is provided as Attachment 2.

The attached revised pages to Holtec Report HI-971779 contain information which is commercially sensitive to Holtec International and is treated by us with strict confidentiality. This information is of the type described in 10CFR2.790(b)(4). The enclosed affidavit sets forth the basis for which the information is required to be withheld by the NRC from further disclosure, consistent with the considerations and pursuant to the provisions of 10CFR2.790(b)(1). It is, therefore, requested that the proprietary attachment be withheld from disclosure in accordance with regulatory review requirements.

If you have any comments or questions, please do not hesitate to contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014198

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

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Concurrences

Dr. Everett Redmond (Shielding Analysis):	[signature]
Dr. John Wagner (Criticality Analyses):	[signature]
Dr. Alan Soler (Structural Analysis):	[signature]
Mr. B. Gutherman(Technical Specifications)	[signature]

Enclosures:

1. Revised TSAR Chapter 6 pages and tables (four copies)
2. Revised TSAR Chapter 5 pages and tables. (four copies)
3. Draft Appendix 12.A - Technical Specifications (four copies)
4. Original Affidavit per 10CFR2.790

Attachments:
1. Holtec Responses to NRC RAI, dated July 24, 1998 (four copies)
2. Revised pages to Holtec Report No. HI-971779 (three copies)

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July 29, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 6

Reference: Holtec Project 5014

Dear Mr. Delligatti:

As a result of revisions made in Chapter 5 to the source terms and the subsequent change in dose rates, Chapters 7, Confinement, and 10, Radiation Protection, were revised. These two chapters are provided herein as Enclosure 1 and 2, respectively, to assist the NRC in the completion of the draft SER. The change in the bounding fuel assembly source term required the calculations summarized in Chapter 7 to be revised. The revision resulted in an increase in the dose at the controlled area boundary under accident conditions, but as shown in the chapter the dose is well below the regulatory limit. The collective dose reported in Chapter 10 changes slightly due to the revised distribution of the neutron radiation and the revised source terms. Chapters 7 and 10 are provided as proposed Revision 8 chapters. These chapters will be provided with Revision 8 to the HI-STAR TSAR to be submitted to the NRC by August 21, 1998.

Enclosure 3 provides the final page changes to the Technical Specifications submitted by the Holtec Comment Resolution Letter No. 5, dated July 27, 1998. Enclosure 3 also includes a draft Certificate of Compliance for your review. To facilitate the NRC's review a disk which contains the Technical Specifications with the page changes incorporated and the draft Certificate of Compliance is provided as requested.

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If you have any comments or questions, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014200

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

Concurrences

Dr. Everett Redmond (Shielding Analysis): ______

Ms. Joy Russell (Confinement Analyses): ______

Mr. B. Gutherman (Technical Specifications): ______

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July 30, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 7

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with the discussions on July 28, 1998 with the SFPO staff on structural issues, Holtec International herein submits this information in response to the NRC's comments. The resolution of these issues will be incorporated into the next revision of the HI-STAR 100 TSAR on August 21, 1998. As required, additional material is enclosed to support SER preparation activities by the NRC staff.

STRUCTURAL

NRC Comment

The NRC staff requested that Holtec provide analysis of the overpack structure at an ambient temperature of –40°F with a loaded MPC. The analysis should consider the most critical thermal gradients in the overpack. Show that the stresses in the overpack are within allowable values and that the closure will not be breached.

Holtec Response

Subsection 3.4.5 discusses the effects on the HI-STAR 100 System as a result of the cold condition (i.e., an ambient temperature of –40°F). The subsection explains that the thermal gradient for the hot ambient (80°F) with maximum fuel decay heat load is the same as the gradient for the cold ambient (-40°F) with maximum decay heat load. Additionally, as the ambient temperature decreases from 80°F to -40°F, the absolute temperature of the helium contained in the cask decreases. In accordance with the Ideal Gas Law, a decrease in the absolute temperature of the helium will produce a proportional reduction in the internal pressure. Since

the stresses under normal storage conditions arise principally from pressure and thermal gradients, it follows that the stress field for the overpack under -40°F ambient would be bounded by the stress field for the overpack under 80°F ambient.

Under the 80°F ambient temperature and the maximum fuel decay heat load, the thermal analysis in Chapter 4 reports the resultant component temperatures. These temperatures were used in Appendices 3.U and 3.W to demonstrate that there was no restraint of free thermal expansion for the MPC-24 and MPC-68 in the HI-STAR overpack. Under the postulated cold ambient temperature of -40°F, the component temperatures will decrease by 80°F minus -40°F or a ΔT of 120°F. Thermal expansion is calculated from the product of the coefficient of thermal expansion, α, and the change in temperature, ΔT. Since the changes in temperature in each component would decrease by 120°F, the resultant thermal expansion would also decrease. This is coupled with the fact that the coefficient of thermal expansion for carbon steel and stainless steel decreases as the temperatures are decreased. Therefore, if the analyses performed in Appendicies 3.U and 3.W demonstrate that there is no restraint of free thermal expansion, analysis performed at component temperatures 120°F less (to account for the cold ambient temperature, -40°F) would also show that there is no constraint of free thermal expansion. The operational clearances predicted in Appendices 3.U and 3.W are a conservative lower bound on the clearances with the ambient temperature corresponding to extreme cold conditions. This discussion has been added to Subsection 3.4.5 which is provided as Attachment 1 to this letter for your information.

To demonstrate that the cold ambient temperature, -40°F, does not affect the closure bolt sealing a new appendix (Appendix 3.AE) will be added to Revision 8 of the HI-STAR TSAR. Appendix 3.AE follows the guidance of NUREG-6007 and is provided as Attachment 2 to this letter. The appendix shows that the closure bolt load decreases by 3.5%. This small decrease in the bolt load will have no effect on the seal and the retention of the helium within the overpack cavity.

NRC Comment

The NRC requested that Holtec provide analysis of the overpack during the fire accident condition. Show that the overpack will not leak helium gas during and after the fire accident.

Holtec Response

Load Case 02 in Table 3.1.5 investigates the effect of fire accident temperatures (T*) and accident internal pressure (P_i*) from a structural point of view.

The status of the joint seal between the overpack closure plate and top flange is acertained by "compression springs" which simulate the O-ring gaskets. The seal is verified by checking the status of these spring elements. If contact between the closure plate and top flange is maintained (indicated by a compressive load in the "compression spring"), then the integrity of the seal is determined to have been maintained. The overpack closure bolts are modeled with beam elements (BEAM4). The top of the beam elements represents the bolt head and are connected to the closure plate. The bottom of the beam elements represents the threaded region of the bolt and are connected to nodes of elements representing the top flange. The bolt pre-load is applied to the overpack model by applying an initial strain to the beam elements representing the bolts.

The results presented in Appendix 3.AB, Table 3.AB.2, report that the "LANDSTAT" value that tracks the status of the compression spring remains "0" for all bolt elements. This establishes that the seal remains intact under the fire accident conditions.

Additionally, Appendix 3.AF (a new appendix also enclosed with this letter as Attachment 3) performs a stress analysis of the closure bolts under the fire accident temperatures and demonstrates that sufficient bolt load is maintained to ensure the integrity of the seal. For this condition, the bolt load decreases by 11.5% from the pre-load condition; however, a large margin exists against unloading of the bolt. The temperature of the main flange is 524°F as reported in Table 11.2.2 in Chapter 11. Appendix 3.AF will be included in Revision 8 to the HI-STAR TSAR.

It should be noted that after extinguishing a postulated fire, the licensee is directed by the fire accident corrective actions, Subsection 11.2.3.4, to verify the continued presence of the helium atmosphere within the overpack cavity. The analysis summarized above demonstrates that the seals will maintain their integrity during and after the postulated fire accident. However, to provide defense in depth and to ensure the safe operation of the HI-STAR 100 System, the overpack cavity helium atmosphere will be required to be verified as a corrective action following the fire accident condition.

