K.4 Thermal Evaluation

K.4.1 Discussion

The NUHOMS®-61BT system is designed to passively reject decay heat during storage and transfer for normal, off-normal and accident conditions while maintaining temperatures and pressures within specified regulatory limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to materials limits to ensure components perform their intended safety functions,
- Determination of temperature distributions for the NUHOMS®-61BT DSC components to support the calculation of thermal stresses for the structural components,
- Determination of maximum internal NUHOMS®-61BT DSC pressures for the normal, off-normal and accident conditions,
- Determination of the maximum fuel cladding temperature, and to confirm that this temperature will remain sufficiently low to prevent unacceptable degradation of the fuel during storage.

The NUHOMS®-61BT DSC falls under the jurisdiction of 10CFR Part 72 when used as a component of an ISFSI. To establish the heat removal capability, several thermal design criteria are established for the basket. These are:

- Maximum temperatures of the confinement structural components must not adversely affect the confinement function.
- The maximum initial storage fuel cladding temperature is determined as a function of the initial fuel age using the guidelines provided by the Commercial Spent Fuel Management Program [4.1]. The temperature threshold accounts for the effects of cladding temperature, decay time, burnup and fission gas build-up at 40 GWD/MTU. Waterside corrosion of 0.002 in. (radially) has been assumed. For normal conditions of storage, a fuel temperature limit of 343°C (649°F) has been established. During loading/unloading, transfer and accident conditions, the fuel temperature limit is 570°C (1058°F) [4.9].
- The maximum DSC cavity internal pressures during normal, off-normal and accident conditions must be below the design pressures of 10 psig, 20 psig and 65 psig, respectively.

The NUHOMS®-61BT DSC is analyzed based on a maximum heat load of 18.3 kW from 61 BWR fuel assemblies. The analyses consider the effect of the decay heat flux varying axially along a fuel assembly. The axial heat flux profile for a BWR fuel assembly shown in Figure K.4-8 and an active length of 144 in. is used for the evaluation. The use of these parameters bounds the peak heat flux for the design basis fuel. A description of the detailed analyses

performed for normal storage conditions is provided in Section K.4.4, off-normal conditions in Section K.4.5, accident conditions in Section K.4.6, and loading/unloading conditions in Section K.4.7. The thermal evaluation concludes that with a design basis heat load of 18.3 kW, all design criteria are satisfied.

K.4.2 Summary of Thermal Properties of Materials

1. BWR Fuel with Helium Backfill [4.7]

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	
	Transverse	Axial
116.8	0.0137	0.0437
214.4	0.0160	...
312.4	0.0186	...
410.7	0.0215	...
509.3	0.0249	...
608.0	0.0288	0.0437

The effective thermal conductivity is the lowest calculated value for the BWR fuel array that may be stored in this cask and corresponds to the GE 10x10 BWR assembly with channels.

2. BWR Fuel w/ Air Backfill [4.7]

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	
	Transverse	Axial
150.8	0.0045	0.0437
240.0	0.0058	...
331.6	0.0073	...
425.1	0.0092	...
520.1	0.0114	...
616.3	0.0141	...
900.0	0.0221*	0.0437

* Determined via linear extrapolation

3. Air [4.2]

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)
-100	0.0009
80	0.0013
260	0.0016
440	0.0019
620	0.0022
980	0.0028
1340	0.0033

4. SA-240, Type 304 Stainless Steel [4.3]

Temperature (°F)	α (ft²/hr)	ρ (lbm/in³)	Thermal Conductivity (Btu/hr-in-°F)	C_p (Btu/lbm-°F)
70	0.151	0.282	0.717	0.117
100	0.152	...	0.725	0.117
150	0.154	...	0.750	0.120
200	0.156	...	0.775	0.122
250	0.158	...	0.800	0.125
300	0.160	...	0.817	0.126
350	0.162	...	0.842	0.128
400	0.165	...	0.867	0.129
450	0.167	...	0.883	0.130
500	0.170	...	0.908	0.131
550	0.172	...	0.925	0.132
600	0.174	...	0.942	0.133
650	0.177	...	0.967	0.134
700	0.179	...	0.983	0.135
750	0.181	...	1.000	0.136
800	0.184	...	1.017	0.136
850	0.186	...	1.042	0.138
900	0.189	...	1.058	0.138
950	0.191	...	1.075	0.138
1000	0.194	0.282	1.100	0.139

5. Helium [4.2].

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)
-280	0.0004
-190	0.0005
-100	0.0055
-10	0.0064
80	0.0072
260	0.0087
440	0.0102
620	0.0119
980	0.0148
1340	0.0175

6. SA-36 Carbon Steel [4.3]

Temperature (°F)	α (ft²/hr)	ρ (lbm/in³)	Thermal Conductivity (Btu/hr-in-°F)	C_p (Btu/lbm-°F)
70	0.529	0.282	2.292	0.107
100	0.512	...	2.300	0.110
150	0.496	...	2.300	0.114
200	0.486	...	2.300	0.116
250	0.467	...	2.283	0.120
300	0.453	...	2.267	0.123
350	0.440	...	2.250	0.126
400	0.428	...	2.225	0.128
450	0.413	...	2.192	0.130
500	0.398	...	2.158	0.133
550	0.387	...	2.125	0.135
600	0.374	...	2.083	0.137
650	0.360	...	2.042	0.139
700	0.346	...	2.000	0.142
750	0.332	...	1.958	0.145
800	0.318	...	1.917	0.148
850	0.305	...	1.883	0.152
900	0.291	...	1.842	0.156
950	0.277	...	1.792	0.159
1000	0.263	0.282	1.750	0.164

7. 6063 Aluminum [4.3]

Temperature (°F)	α (ft²/hr)	ρ (lbm/in³)	Thermal Conductivity (Btu/hr-in-°F)	C_p (Btu/lbm-°F)
70	3.34	0.097	10.067	0.216
100	3.30	...	10.025	0.217
150	3.23	...	9.975	0.221
200	3.18	...	9.925	0.223
250	3.13	...	9.858	0.225
300	3.09	...	9.858	0.228
350	3.04	...	9.825	0.231
400*	3.00	0.097	9.800	0.234

*For temperatures greater than 400°F, the values at 400°F are used.

8. Poison Plates [4.2]

C_p (Btu/lbm-°F)	ρ (lbm/in³)
0.214	0.098

The analyses use interpolated values when appropriate for intermediate temperatures. The interpolation assumes a linear relationship between the reported values.

Thermal radiation effects on the interior surfaces of the basket rails are considered. The emissivity of unfinished stainless steel is 0.587 [4.4]. For additional conservatism an emissivity of 0.500 is used within the analysis.

K.4.3 Specifications for Components

The thermal conductivity of the neutron poison plates will be verified by testing. The neutron poison plates will have the following minimum conductivity:

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)
68	5.78
212	6.98
482	7.22
571	7.22
600	7.22
650	7.22

The thermal conductivity values [4.7] for the neutron poison plates specified above will be bounded by test data.

K.4.4 Thermal Evaluation for Normal Conditions of Storage (NCS) and Transfer (NCT)

The normal conditions of storage are used for the determination of the maximum fuel cladding temperature, component temperatures, NUHOMS®-61BT DSC internal pressure and thermal stresses. These steady state conditions are an ambient temperature of 100 °F and the 10CFR Part 71.71(c) insolation averaged over a 24-hour period.

K.4.4.1 NUHOMS®-61BT DSC Thermal Models

The NUHOMS®-61BT DSC finite element models are developed using the ANSYS computer code [4.5]. ANSYS is a comprehensive thermal, structural and fluid flow analysis package. It is a finite element analysis code capable of solving steady state and transient thermal analysis problems in one, two or three dimensions. Heat transfer via a combination of conduction, radiation and convection can be modeled by ANSYS. The three-dimensional geometry of the DSC was modeled. Solid entities were modeled by SOLID70 three-dimensional thermal elements. Radiation within the basket rails was modeled by MATRIX50 super elements.

The three-dimensional models represents 90° and 180° symmetric sections of the NUHOMS®-61BT DSC, and include the geometry and material properties of the basket components, the basket rails, and DSC. The model simulates the effective thermal properties of the fuel with a homogenized material occupying the volume within the basket where the 144 inch active length of the fuel is stored. The finite element plot of the 90° model is shown in Figure K.4-4. For the normal and off-normal conditions of storage and transfer, where large circumferential temperature gradients are not anticipated, the 90° model is used. For the storage cases, the boundary conditions for the upper half of the DSC are conservatively applied. For transfer cases, the highest calculated DSC boundary condition is conservatively applied the the entire DSC. The blocked vent case utilizes a 180° symmetrical model to permit the large DSC surface temperature variations to be modeled.

Within the models, heat is transferred via conduction through fuel regions, the poison plate and steel of the basket and the gas gaps between the poison plate and steel members. Generally, good surface contact is expected between adjacent components within the basket structure. However to bound the heat conductance uncertainty between adjacent components, conservative gaps between the adjacent components have been included in the model. All heat transfer across the gaps is by gaseous conduction. Other modes of heat transfer are conservatively neglected. Heat is transferred through the basket support rails via conduction. Heat transfer via conduction and radiation across the gas inside of the rails is also modeled, as is radiation across the gap between the rails and the DSC inner surface.

Boundary Conditions, Storage

Normal and off-normal analyses of the NUHOMS®-52B DSC within the HSM have been previously performed in Section 8.1.3 for the following ambient conditions:

- Maximum normal ambient temperature of 100 °F with insolation. This case bounds the lifetime average ambient temperature of 70°F for 50 years service life.

- Minimum off-normal extreme ambient temperature of -40 °F without insolation. This case bounds the 0°F minimum normal (winter) average ambient temperature.
- Maximum off-normal extreme ambient temperature of 125 °F with insolation.

These analyses for the NUHOMS®-52B DSC, which use a total decay heat load of 19.2 kW, determine temperature distributions for the NUHOMS®-52B DSC under normal and off-normal conditions of storage that bound those for the NUHOMS®-61BT with its lower decay heat load of 18.3 kW. These temperature distributions, shown in Figure K.4-1 through Figure K.4-3, which represent the upper half of the DSC in the HSM are applied as boundary conditions to the finite element models for normal and off-normal conditions of storage.

Accident analysis for the 61BT DSC is based on the HSM model described in Section 8.1.3.1 and was performed for the following ambient condition:

- Maximum ambient temperature of 125 °F and maximum insolation with HSM vents totally blocked for 40 hours.

This analysis, which assumed a total decay heat load of 18.3 kw per DSC, provides a two dimensional temperature for the surface of the DSC during blocked vent accident as shown in Figure K.4-4.

Boundary Conditions, Transfer

Analyses of the NUHOMS®-61BT DSC within the OS197 transfer cask is performed for the following ambient conditions:

- Maximum normal ambient temperature of 100 °F with insolation
- Minimum off-normal extreme ambient temperature of -40 °F without insolation
- Vacuum Drying under an ambient of 100 °F without insolation

These analyses, which use a total decay heat load of 18.3 kW per DSC, determine maximum temperatures within the DSC of 378 °F and 308 °F for the maximum normal and minimum off-normal conditions, respectively. A maximum DSC temperature of 369 °F is determined for the vacuum drying condition. These maximum temperatures are conservatively applied to the entire exterior surface of the DSC in the finite element model.

Maximum Fuel Cladding Temperature

The finite element models include a representation of the spent nuclear fuel that is based on a fuel effective conductivity model. The decay heat of the fuel adjusted to account for axial peaking was applied directly to the fuel elements. The maximum fuel temperature reported is based on the results of the temperature distribution in the fuel region of the model. The effective conductivity used in this region is determined in [4.7].

Average Cavity Gas Temperature

For simplicity, the cavity gas temperature is assumed to be the volume averaged temperature of the gaseous elements within the NUHOMS®-61BT DSC models.

Decay Heat Load

The decay heat load is applied as volumetric heat generation in the elements that represent the homogenized fuel. This heat load corresponds to a total heat load of 18.3 kW from 61 BWR assemblies (0.300 kW/assembly). The heat load was adjusted to account for axial peaking. A typical axial heat flux profile for spent BWR fuel was used to distribute the decay heat load in the axial direction within the active length region of the model. This heat flux profile is shown Figure K.4-8.

K.4.4.2 Maximum Temperatures

Steady-state thermal analyses are performed with the 90° symmetry finite element model using the maximum decay heat load of 0.300 kW per assembly (18.3 kW total per DSC) for normal conditions of storage and transfer. A summary of the calculated component temperatures is listed in Table K.4-1 and Table K.4-2.

K.4.4.3 Minimum Temperatures

The off-normal extreme conditions of -40°F ambient without insolation are used to bound both normal and off-normal minimum temperature distributions. Under the minimum temperature condition of -40°F ambient, the resulting DSC component temperatures will approach -40°F if no credit is taken for the decay heat load. Since the DSC materials, including confinement structures, continue to function at this temperature, the minimum temperature condition has no adverse effect on the performance of the NUHOMS®-61BT DSC.

Steady-state thermal analyses are performed with the 90° symmetry finite element model using the maximum decay heat load of 0.300 kW per assembly (18.3 kW total per DSC) and the minimum ambient condition. A summary of the calculated component temperatures are given in Figure K.4-6 and listed in Table K.4-3.

K.4.4.4 Maximum Internal Pressures

During normal conditions, the internal pressure of the NUHOMS®-61BT DSC is calculated assuming that one percent (1%) of the fuel rods are failed. For determination of internal pressure within the DSC, it is assumed that 100 percent of the rods fill gas, and 30 percent of the significant fission gases within the failed fuel rods are available for release into the DSC cavity [4.6].

Free Gas within Fuel Assemblies

The determination of fission gases within the fuel rods is based on SAS2H / ORIGEN-S computer runs [4.7]. I, Kr, and Xe gases are considered following irradiation. Including the 30 percent release fraction for these gases, the total moles of free gas in each of the fuel assembly types to be stored in the NUHOMS®-61BT DSC are tabulated below:

Fuel Design	Fill Gas	Fission Gas	Total	Total
	(kg moles/rod)	(kg moles/rod)	(kg moles/rod)	(lb moles/assy)
7x7-49-0	5.489E-06	6.640E-05	7.189E-05	7.767E-03
8x8-63-1	3.842E-06	4.889E-05	5.273E-05	7.325E-03
8x8-62-2	8.176E-06	4.923E-05	5.741E-05	7.848E-03
8x8-60-4	8.177E-06	5.016E-05	5.834E-05	7.718E-03
8x8-60-1	8.247E-06	5.041E-05	5.866E-05	7.760E-03
9x9-74-2	1.800E-05	3.927E-05	5.727E-05	9.345E-03
10x10-92-2	1.492E-05	3.318E-05	4.810E-05	**9.758E-03**

The bounding case of the General Electric 10x10 fuel assembly is used for the determination of internal pressures.

Initial Helium Fill

The amount of helium present within the DSC is calculated using the ideal gas law and a maximum initial helium fill pressure of 3.5 psig or 1.24 atm. The initial fill temperature of 273°F is conservative and corresponds to the cavity gas temperature for the –40°F ambient case in Table K.4-3.

$$n = \frac{PV}{RT}$$

P = initial DSC fill pressure = 1.24 atm
V = DSC internal free volume = 214.86 ft^3
T = initial fill temperature = 733 °R
R = universal gas constant = 0.730 atm-ft^3/lbmole-°R

$$n = \frac{(214.86)(1.24)}{(0.730)(733)} = 0.498 \text{ lb moles}$$

Maximum Internal Pressures During Storage and Transfer

The average cavity gas temperature during normal conditions of storage and transfer are 403°F and 480°F (863 and 940°R), respectively as shown in Table K.4-1 and Table K.4-2. With rupture of one percent of the fuel rods, the pressures within the DSC are calculated via the ideal gas law:

$$P_{storage} = \frac{nRT}{V} = \frac{(0.498 + (61)(0.01)(9.758E-3))(0.730)(863)}{214.86} = 1.48 \text{ atm } (7.0 \text{ psig})$$

$$P_{transfer} = \frac{nRT}{V} = \frac{(0.498 + (61)(0.01)(9.758E-3))(0.730)(940)}{214.86} = 1.61 \text{ atm } (9.0 \text{ psig})$$

K.4.4.5 Maximum Thermal Stresses

The maximum thermal stresses during normal conditions of storage and transfer are calculated in Section K.3.

K.4.4.6 Evaluation of Cask Performance for Normal Conditions

The temperatures in the NUHOMS® HSM and transfer cask are bounded by the analysis in Section 8.1.3 because of higher heat load for the NUHOMS®-24P or NUHOMS®-52B design. The NUHOMS®-61BT DSC shell and basket are evaluated for the calculated temperatures and pressures in Section K.3. The maximum fuel cladding temperatures are well below the allowable fuel temperature limit of 649°F (343°C). The pressure remains below 10.0 psig during normal conditions of storage and transfer. Based on the thermal analysis, it is concluded that the NUHOMS®-61BT DSC design meets all applicable thermal requirements.

K.4.5 Thermal Evaluation for Off-Normal Conditions

The NUHOMS®-61BT system components are evaluated for the extreme ambient temperatures of –40 °F (winter) and 125 °F (summer). Should these extreme temperatures ever occur, they would be expected to last for a very short duration of time. Nevertheless, these ambient temperatures are conservatively assumed to occur for a significant duration to cause a steady-state temperature distribution in the NUHOMS®-61BT system components.

K.4.5.1 Off-Normal Maximum/Minimum Temperatures during Storage

The thermal performance of the NUHOMS®-61BT DSC within the HSM under the extreme minimum ambient temperature of –40 °F and no insolation is evaluated in Section K.4.4.3.

For the extreme maximum off-normal ambient temperature of 125 °F, a steady state thermal analysis is performed using the 90° symmetric model developed in Section K.4.4.1, the maximum decay heat load of 0.300 kW per assembly (18.3 kW total per DSC), and the DSC temperature distribution shown in Figure K.4-3. A summary of the calculated DSC component temperatures is listed in Table K.4-1.

K.4.5.2 Off-Normal Maximum/Minimum Temperatures during Transfer

The thermal performance of the NUHOMS®-61BT DSC within the OS197 transfer cask under the extreme minimum ambient temperature of –40 °F and no insolation is evaluated in Section K.4.4.3. Administrative controls (NUHOMS®-61BT CoC Technical Specification 1.2.14) prevent transfer operations of a loaded TC/DSC when ambient temperatures exceed 100 °F. For transfer operations when ambient temperatures exceed 100 °F up to 125 °F, a solar shield is to be used to minimize insolation. Since the thermal performance of the DSC without sunshade at an ambient temperature of 100 °F is limiting, the results presented in Table K.4-1 for the 100 °F ambient case envelope the maximum off-normal 125 °F case.

K.4.5.3 Off-Normal Maximum Internal Pressure during Storage/Transfer

Maximum Internal Pressures

During off-normal conditions, the internal pressure of the NUHOMS®-61BT DSC is calculated assuming the 10% of the fuel rods are failed. For determination of internal pressure within the DSC, it is assumed that 100% of the rod fill gas and 30% of the significant fission gases within the failed fuel rods are available for release into the DSC cavity [4.6]. Using the fuel rod data from Section K.4.4.4, the maximum pressures are calculated.

The average cavity gas temperature during off-normal conditions of storage and transfer are 426°F and 480°F (866 and 940 °R), respectively as shown in Table K.4-1 and Table K.4-2. With rupture of 10% of the fuel rods, the pressures within the DSC are calculated via the ideal gas law:

$$P_{storage} = \frac{nRT}{V} = \frac{(0.498 + (61)(0.10)(9.758E-3))(0.730)(866)}{214.86} = 1.68 \text{ atm } (10.0 \text{ psig})$$

$$P_{transfer} = \frac{nRT}{V} = \frac{(0.498 + (61)(0.10)(9.758E-3))(0.730)(940)}{214.86} = 1.78 \text{ atm } (11.5 \text{ psig})$$

K.4.5.4 Maximum Thermal Stresses

The maximum thermal stresses during off-normal conditions of storage and transfer are calculated in Section K.3.

K.4.5.5 Evaluation of Cask Performance for Off-Normal Conditions

The temperatures in the NUHOMS® HSM and transfer cask are bounded by the analysis in Section 8.1.3 because of higher heat load for the NUHOMS®-24P or NUHOMS®-52B DSC designs. The NUHOMS®-61BT DSC shell and basket are evaluated for calculated temperatures and pressures in Section K.3. The maximum fuel cladding temperatures are well below the allowable fuel temperature limit of 1058°F (570°C). The pressures remain below 20.0 psig during off-normal conditions of storage and transfer. The pressures and temperatures associated with off-normal conditions in the NUHOMS®-61BT DSC design meet all applicable thermal requirements.

K.4.6 Thermal Evaluation for Accident Conditions

Since the NUHOMS®-61BT HSMs are located outdoors, there is a remote possibility that the ventilation air inlet and outlet openings could become blocked by debris from such unlikely events as floods and tornadoes. The NUHOMS®-61BT system design features such as the perimeter security fence and redundant protected location of the air inlet and outlet openings reduces the probability of occurrence of such an accident. Nevertheless, for this conservative generic analysis, such an accident is postulated to occur and is analyzed.

It is determined in Section 3.3.6, that the HSM and DSC contain no flammable material and the concrete and steel used for their fabrication can withstand any credible fire accident condition. Fire parameters are dependent on the amount and type of fuel within the transporter and the fire accident condition shall be addressed within site-specific applications. Licensees are required to verify that loadings resulting from potential fires and explosions are acceptable in accordance with 10CFR72.212(b)(2). Nevertheless, for this conservative generic analysis, a hypothetical fire accident is analyzed as described in Section K.4.6.5.

K.4.6.1 Blocked Vent Accident Evaluation

For the postulated blocked vent accident condition, the HSM ventilation inlet and outlet openings are assumed to be completely blocked for a 40 hour period concurrent with the extreme off-normal ambient condition of 125 °F with insolation.

For conservatism, a steady state thermal analysis is performed using the 180° symmetric model developed in Section K.4.4.1, the maximum decay heat load of 0.300 kW per assembly (18.3 kW total per DSC), and the DSC temperature distribution shown in Figure K.4-4.

The calculated temperature distribution within the hottest cross-section is shown in Figure K.4-7. A summary of the calculated NUHOMS®-61BT DSC component temperatures is listed in Table K.4-1.

K.4.6.2 Maximum Internal Pressures

The average cavity gas temperature during the blocked vent accident condition is 651 °F (1111 °R). With rupture of one hundred percent of the fuel rods, the pressures within the DSC are calculated via the ideal gas law:

$$P_{accident} = \frac{nRT}{V} = \frac{(0.498 + (61)(1.00)(9.758E-3))(0.730)(1111)}{214.86} = 4.13\ \text{atm}\ (46.0\ \text{psig})$$

K.4.6.3 Maximum Thermal Stresses

The maximum thermal stresses during accident conditions are calculated in Section K.3.

K.4.6.4 Evaluation of Performance During Accident Conditions

The temperatures in the NUHOMS® HSM are bounded by the analyses in Section 8.1.3 because of higher heat loads for the NUHOMS®-24P or NUHOMS®-52B DSC designs.

The NUHOMS®-61BT DSC shell and basket are evaluated for calculated pressures and temperatures in Section K.3.

The maximum fuel cladding temperature of 809 °F is below the short-term limit (Section K.4.1) of 1058°F (570°C). The accident pressure in the NUHOMS®-61BT DSC of 46.0 psig remains below the accident design criteria of 65.0 psig. It is concluded that the NUHOMS®-61BT system maintains confinement during the postulated accident condition.

K.4.6.5 Hypothetical Fire Accident Evaluation

For the postulated worst case fire accident, a 300 gallon diesel fire is simulated for a NUHOMS®-61BT DSC with a decay heat load of 18.3 kW during transfer in an OS197 TC. This bounds fire scenarios associated with loading operations and storage within the HSM due to the large thermal mass of the HSM and the HSM vent configuration which provides protection for the DSC and payload.