If you have any comments or questions, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014201

Attachments:
1. HI-STAR 100 TSAR, Subsection 3.4.5 (4 copies)
2. HI-STAR 100 TSAR, Appendix 3.AE (4 copies)
3. HI-STAR 100 TSAR, Appendix 3.AF (4 copies)

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

Concurrences

Dr. Alan Soler (Structural Analysis): Alan Soler

Dr. Indresh Rampall (Thermal Analysis): Indresh Rampall

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BY FAX AND HAND DELIVERY

July 30, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 8

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with discussions held with the SFPO staff, Holtec International herein submits this information in response to the NRC's comments. The resolution of these issues will be incorporated into the next revision of the HI-STAR 100 TSAR on August 21, 1998. As required, additional material is enclosed to support SER preparation activities by the NRC staff. Specifically provided as attachments to this letter are Chapters 2, 5, and 6. In each revised chapter, the changes are annotated with a revision bar in the margin.

SHIELDING

NRC Comment

The NRC requested that the textual discussions describing the shielding information submitted by Holtec Comment Resolution Letter No. 5 dated July 27, 1998 be provided to the SFPO to facilitate the SER preparation. Additionally, it was requested that a discussion be provided regarding the determination of the design basis fuel assembly type and the allowable burnup and cooling time values.

Holtec Response

The revised Chapter 5 (without appendices), Shielding Evaluation, is provided in its entirety as Attachment 1 to this letter. The chapter includes all the revised tables previously submitted by Holtec Comment Resolution Letter No. 5 dated July 27, 1998.

In the HI-STAR 100 TSAR Revision 7, the design basis BWR fuel assembly was specified as the GE 8x8R. This determination was based on the knowledge that according to the EIA Service Report "Spent Nuclear Fuel Discharges from U.S. Reactors, 1994", the last discharge of a 7x7

fuel assembly was in 1985 and the maximum average burnup for a 7x7 during their operation was 29,000 MTW/MTU. This clearly indicates that the 7x7 fuel assemblies in storage are well within burnup and cooling times specified in the Technical Specifications of Chapter 12.

Under the approach taken in the HI-STAR TSAR Revision 7, each licensee would be required to verify that the source term for the fuel assemblies to be stored are equal to or less than the values specified in the TSAR. This approach is in accordance with NUREG-1536 and the most recent North Anna Technical Specifications, which specify a neutron and radiation source term. Therefore, this approach ensures that the design basis radiation source term would not be exceeded.

Subsequent to the submittal of the HI-STAR TSAR Revision 7, the SFPO requested that explicit source term calculations be performed for the bounding fuel assembly type in each array size. The source term for each array type was performed at the same burnup, cooling time, and enrichment. Holtec chose to include the GE 7x7 in this evaluation in the interest of conservatism. Also included in this analysis was the GE-12, a 10x10 array. Revision 7 of the HI-STAR TSAR only authorized the SVEA-96 10x10 array. The GE-12 was included at the request of a number of utilities. The source term evaluation for BWR determined that the GE 7x7 was bounding and that the new GE-12 was second. Rather than specifying a separate technical specification limit on the GE 7x7 burnup and cooling time, the GE 7x7 was maintained as the bounding assembly.

The SFPO requested that the source terms be recalculated with lower enrichments to provide additional conservatism. The HI-STAR TSAR Revision 7 was based on a radiation source term technical specification. Therefore, the minimum enrichment is not a factor because each licensee would be required to verify that the fuel to be stored would meet the design basis radiation source term specified in Chapter 12. However, to comply with the SFPO's request Holtec recalculated the source terms based on lower enrichments. This resulted in an increase in the decay heat and radiation source at any given burnup and cooling time. To maintain an equivalent decay heat and radiation source to that used in Revision 7 of the HI-STAR TSAR it was necessary to decrease the allowable burnup at each cooling time.

In the HI-STAR TSAR Revision 7, control components were included by requiring the licensee to ensure that the design basis source term was not exceeded when the source term from the control component is added to the source term of the fuel assembly. The SFPO requested that Holtec determine the bounding control component, a corresponding bounding source term, and the required fuel assembly burnup and cooling to ensure that the fuel assembly source coupled with the control component source is within the design basis. This data was not readily available

and could not be developed in the allotted time. Therefore, control components were removed from the scope of this license. Control components will be added in a future amendment.

CRITICALITY

NRC Comment

The NRC requested that the textual discussions describing the criticality information submitted by Holtec Comment Resolution Letter No. 5 dated July 27, 1998 be provided to the SFPO to facilitate the SER preparation.

Holtec Response

An overview of the revision of Chapter 6, Criticality Evaluation, has been composed and provided as Attachment 2. This document details the changes made to the chapter, as well as, the process used to determine the bounding fuel dimensions for use in the Technical Specifications.

The revised Chapter 6 (without appendices) is provided in its entirety as Attachment 3.

GENERAL

NRC Comment

The NRC requested that any revisions that were required to Chapter 2, Principal Design Criteria, be provided to the SFPO staff to facilitate SER preparation.

Holtec Response

The revised Chapter 2 is provided in Attachment 1. Sections 2.0 and 2.1 are provided in their entirety. The pages that required revision in Sections 2.2 through 2.6 are also provided.

If you have any comments or questions, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014202

Attachments:
1. HI-STAR 100 TSAR, Chapter 5 (4 copies)
2. Overview of the Revision to HI-STAR 100 TSAR, Chapter 6 (4 copies)
3. HI-STAR 100 TSAR, Chapter 6 (4 copies)
4. HI-STAR 100 TSAR, Chapter 2 (4 copies)
5. Revised Pages for the Technical Specifications (4 copies)

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

Concurrences

Dr. Everett Redmond (Shielding Analysis):

Dr. John Wagner (Criticality Analysis):

Distribution (Letter Only):

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Mr. Ken Phy	New York Power Authority	80518
Mr. David Larkin	Washington Public Power Supply System	
Mr. Eric Meils	Wisconsin Electric Power Company	
Mr. Paul Plante	Maine Yankee Atomic Power Company	
Mr. Stan Miller	Vermont Yankee Corporation	
Mr. Jim Clark	SONGS	
Mr. Ray Kellar	ANO	

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SENT BY Fax and FedEx

August 4, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1018
HI-STAR 100 Topical Safety Analysis Report
Comment Resolution Letter No. 9

Reference: Holtec Project 5014

Dear Mr. Delligatti:

As we discussed yesterday, this comment resolution letter is being submitted to provide several corrected pages to the HI-STAR 100 TSAR resulting from changes to the criticality, shielding, and thermal analyses which were completed to resolve NRC comments. Enclosed please find four (4) copies each of the following:

- Table 2.1.5 – This table was revised to list the GE12/14 10x10 (Class 10x10A) and B&W 15x15 (Class 15x15F) as the design basis fuel assemblies for reactivity control for BWR and PWR fuel types, respectively. This table now corresponds to the revised criticality results in Chapter 6 of the TSAR.

- Tables 2.1-1 (pages 2.0-6 and 2.0-7 of the Technical Specifications in Chapter 12) – These tables of the Functional and Operating Limits were revised to place specific minimum cooling time, decay heat load, and average burnup limits on BWR array classes 6x6A, 6x6C, and 8x8A. These limits correspond to the actual fuel conditions evaluated in the revised Chapters 4 and 5 for thermal and shielding limitations, respectively.

- Revision 8 to Appendix 5.C – This appendix containing the sample MCNP input file was revised to incorporate changes in the modeling resulting from the NRC's comments. Specific changes are indicated on pages 5.C-2, -16,-17, and –22.

- Section 4.4.1.1.2 – This thermal analyses section was revised to incorporate thermal conductivity results for the three 10x10 BWR array types evaluated, and shows that the results are bounded by the thermal conductivity design basis fuel assembly.

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These changed pages will be incorporated into the final Revision 8 scheduled to be submitted on August 21, 1998.

If you have any comments or questions, please contact me.

Sincerely,

Gary T. Tjersland
Director of Licensing and Product Development
GTT:nlm

Enclosures: As stated.

Document ID: 5014205

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August 3, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, Revision 7
Comment Resolution Letter No. 10

Reference: Holtec Project 5014

Dear Mr. Delligatti:

The purpose of this letter is to provide a summary of the Spent Fuel Project Office's (SFPO) comments resulting from the final review of the HI-STAR 100 TSAR in preparation for issuance of a draft Safety Evaluation Report (SER), and Holtec International's responses and completed actions to resolve all comments. Enclosure 1 to this letter provides a summary of the NRC comments made to date and Holtec responses documenting Holtec's actions. Each NRC comment received to date has been addressed by Holtec. The final action outstanding is submittal of Revision 8 to the HI-STAR 100 TSAR, which will be provided to the NRC by August 21, 1998. Revision 8 will delete the discussion and analysis of the MPC-32 canister, and will incorporate all final changes resulting from the NRC comment resolution process. The Technical Specifications of Chapter 12 , and Chapters 2, 5, 6, 7, and 10 have already been provided to the NRC with the MPC-32 removed and the changes incorporated.