Steady-state, off-normal conditions are assumed prior to the fire, which consist of a 125 °F ambient condition with solar shield in place on the transfer cask. The fire has a temperature of 1,475°F, and an emittance of 0.9 and a duration of 15 minutes based on the 300 gallon diesel fuel source and complete engulfment of the transfer cask for the duration of the fire. Subsequent to the fire, the transfer cask is subjected to 125 °F ambient conditions with maximum solar load. Note that these hypothetical fire parameters are very conservative.

The calculated temperature response of selected components in the OS197 TC and DSC during the first 2,000 minutes of the fire accident is shown in Figure K.4-9. A summary of the calculated maximum fire transient temperatures for these components is listed in Table K.4-6. The calculated maximum fire transient DSC surface temperature is 499°F, which is less than the blocked vent case maximum DSC temperature of 662 F. Therefore, the NUHOMS®-61BT DSC temperatures and pressures calculated for the blocked vent case bound the hypothetical fire accident case.

K.4.7 Thermal Evaluation for Loading/Unloading Conditions

All fuel transfer operations occur when the NUHOMS®-61BT DSC/transfer cask is in the spent fuel pool. The fuel is always submerged in free-flowing pool water permitting heat dissipation. After fuel loading is complete, the Cask/DSC is removed from the pool, drained, dried, backfilled with helium and sealed.

The loading condition evaluated for the NUHOMS®-61BT DSC is the heatup of the DSC before its cavity can be backfilled with helium. This typically occurs during the performance of the vacuum drying operation of the DSC cavity. A transient thermal analysis is performed to predict the heatup time history for the NUHOMS®-61BT DSC components assuming air is in the DSC cavity.

K.4.7.1 Vacuum Drying Analysis

Heatup of the DSC prior to being backfilled with helium typically occurs as DSC operations are being performed to drain and dry the DSC. The vacuum drying of the DSC generally does not reduce the pressure sufficiently to reduce the thermal conductivity of the air in the DSC cavity. Analyses are performed to determine both steady state temperatures and the transient heat-up during the vacuum drying condition. For both analyses, all gaseous heat conduction within the NUHOMS®-61BT DSC is through air instead of helium. Radiation heat transfer within the basket is neglected.

K.4.7.1.1 Steady State Vacuum Drying Evaluation

A steady state thermal analysis is performed using the 90° symmetric model developed in Section K.4.4.1, the maximum decay heat load of 0.300 kW per assembly (18.3 kW total per DSC), and a maximum DSC temperature of 369 °F. The resulting fuel cladding temperature is 846 °F, well below the loading/unloading short term cladding temperature limit of 1058 °F.

An additional steady state analysis is performed with a total decay heat load of 17.6 kW per DSC. At this heat load, the basket material temperatures do not exceed 800 °F.

K.4.7.1.2 Transient Vacuum Drying Evaluation

A 16 inch cross-section of the finite element model developed in Section K.4.4.1 is used for the transient vacuum drying evaluation. All temperatures within the DSC and basket are initially assumed to be at 100 °F. The decay heat load for the model corresponds to the 18.3 kW total heat load of the DSC. The DSC temperatures after 96 hours of the vacuum drying condition are listed in Table K.4-4. The results show that at the end of 96 hours, the basket material temperatures do not exceed 800 °F.

K.4.7.1.3 Reflooding Evaluation

For unloading operations, the DSC will be filled with the spent fuel pool water through the siphon port. During this filling operation, the DSC vent port is maintained open with effluents

routed to the plant's off-gas monitoring system. The NUHOMS®-61BT DSC operating procedures recommend that the DSC cavity atmosphere be sampled first before introducing any reflood water in the DSC cavity.

When the pool water is added to a DSC cavity containing hot fuel and basket components, some of the water will flash to steam causing internal cavity pressure to rise. This steam pressure is released through the vent port. The procedures also specify that the flow rate of the reflood water be controlled such that the internal pressure in the DSC cavity does not exceed 20 psig. This is assured by monitoring the maximum internal pressure in the DSC cavity during the reflood event. The reflood for the DSC is considered as a service level D event and the design pressure of the DSC is 65 psig. Therefore, there is sufficient margin in the DSC internal pressure during the reflooding event to assure that the DSC will not be over pressurized.

The maximum fuel cladding temperature during reflooding event will be significantly less than the vacuum drying condition due to the presence of water/steam in the DSC cavity. The analysis presented in Section K.4.7.1.1 shows that the maximum cladding temperature during steady state vacuum drying operation is 846°F. Therefore, the maximum cladding temperature during the reflooding operation will be less than 846°F. This is still considerably below the short term cladding temperature limit of 1058°F. Therefore, no cladding damage is expected due to the reflood event. This is also substantiated by the operating experience gained with the loading and unloading of transportation packages like IF-300 [4.10] which show that fuel cladding integrity is maintained during these operations and fuel handling and retrieval is not impacted.

K.4.8 References

4.1 Levy et. al., Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircaloy - Clad Fuel Rods in Inert Gas, Pacific Northwest Laboratory, PNL-6189, 1987.

4.2 Rohsenow et. al., Handbook of Heat Transfer Fundamentals, McGraw-Hill Publishing, New York 1985.

4.3 American Society for Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition Including 1999 Addenda.

4.4 Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year Old PWR Spent Fuel, J. A. Bucholz, ORNL/CSD/TM-149, TTC-9316, January 1983.

4.5 ANSYS, Inc., ANSYS Engineering Analysis System User's Manual for ANSYS Revision 5.6, Houston, PA.

4.6 Standard Review Plan for Dry Cask Storage Systems, NUREG-1536, Nuclear Regulatory Commission.

4.7 Transnuclear, Inc., TN-68 Dry Storage Cask Final Safety Analysis Report, Revision 0, Hawthorne, NY, 2000 (Docket No. 72-1027).

4.8 Transnuclear West, Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel, NUH-003 Revision 5, NUH003.0103, Fremont, CA, August 2000.

4.9 Johnson et. al., Technical Basis for Storage of Zircaloy-Clad Spent Fuel in Inert Gases, PNL-4835, Pacific Northwest Laboratory, 1983.

4.10 Consolidated Safety Analysis Report for IF-300 Shipping Cask, CoC 9001.

Table K.4-1
NUHOMS®-61BT DSC Component Temperatures During Storage

Component	Normal Conditions			Off-Normal Conditions		Accident Conditions	
	Maximum Temperature (°F)	Minimum Temperature* (°F)	Allowable Range (°F)	125 °F Ambient (°F)	Allowable Range (°F)	Blocked Vent Condition (°F)	Allowable Range (°F)
DSC Wall	318	-40	**	345	**	662	**
Basket Rails	423	-40	**	446	**	722	**
Fuel Compartments/	545	-40	**	566	**	787	**
Fuel Cladding	569	-40	649 max.	590	1058 max	809	1,058 max.
Average Cavity Gas	403	-40	N/A	426	N/A	651	N/A

* Assuming no credit for decay heat and a daily average ambient temperature of -40°F. The –40°F off-normal temperature is used to bound the 0°F normal temperature.

** The components perform their intended safety function within the operating range.

Table K.4-2
NUHOMS®-61BT DSC Component Temperatures During Transfer

Component	Normal Conditions		
	Maximum Temperature (°F)	Minimum Temperature* (°F)	Allowable Range (°F)
DSC Wall	378	-40	**
Basket Rails	493	-40	**
Fuel Compartments/ Poison Plates	615	-40	**
Fuel Cladding	638	-40	1058 max.
Average Cavity Gas	480	-40	N/A

* Assuming no credit for decay heat and a daily average ambient temperature of -40°F. The –40°F off-normal temperature is used to bound the 0°F normal temperature.

** The components perform their intended safety function within the operating range.

Table K.4-3
NUHOMS®-61BT DSC Component Temperatures During Storage and Transfer (-40°F Ambient, w/o Insolation)

Component	Maximum Temperature (°F)	
	Storage Conditions	Transfer Conditions
DSC Wall	170	308
Basket Rails	295	430
Fuel Compartments/ Poison Plates	425	556
Fuel Cladding	454	580
Average Cavity Gas	273	416

Table K.4-4
Temperature Distribution within the NUHOMS®-61BT DSC (After 96 Hours of Vacuum Drying Condition)

Component	Maximum Temperature (°F)	Allowable Range (°F)
DSC Wall	370	**
Basket Rails	604	**
Fuel Compartments/ Poison Plates	800	**
Fuel Cladding	827	1,058 max.
Average Cavity Gas	N/A	N/A

** The components perform their intended safety function within the operating range.

Table K.4-5
NUHOMS®-61BT DSC Normal, Off-Normal and Accident Pressures

Case	Maximum Calculated Pressure (psig)		Design Pressure (psig)
	Storage Condition	Transfer Condition	
Normal	7.0	9.0	10.0
Off-Normal	10.0	11.5	20.0
Accident	46.0 (Blocked Vent)	--	65.0

Table K.4-6
Maximum Component Temperatures for the Hypothetical Fire Accident Case for the NUHOMS®-61BT DSC in a OS197 TC

Component	Maximum Temperature (°F)	Allowable Range (°F)
DSC Shell	499	**
Cask Structural Shell	1,420	**
Cask Lead Shielding	369	621
Inside of Cask Lid	331	**
Cask Neutron Shield	688	*

* Cask neutron shield is assumed to be lost during fire event. Effects of loss of shielding are assessed in Section 8.2.5.3.

** The components perform their intended safety function within the operating range.

K.5 Shielding Evaluation

The radiation shielding evaluation for the Standardized NUHOMS® system (during loading, transfer and storage) for the 24P and 52B canisters is discussed in Sections 3.3.5, 7.0 and 8.0. The following radiation shielding evaluation discussion specifically addresses the dose rates due to design basis BWR fuel loaded in the NUHOMS®-61BT DCS. Source terms are calculated for a bounding BWR fuel assembly design, for four different burnup/enrichment combinations. The bounding gamma and the bounding neutron source terms are then combined in the radiation shielding models to conservatively calculate dose rates around the NUHOMS®-61BT system.

The design basis BWR fuel source terms are derived from the GE 7x7, GE2/3 assembly design as defined below. The GE 7x7 assembly is bounding because it has the highest initial heavy metal loading as compared to the 8x8, 9x9 and 10x10 fuel assemblies which are also authorized contents of the NUHOMS®-61BT DSC. In addition, the maximum Co59 content of each hardware region for each assembly type is used to determine the activation source for each assembly region. The burnup, minimum weight percentage (wt.%) enrichment and cooling time cases addressed are as follows:

- 27 GWd/MTU, 2.00 wt. % U-235, 5-year cooled
- 35 GWd/MTU, 2.65 wt. % U-235, 8-year cooled
- 37.2 GWd/MTU, 3.38 wt. % U-235, 6.5-year cooled
- 40 GWd/MTU, 3.4 wt. % U-235, 10-year cooled

These combinations form the basis for the NUHOMS®-61BT system fuel specifications. The methodology, assumptions, and criteria used in this evaluation are summarized in the following subsections.

Table K.5-1 lists the assembly types considered in this application. Note that while the GE fuel designs are specifically listed, storing assemblies of similar design by other manufacturers is also allowed provided an analysis is performed to demonstrate that the limiting features listed in Table K.5-1 bound the specific manufactures replacement fuel. The limiting features are burnup, initial enrichment, cooling time, fissile material type, number of fuel rods, number of water holes, cobalt impurities in the hardware and initial heavy metal.

K.5.1 Discussion and Results

The maximum dose rates due to 61 design basis BWR fuel assemblies in the NUHOMS®-61BT DSC loaded into the Standardized NUHOMS® system are summarized in Table K.5-2. Table K.5-3 provides maximum and average surface dose rates on the HSM loaded with a NUHOMS®-61BT DSC. Table K.5-4 provides the dose rates on and around the TC during fuel loading and transfer operations.

A discussion of the method used to determine the design basis fuel source term is included in Section K.5.2. The model specification and shielding material densities are given in Section K.5.3. The method used to determine the dose rates due to 61-design basis fuel assemblies in the NUHOMS®-61BT DSC is provided in Section K.5.4. A sample input file used for calculating neutron and gamma source terms is included in Section K.5.5.1.

K.5.2 Source Specification

Source terms are calculated with the ORIGEN2 [5.1] computer code. The following section derives the fuel assembly material weights. The ORIGEN2 results are used to develop source terms suitable for use in the shielding calculations.

The design-basis fuel assembly materials and masses for a "composite assembly" comprised of the maximum material for each fuel assembly zone are listed in Table K.5-5. The design basis uranium mass is 0.198 MTU. These masses are irradiated in the appropriate fuel assembly region in the ORIGEN2 models. All of the fuel channel materials are irradiated in the in-core region for conservatism.

The sample input file for the 35 GWd/MTU case is listed and commented in detail in Section K.5.5.1. Parameters that vary between this case and the others are also discussed in detail.

K.5.2.1 Gamma Source

K.5.2.1.1 Energy Group Mapping

The ORIGEN2 gamma ray source is given in an 18-group energy structure that must be converted to the CASK-81 energy group structure [5.2] that is used in the shielding calculations. To map the ORIGEN2 structure into the CASK-81 structure, the particles in each group are assumed to be evenly distributed in logarithmic energy space. This procedure is the same as that used in reference [5.3]. An example of the procedure used is given below.

Example:

ORIGEN2 groups "j" (.45 MeV - .7 MeV) and "k" (.3 MeV - .45 MeV)
CASK group 35 (.4 MeV - .6 MeV)

CASK group 35 contains the portion of ORIGEN2 group j between .45 and .6 MeV. It also contains the portion of group k between .4 and .45 MeV. The portion of ORIGEN2 group j in CASK group 35 is given by,

$$[\log(.6) - \log(.45)]/[\log(.7) - \log(.45)] = .651$$

The portion of ORIGEN2 group k in CASK group 35 is given by,

$$[\log(.45) - \log(.4)]/[\log(.45) - \log(.3)] = .290$$

The formula for mapping the ORIGEN2 spectrum into CASK group 35 would then have the form,

$$F35 = .651*j + .290*k$$

Where F35 is the source in CASK-81 group 35, j is the source in ORIGEN2 group j, and k is the source in ORIGEN2 group k. This procedure is repeated until all ORIGEN2 energy groups have been mapped into the CASK-81 group structure. The mapping functions are shown in Table K.5-6.

K.5.2.1.2 Gamma Source Calculations

Source terms for the 27 GWd/MTU case are calculated with ORIGEN2. For the 5-year post irradiation cooling time used as the design basis for this assembly group, the ORIGEN2 contributions from actinides, fission products, and activation products are summed for each assembly region. These results are shown in Table K.5-7. The results for the 35 GWd/MTU case at a cooling time of 8-years are shown in Table K.5-8. Similar results for the 37.2 GWd/MTU case at a cooling time of 6.5-years are shown in Table K.5-9. Table K.5-10 provides the results for the 40 GWd/MTU case at a cooling time of 10-years.

The bottom nozzle region is modeled as a cylinder 6.65 inches tall with a radius of 33.05 inches. The volume of this cylinder is, therefore, 3.74×10^5 cc. The in-core region is modeled as a cylinder 144 inches tall with a radius of 33.05 inches. The volume of this cylinder is, therefore, 8.10×10^6 cc. For an overall assembly height of 176.2 inches, the remaining height for the top/plenum region is 25.55 inches for a volume of 1.44×10^6 cc. As discussed in Section K.5.3 below, for the axial DORT models, the top and plenum regions are combined into one top/plenum region.

As stated in Section K.5.2.1.1, the ORIGEN2 results are mapped into the CASK-81 energy structure for use in the DORT models. The "whole" results from Table K.5-7 through Table K.5-10 are multiplied by 61 assemblies per DSC and divided by the 8.10×10^6 cc fuel region volume. The resulting volumetric sources are then mapped into the CASK-81 structure using the Table K.5-6 mapping functions. The resulting DORT sources for each case are shown in Table K.5-11.

The most important energy range for the gamma source is between ~0.8 and ~2.0 MeV with respect to the dose rate on the surfaces of the HSM and TC. Therefore as shown in Table K.5-11, the design basis gamma source term is for 27 GWd/MTU, 5-year cooled fuel because it has the largest number of particles in each group between 30 and 33, inclusive (0.8 – 2.0 MeV).

K.5.2.2 Neutron Source Term

The total neutron source is calculated with ORIGEN2. The total neutron sources as a function of cooling time is summarized in Table K.5-12. Neutron source terms are developed for the 27 GWd/MTU, 5-year; 35 GWd/MTU, 8-year; 37.2 GWd/MTU, 6.5-year; and 40 GWd/MTU, 10-year cases for use in the DORT models.

The design basis neutron source term is from the burnup and cooling time combination that produces the largest number of neutrons per second. Therefore, as shown in Table K.5-12, the design basis neutron source term is for 35 GWd/MTU, 8-year cooled fuel because it has the largest neutron source term.

The neutron sources used in the DORT models are shown in Table K.5-13. These sources are calculated by multiplying the ORIGEN2 results by 61 assemblies, dividing by the in-core volume, and then multiplying by the group fraction for each of the 22 CASK-81 neutron groups. Group fractions were taken directly from Table 7.2-2.

K.5.2.3 Axial Peaking

Axial peaking factors for both neutron and gamma sources in BWR fuel are calculated in reference [5.7]. The same peaking factors are used in the DORT analysis presented herein. Table K.5-14 lists the peaking factors for both neutron and gamma sources as a function of active fuel height. These factors are directly applied to each DORT interval in the fuel region.

The axial source term peaking factors from reference [5.7] are determined based on typical axial burnup distributions for BWR assemblies and based upon typical axial water density distribution that occurs during core operation. Using the base SAS2H/ORIGEN-S input for the 7x7 BWR, selected as the design basis assembly for this application, neutron and gamma source terms are generated for axial zones as a function of burnup and moderator density. This estimates both the non-linear behavior of the neutron source with burnup and the core operating moderator density effects on the actinide isotopics (neutron source).

In-core data from an operating BWR facility forms the basis for the evaluation. The data provided the burnup and moderator density for 25 axial locations along the fuel assembly. Five assemblies located in different locations in the reactor core are utilized to generate a burnup (peaking factor) distribution for the assembly. Figure K.5-1 represents this distribution.

For water densities, the nodal data provided is examined and seven assemblies with the lowest densities are selected for evaluation. Of these seven, the assembly with the lowest densities is chosen. The water density data provided shows densities ranging from 0.7608 g/cc at the bottom node to 0.3607 at the top node.

The peaking factors and water densities for the 25 axial locations are collapsed into 12 axial zones and utilized in determining the source terms and axial profiles of the sources for the shielding evaluation. The top and bottom 10% of the assembly is divided into two zones each and the middle 80% divided into 8 equal zones. The peaking factors ranged from 0.2357 and 0.2410 at the bottom and top respectively, to a maximum of 1.20 just below the middle.

The water densities range from 0.3609 at the top zone to 0.7603 at the bottom.

The burnup and water density axial distribution data is utilized to prepare a 12 axial zone fuel assembly model. Twelve SAS2H calculations are performed for the design basis fuel with the power and water density being variables for each zone. The specific power input is the product of the nominal specific power, (5 MW) and the peaking factor. The water density is that value calculated for the zone as described above. Therefore, the fuel assembly is divided into 12 zones, with each zone having a unique gamma and neutron source term, specifically calculated for the burnup and water density in that zone. This data is presented in Table K.5-14.

K.5.3 Model Specification

K.5.3.1 Material Densities

With the exception of the fuel region densities, all material densities are taken directly from the calculations used to support Section 7.0. Fuel densities are calculated by dividing the fuel assembly material weights (defined in Table K.5-5) by the applicable region volume. As stated above, the in-core region volume is 8.10×10^6 cc, the bottom nozzle region is 3.74×10^5 cc and the top/plenum region is 1.44×10^6 cc.

In order to maximize subcritical multiplication, an initial enrichment of 4 wt. % U-235 is used to calculate the amount of U-235 in the shielding models. At an initial enrichment of 4%, there are 7,908 grams of U-235 per assembly and 189,792 grams of U-238.

Summing the mass of the cladding and spacers in the in-core region from Table K.5-5 gives a zircaloy weight of 51,150 g/assy. The spacer springs, 360 g/assy, are assumed iron for simplicity. All other in-core steel and inconel and fuel channels have conservatively been neglected from the shielding models.

For the lateral HSM DORT shielding model only, the homogenized fuel regions also include steel from the DSC basket inner fuel compartment and outer wrapper materials (modeled as iron for simplicity). All other components of the basket such as the neutron poison material, support rails, etc. have been neglected.

The mass density of iron added to each of the fuel region of the lateral HSM model to account for the basket fuel compartments and wrappers is calculated as follows:

Total Cross-Sectional Area of Steel in the Basket			=	258.76 in^2
Total Area of Smeared Fuel Region	=	$\pi(33.05)^2$	=	3431.57 in^2
Area Fraction of Steel	=	258.76/3431.57	=	0.07541
Mass Density of Smeared Steel	=	(7.8 g/cc)(0.07541)	=	0.588 g/cc

Note that a mass density of 7.8 g/cc is assumed for steel. This is conservatively less the 7.87 g/cc used in calculations to support Section 7.0. The mass densities in the in-core region are calculated by dividing the fuel component mass by the in-core volume. The mass density for iron in fuel region (lateral model only) includes the additional 0.588 g/cc contribution from the basket assembly. Table K.5-15 and Table K.5-16 show the results as well as the corresponding number densities (the number density is equal to the mass density multiplied by 0.6022 and divided by the atomic mass). From Table K.5-5, there are 1,260 grams of zircaloy in the bottom region and 4,700 grams of steel (modeled as iron). The resulting mass and number densities are shown in Table K.5-17. From Table K.5-5, there are 6,150 grams of zircaloy in the top region (includes both the top end fitting and the plenum) and 3,180 grams of steel (modeled as iron). Shielding by inconel is neglected. The resulting mass and number densities are shown in Table K.5-18. Table K.5-19 summarizes all of the material densities used in the analysis.

K.5.4 Shielding Evaluation

Dose rate contributions from the Bottom, Core, Plenum/Top regions, as appropriate, from 61 fuel assemblies with a given burnup and cooling time are calculated with the DORT Code [5.8] at each location on the Standardized NUHOMS® HSM, -61BT DSC and TC.

The radiation shielding evaluation for the Standardized NUHOMS®-61BT HSM, DSC and TC with design basis 24P and 52B canister is summarized in Section 7.0. The following shielding evaluation discussion specifically addresses the NUHOMS®-61BT DSC with each of the four sets of source terms determined in Section K.5.2.

The analysis presented in Section 7.0 accounts for the neutron and gamma ray dose rate contributions from a DSC loaded with design basis 24PWR and 52BWR fuel assemblies. In this evaluation, the dose rate from the NUHOMS®-61BT DSC with 61 fuel assemblies is calculated.

K.5.4.1 Computer Programs

DORT [5.8] determines the fluence of particles throughout one-dimensional or two-dimensional geometric systems by solving the Boltzmann transport equation using either the method of discrete ordinates or a diffusion theory approximation. Particles can be generated by either particle interaction with the transport medium or extraneous sources incident upon the system. Anisotropic cross-sections can be expressed in a Legendre expansion of arbitrary order. DORT is an industry standard code distributed by ORNL/RSIC.

The DORT code implements the discrete ordinates method as its primary mode of operation. Balance equations are solved for the flow of particles moving in a set of discrete directions in each cell of a space mesh and in each group of a multigroup energy structure. Iterations are performed until all implicitness in the coupling of cells, directions, groups, and source regeneration is resolved.

DORT was chosen for this application because of its ability to solve two dimensional, cylindrical, deep penetration, radiation transport problems similar applicable to the NUHOMS® system.