Holtec is available at any time to expeditiously respond to any new NRC comments which may arise. If you have any comments or questions, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.:5014203

Enclosure: 1. Summary of NRC Comments and Holtec Responses (Four copies)

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Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

Concurrences

Dr. Everett Redmond (Shielding Analysis):

Dr. John Wagner (Criticality Analysis): for John Wagner

Dr. Alan Soler (Structural Analysis):

Dr. Indresh Rampall (Thermal Analysis): Indresh Rampall

Mr. Brian Gutherman (Technical Spec.): FOR BRIAN GUTHERMAN

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August 6, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report
Comment Resolution Letter No. 11

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with your request, provided below is the listing of the effective Holtec International Calculation Packages which support the HI-STAR 100 Topical Safety Analysis Report (TSAR) Revision 6. These were previously transmitted to you via letter dated November 28, 1997 or as noted on the listing. As a result of preparation of Revision 7 to the TSAR, and responding to NRC's questions, the Calculation Packages are currently being revised to support Revision 8 to the TSAR (scheduled to be submitted to you no later than August 21, 1998). The below listed Calculation Packages are currently effective and previous revisions of the listed calculations, or Calculation Packages not listed below are to be considered as void or superceded and should be appropriately dispositioned or returned to Holtec International.

- HI-STAR 100 Structural Calculation Package, HI-971656, Revision 3
- HI-STAR/HI-STORM Confinement Analysis, HI-971721, Revision 3 (Revision 3 transmittal on July 16, 1998)
- HI-STAR 100 Shielding Design and Analysis for Transport and Storage, HI-951322, Revision 5
- Criticality Evaluation HI-STAR 100 Cask Designs, HI-951321, Revision 6
- Effective Thermal Conductivity Evaluations of LWR Fuel Assemblies in Dry Storage Casks, HI-971789, Revision 0
- HI-STAR 100 System Storage and Transport Condition Thermal Evaluation, HI-971826, Revision 0
- HI-STAR 100 System Overpack Effective Thermal Property Calculations, HI-971784, Revision 0
- Effective Property Evaluations of HI-STAR 100 and HI-STORM Dry Cask System Multi-Purpose Canisters, HI-971788, Revision 0.

- Benchmarking of the Holtec LS-DYNA3D Model for Cask Drop Events, HI-971779, Revision 2. (Revision 2 change page transmitted on July 27, 1998 via Comment Resolution Letter No. 5)

As previously discussed, the revision to the "HI-STAR 100 Shielding Design and Analysis for Transport and Storage" will be submitted to the NRC on August 10, 1998. The final revisions to all the Calculations Packages will be maintained at Holtec's offices as archival records.

If you have any questions or comments, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document ID: 5014206

Approvals:

K.P. Singh, Ph.D.
President

Gary T. Tjersland
Director of Licensing and
Product Development

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August 6, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report
Comment Resolution Letter No. 12

Reference: Holtec Project No. 5014

Dear Mr. Delligatti,

Holtec International appreciates yesterday's management and technical meetings regarding the ongoing HI-STAR 100 System certification effort. We have proceeded to immediately implement the commitments made to the Spent Fuel Project Office (SFPO) management team and technical staff. In particular, Holtec personnel and representatives of the HI-STAR 100 System Owner's group are currently performing a chapter-by-chapter review of the HI-STAR 100 Topical Safety Analysis Report (TSAR) to ensure that assumptions (both explicit and implicit), and design inputs are adequately supported. This review will also ensure that configuration control has been maintained by confirming that information is consistent among the chapters and consistent with the design source documents, such as calculations and drawings. References to the MPC-32 will also be removed.

This effort will be completed by Tuesday, August 11 and a letter documenting the method of the review and the results will be sent to the NRC on Wednesday, August 12. Documentation packages which will provide a record of these reviews will be maintained at Holtec's offices and made available for review upon request by either in-house or external auditors. The NRC Senior Project Manager (PM) will be informed by phone call immediately if Holtec finds any significant changes which could potentially affect the NRC staff's review. If the Senior PM is unavailable, we will continue to attempt to contact members of SFPO management until we speak directly with someone, rather than leave voice mail messages. Since our TSAR review will proceed through the upcoming weekend, we will inform you early on Monday, August 10 of any significant findings discovered during the weekend.

The TSAR will be revised to reflect the changes made in the chapters to resolve NRC questions and comments since Revision 7 was issued. Revision 8 of the TSAR will be submitted to the NRC on or before August 21, 1998 consistent with our prior agreement. We will inform the Senior PM on the day we intend to mail the TSAR to ensure you are aware that it is coming.

Changes made to the HI-STAR 100 storage application which also apply to the HI-STAR 100 transportation and/or the HI-STORM storage application will be incorporated into the appropriate documents which support those applications. In addition, in order to prevent problems with our HI-STAR 100 transportation and our HI-STORM storage applications, Holtec will perform similar assumption and design input reviews of the HI-STAR transportation Safety Analysis Report (SAR) and HI-STORM storage TSAR., respectively, for those designs. Revision 7 of the HI-STAR 100 System transportation SAR will be submitted to the NRC by November 25, 1998. As discussed yesterday, if significant issues are discovered which could affect the NRC's review, we will inform the Senior PM in a timely manner.

With regard to the technical meeting held concurrent with yesterday's management meeting, the following commitments were made and agreed upon between Holtec personnel and the SFPO staff:

SHIELDING ANALYSIS

1. The current mass of uranium in the Technical Specifications (TS), (which represents the maximum mass of uranium authorized for loading in the HI-STAR 100 System), is equal to the value used in TSAR Chapter 5 for the shielding analysis. The mass of uranium in the Technical Specifications will be reduced to reflect actual fuel assembly configurations and to provide margin between the analysis and the actual mass of uranium authorized for loading. The Technical Specification changes will be formally incorporated with other changes required as a result of the ongoing review process and our meeting to discuss the Technical Specifications scheduled for August 18, 1998. Marked-up TS pages will be forwarded via facsimile by 3:00 PM Friday, August 7, 1998.

2. Additional clarification will be provided in Chapter 5 to demonstrate that the calculation of decay heat values is conservative when compared to published data in the 1992 edition of the DOE Characteristics Database. This clarification will show that the decay heat value from the design basis fuel assembly in Chapter 5 bounds the decay heat values from the other assembly types, including the decay heat from non-fuel hardware. The revised affected TSAR pages will be submitted to the NRC by facsimile by noon Friday, August 7, 1998 and overnight mailed the same day.

THERMAL ANALYSIS

1. Additional justification will be provided for the composite MPC cell wall-Boral-air gap-sheathing thickness used in the ANSYS thermal analysis for both basket types.

2. Additional justification will be provided for the aspect ratios used in analyzing the Rayleigh effect for the fuel basket periphery-to MPC shell gap, considering literature correlations for storage conditions.

3. Additional clarification will be provided regarding the parameter R_o found on page F-6 of Holtec Report HI-971788, "Effective Property Evaluations of HI-STAR 100 and HI-STORM Dry Cask System MPCs", and the basket radius shown on page 44 of Holtec Report HI-971826, "HI-STAR 100 System Storage and Transport Condition Thermal Evaluation."

4. Additional justification will be developed for allowing the storage of one longer-cooled fuel assembly in the center cell location with other less-cooled fuel assemblies in the balance of the MPC cells. This justification is intended to support the premise that the longer-cooled fuel assembly will not exceed the PNL fuel cladding temperature acceptance criteria. If adequate justification cannot be developed, appropriate Technical Specification changes will be developed and justified to administratively control fuel loading for both the MPC-68 and MPC-24 canister configurations.

The requested information on the four thermal analysis items will be transmitted via facsimile by 3:00 PM Friday, August 7, and overnight mailed to the NRC the same day.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

BG/bgu

DOCID: 5014209

<u>Approvals:</u>

Gary T. Tjersland, Director
Licensing and Product Development

K. P. Singh, Ph.D.
President and CEO

Technical Concurrence:

Dr. Indresh Rampall (Fluid Mechanics/Heat Transfer) — for I. Rampall

Dr. Everett Redmond (Shielding)

Mr. Brian Gutherman (Technical Specifications)

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August 7, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report
Comment Resolution Letter No. 13

References: 1. Holtec Project No. 5014
2. Holtec letter to NRC dated August 6,1998, DOCID 5014209

Dear Mr. Delligatti,

This correspondence transmits the deliverable for Shielding Analysis item two from Reference 2 above. Attached is the following proposed HI-STAR 100 Topical Safety Analysis Report (TSAR) information which provides the clarification discussed in this commitment:

1. Page 5.2-7 with new Section 5.2.5.3,
2. Page 5.2-36, with new Table 5.2-28, and
3. Page 5.6-2 with new reference 5.2.7.

In addition, discussion of the PWR MOX fuel assembly has been removed from Section 5.2.5.1 as a result of yesterday's discussion with NRC technical staff regarding the criticality review. The affected page is attached to show the information which is being deleted. Note that the page numbering on the attached sheets is not consistent with the draft version of TSAR Revision 8, Chapter 5, submitted last week due to the insertion of new information and the deletion of the PWR MOX fuel discussion. All pagination will be corrected as necessary when the final TSAR Revision 8 is submitted on or before August 21, 1998.

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Also in accordance with yesterday's conference call on criticality issues, Figure 6.3.7 (attached) has been revised to refer to Tables 6.2.1 and 6.2.2 for the active fuel lengths used in the criticality analyses. The following additional commitments were made to reflect discussions in the conference call:

1. Discussion of PWR MOX fuel assemblies will be deleted from Chapter 6 and the Technical Specifications.

2. Fuel Assembly Type 7x7B will be deleted from the list of assemblies authorized for loading in Damaged Fuel Containers (DFCs).

3. Chapter 6 will be revised to correct the fuel assembly reference of 8x8C05 to the correct identification of 8x8C04.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

BG/bgu
DOCID: 5014210

Approvals:

Gary T. Tjersland, Director
Licensing and Product Development

K. P. Singh, Ph.D.
President and CEO

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Technical Concurrence:

Dr. Everett Redmond (Shielding) [signature]

Dr. John Wagner (Criticality) [signature]

Mr. Brian Gutherman (Technical Specifications) [signature]

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August 7, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No. L22019
Comment Resolution Letter No. 14

Reference: Holtec Project 5014

Dear Mr. Delligatti:

We are pleased to provide resolutions to the four thermal analysis related issues raised by the staff in our August 5, 1998 meeting, and documented in our August 6, 1998 letter to you.

Consistent with our schedule commitment, the responses are being forwarded by the 3:00 p.m. deadline set down by the SFPO management.

We trust that the staff will find these responses to be technically acceptable. We will stand ready to answer any additional residual questions which may remain on the thermal analysis chapter. Upon conclusion of your review, we would look to the SFPO for direction as to whether any of the responses provided herein need to be incorporated in the final revision (Revision 8) of the HI-STAR TSAR.

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We appreciate the thorough and comprehensive scrutiny (of the HI-STAR 100 thermal analysis) which is evident from the latest questions raised by the staff.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM 100 Licensing

Document ID: 5014211

Attachments: 1. Attachment A to Holtec Letter 5014211
2. Holtec Position Paper DS-208

Technical Concurrence:

Dr. Indresh Rampall (Fluid Mechanics/ Heat Transfer) — Indresh Rampall

Mr. Evan Rosenbaum (Thermal-Hydraulics) — Evan Rosenbaum

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August 7, 1998

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11555 Rockville Pike
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Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 15

References: 1. Holtec Project No. 5014
2. Holtec letter B. Gilligan to M. Delligatti, NRC dated August 6,1998, Document I.D. 5014209

Dear Mr. Delligatti,

This correspondence transmits the deliverable for Shielding Analysis item one from Reference 2 above. Attached are Technical Specification pages 2.0-17 through 2.0-23 showing the reduced uranium masses allowed for fuel assemblies authorized for loading in the HI-STAR 100 System.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Attachments: As stated

Document I.D.: 5014212

Approvals:

Gary T. Tjersland, Director
Licensing and Product Development

K. P. Singh, Ph.D.
President and CEO

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Technical Concurrence:

Dr. Everett Redmond (Shielding) [signature]

Mr. Brian Gutherman (Technical Specifications) [signature]

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August 7, 1998

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U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No. L22019
Comment Resolution Letter No. 16

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with today's telephone conference discussions regarding the HI-STAR 100 confinement analyses, Holtec International will provide responses to the seven RAIs of your August 7, 1998 facsimile transmission. An updated Revision 8 to the HI-STAR 100 Confinement chapter incorporating the revised analyses resulting from the responses to the RAIs will also be submitted. All responses and revised documents will be submitted to the NRC by close of business on August 12, 1998.

If you have any additional questions, please contact me.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM 100 Licensing

Document ID: 5014213

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Approvals:

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Director of Licensing and
Product Development

K.P. Singh, Ph.D., PE
President and CEO

Technical Concurrence:

Ms. Joy Russell (Confinement)

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BY FEDEX

August 8, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 17

Reference: Holtec Project No. 5014

Dear Mr. Delligatti,

This correspondence transmits Revision 6 to Holtec International Report Number HI-951322, "HI-STAR Shielding Design and Analysis for Transport and Storage." Revision 6 of this report supports Revision 8 of TSAR Chapter 5. This enclosed report is currently effective and the previous revision of the report is to be considered void or superceded and should be appropriately dispositioned or returned to Holtec International.

In addition, clarification was added to Table 5.2.26 to distinguish the source term differences between the WE14x14 and WE15x15 with zircaloy and stainless steel guide tubes. Typographical errors were corrected on Tables 5.2.1, 5.1.3, 5.4.5, 5.4.7, and 5.4.9. These corrections are noted with double revision bars in the right margin.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Enclosures:

1. Report Number HI-951322, "HI-STAR Shielding Design and Analysis for Transport and Storage", Revision 6 (3copies).

2. HI-STAR 100 TSAR pages 5.2-8, -10, -14, -16, -18, and –34.

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Document I.D.: 5014214

Approvals:

Gary T. Tjersland, Director
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K. P. Singh, Ph.D.
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Technical Concurrence:

Dr. Everett Redmond (Shielding)

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August 11, 1998

Mr. Mark Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 18

References: Holtec Project No. 5014

Dear Mr. Delligatti,

This correspondence confirms the discussions and commitments made during telephone conversations held between you, Holtec and NRC technical staff members on Monday, August 10, 1998. We re-confirm that the ongoing enhancements in the HI-STAR 100 Topical Safety Analysis Report, (TSAR) which also pertain to other Holtec applications for spent fuel storage or transportation will be similarly addressed in the Safety Analysis Reports for those applications.

__Structural Analysis__

The technical staff requested analysis and TSAR discussion justifying the 30 psig set pressure on the overpack neutron shield enclosure rupture disk. Specifically, it should be confirmed by analysis that the 30 psig set pressure will not be reached during normal storage operations due to any potential off-gassing of the neutron shielding material in the overpack. In addition, the neutron shield enclosure shall be demonstrated to withstand the 30 psig internal pressure under normal conditions. Analysis of the 30 psig internal pressure on the overpack neutron shield enclosure under normal conditions will be provided in a separate appendix in TSAR Chapter 3. The appendix will also demonstrate that the resultant pressure from any potential off-gassing will not actuate the rupture disk under normal conditions. This appendix will be submitted to the NRC by 3:00 PM Monday, August 17, 1998.

On a later telephone call, clarification was requested regarding differences between acceleration time-history curves in Holtec's generic cask report (Figures A12 and A16) and Figure D-10 from NUREG/CR-6608. The differences in the curves were explained as arising from an expected result of Holtec appropriately modeling the gap between the MPC and the overpack. No further action is considered necessary to address this issue.