K.5.4.2 Spatial Source Distribution

The source components are:

- A neutron source due to the active fuel regions of the 61 fuel assemblies,
- A gamma source due to the active fuel regions of the 61 fuel assemblies,
- A gamma source due to the plenum regions of the 61 fuel assemblies,
- A gamma source due to the top nozzle regions of the 61 fuel assemblies,
- A gamma source due to the bottom nozzle region of the 61 fuel assemblies,
- A gamma source due to the 61 fuel channels in the active fuel regions

The U-235 fission spectrum is input into the 1* array of the DORT input file to account for subcritical multiplication, increasing the neutron source in the active fuel region. Axial peaking is accounted for in the active fuel region by inputting a relative flux factor at each node in the 97* array. The flux factor data is taken from Table K.5-14 as discussed in Section K.5.2.3.

K.5.4.3 Cross-Section Data

The cross-section data used in this analysis is taken from the CASK-81 22 neutron, 18 gamma-ray energy group, coupled cross-section library [5.2]. CASK-81 is an industry standard cross-section library compiled for performing calculations of spent fuel shipping casks and is distributed by ORNL/RSIC. The cross-section data allows coupled neutron/gamma-ray dose rate evaluation to be made that account for secondary gamma radiation (n,γ).

Microscopic P_3 cross-sections are taken from the CASK-81 library and mixed using the GIP-PC computer program distributed with DORT [5.8] to provide macroscopic cross-sections for the materials in the cask model.

An additional element and material, "fluxdosium," is included in the cross-section data and mixing table in the GIP input file. Fluxdosium is used to provide flux-to-dose rate conversion factors as described in Section K.5.4.4 for use in activity calculations. The presence of fluxdosium in the cross-section data does not affect the actual flux calculations.

K.5.4.4 Flux-to-Dose-Rate Conversion

The flux distribution calculated by the DORT code is converted to dose rates using the same flux-to-dose rate conversion factors from ANSI/ANS-6.1.1-1977. The flux-to-dose rate conversion factors are entered into DORT through the cross section tables as material "fluxdosium".

The dose rate at each node in the DORT models is calculated using the activity calculation feature of DORT. The "cross-section" data for "fluxdosium" is specified for the activity calculations, which determine the gamma and neutron dose rate at each node.

K.5.4.5 Methodology

The methodologies used in the shielding analysis are similar to those previously used to support NUHOMS® storage and transportation applications. The computer codes, basic modeling techniques, and analyses are based in large part on those used to support the Sacramento Municipal Utility Districts storage license at their Rancho Seco Nuclear Generating Station (TAC Number L10017, Materials License Number SNM-2510). The methodology used herein is summarized below.

1. The four source term cases evaluated in Section K.5.2 are inspected to determine the bounding neutron and gamma source terms. These are combined to serve as a composite design basis source term for the NUHOMS®-61BT system.

2. Volumetric sources in the CASK-81 [5.2] format are developed for all fuel regions including the fuel channels as documented in Section K.5.2. Source regions include the active fuel region, bottom end fitting (including all materials below the active fuel region), and top end fitting (including all materials above the active fuel region).

3. Suitable shielding material densities are calculated for the fuel, DSC, HSM, and cask. Most material properties are discussed in Section K.5.3.1. Fuel channels and basket materials are conservatively neglected (some basket materials are included in a limited number of purely radial models as discussed below).

4. The 2-D discrete ordinates code DORT [5.8] is used to calculate dose rates on and around the DSC, HSM, and transfer cask. The DORT code was selected because of its ability to readily handle thick, multi-layered shields and account for streaming through both the HSM air vents and cask/DSC annulus. The simple NUHOMS® geometry lends itself to 2-D models (RZ models are used for the cask and both RZ and XY models are used for the HSM). Discrete-ordinates codes such as DORT are preferred to monte-carlo methods for this calculation because they can quickly and reliably calculate dose rate distributions around the cask and HSM without the need to fine-tune biasing parameters for each case addressed. Additionally, the surface or volume crossing estimators typically used in monte-carlo calculations tend to average dose rates across an area or volume and may therefore underpredict the magnitude of radiation streaming. While DORT is subject to instabilities commonly referred to as "ray effects", these tend to result in conservative overpredictions of radiation streaming.

5. The DORT results are area-averaged to provide input to offsite exposure calculations.

6. DORT models are also generated to determine the effects of accident scenarios including HSM sliding, loss of cask neutron shield, and damaged fuel.

7. The results of the DORT models are used to estimate the occupational exposure for each phase of the cask loading operations. The NUHOMS®-61BT operating procedures serve as the template for this evaluation. The previous NUHOMS® loading experience is used to estimate manpower, locations, times, and occupancy during the loading operations. Exposures during loading operations bound those from unloading operations because while the basis steps and equipment are the same, the fuel source terms continue to decay over time.

K.5.4.5.1 Assumptions

The following general assumptions are used in the analyses.

Source Terms

- All 61 assemblies are assumed the same, with design-basis neutron and gamma source terms.

- Three source regions (top, active fuel, and bottom) are assumed, similar to previous NUHOMS® analyses, to model the fuel and irradiated hardware.

- Axial peaking is modeled in the source region on an interval-by-interval basis.

Shielding Materials

- Source regions are homogenized (smeared) to simplify the shielding calculations.

- With the exception of the lateral, "XY" HSM models, the DSC basket components are neglected in the material property calculations. The lateral HSM models are purely radial in nature and the basket's fuel compartments will provide some shielding of the fuel source. Their inclusion in this model is, therefore, considered appropriate.

- While the activation of the fuel channels is included in the design basis source term, all shielding by the channels is neglected. This ensures that the calculations bound both channeled and unchanneled fuel assemblies.

- Shielding materials outside the DSC cavity are taken from Chapter 7. As in Chapter 7, all steel materials and alloys are modeled as pure iron for simplicity. This assumption has little effect on the results.

HSM Dose Rates

- The DSC and fuel assemblies are positioned as close to the front door as possible to maximize the front wall dose rates.

- Cylindrical (RZ) models are used to calculate dose rates on the front and back walls. Planes of reflection are used to simulate adjacent HSMs. Although the actual HSM geometry is rectangular, the cylindrical models conservatively calculate dose rates along the centerline of each HSM surface.

- Cartesian (XY) models are used to calculate the peak dose rates on the roof and side walls. Additional cylindrical results are used to estimate the dose rate distribution along the DSC axis.

- In the cartesian models, the DSC and fuel are modeled as a square source region. The size of this region was selected to maintain the total source volume.

- Fully symmetric S16 quadrature is used for all cylindrical models. An upward biased, 210-direction quadrature set [5.9] is used for the cartesian models.

- Reinforcing bar and embedments in the HSM concrete are neglected.

- For the accident case, an HSM is assumed to slide against its neighbor, opening a 12-inch gap between HSMs.

Cask Dose Rates

- The cask and DSC are modeled in cylindrical coordinates.
- Three inches of supplemental neutron shielding and one inch of steel are assumed to be placed on top the DSC d uring welding. This assumption is identical to the existing NUHOMS® licensing basis.
- During the accident case, the water in the cask neutron shield is assumed lost. In addition, seven rods from each of the potential 16 damaged fuel assemblies in the DSC are assumed to collect against the DSC shell at the bottom of the DSC.

Occupational Exposures

- Durations and manpower are estimated based on previous NUHOMS® experience. These may vary from utility to utility and additional, site-specific evaluations may be required.
- Dose rates around the cask and HSM are estimated using the results of the shielding analyses.

K.5.4.6 HSM Dose Rates

Dose rates on and around an HSM containing a design basis NUHOMS®-61BT DSC are calculated using the DORT 2-D discrete-ordinates code [5.8]. Four sets of HSM models are generated. These models are discussed and listed in the following sections.

K.5.4.7 HSM Roof Model

The HSM roof model is a cylindrical model representing a vertical plane through the DSC, HSM front and back walls, and HSM roof. This model is used to calculate dose rates on and around the upper half of the HSM. Note that a similar model (discussed in the next section as HSM floor model) is used to calculate dose rates around the lower half of the HSM.

The geometry of the roof model is shown in Figure K.5-2. Four DORT runs are used to represent the neutron source, in-core gamma source, top gamma source, and bottom gamma source. An additional four runs are used with a plane of symmetry (as denoted by the dashed line in Figure K.5-2) to account for contributions from an adjacent HSM. Sources and materials are as defined above.

K.5.4.8 HSM Floor Model

The HSM floor model is similar to the roof model. It is used to calculate the dose rates on the front and back walls of the HSM below the centerline of the DSC. The geometry of the floor

model is shown in Figure K.5-3. As with the roof model, two sets of four runs are made to represent the four source regions and to model an adjacent HSM.

K.5.4.9 HSM Side Model

The HSM side model is similar to the roof and floor models. It is used to calculate the dose rates near the front vent and on the end shield wall. The geometry of the side model is shown in Figure K.5-4. This model represents a horizontal plane that includes the DSC centerline. As such, the air vents through the side wall (located well above and below the DSC centerline) are not included in the model. This is not expected to affect the results since the vents are well away from the DSC and particles would have to scatter several times before passing through the vents. The primary contribution to the dose rate in the front vent area is from particles passing through the relatively thin side wall and scattering off the adjacent HSM towards the front wall.

As with the roof model, two sets of four runs are made to represent the four source regions and to model an adjacent HSM

K.5.4.10 HSM Lateral Model

The HSM lateral models represent a vertical plane that is perpendicular to the longitudinal axis of the DSC. This model is used to calculate the dose rate distribution on the HSM roof and end shield wall. This XY cartesian model is shown in Figure K.5-5. The source region is modeled as a square 58.58 inches on a side in order to keep its volume (and hence the total source strength) the same as in the cylindrical models. The "fuel with basket" number densities are used in this model as stated in Section K.5.3.1. Two sets of two runs are made to represent the two source regions (in-core neutron and in-core gamma) and to model an adjacent HSM. The presence of an adjacent HSM is approximated using a plane of reflection in the center of the air vent.

K.5.4.11 Data Reduction and Dose Rate Results

The dose rate distribution for each case is calculated by summing the neutron and gamma DORT results. Surface average dose rates for each HSM surface are calculated as discussed below.

K.5.4.11.1 Front Surface

The dose rates on the HSM front are calculated using the floor (reflection at rear), roof (reflection at rear), and side (reflection in vent) models. The dose rates along the vertical centerline of the HSM front wall, from the floor and roof models, are shown in Figure K.5-6. Also shown in Figure K.5-6 (for comparison) is the total dose rate from the side model. As expected, the side model results track closely with the roof results until the vent streaming begins to dominate. This occurs about 44 inches from the DSC centerline (located at 102 inches in Figure K.5-6).

Based on the information in Figure K.5-6, the average dose rate on the HSM front wall is conservatively estimated by using the surface average dose rate from the floor/roof models in the

center region of the HSM (50.0 mrem/hr gamma and 10.6 mrem/hr neutron) and the surface average dose rate from the side model in the areas adjacent to and including the vents (259.6 mrem/hr gamma and 3.2 mrem/hr neutron). This is shown in Figure K.5-7 and conservatively assumes that the peak front vent dose rate (at the same height as the DSC centerline) exists along the entire height of the front vent. The resulting peak and average dose rates on the HSM front wall are shown in Table K.5-3.

K.5.4.11.2 Back Surface

The dose rates on the HSM rear shield wall are calculated using the floor and roof models (no reflection, rear shield wall included. Note that the side model results are bounded by the floor/roof models on the rear shield wall. The dose rates along the vertical centerline of the HSM front wall, from the floor and roof models, are shown in Figure K.5-8. The surface average dose rate on the rear shield wall is conservatively estimated using the surface-average results from the floor and roof models (these results are taken on the DSC centerline). The rear shield wall peak and average dose rates are shown in Table K.5-3.

K.5.4.11.3 HSM Roof

The HSM roof dose rates are calculated using the lateral and roof models. The lateral model provides the peak dose rates across the width of the HSM as shown in Figure K.5-9 (lateral model with adjacent HSM shown). The roof model results, which are orthogonal to those in Figure K.5-9, are used to estimate an overall average on the HSM roof. The length-average dose rates from the lateral model (as shown in Figure K.5-9) are 162.3 mrem/hr and 1.3 mrem/hr for gammas and neutrons, respectively. Because the lateral model is a cross-section at the center of the DSC, these are the peak "average" dose rates along the DSC length. By multiplying these results by the ratio of average to peak from the roof model, an overall surface average dose rate can be estimated (refer to Figure K.5-10). The resulting roof dose rates are listed in Table K.5-3.

K.5.4.11.4 End Shield Wall

The HSM end shield wall dose rates are calculated using the lateral and side models. The lateral model provides the peak dose rates down the side of the end shield wall. The side model results, which are orthogonal to those in the lateral model, are used to estimate an overall average on the HSM end shield wall. The average dose calculation is performed in the same manner as was used on the HSM roof. The length-average dose rates from the lateral model are 5.61 mrem/hr and 0.094 mrem/hr for gammas and neutrons, respectively. Because the lateral model is a cross-section at the center of the DSC, these are the peak "average" dose rates along the DSC length. By multiplying these results by the ratio of average to peak from the side model, an overall surface average dose rate can be estimated (refer to Figure K.5-10). The resulting end shield wall dose rates are listed in Table K.5-3.

K.5.4.12 Cask Dose Rates

The NUHOMS®-OS197 cask containing a NUHOMS®-61BT DSC is modeled in cylindrical coordinates using 26 material zones as shown in Figure K.5-11. The materials used in zones 18-

23 shown in Figure K.5-11 are varied to model the various welding and decontamination cases. Four runs are made for each case, one for each of the four source regions.

The onsite transfer case, listed and commented below, includes all cask and DSC covers (zones 18, 19, 21-26), air in the DSC cavity (air versus helium has no effect on the results), air in the cask/DSC annulus (zones 7 and 16), and water in the neutron shield cavity (zone 9). The decontamination model includes water only in the cask/DSC annulus (all the way to the top of the DSC - zones 7 and 16), no water in the DSC cavity or neutron shield, and both the DSC and cask top covers removed. In the welding models, the DSC cavity is empty and the annulus is drained 12 inches below the top of the DSC. The inner cover welding case includes the DSC inner top cover (zone 18) and supplemental shielding consisting of three inches of NS-3 (zones 19 and 20, some NS-3 neglected for simplicity) and one inch of steel (zone 21). The outer cover welding case is identical except that the DSC outer cover (zone 19) is installed as well (supplemental NS-3 in zones 20-22, steel in zone 23).

K.5.4.12.1 Transfer Operations

The cask normal operation (onsite transfer) dose rate results are summarized in Table K.5-4 and Figure K.5-12. The results are applicable to most activities performed outside the plant reactor building. The relatively high dose rate on the cask bottom surface is due to the area with reduced shielding directly below the DSC grapple ring and conservative assumptions of no basket material shielding credit in the dose rate calculations.

K.5.4.13 Decontamination Operations

The results from the cask decontamination models are shown in Figure K.5-13. Average dose rates at the cask top end are area-averages calculated using:

$$D_{avg} = \frac{\sum_i D_i \left(r_i^2 - r_{i-1}^2\right)}{\sum_i r_i^2 - r_{i-1}^2} \qquad (1)$$

Where D_{avg} is the area-average dose rate, D_I is the dose rate in interval i, r_i is the outer radius of interval i, and r_{i-1} is the inner radius of interval i.

K.5.4.14 Inner Cover Welding

The dose rates during inner cover welding are shown in Figure K.5-14.

K.5.4.15 Outer Cover Welding

The dose rates during outer cover welding are shown in Figure K.5-15.

K.5.5 Appendix

Section K.5.5.1 includes a sample ORIGEN2 code input file used for the NUHOMS®-61BT system. The DORT code models are described in Section K.5.4. Section K.5.5.2 includes a sample DORT code input file used for the HSM analysis. Section K.5.5.3 includes a sample DORT code input file used for the TC analysis.

K.5.5.1 Sample ORIGEN2 Input File

```
-1
-1
-1
RDA     ##########################################################
RDA          NUHOMS-61B Source Term Calculation
RDA          BWR Fuel Qualification Model
RDA          Design Basis BWR Source - GE 7x7 GE2/3 TN
RDA          Input Filename:      35GETN27.INP
RDA          Creation Date:       6/7/2000
RDA          Fuel Type:           2.65% GE 7x7 GE2/3 TN
RDA          Burnup:              35000 MWd/MTU
RDA
RDA     ##########################################################
RDA
LIP     0  0  0
```

The LIB card defines the libraries used in the model. Each of the models used in this calculation use the extended burnup BWR libraries (657, 658, and 659) as defined in [5.4].

```
LIB     -1 1 2 3      657       658       659   9   3   0   1   42
```

The standard photon libraries are used (101, 102, and 103) on the PHO card.

```
PHO     101  102  103  10
RDA    READ UNIT AMOUNTS OF FUEL AND FUEL MATERIALS WITH CHANNELS
```

The following cards read the material compositions and impurities for each material in the fuel assembly. This information is read from tables at the end of the input deck, which are described later. Note that not all of these materials are used in the design basis BWR fuel assembly.

```
INP           -1  1  -1  -1  1  1  ONE MTIHM UO2
INP           -2  1  -1  -1  1  1  ONE KG ZIRCALOY-4
INP           -3  1  -1  -1  1  1  ONE KG ZIRCALOY-2
INP           -4  1  -1  -1  1  1  ONE KG INCONEL-X750
INP           -5  1  -1  -1  1  1  ONE KG INCONEL-718
INP           -6  1  -1  -1  1  1  ONE KG SS 302
INP           -7  1  -1  -1  1  1  ONE KG SS 304
INP           -8  1  -1  -1  1  1  ONE KG NICROBRAZE
RDA     MIX TOP - PLENUM - IN-CORE AND BOTTOM MIXTURES
```

The following sections mix the four zones modeled for each fuel assembly: top, plenum, in-core, and bottom. The mass of each material in each region is summed from Table K.5-5. As stated above, all channel materials are conservatively assumed to be in the in-core region.

```
RDA     MIX TOP ZONE
MOV           -2        -9        0     0.000 ZIRCALOY-4
ADD           -3        -9        0     1.260 ZIRCALOY-2
ADD           -4        -9        0     0.430 INCONEL-X750
ADD           -5        -9        0     0.000 INCONEL-718
ADD           -6        -9        0     0.000 SS302
ADD           -7        -9        0     2.130 SS304
ADD           -8        -9        0     0.000 NICROBRAZE
RDA     MIX PLENUM ZONE
MOV           -2        -10       0     0.000 ZIRCALOY-4
ADD           -3        -10       0     4.890 ZIRCALOY-2
ADD           -4        -10       0     0.000 INCONEL-X750
ADD           -5        -10       0     0.000 INCONEL-718
ADD           -6        -10       0     0.000 SS302
ADD           -7        -10       0     1.050 SS304
ADD           -8        -10       0     0.000 NICROBRAZE
```

```
RDA      MIX IN-CORE ZONE - SANS UO2
MOV          -2        -11       0     0.000 ZIRCALOY-4
ADD          -3        -11       0     88.250 ZIRCALOY-2
ADD          -4        -11       0     0.490 INCONEL-X750
ADD          -5        -11       0     0.000 INCONEL-718
ADD          -6        -11       0     0.000 SS302
ADD          -7        -11       0     0.590 SS304
ADD          -8        -11       0     0.000 NICROBRAZE
RDA      MIX BOTTOM ZONE
MOV          -2        -12       0     0.000 ZIRCALOY-4
ADD          -3        -12       0     1.260 ZIRCALOY-2
ADD          -4        -12       0     0.050 INCONEL-X750
ADD          -5        -12       0     0.000 INCONEL-718
ADD          -6        -12       0     0.000 SS302
ADD          -7        -12       0     4.700 SS304
ADD          -8        -12       0     0.000 NICROBRAZE
RDA      IRRADIATE ONE MTIHM OF UO2 AT 100% POWER
```

The following cards irradiate one MTIHM of UO_2 fuel at a power suitable for creating the desired burnup. The fuel is irradiated in four equal cycles at a specific power of 25.9 MW/MTU. Each cycle is further divided into three equal steps as recommended by the ORIGEN2 manual. The length of each step is calculated to produce the desired burnup. For the 35 GWd/MTU case shown below, the step length is 35000/25.9/12 = 112.61 days. Similarly, the step lengths for the 27 GWd/MTU, 37.2 GWd/MTU and 40 GWd/MTU cases are 86.87 days, 119.69 days and 128.70 days, respectively. Refueling outages are assumed to last 50 days.

```
BUP
IRP      112.61     25.9      -1        1   4   2  BURNUP
IRP      225.23     25.9       1        1   4   0  BURNUP
IRP      337.84     25.9       1        1   4   0  BURNUP
DEC      387.84                1        1   4   0  OUTAGE
IRP      500.45     25.9       1        1   4   0  BURNUP
IRP      613.06     25.9       1        1   4   0  BURNUP
IRP      725.68     25.9       1        1   4   0  BURNUP
DEC      775.68                1        1   4   0  OUTAGE
IRP      888.29     25.9       1        1   4   0  BURNUP
IRP      1000.9     25.9       1        1   4   0  BURNUP
IRP      1113.5     25.9       1        1   4   0  BURNUP
DEC      1163.5                1        1   4   0  OUTAGE
IRP      1276.1     25.9       1        1   4   0  BURNUP
IRP      1388.7     25.9       1        1   4   0  BURNUP
IRP      1501.4     25.9       1        1   4   0  BURNUP
BUP
RDA
RDA      IRRADIATE TOP ZONE MATERIAL AT 10% FLUX
```

The top zone materials are irradiated at 10% of the in-core flux [5.5].

```
IRF      112.61     -0.1      -9        9       4       2
IRF      225.23     -0.1       9        9       4       0
IRF      337.84     -0.1       9        9       4       0
DEC      387.84                9        9       4       0
IRF      500.45     -0.1       9        9       4       0
IRF      613.06     -0.1       9        9       4       0
IRF      725.68     -0.1       9        9       4       0
DEC      775.68                9        9       4       0
IRF      888.29     -0.1       9        9       4       0
IRF      1000.9     -0.1       9        9       4       0
IRF      1113.5     -0.1       9        9       4       0
DEC      1163.5                9        9       4       0
IRF      1276.1     -0.1       9        9       4       0
IRF      1388.7     -0.1       9        9       4       0
IRF      1501.4     -0.1       9        9       4       0
RDA
RDA      IRRADIATE PLENUM ZONE MATERIAL AT 20% FLUX
```

The plenum zone materials are irradiated at 20% of the in-core flux [5.5].

```
IRF      112.61     -0.2      -10       10      4       2
IRF      225.23     -0.2       10       10      4       0
IRF      337.84     -0.2       10       10      4       0
DEC      387.84                10       10      4       0
IRF      500.45     -0.2       10       10      4       0
IRF      613.06     -0.2       10       10      4       0
```

```
IRF      725.68    -0.2      10       10       4       0
DEC      775.68              10       10       4       0
IRF      888.29    -0.2      10       10       4       0
IRF      1000.9    -0.2      10       10       4       0
IRF      1113.5    -0.2      10       10       4       0
DEC      1163.5              10       10       4       0
IRF      1276.1    -0.2      10       10       4       0
IRF      1388.7    -0.2      10       10       4       0
IRF      1501.4    -0.2      10       10       4       0
RDA
RDA      IRRADIATE CORE ZONE (SANS UO2) AT 100% FLUX
```

The core zone structural materials are irradiated at 100% of the in-core (UO_2) flux [5.5].

```
IRF      112.61    -1.0     -11       11       4       2
IRF      225.23    -1.0      11       11       4       0
IRF      337.84    -1.0      11       11       4       0
DEC      387.84              11       11       4       0
IRF      500.45    -1.0      11       11       4       0
IRF      613.06    -1.0      11       11       4       0
IRF      725.68    -1.0      11       11       4       0
DEC      775.68              11       11       4       0
IRF      888.29    -1.0      11       11       4       0
IRF      1000.9    -1.0      11       11       4       0
IRF      1113.5    -1.0      11       11       4       0
DEC      1163.5              11       11       4       0
IRF      1276.1    -1.0      11       11       4       0
IRF      1388.7    -1.0      11       11       4       0
IRF      1501.4    -1.0      11       11       4       0
RDA
RDA      IRRADIATE BOTTOM ZONE MATERIAL AT 15% FLUX
```