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Containment/Confinement

Holtec described its method of calculating an effective dose conversion factor (DCF) for the dose contribution from fines using a weighted average of the DCFs for those radionuclides in quantities greater than one Curie per fuel assembly. This weighted average DCF was then applied to the entire fine radionuclide inventory. The NRC staff questioned why the DCFs for all of the individual radionuclides were not used and how the value of one Curie was chosen. After some discussion, Holtec agreed to use the individual isotopic DCFs for all isotopes with a quantity greater than or equal to $1x10^{-5}$ Curies per assembly. This value is considered reasonable based on engineering judgement to ensure accurate, conservative dose calculations without unnecessarily including isotopes in negligible quantities. For each isotope, the DCF will be multiplied by the quantity in Curies. These products will then be summed and divided by the total quantity of Curies in a fuel assembly. The result will be an effective DCF for use in the calculation of the dose from fines. This methodology is equivalent to calculating a dose contribution from each nuclide and summing over all nuclides to determine a total dose. The revised TSAR confinement chapter (Chapter 7) and responses to the associated NRC Requests for Additional Information (RAI) will be submitted to the Spent Fuel Project Office on August 12, 1998.

On a second item, Holtec requested clarification of question 7-1 of the Chapter 7 RAI received Friday, August 7, 1998. It was agreed the intent of the question was to provide assurance that the helium would remain in the MPC cavity for the 20-year duration of the Certificate of Compliance.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014216

Approvals:

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Dr. Alan Soler (Structural Mechanics) For A. Soler [signature]

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August 11, 1998

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Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 19

Reference: Holtec Project No. 5014

Dear Mr. Delligatti,

In accordance with today's telecon regarding evaluation of the effects on the decay heat of the spent fuel assemblies due to neutron flux peaking effects (Enclosure 1), enclosed please find the ORIGEN-S results showing the effect to be less than one percent for PWR fuel and less than two percent for BWR fuel. We therefore conclude that the change in decay heat is negligible considering the conservative methodology used in preparation of the source terms and decay heat values. Also enclosed are the results of an evaluation of utilizing a more realistic value for the average specific power. Using published sources, the ORIGEN-S results show a greater than three percent decrease in fuel assembly decay heat, thereby showing that the values reported in the HI-STAR 100 TSAR are conservative. These evaluations were conservatively performed using a single cycle with no downtime.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Enclosure: Decay Heat Study (three pages)

Document I.D.: 5014217

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Notes on the Calculation of Decay Heat

The attached two pages compare the calculation of assembly decay heat rates using different methods. The methods are:

1. Calculating the total decay heat rate with ORIGEN-S using the assembly average burnup.
2. Calculating the total decay heat rate with ORIGEN-S by calculating the decay heat rate in each individual axial node using the node specific burnup.
3. Estimating the total decay heat rate by calculating the decay heat rate with ORIGEN-S using the assembly average burnup and increasing the decay heat value from the actinides by a multiplicative factor. This multiplicative factor is equal to the total increase in neutron source term because of the non-linear change in neutron production as a function of burnup.
4. Calculating the total decay heat rate with ORIGEN-S using the assembly average burnup with a lower power density. The power density was derived from data in "World Nuclear Industry Handbook", 1991, a publication of the Nuclear Engineering International magazine.

The results of these comparisons demonstrate that there is negligible difference between calculating the total decay heat rate using the average burnup and calculating the decay heat rate explicitly for each axial node. Therefore using the average burnup is correct. In addition the results demonstrate that using a conservative specific power provides additional margin in the calculation of the decay heat rates.

PWR fuel axial burnup distribution

Calculation of Assembly Burnup Using Average Burnup **Power = 40 MW/MTU**

Node	Burnup	watts/assem.
average	*30000*	*827.53*

Calculation of Assembly Burnup Explicitly **Power = 40 MW/MTU**

Average Burnup=30000 MWD/MTU

Node	Relative Burnup	Actual Burnup	watts/assem.		node height	watts per node
1	0.5485	16455	429.2		6	17.88
2	0.8477	25431	686.5		6	28.60
3	1.077	32310	900.6		12	75.05
4	1.105	33150	928.6		24	154.77
5	1.098	32940	921.6		24	153.60
6	1.079	32370	903.6		24	150.60
7	1.0501	31503	874.6		24	145.77
8	0.9604	28812	789.6		12	65.80
9	0.7338	22014	585.6		6	24.40
10	0.467	14010	363.2		6	15.13
				Total	144	831.60

Calculation of Assembly Burnup Using Actinide Scaling Factor **Power = 40 MW/MTU**

Average 30000 MWD/MTU 1.15568 adjustment

	watts per assembly	watts per assembly with 1.15568 adjustment to actinides
Light Elem	0.53	0.53
Actinides	99.00	114.41
Fiss. Prod.	728.00	728.00
	827.53	842.94

Calculation of Assembly Burnup Using Average Burnup **Power = 31 MW/MTU**

Node	Burnup	watts/assem.
average	*30000*	*797.5*

Comparison of Methods

	watts per assembly	% difference
Reference: decay power from average burnup - 40 MW/MTU	827.53	
decay power explicitly	831.60	**0.49**
decay power from scaling actinides	842.94	1.86
decay power from average burnup - 31 MW/MTU	797.50	-3.63

BWR fuel axial burnup distribution

Calculation of Assembly Burnup Using Average Burnup **Power = 30 MW/MTU**

Node	Burnup	watts/assem.
average	*30000*	*315.65*

Calculation of Assembly Burnup Explicitly **Power = 30 MW/MTU**

Average Burnup = 30,000 MWD/MTU

Node	Relative Burnup	Actual Burnup	watts/assem.		node height	watts per node
1	0.22	6600	65.77		6	2.74
2	0.76	22800	233.6		6	9.73
3	1.035	31050	328.2		12	27.35
4	1.1675	35025	378.4		24	63.07
5	1.195	35850	389.1		24	64.85
6	1.1625	34875	376.8		24	62.80
7	1.0725	32175	342.1		24	57.02
8	0.865	25950	268.4		12	22.37
9	0.62	18600	187.6		6	7.82
10	0.22	6600	65.77		6	2.74
				Total	144	320.48

Calculation of Assembly Burnup Using Actinide Scaling Factor **Power = 30 MW/MTU**

Average 30000 MWD/MTU 1.36942 adjustment

	watts per assembly	watts per assembly with 1.36942 adjustment to actinides
Light Elem	0.35	0.35
Actinides	38.30	52.45
Fiss. Prod.	277.00	277.00
	315.65	329.80

Calculation of Assembly Burnup Using Average Burnup **Power = 21 MW/MTU**

Node	Burnup	watts/assem.
average	*30000*	*297.6*

Comparison of Methods

	watts per assembly	% difference
Reference: decay power from average burnup - 30 MW/MTU	315.65	
decay power explicitly	320.48	1.53
decay power from scaling actinides	329.80	4.48
decay power from average burnup - 21 MW/MTU	297.60	-5.72

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August 12, 1998

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Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 20

References: Holtec Project No. 5014

Dear Mr. Delligatti,

This correspondence provides the responses to the NRC's Request for Additional Information (RAI) received on August 7, 1998 regarding confinement issues in Chapter 7 of the HI-STAR 100 Topical Safety Analysis Report, (TSAR).

Section 7.2.2 Pressurization of the Confinement Vessel

Question 7-1

Clarify the "predetermined mass of helium" that the MPC will be inerted with. Confirm that this mass of Helium will maintain the cask at the minimum pressure used in the release analysis over the lifetime of the cask.

NOTE: The intent of this question was clarified by the NRC during a telephone call on August 10, 1998 to mean that assurance should be provided that helium would remain in the MPC cavity for the 20-year duration of the Certificate of Compliance.

Response to Question 7-1

The pre-determined mass of helium with which the MPC must be inerted corresponds to the density of helium, in gram-moles per liter, required to achieve the desired internal MPC pressure based on supporting calculations. This density is specified in the HI-STAR 100 Technical Specifications to be verified during fuel loading operations. The desired pressures vary with MPC type and were originally chosen to support the MPC thermal analyses based on internal thermosiphon flow. While reliance on helium density is no longer necessary since credit for MPC basket thermosiphon action has been eliminated from the thermal analyses, the pressures

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and associated helium backfill densities are appropriate and conservative to ensure sufficient helium is maintained inside the MPC for 20-year duration of the Certificate of Compliance.

During storage conditions, the MPC cavity pressure will rise from ambient to design basis normal conditions due to heat up from decay heat emission by the stored assemblies. The design basis normal condition MPC cavity pressures and temperatures are summarized in Chapter 4 of the HI-STAR TSAR (Holtec Report HI-941184, Rev. 7). During the storage lifetime of the cask, the decay heat attenuates, resulting in a monotonic reduction in the cavity temperatures and pressures. The following bounding calculation demonstrates that the loss of helium over the lifetime of the cask resulting from leakage at the Technical Specification limit at design basis normal condition MPC temperature and pressure is negligibly small. The leak rate calculation is performed at the computed hole diameter based on test conditions and leak rate criteria discussed in Chapter 7 of the HI-STAR TSAR. The input parameters for the leakage rate calculation are presented below:

P_u (upstream pressure) = 58.3 psig (maximum MPC cavity normal condition pressure, Table 4.4.15 of HI-STAR TSAR)

= 4.97 atm

P_d (downstream pressure) = 1 atm (ambient)

$P_a = (P_u + P_d)/2 = 2.98$ atm

a (leakage path length) = 1.9 cm (from TSAR Chapter 7)

d (leak hole diameter) = 11.658×10^{-4} cm (from TSAR Chapter 7)

T (highest MPC cavity average temperature) = 499.2°K (Holtec Calculation Package HI-971826 referenced in HI-STAR TSAR, reference number [4.4.10]).

μ (helium viscosity at T) = 0.028 cp ("Handbook of Heat Transfer", Rohsenow and Hartnett, McGraw Hill, 1973)

M (helium molecular weight) = 4.0 gm/mole (ANSI N14.5, Table B1 referenced in HI-STAR TSAR, reference number [7.3.9]).

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Therefore, the leakage rate based on average pressure P_a is calculated as follows:

$$L_a = (2.49x10^6 \frac{D^4}{a\mu} + 3.81x10^3 \frac{D^3}{aP_a}\sqrt{\frac{T}{M}})(P_u - P_d)$$

Substituting the input parameters, the leakage rate (L_a) is computed to be 3.901 x 10^{-4} cm^3/s. The leakage rate corresponding to upstream conditions (L_a multiplied by the P_a/P_u correction factor) is 2.343 x 10^{-4} cm^3/s. Over a 20-year time frame, the helium loss can therefore be readily calculated based on this <u>constant</u> leak rate. Note that this is conservative relative to a decreasing pressure and temperature time-history of the MPC, both of which would cause the computed leak rate to also drop. The total loss of helium, based on this conservative assumption and bounding leak rate, is equal to $1.478x10^5$ cm^3. Comparing this to the smallest MPC-68 cavity free volume reported in Table 4.4.14 of the Holtec HI-STAR TSAR (i.e., 5,989 liters), the loss of helium is limited to 2.5% of the backfilled amount. This ensures an adequate amount of helium remains in the MPC to support the heat transfer analyses.

Section 7.3.1 Fuel Fission Gases, Volatiles, and Particulates

<u>Question 7-2</u>

Revise Table 7.3.1 and, accordingly, the confinement hypothetical accident evaluation to consider release fraction values from Table 6.2 of NUREG/CR-6487, "Containment Analysis for Type B Packages Used to Transport Various Contents," rather than Table 7.1 of NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems." In addition revise the analysis based on a source term including all isotopes that would be expected to exist in the fuel. The use of an NRC approved code such as SAS2H to generate this source term or the shielding source term is acceptable to the staff for this analysis.

The release fractions in NUREG-1536 are outdated. In addition the analysis does not account for the release of volatiles and fines. The fractions in NUREG/CR-6487 are bounding, and based on more recent experimental data. Further, using this methodology to determine the confinement source terms is consistent with a similar analysis provided under 10 CFR Part 71.

NOTE: In order to perform this calculation correctly, it is important to use the correct release fraction for each element taken into consideration, depending upon whether it is a gas, volatile, or fine (aerosol).

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Response to Question 7-2

In accordance with the NRC's latest guidance on release fractions, Table 7.3.1 has been revised and the confinement hypothetical accident evaluation was performed to consider the release fraction values in Table 6.2 of NUREG/CR-6487 rather than Table 7.1 of NUREG-1536. ORIGEN-S was used to generate the source terms of all isotopes in a quantity greater than or equal to 1×10^{-5} Curies per fuel assembly. For the calculated source terms, the release fraction for each isotope was taken into consideration, depending upon whether it is a gas, volatile, or fine (aerosol). TSAR Chapter 7 text has been revised to reflect these changes. Draft Revision 8 of TSAR Chapter 7 is enclosed with this correspondence.

Section 7.3.3.1 Seal Leakage Rate

Question 7-3

Clarify why an upper limit of 70°F was chosen for the test condition temperature.

Based on Equation 7-2, a test done at a higher temperature would yield a larger calculated leakage rate at test conditions, L (1.5 ATM, 294.1K). The choice of this temperature as an upper bound during the calculation would appear to limit the leakage testing allowable conditions to no higher than 70°F. Thus if the temperature was above this value, it would not be possible to show compliance with 10 CFR Part 72.106 based on this calculation for a loaded MPC.

Response to Question 7-3

The previous version of Chapter 7 used an upper limit of 70° F for the test condition temperature. The leakage rate evaluation was re-performed using the helium gas temperature at test conditions of both 70°F and 212°F. These temperatures of the helium gas in the confinement vessel during the helium leak test are based on an assumed ambient temperature of 70°F and an upper bound of 212°F. Since there is water in the MPC during the helium leak test of the MPC lid and the thermal analysis specifies a "time to boil" time limit, the upper bound for the test condition was chosen as 212°F. From the two calculations, it was determined that the higher temperature (212°F) results in a greater leakage rate. Therefore, the confinement hypothetical accident evaluation was revised using the leakage rate determined at the higher temperature. Chapter 7 text has been revised to clarify this information.

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Question 7-4

Revise the seal leakage rate calculation using the methods in ANSI N14.5-1997.

The initial D value determination at test conditions using equation 7-3 appears to be missing the P_a/ P_d correction factor that is included in Equation B-5 of ANSI N14.5-1997.

Since the leakage rate correlation used is an average conditions determination, the correlation must be corrected to the location that the leakage rate is measured at.

Response to Question 7-4

Draft Revision 8 TSAR Equation 7-3 did not contain the P_a/P_d correction factor that is included in Equation B-5 of ANSI 114.5-1997. However, this correction factor was accounted for by using Draft Revision 8 TSAR Equation 7-4. For clarity, TSAR Chapter 7 has been revised to combine Equation 7-3 and Equation 7-4 to reflect Equation B-5 of ANSI N14.5-1997. The leakage rate is not affected as a result of this change.

Question 7-5

In Equation 7-3, define the variable $L_{@PY}$

It is unclear whether this variable is the leakage rate at average pressure as specified by $L_{@Pa}$ on page 7.3.4.

Response to Question 7-5

Draft Revision 8 TSAR Equation 7-3 did contain a typographical error. The term should be $L_{@Pa}$ This error has been corrected.

Question 7-6

Update all applicable sections of the SAR to conform to the requested analyses in questions 7-2 through 7-5.

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Response to Question 7-6

Applicable sections of the TSAR have been revised to reflect these changes and clarifications. Final Revision 8 of the HI-STAR 100 TSAR will be provided to the NRC by August 21, 1998 with all applicable sections updated to conform to the responses provided here.

Section 7.3.4 Postulated Accident Doses

Question 7-7

Show how the HOLTEC HI-STAR 100 system complies with the dose limit of 10 CFR Part 72.106(b) and Part 20 for the accident conditions using the revised release fractions, source term, and measured leak rate.

Response to Question 7-7

Chapter 7, Table 7.3.2 presents the revised calculated doses to a real individual at the controlled area boundary (100 meters) determined using the release fractions specified in NUREG/CR-6487. A discussion of the dose limit compliance with regulatory limits is also included in the chapter.

Enclosed is an updated draft Revision 8 to Chapter 7 which incorporates the revised analyses in response to the RAI

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Enclosure: Revised Draft Revision 8 of HI-STAR 100 TSAR Chapter 7 (4 copies)

Document I.D.: 5014215

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August 12, 1998

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Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 21

References: Holtec Project No. 5014

Dear Mr. Delligatti,

Pursuant to our meeting on August 5, 1998 and Comment Resolution Letter Number 12 dated August 6, 1998, Holtec International herein provides a summary of our review of the HI-STAR 100 Topical Safety Analysis Report (TSAR). The purpose of the review was to identify inadequately supported assumptions or design inputs and inconsistencies within the TSAR. The review took place at Holtec's offices between Thursday, August 6 and Wednesday, August 12 and was a joint effort between Holtec and its cask owners from Southern Nuclear Operating Company, New York Power Authority, and Commonwealth Edison Company.