The bottom zone materials are irradiated at 15% of the in-core flux [5.5].

```
IRF      112.61    -0.15    -12       12       4       2
IRF      225.23    -0.15     12       12       4       0
IRF      337.84    -0.15     12       12       4       0
DEC      387.84              12       12       4       0
IRF      500.45    -0.15     12       12       4       0
IRF      613.06    -0.15     12       12       4       0
IRF      725.68    -0.15     12       12       4       0
DEC      775.68              12       12       4       0
IRF      888.29    -0.15     12       12       4       0
IRF      1000.9    -0.15     12       12       4       0
IRF      1113.5    -0.15     12       12       4       0
DEC      1163.5              12       12       4       0
IRF      1276.1    -0.15     12       12       4       0
IRF      1388.7    -0.15     12       12       4       0
IRF      1501.4    -0.15     12       12       4       0
RDA
RDA      MIX A COMBINED IN-CORE ZONE
```

The following cards create a combined in-core zone by adding 0.198 MTU of uranium to the in-core structural material masses defined in vector 11.

```
MOV          11       13        0       1.0
ADD           1       13        0       0.198
RDA      MIX A WHOLE ASSEMBLY OUT OF THE PARTS
```

The following cards sum each of the assembly zones to create a complete BWR fuel assembly in vector 14.

```
MOV           9       14        0       1.0 TOP ZONE
ADD          10       14        0       1.0 PLENUM ZONE
ADD          12       14        0       1.0 BOTTOM ZONE
ADD          13       14        0       1.0 (COMBINED) IN-CORE ZONE
RDA      MOVE ASSEMBLY PARTS TO SCRATCH VECTORS
MOV           9       -1        0       1.0 TOP ZONE
MOV          10       -2        0       1.0 PLENUM ZONE
MOV          13       -3        0       1.0 (COMBINED) IN-CORE ZONE
MOV          12       -4        0       1.0 BOTTOM ZONE
MOV          14       -5        0       1.0 WHOLE ASSEMBLY
TIT      SOURCE CHARACTERISTICS OF 2.65% 35 GWD/MTIHM FUEL AFTER 5.0 YEARS
BAS      ONE GE 7x7 GE2/3 TN FUEL ASSEMBLY
OPTL     8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
OPTA     8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
OPTF     8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
```

```
CUT      9 .01  25 .01  26 .01  27 .01      -1
```

The output parameters are defined above. Refer to the ORIGEN2 manual for more information. The fuel assembly zones (and the whole assembly summary) are each decayed five years in the following cards. The resulting sources are then output per the OUT card. This is repeated for each of the cooling times addressed herein.

```
DEC             5.0        -1        1        5        4
DEC             5.0        -2        2        5        4
DEC             5.0        -3        3        5        4
DEC             5.0        -4        4        5        4
DEC             5.0        -5        5        5        4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT      -5   1   -1   0
TIT      SOURCE CHARACTERISTICS OF 2.65% 35 GWD/MTIHM FUEL AFTER 6.5 YEARS
BAS      ONE GE 7x7 GE2/3 TN FUEL ASSEMBLY
DEC             6.5        -1        1        5        4
DEC             6.5        -2        2        5        4
DEC             6.5        -3        3        5        4
DEC             6.5        -4        4        5        4
DEC             6.5        -5        5        5        4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT      -5   1   -1   0
TIT      SOURCE CHARACTERISTICS OF 2.65% 35 GWD/MTIHM FUEL AFTER 8.0 YEARS
BAS      ONE GE 7x7 GE2/3 TN FUEL ASSEMBLY
DEC             8.0        -1        1        5        4
DEC             8.0        -2        2        5        4
DEC             8.0        -3        3        5        4
DEC             8.0        -4        4        5        4
DEC             8.0        -5        5        5        4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT      -5   1   -1   0
TIT      SOURCE CHARACTERISTICS OF 2.65% 35 GWD/MTIHM FUEL AFTER 10.0 YEARS
BAS      ONE GE 7x7 GE2/3 TN FUEL ASSEMBLY
DEC             10.0        -1        1        5        4
DEC             10.0        -2        2        5        4
DEC             10.0        -3        3        5        4
DEC             10.0        -4        4        5        4
DEC             10.0        -5        5        5        4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT      -5   1   -1   0
TIT      SOURCE CHARACTERISTICS OF 2.65% 35 GWD/MTIHM FUEL AFTER 12.0 YEARS
BAS      ONE GE 7x7 GE2/3 TN FUEL ASSEMBLY
DEC             12.0        -1        1        5        4
DEC             12.0        -2        2        5        4
DEC             12.0        -3        3        5        4
DEC             12.0        -4        4        5        4
DEC             12.0        -5        5        5        4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT      -5   1   -1   0
TIT      SOURCE CHARACTERISTICS OF 2.65% 35 GWD/MTIHM FUEL AFTER 15.0 YEARS
BAS      ONE GE 7x7 GE2/3 TN FUEL ASSEMBLY
```

```
DEC             15.0      -1        1        5        4
DEC             15.0      -2        2        5        4
DEC             15.0      -3        3        5        4
DEC             15.0      -4        4        5        4
DEC             15.0      -5        5        5        4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT      -5    1    -1    0
END
```

The following tables define the compositions and impurities of each of the fuel assembly materials. With the exception of the uranium and oxygen components of the UO_2, the impurities are taken directly from [5.4]. The mass of U-235 is simply the initial enrichment of the fuel assembly (26500 g/MTU, 33800 g/MTU, and 34000 g/MTU). The mass of U-238 is equal to 1,000,000 g/MTU less the quantities of U-234, U-235, and U-236. The mass of oxygen in the fuel is given by:

$$[(\text{enrich}/235.04) + (1\text{-enrich})/238.05]*2*15.9994*1000000$$

Where "enrich" is the initial enrichment of the assembly, 235.04 is the atomic mass of U-235 [5.6], 238.05 is the atomic mass of U-238 [5.6], 2 is the number of oxygen atoms per uranium atom, and 15.9994 is the atomic mass of oxygen [5.6]. For each of the initial enrichments addressed herein, the quantity of oxygen in the fuel is $1.34\text{x}10^5$ grams/MTU.

```
      2   922340    350.00   922350   26500.0    922360      130.0    922380 973020.0      1 MTIHM
FUEL ACTINIDES
      4    30000 1.00E+00     50000 1.00E+00     60000 8.94E+01     70000 2.50E+01      1 MTIHM
FUEL IMPUR
      4    80000 1.34E+05     90000 1.07E+01    110000 1.50E+01    120000 2.00E+00      1 MTIHM
FUEL IMPUR
      4   130000 1.67E+01    140000 1.21E+01    150000 3.50E+01    170000 5.30E+00      1 MTIHM
FUEL IMPUR
      4   200000 2.00E+00    220000 1.00E+00    230000 3.00E+00    240000 4.00E+00      1 MTIHM
FUEL IMPUR
      4   250000 1.70E+00    260000 1.80E+01    270000 1.00E+00    280000 2.40E+01      1 MTIHM
FUEL IMPUR
      4   290000 1.00E+00    300000 4.03E+01    420000 1.00E+01    470000 1.00E-01      1 MTIHM
FUEL IMPUR
      4   480000 2.50E+01    490000 2.00E+00    500000 4.00E+00    640000 1.57E+03      1 MTIHM
FUEL IMPUR
      4   740000 2.00E+00    820000 1.00E+00    830000 4.00E-01         0 0.00E+00      1 MTIHM
FUEL IMPUR
      0
      4    10000 1.30E-02     50000 3.30E-04     60000 1.20E-01     70000 8.00E-02      1 KG
ZIRC-4
      4    80000 9.50E-01    130000 2.40E-02    160000 3.50E-02    220000 2.00E-02      1 KG
ZIRC-4
      4   230000 2.00E-02    240000 1.25E+00    250000 2.00E-02    260000 2.25E+00      1 KG
ZIRC-4
      4   270000 1.00E-02    280000 2.00E-02    290000 2.00E-02    400000 9.79E+02      1 KG
ZIRC-4
      4   480000 2.50E-04    500000 1.60E+01    720000 7.80E-02    740000 2.00E-02      1 KG
ZIRC-4
      4   922340 2.00E-04         0 0.00E+00         0 0.00E+00         0 0.00E+00      1 KG
ZIRC-4
      0
      4    10000 1.30E-02     50000 3.30E-04     60000 1.20E-01     70000 8.00E-02      1 KG
ZIRC-2
      4    80000 9.50E-01    130000 2.40E-02    160000 3.50E-02    220000 2.00E-02      1 KG
ZIRC-2
      4   230000 2.00E-02    240000 1.00E+00    250000 2.00E-02    260000 1.50E+00      1 KG
ZIRC-2
      4   270000 1.00E-02    280000 5.00E-01    290000 2.00E-02    400000 9.80E+02      1 KG
ZIRC-2
      4   480000 2.50E-04    500000 1.60E+01    720000 7.80E-02    740000 2.00E-02      1 KG
ZIRC-2
```

```
        4   922340 2.00E-04         0 0.00E+00         0 0.00E+00         0 0.00E+00      1 KG
ZIRC-2
        0
        4    60000 3.99E-01     70000 1.30E+00    130000 7.98E+00    140000 2.99E+00      1 KG
INC-750
        4   160000 7.00E-02    220000 2.49E+01    240000 1.50E+02    250000 6.98E+00      1 KG
INC-750
        4   260000 6.78E+01    270000 6.49E+00    280000 7.22E+02    290000 4.99E-01      1 KG
INC-750
        4   410000 8.98E+00         0 0.00E+00         0 0.00E+00         0 0.00E+00      1 KG
INC-750
        0
        4    60000 4.00E-01     70000 1.30E+00    130000 5.99E+00    140000 2.00E+00      1 KG
INC-718
        4   160000 7.00E-02    220000 7.99E+00    240000 1.90E+02    250000 2.00E+00      1 KG
INC-718
        4   260000 1.80E+02    270000 4.69E+00    280000 5.20E+02    290000 9.99E-01      1 KG
INC-718
        4   410000 5.55E+01    420000 3.00E+01         0 0.00E+00         0 0.00E+00      1 KG
INC-718
        0
        4    60000 1.50E+00     70000 1.30E+00    140000 1.00E+01    150000 4.50E-01      1 KG SS-
302
        4   160000 3.00E-01    240000 1.80E+02    250000 2.00E+01    260000 6.98E+02      1 KG SS-
302
        4   270000 8.00E-01    280000 8.92E+01         0 0.00E+00         0 0.00E+00      1 KG SS-
302
        0
        4    60000 8.00E-01     70000 1.30E+00    140000 1.00E+01    150000 4.50E-01      1 KG SS-
304
        4   160000 3.00E-01    240000 1.90E+02    250000 2.00E+01    260000 6.88E+02      1 KG SS-
304
        4   270000 8.00E-01    280000 8.92E+01         0 0.00E+00         0 0.00E+00      1 KG SS-
304
        0
        4    50000 5.00E-02     60000 1.00E-01     70000 6.60E-02     80000 4.30E-02      1 KG
NICROBRAZE
        4   130000 1.00E-01    140000 5.11E-01    150000 1.03E+02    160000 1.00E-01      1 KG
NICROBRAZE
        4   220000 1.00E-01    240000 1.50E+02    250000 1.00E-01    260000 4.71E-01      1 KG
NICROBRAZE
        4   270000 3.81E-01    280000 7.44E+02    400000 1.00E-01    740000 1.00E-01      1 KG
NICROBRAZE
        0
        END
```

K.5.5.2 Sample HSM DORT Model (RZ Roof Neutron Model)

```
/   In-Core Neutron Source
/   Includes Rear Shield Wall
/   Cylindrical Source Region
/   Standard HSM Dimensions
/   Design Basis BWR Source
/   S16 Quadrature, Symmetry Around Middle
61$$
/       ntflx  ntfog  ntsig  ntbsi  ntdsi
          0      0      8      0      2
/       ntfci  ntibi  ntibo  ntnpr  ntdir
          0      0      0      0      0
/       ntdso
          0      e
62$$
/       iadj   isctm   izm    im     jm
          0      3     19     84     178
```

```
/          igm     iht     ihs     ihm    mixl
            40       3       4      43      0
/         mmesh    mtp     mtm    idfac    mm
             0      32      32      0      160
/        ingeom    ibl     ibr     ibb     ibt
             1       1       0      0       0
/         isrmx  ifxmi   ifxmf   mode    ktype
            20      -1      50      2       0
/          iacc   kalf  igtype  inpfxm  inpsrm
             2       0       0      0       3
/        njntsr nintsr  njntfx  nintfx   iact
             0       0       0      0       2
/          ired   ipdb2  ifxprt  icsprt  idirf
            -1       0       1      1       0
/         jdirf   jdirl   nbuf   iepsbz  minblk
             0       0       0      0       0
/        maxblk   isbt    msbt    msdm   ibfscl
             1       1       1      1       2
/        intscl  itmscl  nofis  ifdb2z   iswp
             1      99       0      0       0
/         keyjn   keyin  nsigtp  norpos  normat
             0       0       0      0       0
             0 -1    f0      e
63**
/          tmax    xnf     eps     epp     epv
            0.0     0.0     0.0   5.0e-3  5.0e-3
/           epf   ekobj    evth   evchm   evmax
         1.0e-2     1.0     0.0     0.0     0.0
/         evkmx    evi   devdki  evdelk  sormin
            0.0     0.0     0.0     0.0     5.0
/        conacc  conscl  coneps  wsoloi  wsolii
         5.0e-2  5.0e-3   0.01     0.0    -1.5
/        wsolcn    orf   fsnacc  flxmin  smooth
            2.0     0.6     0.0  1.0e-30   0.0
/           epo  extrcv   theta
            0.0     0.2     0.9      e
  t
  t
/  S16 Symmetrical Quadrature
82*
 0 -21082- 5 0 -14907- 5 0 +14907- 5 0 -42164- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 -55777- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 -66667- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 -76012- 5 0 -74536- 5 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 +64979- 5 0 +74536- 5 0 -
84327- 5
 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 +64979- 5 0 +74536- 5 0
+82999- 5
```

```
 0 -91894- 5 0 -90676- 5 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 +82999- 5 0 +90676- 5 0 -98883- 5 0 -97753- 5 0 -
90676- 5
 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 +64979- 5 0 +74536- 5 0
+82999- 5
 0 +90676- 5 0 +97753- 5 0 -21082- 5 0 -14907- 5 0 +14907- 5 0 -
42164- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 -55777- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 -
66667- 5
 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -14907- 5 0 +14907- 5 0
+39441- 5
 0 +53748- 5 0 +64979- 5 0 -76012- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 -84327- 5 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 +82999- 5 0 -91894- 5 0 -90676- 5 0 -82999- 5 0 -
74536- 5
 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -14907- 5 0 +14907- 5 0
+39441- 5
 0 +53748- 5 0 +64979- 5 0 +74536- 5 0 +82999- 5 0 +90676- 5 0 -
98883- 5
 0 -97753- 5 0 -90676- 5 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 +82999- 5 0 +90676- 5 0 +97753- 5
83*
 3r-97753- 5 5r-90676- 5 7r-82999- 5 9r-74536- 511r-64979- 513r-
53748- 5
15r-39441- 517r-14907- 5 3r+97753- 5 5r+90676- 5 7r+82999- 5
9r+74536- 5
11r+64979- 513r+53748- 515r+39441- 517r+14907- 5
81*
 0 +     0+ 0 2r+13586- 6 0 +     0+ 0 0 +97681- 7 2r+97681- 7 0
+97681- 7
 0 +     0+ 0 0 +64738- 7 0 +50390- 7 2r+64738- 7 0 +50390- 7 0
+64738- 7
 0 +     0+ 0 0 +64634- 7 0 +71124- 7 0 +71124- 7 2r+64634- 7 0
+71124- 7
 0 +71124- 7 0 +64634- 7 0 +     0+ 0 0 +64634- 7 0 +14381- 7 0
+36342- 7
 0 +14381- 7 2r+64634- 7 0 +14381- 7 0 +36342- 7 0 +14381- 7 0
+64634- 7
 0 +     0+ 0 0 +64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0
+71124- 7
```

```
 2r+64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0 +71124- 7 0
+64738- 7
 0 +    0+ 0 0 +97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 2r+97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 0 +97681- 7 0 +    0+ 0 0 +13586- 6 0 +97681- 7 0
+64738- 7
 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 2r+13586- 6 0
+97681- 7
 0 +64738- 7 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 0
+13586- 6
 0 +    0+ 0 2r+13586- 6 0 +    0+ 0 0 +97681- 7 2r+97681- 7 0
+97681- 7
 0 +    0+ 0 0 +64738- 7 0 +50390- 7 2r+64738- 7 0 +50390- 7 0
+64738- 7
 0 +    0+ 0 0 +64634- 7 0 +71124- 7 0 +71124- 7 2r+64634- 7 0
+71124- 7
 0 +71124- 7 0 +64634- 7 0 +    0+ 0 0 +64634- 7 0 +14381- 7 0
+36342- 7
 0 +14381- 7 2r+64634- 7 0 +14381- 7 0 +36342- 7 0 +14381- 7 0
+64634- 7
 0 +    0+ 0 0 +64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0
+71124- 7
 2r+64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0 +71124- 7 0
+64738- 7
 0 +    0+ 0 0 +97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 2r+97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 0 +97681- 7 0 +    0+ 0 0 +13586- 6 0 +97681- 7 0
+64738- 7
 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 2r+13586- 6 0
+97681- 7
 0 +64738- 7 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 0
+13586- 6
  t
/  U-235 Fission Spectrum
```

U-235 fission spectrum used for subcritical multiplication.

```
1**
  1.984e-04  1.064e-03  4.013e-03  1.559e-02  3.676e-02
  5.035e-02  1.093e-01  9.024e-02  2.149e-02  1.190e-01
  2.138e-01  1.928e-01  1.298e-01  1.549e-02  7.893e-05
  5.740e-06  3.775e-07  5.453e-08  1.176e-08  1.832e-09
  4.039e-10  1.166e-10  f0.0
/  Fine Mesh in the Z-direction
```

The Z mesh is defined below. 13 intervals are included in the outside air regions to calculate dose rates at distances of up to 2-meters from the HSM surface.

```
2**
/  Front Air
  -281.68  -251.68  -226.68  -201.68  -176.68
  -156.68  -136.68  -116.68  -97.68  -81.68
  -73.68  -69.68  -67.68
/  HSM Intervals
 2i-66.68 5i-62.87 1i-47.96 7i-46.69 9i0.00
```

```
 1i13.34 9i19.05 35.94
/  Active Fuel Intervals
    39.60  43.26  50.57  57.89  65.20
    72.52  79.83  87.15  94.46 101.78
   109.09 116.41 123.72 131.04 145.67
   160.30 174.93 189.56 204.19 218.82
   233.45 248.08 262.71 277.34 291.97
   306.60 313.92 321.23 328.55 335.86
   343.18 350.49 357.81 365.13 372.44
   379.76 387.07 394.39 398.04
/  HSM Intervals
 9i401.70 1i466.60
 13i474.78 2i492.56 2i494.46 2i497.64 11i511.18
 23i541.66 602.62
/  Back Air
  603.62  605.62  609.62  617.62  633.62
  652.62  672.62  692.62  712.62  737.62
  762.62  787.62  817.62
/  Fine Mesh in the R-direction
4**
```

> The R mesh is defined in the same manner as the Z mesh. Dose rates are calculated up to 2-meters from the HSM surface.

```
/  DSC and HSM
 19i0.00 1i83.95 1i84.15 1i85.42 4i87.96
 1i100.66 1i106.05 35i106.68 198.12
/  Top Air
  199.12  201.12  205.12  213.12  229.12
  248.12  268.12  288.12  308.12  333.12
  358.12  383.12  413.12
/  Material Zone by Mesh
/  left to right (rsmall to rlarge)
/  bottom to top (zsmall to zlarge)
```

> The material zones are defined below. The zone numbers correspond to the circled numbers in Figure K.5-2.

```
8$$
  71r1   13r2   12q84
  33r3   38r1   13r2   2q84
  31r4   40r5   13r2   5q84
  31r6   40r5   13r2   1q84
  26r7   45r5   13r2   7q84
  22r8   2r9    2r7    45r5   13r2   9q84
  22r8   2r9    11r7   36r5   13r2   1q84
  20r10  2r11   2r9    11r7   36r5   13r2   9q84
  20r12  2r11   2r9    11r7   36r5   13r2   39q84
  20r13  2r11   2r9    11r7   36r5   13r2   9q84
  20r17  2r11   2r9    11r7   36r5   13r2   1q84
  22r14  2r9    11r7   36r5   13r2   13q84
  22r15  2r9    11r7   36r5   13r2   2q84
  22r16  2r9    11r7   36r5   13r2   2q84
  35r7   36r5   13r2   2q84
  71r5   13r2   11q84
  71r18  13r2   23q84
  71r19  13r2   12q84
/  Mixture by Material Zone
```

> Mixture numbers correspond to those in the GIP models.

```
/  1  = Fluxdosium     5  = Fuel Bskt      9  = Fuel Only
```

```
/  13 = Top               17 = Bottom          21 = Concrete
/  25 = Air               29 = Steel
9$$  25 25 29 21 21        29 25 29 29 17
     25  9 13 29 29        29 25 21 25
/  Material for use in Activity Calculations
```

Material 1 is used to convert fluxes to dose rates in DORT's activity tables. Positions 2 (neutron) and 3 (gamma) are used herein.

```
25$$ f-1
/  Position in Cross-Section Table for Activity Calcs
/  1 = Total    2 = Neutron    3 = Gamma
26$$ 2 3
/  Activity Multiplication Factors
27** 1.0 1.0
/  Initial Iteration Limits by Energy Group
28$$ 22r5 f1  t
/  Source Multiplication in the R direction
96** 20r1.0 f0.0 t
/  Source Multiplication in the Z direction
```

Axial peaking factors from Table K.5-14 are applied to each fuel interval.

```
97** 44r0.0
     10r0.0
     0.0018 0.0018 0.0018 0.1683 0.1683
     0.1683 0.8447 0.8447 0.8447 0.8447
     0.8447 1.3859 1.3859 1.3859 1.3859
     1.5288 1.5288 1.5775 1.5775 1.5775
     1.5624 1.5624 1.5624 1.3842 1.3842
     1.0707 1.0707 1.0707 1.0707 0.5047
     0.5047 0.5047 0.5047 0.5047 0.1093
     0.1093 0.1093 0.0028 0.0028 0.0028
     10r0.0
     f0.0 t
/  Group Volumetric Sources
98**
```

Volumetric neutron sources from Table K.5-13 are input below.

```
     1.349e-1 1.147e+0 3.155e+0 1.573e+1 3.983e+1
     5.267e+1 1.322e+2 1.082e+2 2.646e+1 1.366e+2
     2.435e+2 2.159e+2 9.946e+1 4.285e-3 0.000e+0
     0.000e+0 0.000e+0 0.000e+0 0.000e+0 0.000e+0
     0.000e+0 0.000e+0 f0.0
     t
```