In addition to the independent reviews by Owners' representatives, Holtec personnel engaged in the preparation of Revision 8 of the TSAR were also asked to comb through the entire document to identify any internal inconsistencies, lack of clarity, absence of adequate justification for assumptions, or unarticulated assumptions. We are pleased to advise you that while this week-long focussed effort identified some typographical errors and editorial improvement opportunities, no internal inconsistencies were found. One unsubstantiated assumption was, however, discovered which is explained below.

The unsubstantiated assumption pertains to the Damaged Fuel Container (DFC) for BWR fuel. In Section 2.1.3 of the present revision of the TSAR (Revision 7), we state, without supporting analysis, that the long cooling time (and, therefore, reduced decay heat loads) of the spent nuclear fuel permitted to be loaded into the DFC ensures that the cladding temperature of the fuel in the DFC will not be governing. We have now performed explicit analyses which justify the veracity of this assumption. We will clarify this matter in Revision 8 of the TSAR.

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As previously committed, Revision 8 of the TSAR will be delivered to the NRC by August 21, 1998. Our clients' representatives continue to strive along with our project team personnel to deliver an error-free (MPC-32 deleted) Revision 8 document to you by the scheduled deadline.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014219

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Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 22

Reference: Holtec Project No. 5014

Dear Mr. Delligatti,

Two telephone calls were held Wednesday, August 12, 1998 and Thursday, August 13, 1998 between the NRC Spent Fuel Project Office (SFPO) and Holtec International to discuss issues related to the NRC staff review of the HI-STAR 100 System Topical Safety Analysis Report (TSAR). This correspondence confirms the commitments and resolutions made during those telephone calls regarding radiation protection, quality assurance, criticality, and Technical Specifications.

Radiation Protection (TSAR Chapter 10)

NRC Comment

Section 10.3 needs additional rationale for the number of workers and task durations assumed for the dose estimates.

Response

The TSAR text will be revised to include the additional rationale. The revised draft Revision 8 Chapter 10 TSAR pages will be provided to the NRC on August 17,1998.

NRC Comment

Table 10.3.1 has zeroes in the dose column with non-zero numbers in the dose rate, duration, and number of workers columns.

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Mr. Mark Delligatti
U. S. Nuclear Regulatory Commission
August 13, 1998

Response

The final TSAR Revision 8 of Technical Specification Table 2.1-3 will be submitted to the SFPO incorporating the requested changes by August 21, 1998.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014220

Approvals:

Gary T. Tjersland, Director
Licensing and Product Development

K. P. Singh, Ph.D.
President and CEO

Technical Cocurrence:

Dr. Everett Redmond (Shielding)

Dr. John Wagner (Criticality)

Mr. Stephen Agace (Radiation Protection)

Mr. Vik Gupta (Quality Assurance)

Mr. Brian Gutherman (Technical Specifications)

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BY FEDEX

August 15, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 23

References:
1. Holtec Project No. 5014
2. Holtec Comment Resolution Letter No. 18 (Gilligan) to NRC (Delligatti) dated August 11, 1998
3. Holtec Comment Resolution Letter No. 22 (Gilligan) to NRC (Delligatti) dated August 13, 1998

Dear Mr. Delligatti,

In References 2 and 3 above, Holtec International committed to providing revised information regarding the structural and radiation protection evaluations, respectively, for the HI-STAR 100 System Topical Safety Analysis Report (TSAR). Four copies each of the following documents are enclosed for your review:

1. Draft new Appendix 3AG to Chapter 3, Structural Evaluation. The rupture disk on the overpack neutron shield enclosure has a set pressure of 30 psig. This new appendix provides the structural analysis which demonstrates that the neutron shield enclosure is designed to withstand the 30 psig internal pressure under normal operating conditions. It also confirms that the resultant pressure from any potential offgassing of the neutron shielding material during normal operation will not actuate the rupture disk.

2. Revised draft Revision 8 TSAR Section 10.3. This section has been revised to include additional rationale for the number of workers and task durations assumed for the dose estimates.

3. Revised draft Revision 8 TSAR Table 10.3.1. This table has been revised to provide the corrected dose values for the various cask loading, unloading, and transfer activities.

4. Revised draft Revision 8 TSAR Section 10.4.1. This section has been expanded to include clarifying information from the shielding chapter (Chapter 5). Specifically, the section has

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been revised to include the annual dose from a single cask at 100 meters, and the dose and distances at which the annual 25 mRem dose limit will be satisfied for both a single cask and a 2x5 cask array. The section has also been revised to include discussion of the major assumptions (i.e., the concrete surface and the array pitch) used in the shielding analyses.

5. Revised draft Revision 8 TSAR Section 10.4.2. This section has been expanded to include information from the shielding chapter (Chapter 5) for the loss of neutron shield accident condition and from the confinement chapter (Chapter 7) for the postulated loss of confinement accident condition.

All of the above information will be included in Revision 8 TSAR to be submitted to the Spent Fuel Project Office on August 21, 1998.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014222

Enclosures: As stated

Approvals:

Gary T. Tjersland, Director
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K. P. Singh, Ph.D.
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Dr. Alan I. Soler (Structural Analysis)

Mr. Stephen Agace (Radiation Protection)

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BY FAX AND HAND-DELIVERY

August 17, 1998

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U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No, 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No.L22019
Comment Resolution Letter No. 24

Reference: Holtec Project No. 5014

Dear Mr. Delligatti,

Enclosed please find four copies of revised draft Revision 8 Table 10.3.3 for the HI-STAR 100 System Topical Safety Analysis Report (TSAR). This table has been revised to reflect new dose rates and doses arising from our review of the tasks involved in cask security surveillance and maintenance activities. Specifically, the estimated dose rates have been reduced for security surveillance from 27.5 mrem/hr to 4 mrem/hr and for annual maintenance from 53.1 mrem/hr to 50 mrem/hr. Both dose rates have been reduced to reflect the revised shielding analyses. The dose rate for security surveillance has been additionally reduced to reflect the fact that the surveillance activity will be performed outside the ISFSI perimeter, providing more distance between the casks and security personnel than previously assumed. The value of 4 mrem/hr was chosen based on the regulatory limit of 2 mrem/hr from 10CFR20.1301(a)(2) for an unrestricted area, plus margin.

Revised Table 10.3.3 will be included in Revision 8 of the TSAR to be submitted to the Spent Fuel Project Office (SFPO) on August 21, 1998.

In a telephone call this morning, two items regarding the shielding and criticality evaluations were clarified:

1. TSAR Figure 5.3.10 and the text in Section 5.3.1 will be revised to reflect the different Multi-Purpose Canister (MPC) lid thicknesses between the MPC-24 (9 ½ inches) and the MPC-68 (10 inches). The shielding analyses used the appropriate MPC lid thickness for the respective MPC designs. The enhanced figure and text will be included in TSAR Revision 8 to be submitted to the SFPO on August 21, 1998.

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2. The water rod thickness for the 10x10A class assembly will be corrected in TSAR Tables 2.1.4 and 6.2.30, and Technical Specification Table 2.1-3. The correct water rod thickness for this assembly is 0.0300 inch. The revised tables will be included in Revision 8 of the TSAR to be submitted to the SFPO on August 21, 1998.

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014223

Enclosure: Revised Draft Revision 8 of TSAR Table 10.3.3 (4 copies)

Approvals:

for Gary T. Tjersland, Director
Licensing and Product Development

K. P. Singh, Ph.D.
President and CEO

Technical Concurrence:

Mr. Stephen Agace (Radiation Protection)

Dr. Everett Redmond (Shielding)

Dr. John Wagner (Criticality)

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SENT BY FAX AND MAIL

August 18, 1998

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No. L22019
Comment Resolution Letter No. 25

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In accordance with your request, enclosed are four (4) copies of the Revision 8 draft of Chapter 11 (Accident Analyses) of the HI-STAR 100 TSAR. The final TSAR Revision 8 will be submitted on August 21, 1998.

If you have any final questions, please contact us.

Sincerely yours,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.:5014226

Enclosures: As stated.