K.5.5.3 Sample TC DORT Model (RZ Transfer Configuration)

```
NUHOMS-61B Cask Normal RZ Model
/   Neutron Source
/   Normal Operation
/   Transfer Configuration
/   Water in Neutron Shield
/   Cylindrical Source Region
/   OS197 Cask Dimensions
/   Design Basis BWR Source
/   S16 Quadrature, Symmetry Around Middle
61$$
/        ntflx  ntfog  ntsig  ntbsi  ntdsi
           0      0      8      0      2
/        ntfci  ntibi  ntibo  ntnpr  ntdir
           0      0      0      0      0
/        ntdso
           0      e
62$$
/         iadj  isctm   izm     im     jm
           0      3     26     103    191
/         igm    iht    ihs    ihm    mixl
          40      3      4     43      0
/        mmesh   mtp    mtm   idfac    mm
           0     36     36      0     160
/       ingeom   ibl    ibr    ibb    ibt
           1      1      0      0      0
/        isrmx  ifxmi  ifxmf  mode   ktype
          20     -1     50      2      0
/         iacc   kalf  igtype inpfxm inpsrm
           2      0      0      0      3
/       njntsr nintsr njntfx nintfx  iact
           0      0      0      0      2
/         ired   ipdb2 ifxprt icsprt idirf
          -1      0      1      1      0
/        jdirf  jdirl   nbuf  iepsbz minblk
           0      0      0      0      0
/       maxblk   isbt   msbt   msdm  ibfscl
           1      1      1      1      2
/       intscl itmscl  nofis ifdb2z  iswp
           1     99      0      0      0
/        keyjn  keyin nsigtp norpos normat
           0      0      0      0      0
         0 -1    f0      e
63**
/         tmax    xnf    eps    epp    epv
          0.0    0.0    0.0  5.0e-3 5.0e-3
/          epf  ekobj   evth  evchm  evmax
        1.0e-2   1.0    0.0    0.0    0.0
/        evkmx    evi devdki evdelk sormin
          0.0    0.0    0.0    0.0    5.0
/       conacc conscl coneps wsoloi wsolii
        5.0e-2 5.0e-3  0.01    0.0   -1.5
/       wsolcn    orf fsnacc flxmin smooth
          2.0    0.6    0.0  1.0e-30  0.0
```

```
/         epo   extrcv  theta
          0.0    0.2     0.9      e
  t
  t
/  S16 Symmetrical Quadrature
82*
 0 -21082- 5 0 -14907- 5 0 +14907- 5 0 -42164- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 -55777- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 -66667- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 -76012- 5 0 -74536- 5 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 +64979- 5 0 +74536- 5 0 -
84327- 5
 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 +64979- 5 0 +74536- 5 0
+82999- 5
 0 -91894- 5 0 -90676- 5 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 +82999- 5 0 +90676- 5 0 -98883- 5 0 -97753- 5 0 -
90676- 5
 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -
14907- 5
 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 +64979- 5 0 +74536- 5 0
+82999- 5
 0 +90676- 5 0 +97753- 5 0 -21082- 5 0 -14907- 5 0 +14907- 5 0 -
42164- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 -55777- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0 -
66667- 5
 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -14907- 5 0 +14907- 5 0
+39441- 5
 0 +53748- 5 0 +64979- 5 0 -76012- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 -84327- 5 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 +82999- 5 0 -91894- 5 0 -90676- 5 0 -82999- 5 0 -
74536- 5
 0 -64979- 5 0 -53748- 5 0 -39441- 5 0 -14907- 5 0 +14907- 5 0
+39441- 5
 0 +53748- 5 0 +64979- 5 0 +74536- 5 0 +82999- 5 0 +90676- 5 0 -
98883- 5
 0 -97753- 5 0 -90676- 5 0 -82999- 5 0 -74536- 5 0 -64979- 5 0 -
53748- 5
```

```
 0 -39441- 5 0 -14907- 5 0 +14907- 5 0 +39441- 5 0 +53748- 5 0
+64979- 5
 0 +74536- 5 0 +82999- 5 0 +90676- 5 0 +97753- 5
83*
 3r-97753- 5 5r-90676- 5 7r-82999- 5 9r-74536- 511r-64979- 513r-
53748- 5
15r-39441- 517r-14907- 5 3r+97753- 5 5r+90676- 5 7r+82999- 5
9r+74536- 5
11r+64979- 513r+53748- 515r+39441- 517r+14907- 5
81*
 0 +     0+ 0 2r+13586- 6 0 +     0+ 0 0 +97681- 7 2r+97681- 7 0
+97681- 7
 0 +     0+ 0 0 +64738- 7 0 +50390- 7 2r+64738- 7 0 +50390- 7 0
+64738- 7
 0 +     0+ 0 0 +64634- 7 0 +71124- 7 0 +71124- 7 2r+64634- 7 0
+71124- 7
 0 +71124- 7 0 +64634- 7 0 +     0+ 0 0 +64634- 7 0 +14381- 7 0
+36342- 7
 0 +14381- 7 2r+64634- 7 0 +14381- 7 0 +36342- 7 0 +14381- 7 0
+64634- 7
 0 +     0+ 0 0 +64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0
+71124- 7
 2r+64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0 +71124- 7 0
+64738- 7
 0 +     0+ 0 0 +97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 2r+97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 0 +97681- 7 0 +     0+ 0 0 +13586- 6 0 +97681- 7 0
+64738- 7
 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 2r+13586- 6 0
+97681- 7
 0 +64738- 7 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 0
+13586- 6
 0 +     0+ 0 2r+13586- 6 0 +     0+ 0 0 +97681- 7 2r+97681- 7 0
+97681- 7
 0 +     0+ 0 0 +64738- 7 0 +50390- 7 2r+64738- 7 0 +50390- 7 0
+64738- 7
 0 +     0+ 0 0 +64634- 7 0 +71124- 7 0 +71124- 7 2r+64634- 7 0
+71124- 7
 0 +71124- 7 0 +64634- 7 0 +     0+ 0 0 +64634- 7 0 +14381- 7 0
+36342- 7
 0 +14381- 7 2r+64634- 7 0 +14381- 7 0 +36342- 7 0 +14381- 7 0
+64634- 7
 0 +     0+ 0 0 +64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0
+71124- 7
 2r+64738- 7 0 +71124- 7 0 +36342- 7 0 +36342- 7 0 +71124- 7 0
+64738- 7
 0 +     0+ 0 0 +97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 2r+97681- 7 0 +50390- 7 0 +71124- 7 0 +14381- 7 0
+71124- 7
 0 +50390- 7 0 +97681- 7 0 +     0+ 0 0 +13586- 6 0 +97681- 7 0
+64738- 7
 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 2r+13586- 6 0
+97681- 7
```

```
 0 +64738- 7 0 +64634- 7 0 +64634- 7 0 +64738- 7 0 +97681- 7 0
+13586- 6
  t
/  U-235 Fission Spectrum
1**
  1.984e-04  1.064e-03  4.013e-03  1.559e-02  3.676e-02
  5.035e-02  1.093e-01  9.024e-02  2.149e-02  1.190e-01
  2.138e-01  1.928e-01  1.298e-01  1.549e-02  7.893e-05
  5.740e-06  3.775e-07  5.453e-08  1.176e-08  1.832e-09
  4.039e-10  1.166e-10  f0.0
/  Fine Mesh in the Z-direction
2**
/  Bottom Air
  -227.70  -197.70  -172.70  -147.70  -122.70
  -102.70  -82.70  -62.70  -43.70  -27.70
  -19.70  -15.70  -13.70
/  Cask Intervals
 2i-12.70 1i-10.80 5i-10.16 5i-7.62 5i-5.08
 5i0.00 1i5.08 1i6.10 3i7.37 7i10.16
 9i19.05 35.94
/  Active Fuel Intervals
    39.60  43.26  50.57  57.89  65.20
    72.52  79.83  87.15  94.46 101.78
   109.09 116.41 123.72 131.04 145.67
   160.30 174.93 189.56 204.19 218.82
   233.45 248.08 262.71 277.34 291.97
   306.60 313.92 321.23 328.55 335.86
   343.18 352.43 357.81 365.13 372.44
   379.76 387.07 394.39 398.04
/  Cask Intervals
 9i401.70 1i466.60 1i474.35 5i474.78 1i480.70
 1i483.24 1i484.51 3i485.78 1i489.59 3i492.56
 3i494.46 3i497.64 5i499.75 5i502.29 3i505.26
 7i507.37 1i512.45 513.08
/  Top Air
  514.08  516.08  520.08  528.08  544.08
  563.08  583.08  603.08  623.08  648.08
  673.08  698.08  728.08
/  Fine Mesh in the R-direction
4**
/  DSC and Cask
 5i0.00 3i27.94 9i35.56 1i83.95 1i84.15
 1i85.42 1i86.36 3i87.63 15i89.05 15i91.59
 7i96.67 1i99.85 3i100.48 9i101.75 1i108.10
 108.59
/  Side Air
  109.59  111.59  115.59  123.59  139.59
  158.59  178.59  198.59  218.59  243.59
  268.59  293.59  323.59
/  Material Zone by Mesh
/  left to right (rsmall to rlarge)
/  bottom to top (zsmall to zlarge)
8$$
   103r1 12q103
   74r2  29r1   2q103
   10r2  38r4   26r2  29r1  1q103
   6r3   4r2    38r4  26r2  29r1  5q103
```

```
    6r3   4r2    22r4  42r2  29r1  5q103
    6r3   68r2   29r1  5q103
    22r5  2r6    2r7   48r2  29r1  5q103
    22r5  2r6    2r7   2r2   20r8  26r2  29r1  1q103
    22r5  2r6    2r7   2r2   20r8  26r2  16r10 13r1  1q103
    22r5  2r6    2r7   2r2   20r8  26r2  14r9  2r10  13r1  3q103
    22r5  2r6    2r7   2r2   36r8  10r2  14r9  2r10  13r1  7q103
    20r11 2r12   2r6   2r7   2r2   36r8  10r2  14r9  2r10  13r1
9q103
    20r13 2r12   2r6   2r7   2r2   36r8  10r2  14r9  2r10  13r1
31q103
    20r13 2r12   2r6   2r7   2r2   36r8  14r2  10r9  2r10  13r1
7q103
    20r14 2r12   2r6   2r7   2r2   36r8  14r2  10r9  2r10  13r1
9q103
    20r15 2r12   2r6   2r16  2r2   36r8  14r2  10r9  2r10  13r1
1q103
    20r15 2r12   2r6   2r16  2r2   36r8  10r2  14r9  2r10  13r1
1q103
    22r17 2r6    2r16  2r2   36r8  10r2  14r9  2r10  13r1  5q103
    22r17 2r6    2r16  2r2   20r8  26r2  14r9  2r10  13r1  1q103
    22r17 2r6    2r16  2r2   20r8  26r2  16r10 13r1  1q103
    22r17 2r6    2r16  2r2   20r8  26r2  29r1  1q103
    22r17 2r6    2r16  48r2  29r1  3q103
    22r17 2r6    4r16  46r2  29r1  1q103
    22r18 2r6    4r16  46r2  29r1  3q103
    22r19 2r6    4r16  46r2  29r1  3q103
    22r20 6r16   46r2  29r1  3q103
    22r21 6r24   46r2  29r1  5q103
    22r22 52r24  29r1  5q103
    22r23 52r24  29r1  3q103
    72r25 2r26   29r1  7q103
    74r26 29r1   1q103
    103r1 12q103
/  Mixture by Material Zone
/  1  = Fluxdosium     5  = Fuel Only      9  = Top
/  13 = Bottom         17 = NS-3           21 = Water
/  25 = Air            29 = Lead           33 = Steel
9$$  25 33 25 17 33     33 25 29 21 33
     13 25  5  9 25     25 33 33 33 25
     33 33 33 33 17     33
/  Material for use in Activity Calculations
25$$ f-1
/  Position in Cross-Section Table for Activity Calcs
/  1 = Total   2 = Neutron   3 = Gamma
26$$ 2 3
/  Activity Multiplication Factors
27** 1.0 1.0
/  Initial Iteration Limits by Energy Group
28$$ 22r5 f1  t
/  Source Multiplication in the R direction
96** 20r1.0 f0.0 t
/  Source Multiplication in the Z direction
97** 58r0.0
     10r0.0
     0.0018 0.0018 0.0018 0.1683 0.1683
     0.1683 0.8447 0.8447 0.8447 0.8447
```

```
     0.8447 1.3859 1.3859 1.3859 1.3859
     1.5288 1.5288 1.5775 1.5775 1.5775
     1.5624 1.5624 1.5624 1.3842 1.3842
     1.0707 1.0707 1.0707 1.0707 0.5047
     0.5047 0.5047 0.5047 0.5047 0.1093
     0.1093 0.1093 0.0028 0.0028 0.0028
     10r0.0
     f0.0 t
/  Group Volumetric Sources
98**
     1.349e-1 1.147e+0 3.155e+0 1.573e+1 3.983e+1
     5.267e+1 1.322e+2 1.082e+2 2.646e+1 1.366e+2
     2.435e+2 2.159e+2 9.946e+1 4.285e-3 0.000e+0
     0.000e+0 0.000e+0 0.000e+0 0.000e+0 0.000e+0
     0.000e+0 0.000e+0 f0.0
     t
```

K.5.6 References

5.1 "ORIGEN2.1 – Isotope Generation and Depletion Code – Matrix Exponential Method," CCC-371, Oak Ridge National Laboratory, RSIC Computer Code Collection, August 1991.

5.2 CASK-81 - 22 Neutron, 18 Gamma-Ray Group, P3, Cross Sections for Shipping Cask Analysis," DLC-23, Oak Ridge National Laboratory, RSIC Data Library Collection, June 1987.

5.3 NUHOMS® MP187 Multi-Purpose Cask Transportation Safety Analysis Report," Revision 9, NRC Docket Number 71-9255.

5.4 Ludwig, S.B., and J.P. Renier, "Standard- and Extended-Burnup PWR and BWR Reactor Models for the ORIGEN2 Computer Code," ORNL/TM-11018 Oak Ridge National Laboratory, December 1989.

5.5 "Characteristics of Potential Repository Wastes," Department of Energy, Office of Civilian Radioactive Waste Management, DOE/RW-0184-R1, July, 1992.

5.6 LaMarsh, John R., Introduction to Nuclear Engineering, Second Edition, Addison-Wesley Publishing Company, Reading, Massachusetts, 1983.

5.7 "Final Safety Analysis Report for the TN-68 Dry Storage Cask," Revision 0, NRC Docket Number 72-1027.

5.8 "DORT-PC - Two-Dimensional Discrete Ordinates Transport Code System," CCC-532, Oak Ridge National Laboratory, RSIC Computer Code Collection, Version 2.10.1, October 1991.

5.9 Jenal, J. P., P. J. Erickson, W. A. Rhoades, D. B. Simpson, and M. L. Williams, "The Generation of a Computer Library for Discrete Ordinates Quadrature Sets," ORNL/TM-6023, Oak Ridge National Laboratory, October 1977.

Table K.5-1
Fuel Assembly Designs Considered

Manufacturer[1]	Array	Version[2]	Active Fuel Length (in)	Number Fuel Rods per Assembly	Number Water Holes per Assembly	Fuel Loading (MTU)[3]
GE	7x7	GE2	144	49	NA	0.198
GE	7x7	GE3	144	49	NA	0.198
GE	8x8	GE4	146	63	1	0.188
GE	8x8	GE5	150	62	2	0.186
GE	8x8	GE-Pres	150	62	2	0.186
GE	8x8	GE-Barrier	150	62	2	0.186
GE	8x8	GE8 Type I	150	62	2	0.186
GE	8x8	GE8 Type II	150	60	1	0.183
GE	8x8	GE9	150	60	1	0.184
GE	8x8	GE10	150	60	1	0.184
GE	9x9	GE11	146-Full 90-Partial	66-Full 8-Partial	2	0.177
GE	9x9	GE13	146-Full 90-Partial	66-Full 8-Partial	2	0.177
GE	10x10	GE12	150-Full 93-Partial	78-Full 14-Partial	2	0.187

(1) Or equivalent reload fuel that is enveloped by the fuel assembly design characteristics listed in this Table.

(2) Maximum Co59 content in the Top End Fitting Region is 4.5 gms per assembly.
Maximum Co59 content in the Plenum Regions is 0.9 gm per assembly.
Maximum Co59 content in the Active Fuel Region is 4.5 gm per assembly
Maximum Co59 content in the Bottom Tie Plate Region is 4.1 gms per assembly.

(3) Fissile Material is limited to UO_2.

Table K.5-2
Dose Rates Due to the 61 BWR Assemblies

DOSE RATE LOCATION	Gamma (mrem/hr)	Neutron (mrem/hr)	Total (mrem/hr)
HSM Roof (centerline)	66.6	0.6	67.2
HSM Roof Birdscreen	2770.0	15.6	2785.6
HSM End Shield Wall Surface	13.5	0.2	13.7
HSM Door Exterior Surface (centerline)	160.0	33.4	193.4
HSM Front Birdscreen	1230.0	10.3	1240.3
HSM Back Shield Wall	3.16	0.07	3.23
Centerline Top DSC Cover Plate w/ 3"ns3+1"steel Dry Welding	208.0	9.0	217.0
Outer Edge Centerline Top DSC (Peak Annulus)	3950.0	42.9	3992.9
Cask Surface (Radial) Contact Normal Condition	872.0	284.0	1156.0
3 ft from Cask Surface (Radial) Normal Condition	362.0	96.3	458.3
Cask Surface (Radial) Contact Accident Condition	4820.0	3700.0	8520.0
Cask Top Axial Surface	126.0	17.5	143.5
Cask Bottom Axial Surface	1930.0	608.0	2538.0

Table K.5-3
Summary of HSM Dose Rates

Surface	Dose Rate Component	Maximum Dose Rate (mrem/hr)	Average Surface Dose Rate (mrem/hr)
Rear(1)	Gamma	3.16	1.04
	Neutron	0.065	0.025
Front	Gamma	1230	109
	Neutron	33.4	8.54
Roof	Gamma	2770	109
	Neutron	156	0.6
Side(1)	Gamma	13.5	3.57
	Neutron	0.18	0.04

(1) Includes 24 inch shield wall.

Table K.5-4
Summary of Cask Onsite Transfer Dose Rates

	Cask Surface		
	Side (mrem/hr)	Top (mrem/hr)	Bottom (mrem/hr)
Neutron	2.84E+02	1.75E+01	6.08E+02
Gamma	8.72E+02	1.26E+02	1.93E+03
Total	1.16E+03	1.32E+02	2.54E+03
	1-Meter from Cask Surface		
	Side (mrem/hr)	Top (mrem/hr)	Bottom (mrem/hr)
Neutron	9.63E+01	6.02E+00	6.01E+01
Gamma	3.62E+02	2.06E+01	4.41E+02
Total	4.58E+02	2.36E+01	5.01E+02
	2-Meters from Cask Surface		
	Side (mrem/hr)	Top (mrem/hr)	Bottom (mrem/hr)
Neutron	4.79E+01	2.39E+00	1.80E+01
Gamma	2.09E+02	9.78E+00	1.38E+02
Total	2.57E+02	1.20E+01	1.56E+02

Table K.5-5
BWR Fuel Assembly Materials and Masses

Fuel Assembly Components	Material	Mass (kg/assy)
Fuel Zone		
Cladding	Zircaloy-2	49.2
Spacers	Zircaloy-2	1.95
Spacer Springs	Inconel X-750	0.36
Fuel-Gas Plenum Zone		
Cladding	Zircaloy-2	4.89
Springs	SS304	1.05
Top End Fitting Zone		
Upper Tie Plate	SS304	2.08
Lock Tab Washers & Nuts	SS304	0.05
Expansion Springs	Inconel X-750	0.43
End Plugs	Zircaloy-2	1.26
Bottom End Fitting Zone		
Finger Springs	Inconel X-750	0.05
End Plugs	Zircaloy-2	1.26
Lower Tie Plate	SS304	4.7
Channel		
Channel Sleeve	Zircaloy-2	37.1
Channel Spacer & Rivet	SS304	0.13
Channel Guard	SS304	0.46
Channel Spring & Bolt	Inconel X-750	0.13

Table K.5-6
Gamma Energy Group Mapping Functions

ORIGEN2 [5.1]				CASK-81 [5.2]			Formula
Group	E_{mean} (MeV)	E_{upper} (MeV)	$Ln(E_{mean})$	Group	E_{upper} (MeV)	$Ln(E_{mean})$	(ORIGEN2-CASK)
a	9.500	11.000	1.041	23	10.000	1.000	+a
b	7.000	8.000	0.903	24	8.000	0.903	+0.722*b
c	5.000	6.000	0.778	25	6.500	0.813	+0.278*b+0.450*c
d	3.500	4.000	0.602	26	5.000	0.699	+0.550*c
e	2.750	3.000	0.477	27	4.000	0.602	+d
f	2.250	2.500	0.398	28	3.000	0.477	+e
g	1.750	2.000	0.301	29	2.500	0.398	+f
h	1.250	1.500	0.176	30	2.000	0.301	+0.648*g
i	0.850	1.000	0.000	31	1.660	0.220	+0.352*g+0.297*h
j	0.575	0.700	-0.155	32	1.330	0.124	+0.703*h
k	0.375	0.450	-0.347	33	1.000	0.000	+0.626*i
l	0.225	0.300	-0.523	34	0.800	-0.097	+0.374*i+0.349*j
m	0.125	0.150	-0.824	35	0.600	-0.222	+0.651*j+0.290*k
n	0.085	0.100	-1.000	36	0.400	-0.398	+0.710*k
o	0.058	0.070	-1.155	37	0.300	-0.523	+0.585*l
p	0.038	0.045	-1.347	38	0.200	-0.699	+0.415*l+m
q	0.025	0.030	-1.523	39	0.100	-1.000	+n+0.762*o
r	0.010	0.020	-1.699	40	0.050	-1.301	+0.238*o+p+q+r
					0.010		

Table K.5-7
ORIGEN2 Gamma Sources for 27 GWd/MTU, 5-Year Cooled BWR Fuel

		ORIGEN2 γ/s/assy			
Emean (MeV)	Top	Plenum	In-Core	Bottom	Whole
0.01	8.060E+10	3.892E+10	4.864E+14	1.113E+11	4.866E+14
0.025	2.145E+10	6.659E+10	1.220E+14	3.023E+10	1.221E+14
0.0375	9.680E+09	1.825E+10	1.270E+14	1.342E+10	1.270E+14
0.0575	8.759E+09	3.894E+09	9.809E+13	1.190E+10	9.812E+13
0.085	3.447E+09	1.556E+09	6.385E+13	4.683E+09	6.386E+13
0.125	1.369E+09	9.486E+08	6.506E+13	1.866E+09	6.507E+13
0.225	1.118E+09	5.482E+09	5.372E+13	1.614E+09	5.373E+13
0.375	4.193E+09	3.160E+10	3.555E+13	6.267E+09	3.559E+13
0.575	5.240E+09	4.055E+10	8.468E+14	7.853E+09	8.469E+14
0.85	6.970E+09	6.666E+09	1.923E+14	2.222E+10	1.924E+14
1.25	2.947E+12	1.152E+12	6.670E+13	4.000E+12	7.480E+13
1.75	1.896E+02	8.200E+01	1.395E+12	2.511E+02	1.395E+12
2.25	1.562E+07	6.103E+06	6.823E+11	2.120E+07	6.823E+11
2.75	4.833E+04	1.889E+04	2.634E+10	6.560E+04	2.634E+10
3.5	2.559E-14	1.944E-18	3.386E+09	9.733E-15	3.386E+09
5	0.000E+00	0.000E+00	4.127E+06	0.000E+00	4.127E+06
7	0.000E+00	0.000E+00	4.759E+05	0.000E+00	4.759E+05
9.5	0.000E+00	0.000E+00	5.468E+04	0.000E+00	5.468E+04
Total	3.090E+12	1.366E+12	2.160E+15	4.211E+12	2.168E+15