Approvals:

Gary T. Tjersland
Director of Licensing and Product Development

K.P. Singh, Ph.D., PE
President and CEO

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SENT BY FAX

August 20, 1998

Mr. Mark S. Delligatti
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United States Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No. L22019
Comment Resolution Letter No. 26

Reference: Holtec Project 5014

Dear Mr. Delligatti:

This comment resolution letter documents the information provided by Holtec International to the SFPO staff on the thermal issues in the August 18, 1998 meeting. The issues raised by the staff were the following:

1. Explain the discrepancy between the effective SNF conductivity listed in the TSAR and ANSYS data provided to the staff.

2. Evaluate the consequence of the aspect ratio in certain peripheral regions exceeding 40.

3. Confirm that the in-plane equivalent conductivity of the composite box wall is correct.

The responses to these questions are provided in Attachments 1, 2 and 3, respectively.

This comment resolution letter will be included in Chapter 12 of the TSAR (Revision 8) due to be sent by FedEx to the SFPO this evening.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing
BG:nlm
Document I.D. 5014227

Attachments: Attachment 1 (ten pages)
Attachment 2 (one page)
Attachment 3 (three pages, including a figure)

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Approvals:

Gary T. Tjersland, Director
Licensing and Product Development

(Exec V.P.) for KP Singh
K. P. Singh, Ph.D.
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Technical Concurrences:

Dr. Indresh Rampall (Thermal-Hydraulic): Indresh Rampall

Mr. Evan Rosenbaum (Thermal-Hydraulic): Evan Rosenbaum

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August 20, 1998

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United States Nuclear Regulatory Commission
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Rockville, MD 20852

Subject: USNRC Docket No. 72-1008
HI-STAR 100 Topical Safety Analysis Report, TAC No. L22019
Comment Resolution Letter No. 27

Reference: Holtec Project 5014

Dear Mr. Delligatti:

In today's telephone conference calls between the NRC and Holtec, the SFPO staff requested the following clarifications and changes in assumptions:

STRUCTURAL

NRC Comment

Regarding Holtec Design Drawing No. 1399, Sheet 3 of 3, the NRC requested clarification on whether the rear pocket trunnion penetrated the inner shell of the HI-STAR 100 overpack.

Holtec Response

Holtec advised that only the intermediate shells were represented on the drawing and that the base of the pocket trunnion does not penetrate the cask's inner shell. As shown in Section "N-N" of the drawing, the inner shell weld prep of the baseplate is shown, but the inner shell was left out for clarity.

No further action is required for this comment.

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CONFINEMENT

NRC Comment

The NRC staff requested that Holtec not use an effective dose conversion factor (DCF) for fires. The NRC recommended that isotopes contributing 0.1% or greater to the total inventory be considered as fires and that the specific DCF for these isotopes be applied. The staff also advised that an accident duration of 30 days may be more appropriate than the previously assumed 365 days, as any accident which could cause 100% fuel rod rupture would be observed by the required visual surveillance, and appropriate corrective actions would then be taken to mitigate the accident.

Holtec Response

Holtec will perform the re-analysis of the accident condition release in Chapter 7 of the TSAR based on the 30-day duration and utilizing the actual DCFs for each major contributing radionuclide available for release (>0.1% of inventory in Curies).

NRC Comment

Due to changes in regulatory guidance regarding storage confinement analyses to bring it into conformance with standard transport cask leakage analyses, the NRC requested that Holtec perform an analysis of normal condition leakage from the MPC, and determine the annual dose at 100 meters.

Holtec Response

Holtec will perform an annual dose assessment at 100 meters for normal storage condition leakage. The tested leakage rate plus the test sensitivity will be used as the total leak rate from the MPC. The radionuclides available for release from the MPC will be based on 1% fuel rod failure. The analysis results will be reported in Chapters 7 and 10.

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TECHNICAL SPECIFICATION

The NRC staff requested that the Technical Specifications include a definition of Planar Average Enrichment for BWR fuel assemblies.

Holtec Response

The Technical Specifications will include a definition of Planar Average Enrichment for BWR fuel assemblies. Also, the maximum planar average enrichment will be specified in Technical Specification Table 2.1-1.

The revised confinement analyses and the correction to the Technical Specifications will be incorporated into the final Revision 8 of the TSAR to be submitted to the NRC on August 21, 1998.

If you have further comments, please contact me.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing
Document I.D. 5014228

Approvals:

Gary T. Tjersland, Director
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Technical Concurrences:

Dr. Alan Soler (Structural): [signature]

Ms. Joy Russell (Confinement): [signature]

Mr. Brian Gutherman (Technical Specifications): [signature]

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CHAPTER 13†: QUALITY ASSURANCE

13.0 QUALITY ASSURANCE PROGRAM

13.0.1 Overview

This chapter provides a summary of the quality assurance program implemented for activities related to the design, qualification analyses, material procurement, fabrication, assembly, testing and use of structures, systems, and components of the HI-STAR 100 System designated as important to safety.

Important-to-safety activities related to construction and deployment of the HI-STAR 100 System are controlled under the NRC-approved Holtec Quality Assurance Program. The NRC approved the Holtec QA program manual (Reference [13.0.2]) under Docket 71-0784 (Reference [13.0.4]). The Holtec QA program satisfies the requirements of 10 CFR 72, Subpart G and 10 CFR 71, Subpart H. In accordance with 10 CFR 72.140(d), this approved 10 CFR 71 QA program will be applied to spent fuel storage cask activities under 10 CFR 72. The additional recordkeeping requirements of 10 CFR 72.174 are addressed in the Holtec QA program manual and must also be complied with.

The Holtec QA program is implemented through a hierarchy of procedures and documentation, listed below.

1. Holtec Quality Assurance Program Manual
2. Holtec Quality Assurance Procedures
3. a. Holtec Standard Procedures
   b. Holtec Project Procedures

Quality activities performed by others on behalf of Holtec are governed by the supplier's quality assurance program or Holtec's QA program extended to the supplier. The type and extent of Holtec QA control and oversight is specified in the procurement documents for the specific item or service being procured. The fundamental goal of the supplier oversight portion of Holtec's QA program is to provide assurance that activities performed in support of the supply of safety-significant items and services are performed correctly and in compliance with the procurement documents.

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the intent of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

13.0.2 Graded Approach to Quality Assurance

For the HI-STAR 100 System, Holtec uses a graded approach to quality assurance. This graded approach is controlled by Holtec Quality Assurance (QA) program documents as described in Section 13.0.1.

NUREG/CR-6407 [13.0.1] provides descriptions of quality categories A, B and C. Using the guidance in NUREG/CR-6407, Holtec International assigns a quality category to each individual, important-to-safety component of the HI-STAR 100 System. The categories assigned to the cask components are identified in Table 2.2.6. Quality categories for ancillary equipment are provided in Table 8.1.4 on a generic basis. Quality categories for other equipment needed to deploy the HI-STAR 100 System at a licensee's ISFSI are defined on a case-specific basis considering the component's design function.

Activities affecting quality are defined by the purchaser's procurement contract for use of the HI-STAR 100 System at an independent spent fuel storage installation (ISFSI) under the general license provisions of 10CFR72, Subpart K. They may include any or all of the following: design, procurement, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair and monitoring of HI-STAR 100 structures, systems, and components that are important to safety.

The quality assurance program described in the QA Program Manual fully complies with the requirements of 10CFR72 Subpart G and the intent of NUREG-1536 [13.0.3]. However, NUREG-1536 does not explicitly address incorporation of a QA program manual by reference. Therefore, invoking the NRC-approved QA program in this FSAR constitutes a literal deviation from NUREG-1536 and has accordingly been added to the list of deviations in Table 1.0.3. This deviation is acceptable since important-to-safety activities are implemented in accordance with the latest revision of the Holtec QA program manual and implementing procedures. Further, incorporating the QA Program Manual by reference in this FSAR avoids duplication of information between the implementing documents and the FSAR and any discrepancies that may arise from simultaneous maintenance to the two program descriptions governing the same activities.

13.1 through 13.5 INTENTIONALLY DELETED

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the intent of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

13.6 REFERENCES

[13.0.1] NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety," February 1996.

[13.0.2] Holtec International Quality Assurance Program, Latest Approved Revision.

[13.0.3] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," January 1997.

[13.0.4] NRC QA Program Approval for Radioactive Material Packages No. 0784, Docket 71-0784.