Table K.5-8
ORIGEN2 Gamma Sources for 35 GWd/MTU, 8-Year Cooled BWR Fuel

	ORIGEN2 γ/s/assy				
Emean (MeV)	Top	Plenum	In-Core	Bottom	Whole
0.01	6.033E+10	2.701E+10	4.099E+14	8.205E+10	4.101E+14
0.025	1.418E+10	3.439E+10	9.280E+13	1.978E+10	9.286E+13
0.0375	6.849E+09	1.011E+10	1.121E+14	9.432E+09	1.121E+14
0.0575	6.610E+09	2.819E+09	8.188E+13	8.968E+09	8.190E+13
0.085	2.600E+09	1.122E+09	4.998E+13	3.528E+09	4.999E+13
0.125	1.022E+09	6.111E+08	5.102E+13	1.390E+09	5.102E+13
0.225	6.791E+08	2.858E+09	4.035E+13	9.710E+08	4.035E+13
0.375	2.184E+09	1.625E+10	2.242E+13	3.260E+09	2.244E+13
0.575	2.695E+09	2.084E+10	7.932E+14	4.038E+09	7.932E+14
0.85	7.650E+08	6.240E+08	1.116E+14	2.102E+09	1.116E+14
1.25	2.229E+12	8.695E+11	5.331E+13	3.023E+12	5.943E+13
1.75	9.545E-01	1.472E+01	8.948E+11	2.142E+00	8.948E+11
2.25	1.181E+07	4.608E+06	6.145E+10	1.602E+07	6.148E+10
2.75	3.655E+04	1.426E+04	3.656E+09	4.957E+04	3.656E+09
3.5	3.109E-14	1.015E-15	4.730E+08	1.198E-14	4.730E+08
5	0.000E+00	0.000E+00	6.161E+06	0.000E+00	6.161E+06
7	0.000E+00	0.000E+00	7.105E+05	0.000E+00	7.105E+05
9.5	0.000E+00	0.000E+00	8.162E+04	0.000E+00	8.162E+04
Total	2.327E+12	9.861E+11	1.819E+15	3.159E+12	1.826E+15

Table K.5-9
ORIGEN2 Gamma Sources for 37.2 GWd/MTU, 6.5-Year Cooled BWR Fuel

	ORIGEN2 γ/s/assy				
Emean (MeV)	Top	Plenum	In-Core	Bottom	Whole
0.01	6.906E+10	3.180E+10	5.095E+14	9.428E+10	5.097E+14
0.025	1.707E+10	4.618E+10	1.185E+14	2.393E+10	1.186E+14
0.0375	8.040E+09	1.324E+10	1.351E+14	1.110E+10	1.352E+14
0.0575	7.557E+09	3.277E+09	1.008E+14	1.026E+10	1.009E+14
0.085	2.974E+09	1.307E+09	6.346E+13	4.036E+09	6.347E+13
0.125	1.174E+09	7.467E+08	6.344E+13	1.598E+09	6.344E+13
0.225	8.519E+08	3.855E+09	5.168E+13	1.223E+09	5.169E+13
0.375	2.947E+09	2.206E+10	2.996E+13	4.402E+09	2.999E+13
0.575	3.660E+09	2.831E+10	9.562E+14	5.484E+09	9.563E+14
0.85	2.073E+09	1.897E+09	1.755E+14	6.334E+09	1.755E+14
1.25	2.546E+12	9.938E+11	6.433E+13	3.454E+12	7.132E+13
1.75	1.734E+00	1.436E+01	1.136E+12	3.133E+00	1.136E+12
2.25	1.350E+07	5.267E+06	2.094E+11	1.831E+07	2.094E+11
2.75	4.176E+04	1.630E+04	9.245E+09	5.664E+04	9.246E+09
3.5	2.582E-14	4.846E-16	1.189E+09	9.792E-15	1.189E+09
5	0.000E+00	0.000E+00	5.006E+06	0.000E+00	5.006E+06
7	0.000E+00	0.000E+00	5.772E+05	0.000E+00	5.772E+05
9.5	0.000E+00	0.000E+00	6.631E+04	0.000E+00	6.631E+04
Total	2.661E+12	1.146E+12	2.270E+15	3.617E+12	2.277E+15

Table K.5-10
ORIGEN2 Gamma Sources for 40 GWd/MTU, 10-Year Cooled BWR Fuel

	ORIGEN2 γ/s/assy				
Emean (MeV)	Top	Plenum	In-Core	Bottom	Whole
0.01	4.660E+10	2.024E+10	4.383E+14	6.327E+10	4.385E+14
0.025	1.027E+10	2.128E+10	9.367E+13	1.426E+10	9.372E+13
0.0375	5.115E+09	6.456E+09	1.162E+14	7.022E+09	1.162E+14
0.0575	5.096E+09	2.131E+09	8.772E+13	6.913E+09	8.773E+13
0.085	2.005E+09	8.462E+08	5.196E+13	2.719E+09	5.197E+13
0.125	7.839E+08	4.331E+08	5.112E+13	1.065E+09	5.113E+13
0.225	4.636E+08	1.737E+09	4.226E+13	6.587E+08	4.226E+13
0.375	1.327E+09	9.756E+09	2.070E+13	1.978E+09	2.071E+13
0.575	1.618E+09	1.251E+10	7.891E+14	2.424E+09	7.891E+14
0.85	2.560E+08	1.384E+08	7.522E+13	4.777E+08	7.522E+13
1.25	1.720E+12	6.708E+11	4.475E+13	2.333E+12	4.947E+13
1.75	9.384E-01	1.455E+01	8.067E+11	2.110E+00	8.067E+11
2.25	9.118E+06	3.555E+06	1.255E+10	1.236E+07	1.258E+10
2.75	2.821E+04	1.100E+04	1.014E+09	3.825E+04	1.014E+09
3.5	2.931E-14	1.078E-15	1.262E+08	1.134E-14	1.262E+08
5	0.000E+00	0.000E+00	5.860E+06	0.000E+00	5.860E+06
7	0.000E+00	0.000E+00	6.757E+05	0.000E+00	6.757E+05
9.5	0.000E+00	0.000E+00	7.763E+04	0.000E+00	7.763E+04
Total	1.794E+12	7.463E+11	1.812E+15	2.434E+12	1.817E+15

Table K.5-11
Gamma Sources for DORT Code Models

Cask Group	Source Term (gamma/sec/cc)			
	27 GWd/MTU	35 GWd/MTU	37.2 GWd/MTU	40 GWd/MTU
23	4.12E-01	6.15E-01	5.00E-01	5.85E-01
24	2.59E+00	3.86E+00	3.14E+00	3.68E+00
25	1.50E+01	2.24E+01	1.82E+01	2.13E+01
26	1.71E+01	2.55E+01	2.07E+01	2.43E+01
27	2.55E+04	3.56E+03	8.95E+03	9.51E+02
28	1.98E+05	2.75E+04	6.96E+04	7.64E+03
29	5.14E+06	4.63E+05	1.58E+06	9.47E+04
30	6.81E+06	4.37E+06	5.54E+06	3.94E+06
31	1.71E+08	1.35E+08	1.63E+08	1.13E+08
32	3.96E+08	3.15E+08	3.78E+08	2.62E+08
33	9.07E+08	5.26E+08	8.28E+08	3.55E+08
34	2.77E+09	2.40E+09	3.01E+09	2.29E+09
35	4.23E+09	3.94E+09	4.76E+09	3.92E+09
36	1.90E+08	1.20E+08	1.60E+08	1.11E+08
37	2.37E+08	1.78E+08	2.28E+08	1.86E+08
38	6.58E+08	5.11E+08	6.40E+08	5.17E+08
39	1.04E+09	8.47E+08	1.06E+09	8.95E+08
40	5.72E+09	4.78E+09	5.93E+09	5.04E+09
Total	1.63E+10	1.38E+10	1.72E+10	1.37E+10

Table K.5-12
Total Neutron Source Summary

Burnup/ Cooling Time (GWd/MTU)/ (years)	neutrons/sec per assembly
27/5	9.56E+07
35/8	1.43E+08
37.2/6.5	1.16E+08
40/10	1.36E+08

Table K.5-13
Volumetric Design Basis Neutron Source

Group	Eupper (eV)	Fraction	In-Core (n/s/cc)
1	1.49E+07	1.26E-04	1.349e-01
2	1.22E+07	1.07E-03	1.147e+00
3	1.00E+07	2.94E-03	3.155e+00
4	8.18E+06	1.46E-02	1.573e+01
5	6.36E+06	3.71E-02	3.983e+01
6	4.96E+06	4.90E-02	5.267e+01
7	4.06E+06	1.23E-01	1.322e+02
8	3.01E+06	1.01E-01	1.082e+02
9	2.46E+06	2.46E-02	2.646e+01
10	2.35E+06	1.27E-01	1.366e+02
11	1.83E+06	2.27E-01	2.435e+02
12	1.11E+06	2.01E-01	2.159e+02
13	5.50E+05	9.25E-02	9.946e+01
14	1.11E+05	3.99E-06	4.285e-03
15	3.35E+03	0	0.000e+00
16	5.83E+02	0	0.000e+00
17	1.01E+02	0	0.000e+00
18	2.90E+01	0	0.000e+00
19	1.01E+01	0	0.000e+00
20	3.06E+00	0	0.000e+00
21	1.12E+00	0	0.000e+00
22	4.14E-01	0	0.000e+00
Total		1.00E+00	1.075e+03

Table K.5-14
Source Term Peaking Summary
(Neutron and Gamma Source As a Function of Burnup, Water Density and Active Core Height)

7x7 Fuel Assembly: 40,000 MWd/MTU; Average Burnup: 10 Years Cool Time ; Power (MW): 5;
Cycle Length (days): 527.2

Zone	Frac Core Height	Burnup Peaking Factor	Burnup (MWd/MtU)	SAS2H Power (MW)	Water Density (g/cc)	Neutron Source (n/s)	Neutron Peaking Factor	Gamma Source (g/s)	Gamma Peaking Factor
12	0.95-1.0	0.2410	9640	1.205	0.3609	1.661E+04	0.0028	1.574E+13	0.2303
11	0.90-0.95	0.6330	25320	3.165	0.3631	6.500E+05	0.1093	4.275E+13	0.6255
10	0.8-0.9	0.8973	35891	4.486	0.3701	6.005E+06	0.5047	1.238E+14	0.9053
9	0.7-0.8	1.0766	43065	5.383	0.3861	1.274E+07	1.0707	1.499E+14	1.0964
8	0.6-0.7	1.1515	46061	5.758	0.4118	1.647E+07	1.3842	1.535E+14	1.1227
7	0.5-0.6	1.1912	47649	5.956	0.4375	1.859E+07	1.5624	1.663E+14	1.2164
6	0.4-0.5	1.2000	48000	6.000	0.4708	1.877E+07	1.5775	1.674E+14	1.2244
5	0.3-0.4	1.2000	48000	6.000	0.5251	1.819E+07	1.5288	1.671E+14	1.2223
4	0.2-0.3	1.1836	47345	5.918	0.5945	1.649E+07	1.3859	1.644E+14	1.2027
3	0.1-0.2	1.0750	43001	5.375	0.7008	1.005E+07	0.8447	1.484E+14	1.0854
2	0.05-0.1	0.7746	30985	3.873	0.7541	1.002E+06	0.1683	5.245E+13	0.7674
1	0.0-0.05	0.2357	9426	1.178	0.7603	1.100E+04	0.0018	1.542E+13	0.2256
Average/Total		**0.9917**	**39670**	**4.959**	**0.5016**	**1.190E+08**	**1.0000**	**1.367E+15**	**1.0000**

Table K.5-15
In-Core Region Material Densities
(without basket materials and fuel channels)

Element	Atomic Mass (g/mol)	Mass Density (g/cc)	Number Density (atoms/b-cm)
O	15.9994	2.00E-01	7.54E-03
Fe	55.847	2.71E-03	2.92E-05
Zr	91.22	3.85E-01	2.54E-03
U-235	235.0439	5.96E-02	1.53E-04
U-238	238.0508	1.43E+00	3.62E-03
Total		2.08E+00	1.39E-02

Table K.5-16
In-Core Material Densities
(with basket materials, without fuel channels)

Element	Atomic Mass (g/mol)	Mass Density (g/cc)	Number Density (atoms/b-cm)
O	15.9994	2.00E-01	7.54E-03
Fe	55.847	5.91E-01	6.37E-03
Zr	91.22	3.85E-01	2.54E-03
U-235	235.0439	5.96E-02	1.53E-04
U-238	238.0508	1.43E+00	3.62E-03
Total		2.67E+00	2.02E-02

Table K.5-17
Bottom Region Material Densities
(without basket materials)

Element	Atomic Mass (g/mol)	Mass Density (g/cc)	Number Density (atoms/b-cm)
Fe	55.847	7.67E-01	8.27E-03
Zr	91.22	2.06E-01	1.36E-03
Total		9.72E-01	9.62E-03

Table K.5-18
Top Region Material Densities
(without basket materials)

Element	Atomic Mass (g/mol)	Mass Density (g/cc)	Number Density (atoms/b-cm)
Fe	55.847	1.35E-01	1.46E-03
Zr	91.22	2.61E-01	1.72E-03
Total		3.96E-01	3.18E-03

Table K.5-19
Summary of Material Densities

Element	Atomic Number	Number Density (atoms/b-cm) Fuel (w/basket)	Fuel (w/o basket)	Top End Fitting	Bottom End Fitting	NS-3	Concrete	Water	Air	Lead	Steel
H	1					4.59E-02	7.77E-03	6.69E-02			
C	6					8.25E-03					
N	7								1.98E-05		
O	8	7.54E-03	7.54E-03			3.78E-02	4.39E-02	3.34E-02	5.28E-06		
Na	11						1.05E-03				
Mg	12						1.49E-04				
Al	13					7.03E-03	2.39E-03				
Si	14					1.27E-03	1.53E-02				
K	19						6.93E-04				
Ca	20					1.48E-03	2.92E-03				
Fe	26	6.37E-03	2.92E-05	1.46E-03	8.27E-03	1.06E-04	3.13E-04				8.49E-02
Zr	40	2.54E-03	2.54E-03	1.72E-03	1.36E-03						
Pb	82									3.30E-02	
U-235	92	1.53E-04	1.53E-04								
U-238	92	3.62E-03	3.62E-03								

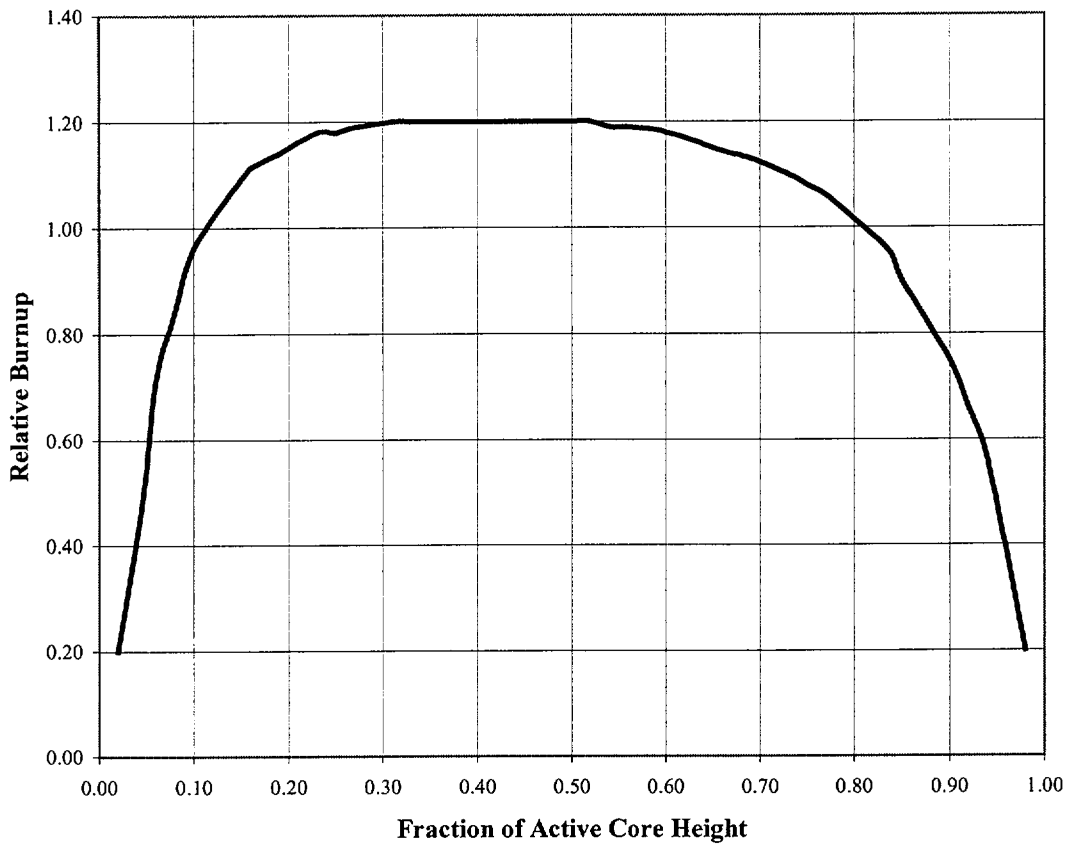

Figure K.5-1
Axial Burnup Profile For Design Basis Fuel

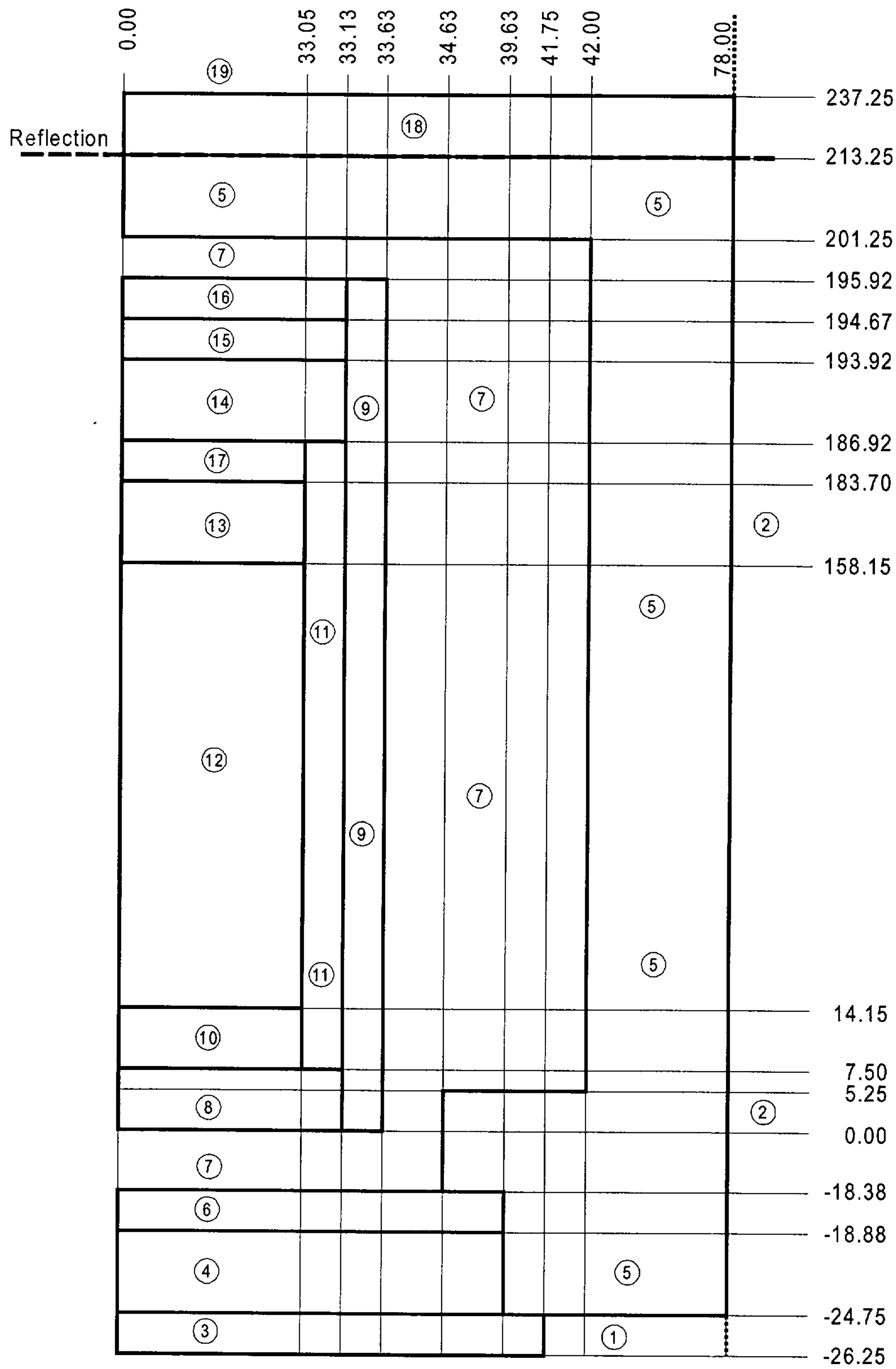

Figure K.5-2
HSM Roof Model Geometry

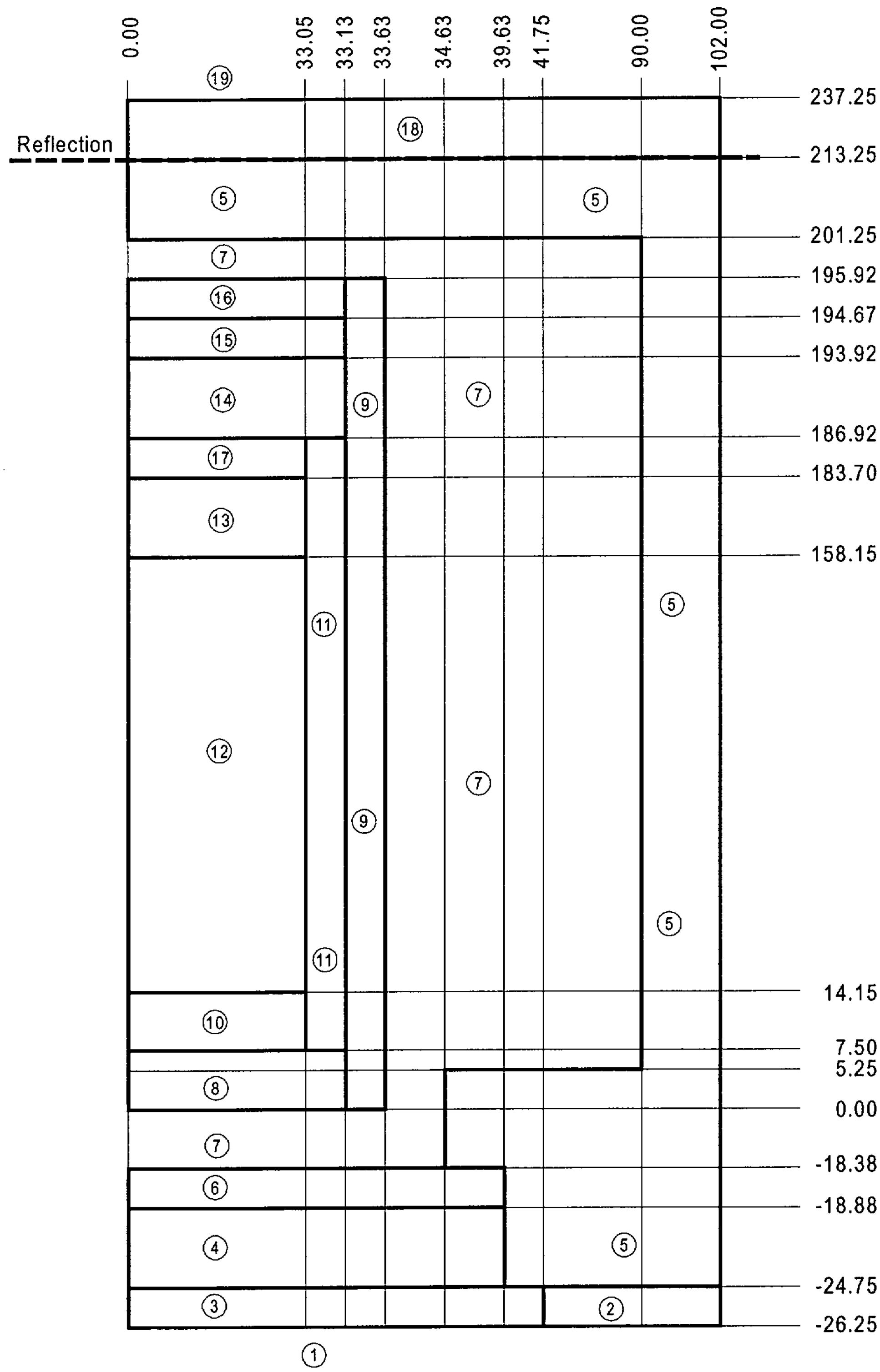

Figure K.5-3
HSM Floor Model Geometry

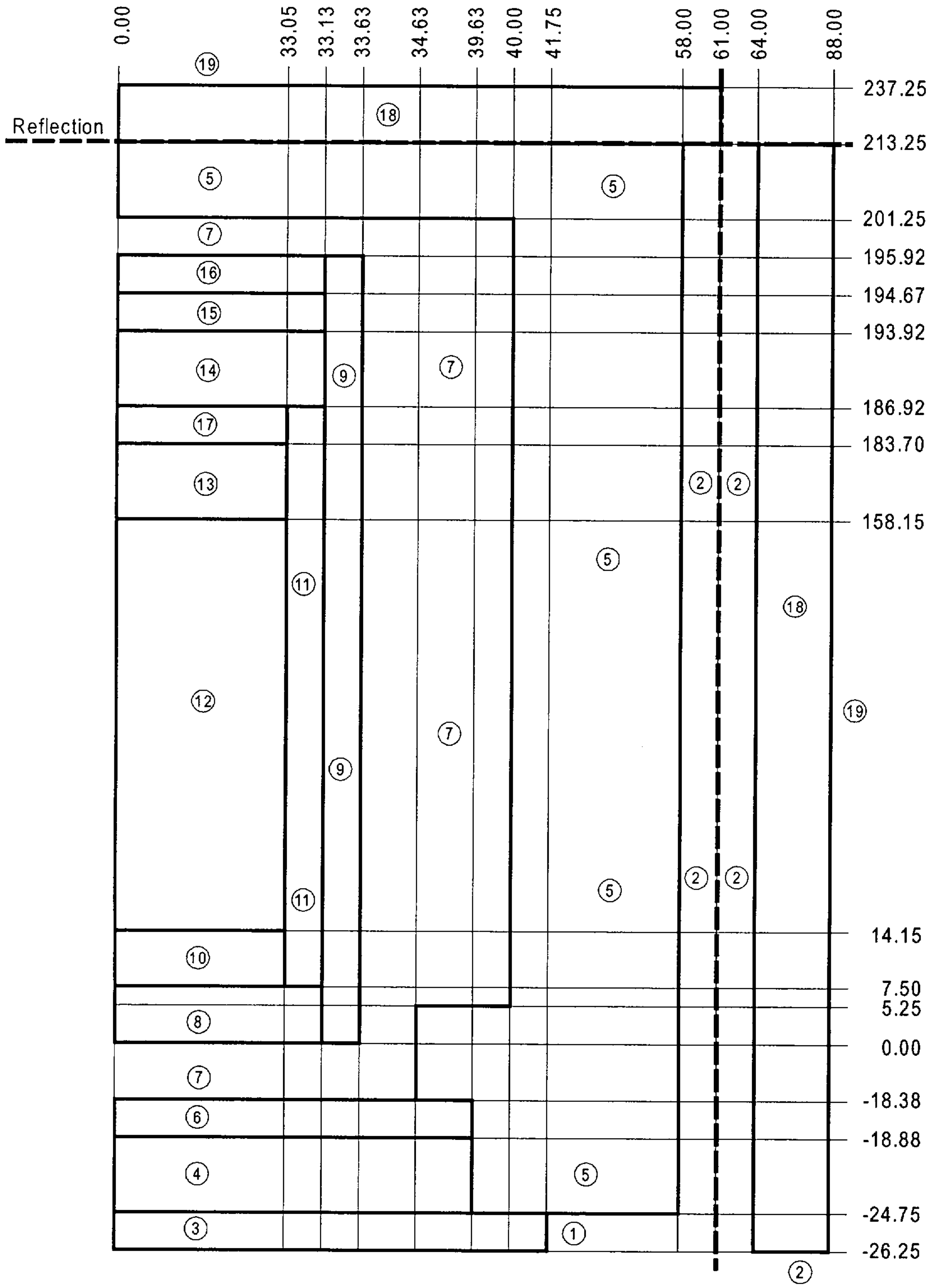

Figure K.5-4
HSM Side Model Geometry

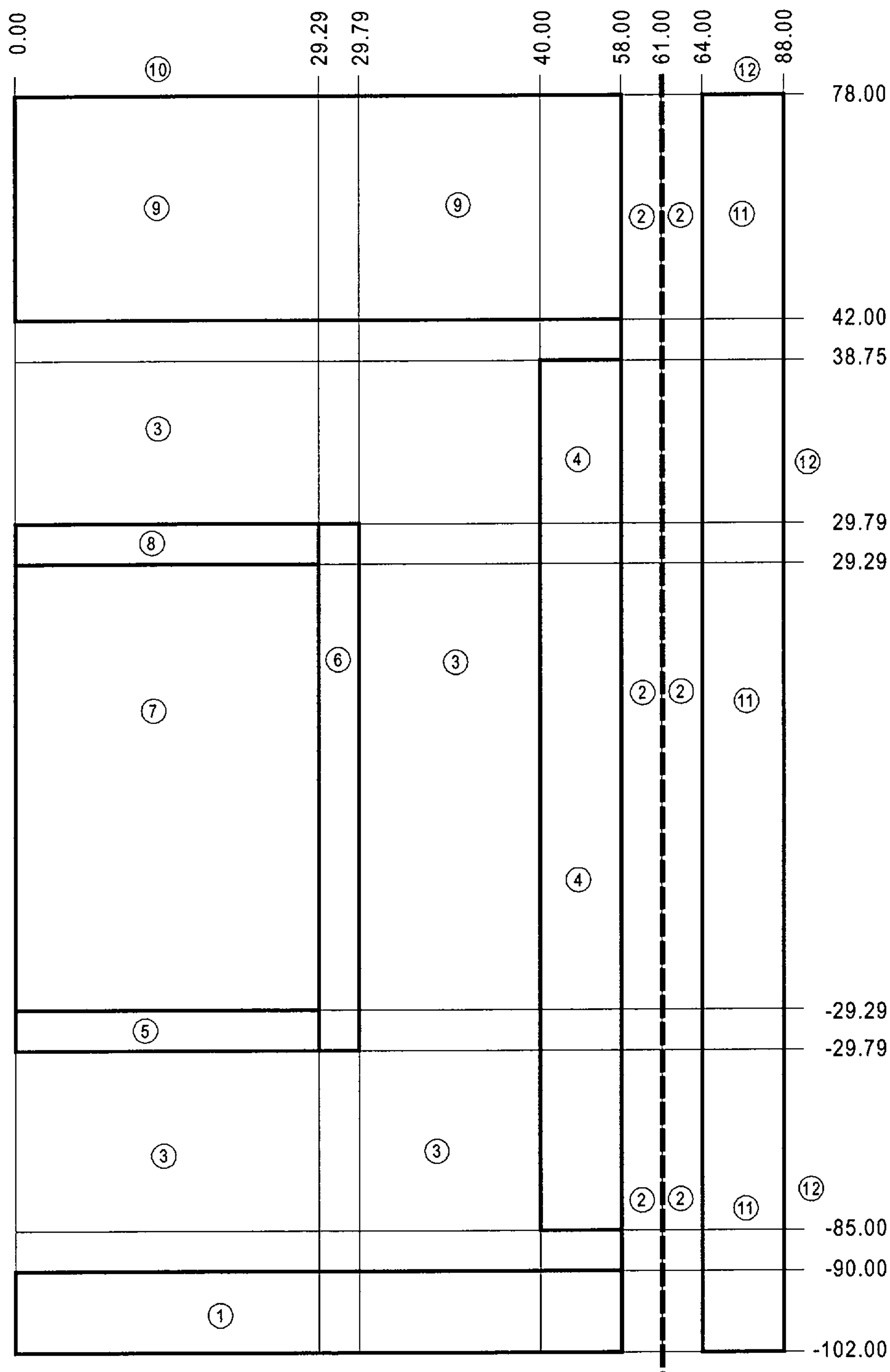

Figure K.5-5
HSM Lateral Model Geometry

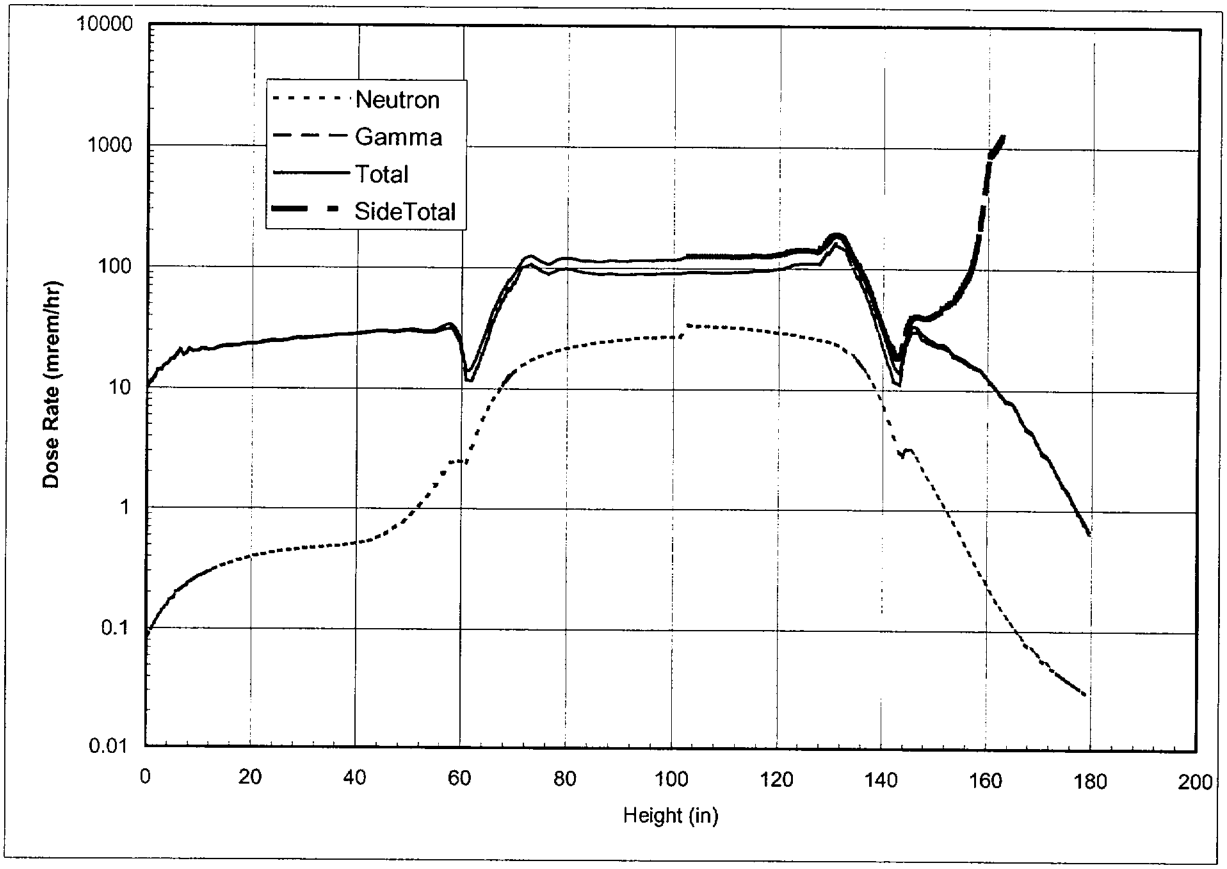

Figure K.5-6
HSM Front Wall Dose Rate Distribution

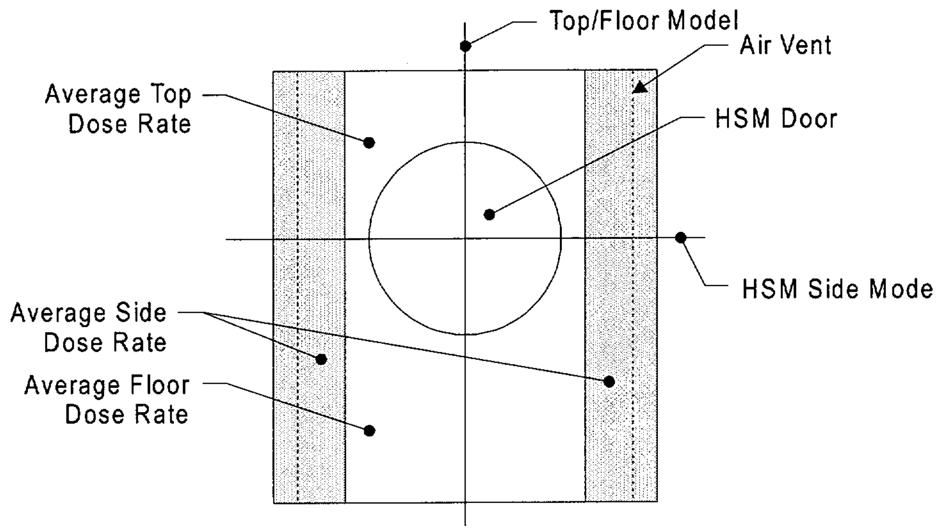

Figure K.5-7
Geometry for Front Wall Average Dose Rate Calculation

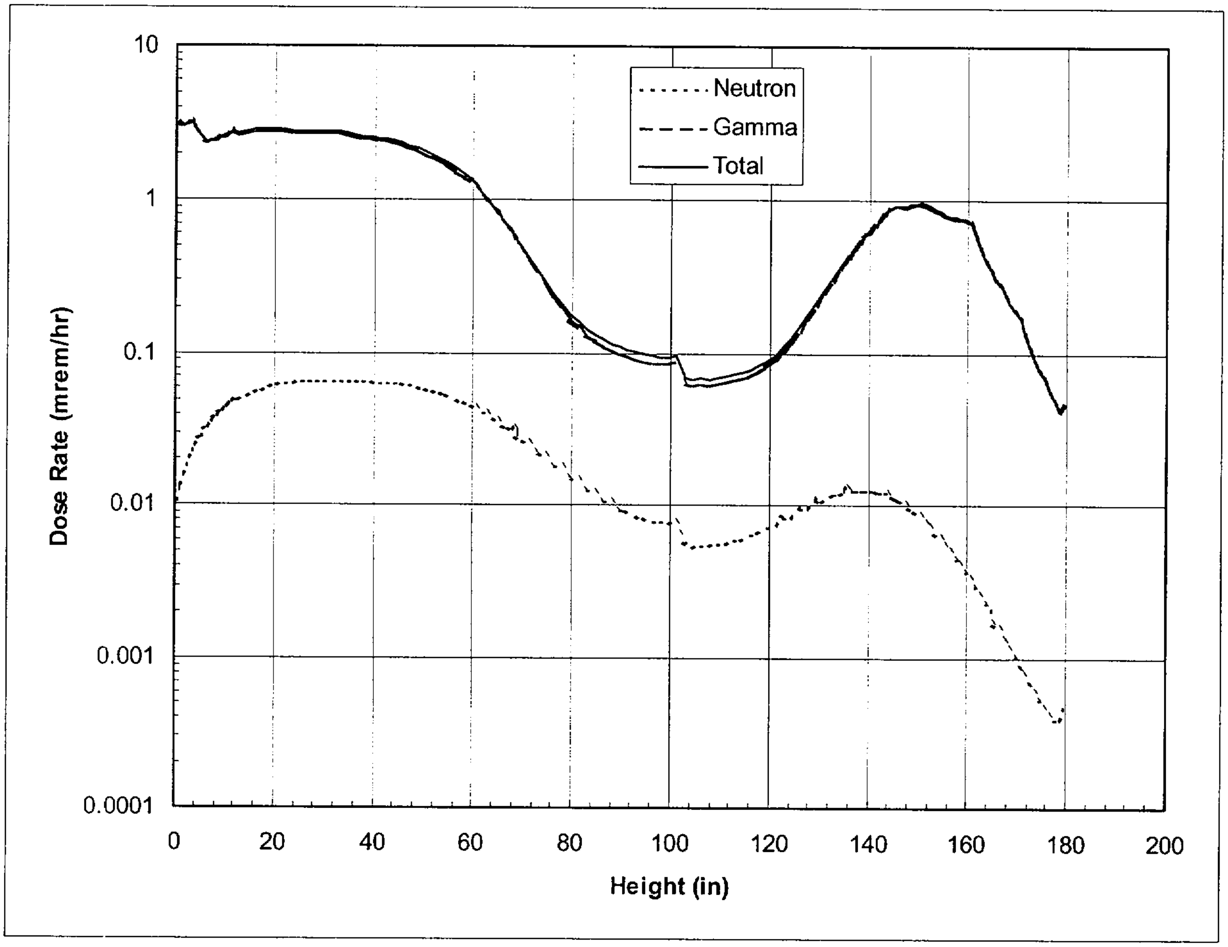

Figure K.5-8
HSM Back Wall Dose Rate Distribution

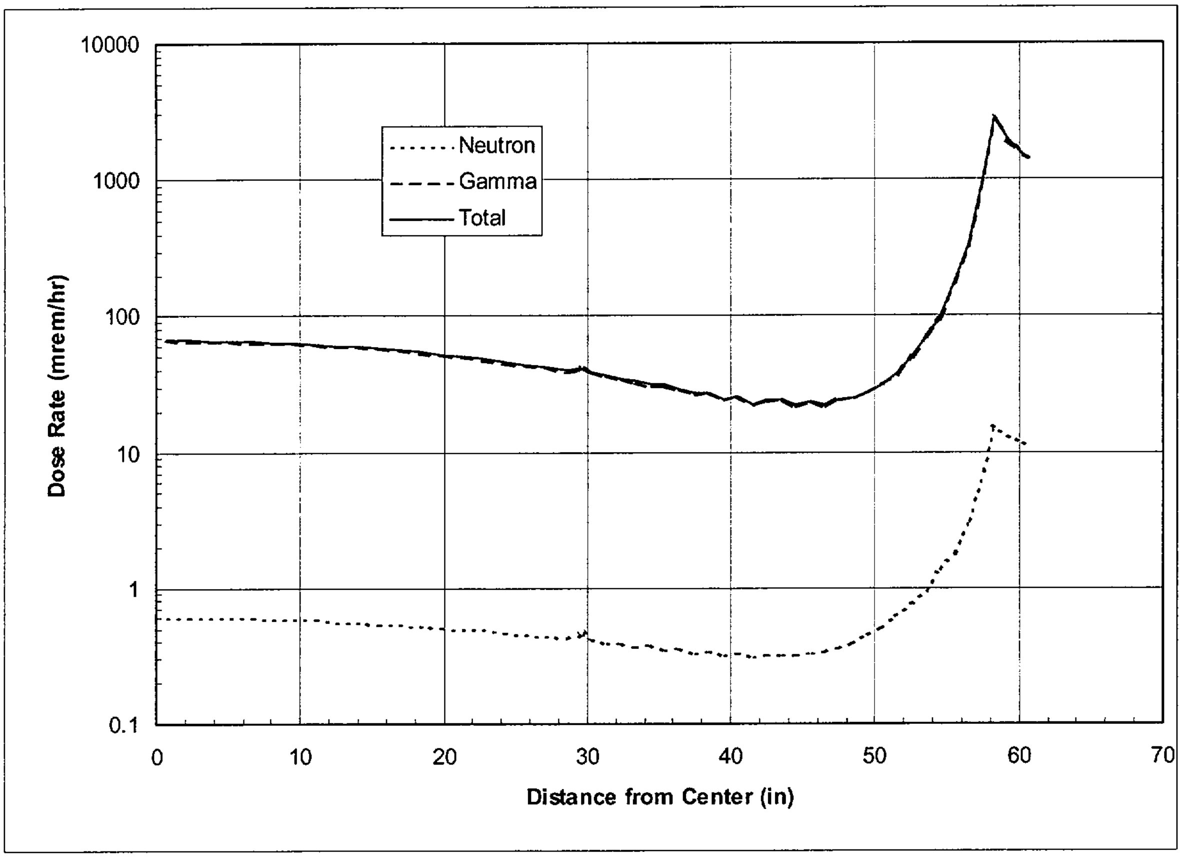

Figure K.5-9
HSM Roof Dose Rate Distribution

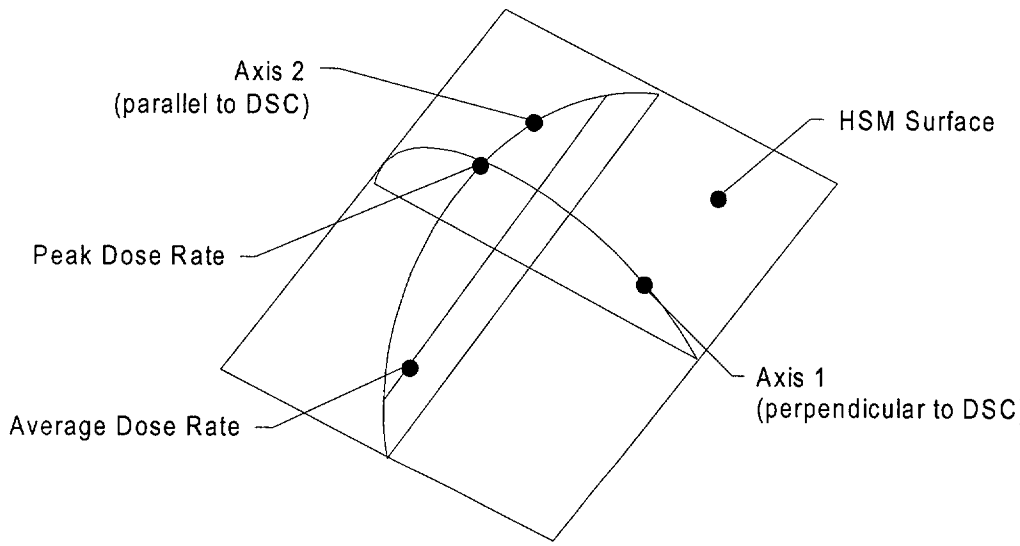

Figure K.5-10
Surface Average Calculation Geometry

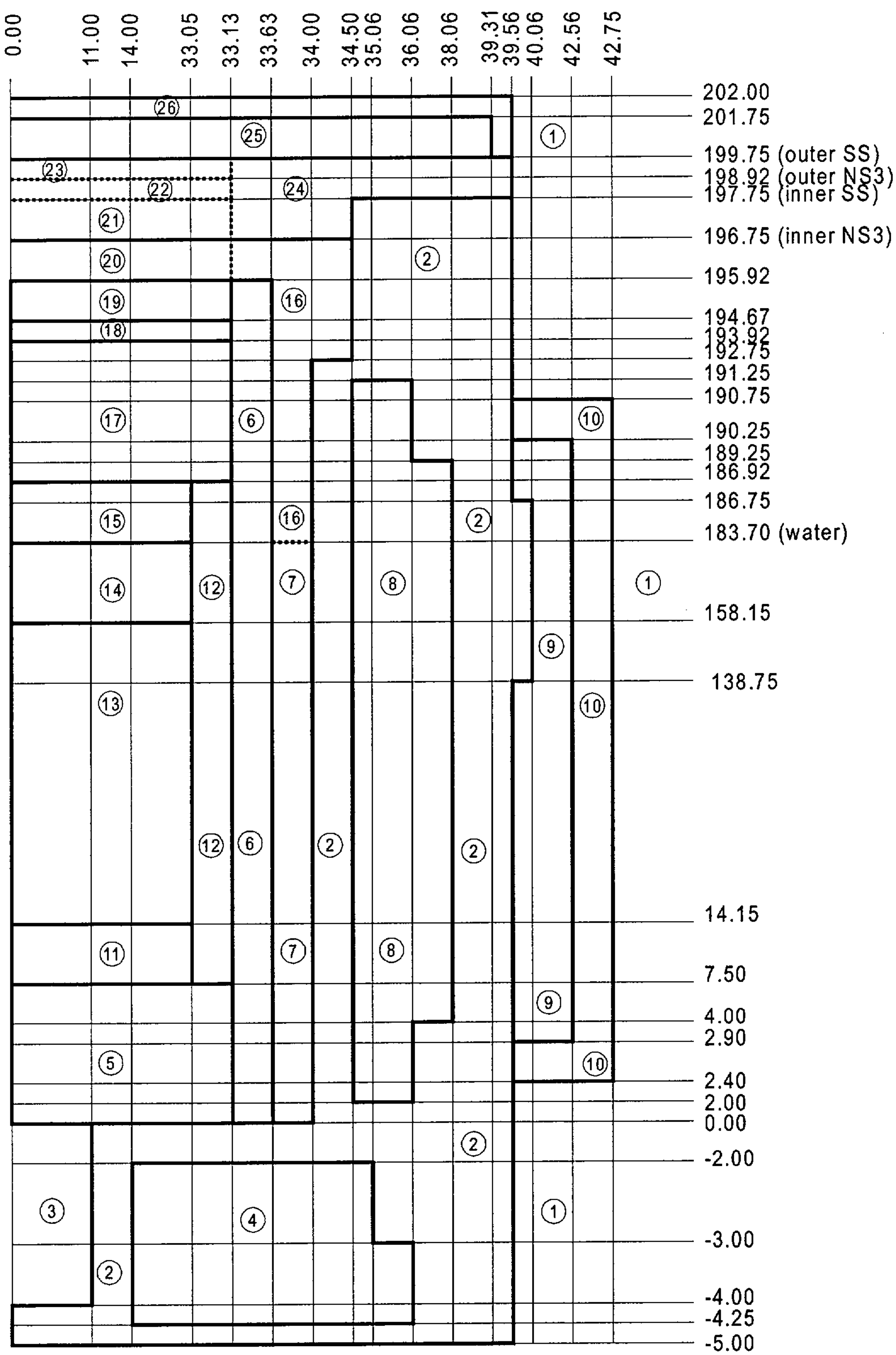

Figure K.5-11
Cask Model Geometry

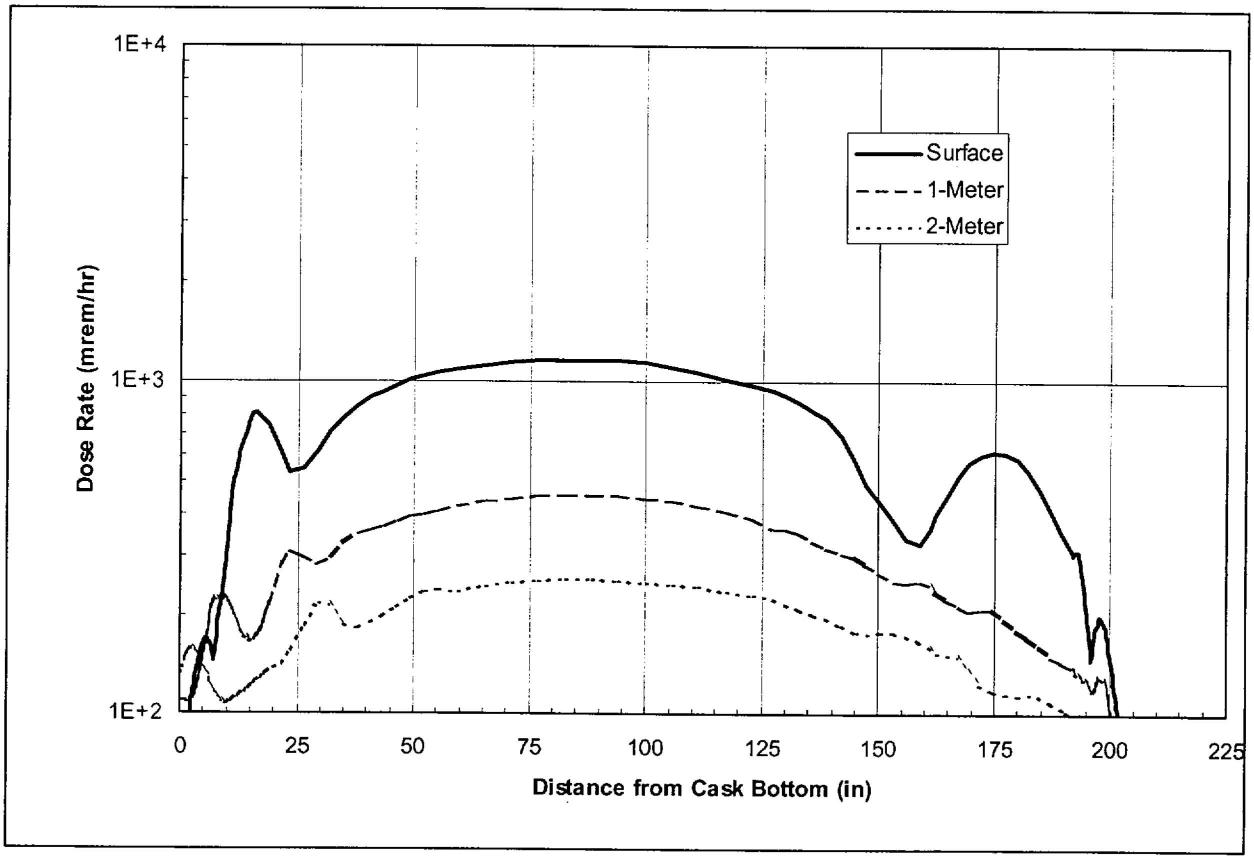

Figure K.5-12
Cask Normal Operation Dose Rate Distribution

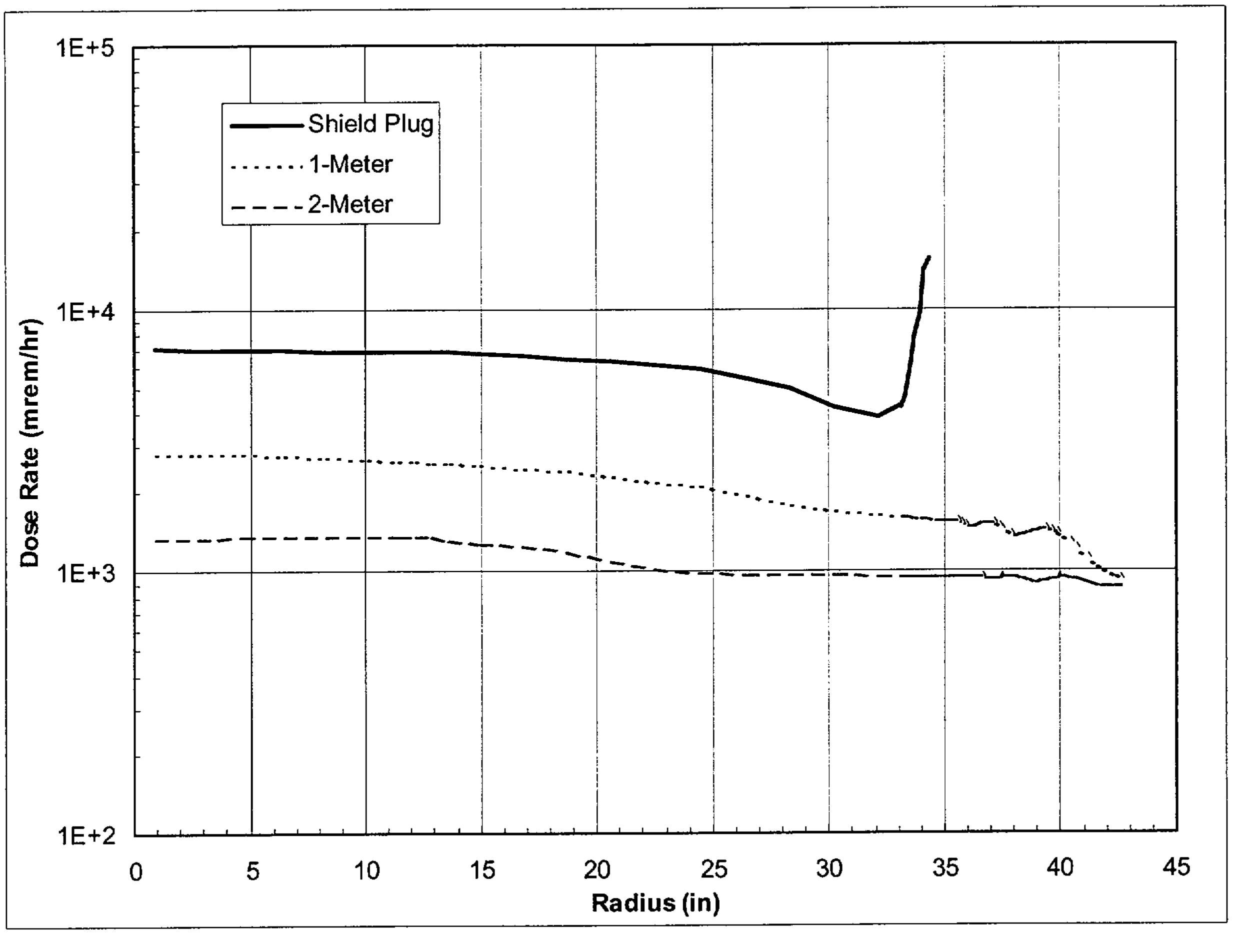

Figure K.5-13
Cask Top-End Dose Rates During Decontamination

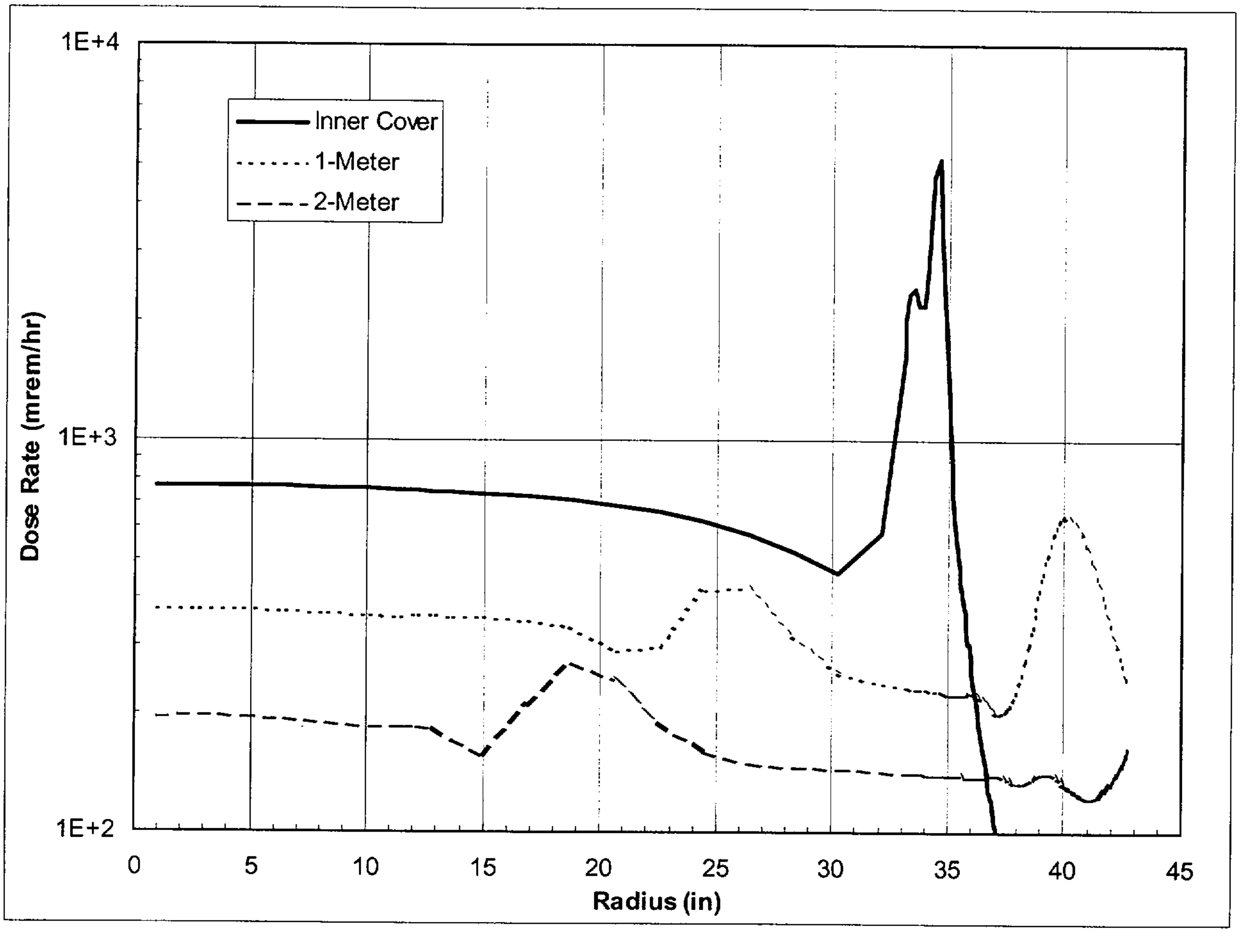

Figure K.5-14
Cask Top-End Dose Rates During Inner Cover Welding

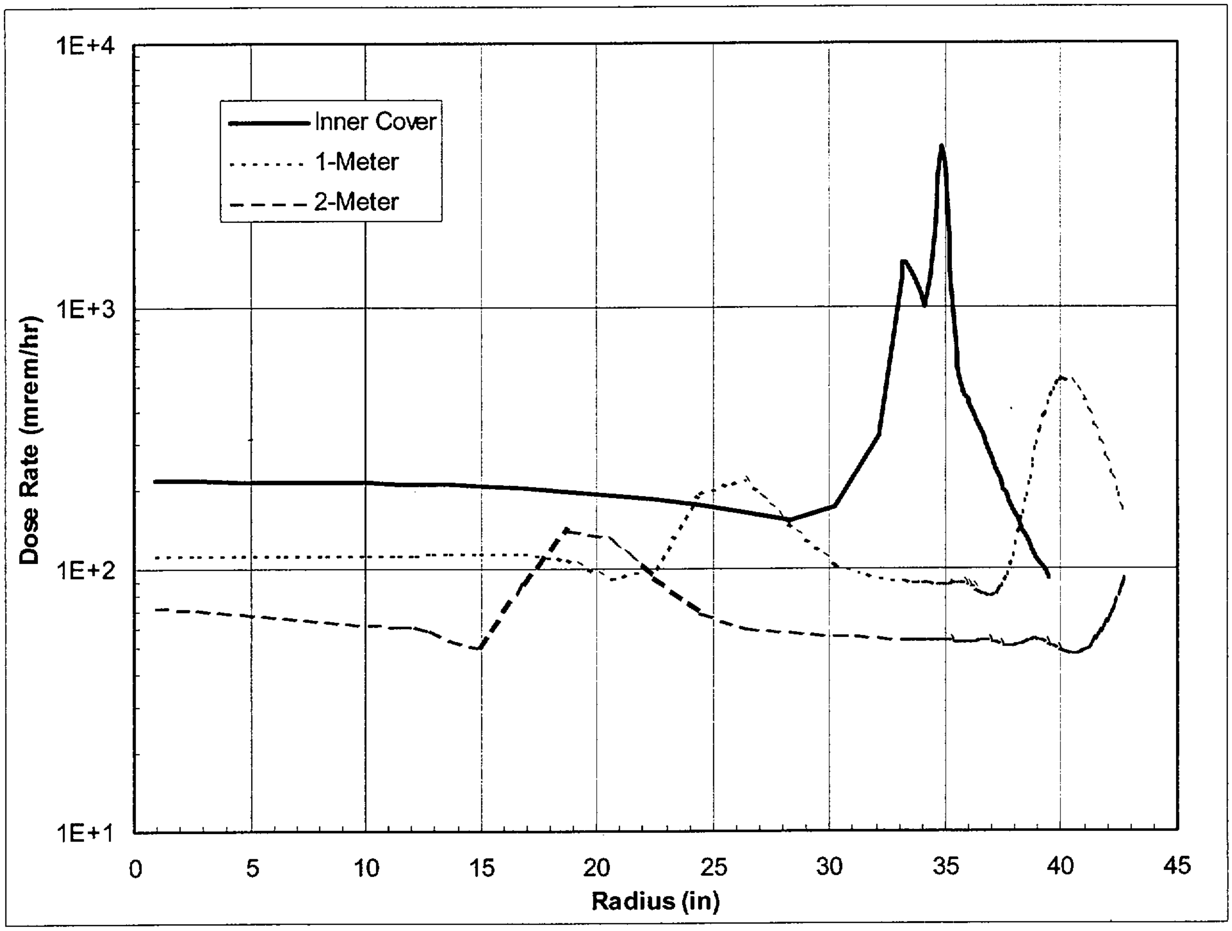

Figure K.5-15
Cask Top-End Dose Rates During Outer Cover Welding

K.6 Criticality Evaluation

The design criteria for the NUHOMS®-61BT Dry Shielded Canister (DSC) to be stored in the standardized NUHOMS®-61BT system requires that the NUHOMS®-61BT DSC be designed to remain subcritical under normal, off-normal, and accident conditions as defined in both 10CFR Part 72 and 10CFR Part 71.

The NUHOMS®-61BT system's criticality safety is ensured by both fixed neutron absorbers and favorable geometry. Burnup credit is not taken in this criticality evaluation. The fixed neutron absorber is present in the form of borated metallic plates. This material is ideal for long-term use in radiation and thermal environments of a DSC. The required B10 loading is a function of assembly lattice average enrichment. Table K.6-1 lists the minimum B10 poison loading required as a function of assembly initial lattice average enrichment.

K.6.1 Discussion and Results

Figure K.6-1 shows the cross section of the NUHOMS®-61BT DSC. The analysis presented herein is performed for a NUHOMS®-61BT DSC in a generic transportation/transfer cask. The generic cask consists of an inner stainless steel shell, and lead gamma shield, a stainless steel structural shell and a hydrogenous neutron shield. This analysis is applicable to any licensed cask of similar construction. The NUHOMS®-61BT DSC/Cask configuration is shown to be subcritical under both normal, off-normal and accident conditions.

The criticality calculations assume the General Electric (GE) 10x10-fuel assembly because it is the most reactive fuel assembly allowed by the authorized contents. The calculations determine k_{eff} with the CSAS25 control module of SCALE-4.4 [6.1] for various configurations and initial enrichments, including all uncertainties to assure criticality safety under all credible conditions.

The results of the evaluation demonstrate that the maximum k_{eff} - including statistical uncertainty - is less than the Upper Subcritical Limit (USL) determined from a statistical analysis of benchmark criticality experiments. The statistical analysis procedure includes a confidence band with an administrative safety margin of 0.05.

K.6.2 Package Fuel Loading

The NUHOMS®-61BT DSC is capable of transferring and storing standard BWR fuel assemblies with or without fuel channels and as intact or damaged fuel assemblies. The fuel assemblies considered as authorized contents are listed in Table K.6-2.

NOTE: As noted in the SER [6.5], the NRC has accepted the criticality analysis presented in this section for damaged fuel. However, damaged fuel is not authorized for storage in NUHOMS®-61BT DSC as discussed on page K.1-1.

Table K.6-3 lists the fuel parameters for the standard BWR fuel assemblies. The design basis fuel chosen for the NUHOMS®-61BT system criticality analysis is the GE 10x10 fuel assembly. The GE 10x10 assembly is used because, as demonstrated in Section K.6.4, it is the most reactive assembly of those authorized to be stored in the NUHOMS®-61BT DSC.

K.6.3 Model Specification

The following subsections describe the physical models and materials of the NUHOMS®-61BT system used for input to the CSAS25 module of SCALE-4.4 [6.1] to perform the criticality evaluation.

K.6.3.1 Description of Calculational Model

The cask and DSC were explicitly modeled using the appropriate geometry options in KENO V.a of the CSAS25 module in SCALE-4.4.

Three models were developed. The first model is a full-active fuel height model and full-radial cross section of the DSC alone with water boundary conditions on the ends and reflective boundary conditions on the sides. The model does not include the gaps between the poison plates. This model is more fully described in Section K.6.4.2. This model is only used to determine the most reactive fuel assembly/channel combination and to justify use of the lattice average enrichment for the intact fuel analysis. The second model is a full-active fuel height model and full radial cross section of the cask and DSC with reflective boundary conditions on all sides. This model includes the worst case gaps between the poison plates and the basket internals modeled at minimum material conditions. This model includes the GE12 10x10-fuel assembly only because this assembly type is determined to be the most reactive fuel assembly type of the authorized contents. The GE12 10x10-fuel assembly is modeled as a 10x10 array comprising 92 fuel rods, including fuel, gap and cladding and two large water holes. The fuel cladding OD is also reduced by 0.010 inches in the final models to conservatively bound fuel manufacturing tolerances. The cask neutron shield and outer steel skin is modeled as water.

The third model conservatively models 45 intact fuel assemblies and 16 "failed" fuel assemblies in the four 2x2 compartments in the corners of the basket. This model is very similar to the second model with the following changes:

- Both the 7x7-fuel assembly (GE2) and the 8x8-fuel assembly (GE9) were modeled.
- The axial boundary conditions are water rather than reflective.
- One row of fuel rods (seven for the 7x7 array and eight for the 8x8 array) is assumed to shear off from the rest of the assembly.
- The single row of "failed" rods is assumed to slide 12.5 inches above the bottom of the poison plates (Single-Break).
- For the case of double ended shear, an extra row of fuel is assumed to be present in each damaged fuel cell to simulate a portion of the severed rods breaking off and moving adjacent to the rest of the assembly in the fuel cell. This is a very conservative assumption because the total fuel loading in the fuel assembly (kg U) is increased by more than 14%.

- A lattice average enrichment of 4.0 weight percent (wt. %) U-235 is used for all of the fuel. The "failed" row of fuel is modeled with a peak enrichment of 4.4 wt. % U-235.

Figure K.6-2 is a sketch of each KENO V.a unit showing all materials and dimensions for each Unit and an annotated cross section map showing the assembled geometry units in the radial direction of the model. The assembly-to-assembly pitch is a variable in the model with the fuel assemblies modeled in the center of the fuel cells and pushed towards the center and away from the center of the basket. The poison plates are modeled with minimum plate thickness, width and length. The maximum gap between the plates is modeled in the worst case orientation to maximize the amount of "uncovered" fuel. The gaps between the poison plates are due to the need to provide space for thermal expansion of the poison plates relative to the stainless steel parts of the basket and to allow for fabrication tolerances in the basket. In addition, the NUHOMS®-61BT DSC design allows the poison plates to be fabricated in sections, rather than one continuous piece. In the axial direction, all gaps are modeled at the maximum width. Table K.6-4 provides the axial position of the assembled KENO V.a geometry units.

K.6.3.2 Package Regional Densities

The Oak Ridge National Laboratory (ORNL) SCALE code package [6.1] contains a standard material data library for common elements, compounds, and mixtures. All the materials used for the cask and DSC analysis are available in this data library. The neutron shield material in the cask is modeled as water and a cask neutron shield skin is not modeled.

Table K.6-5 provides a complete list of all the relevant materials used for the criticality evaluation. The material density for the B10 in the poison plates includes a 10% reduction for poison plates made of a Boron-Aluminum alloy or Boralyn® and a 25% reduction for poison plates made with Boral® and Metamic®. The cask neutron shield material is conservatively modeled as water. The actual neutron shield hydrogen atom density is lower than that of water; therefore, replacing the neutron shield with water is slightly conservative.

K.6.4 Criticality Calculation

This section describes the models used for the criticality analysis. The analyses were performed with the CSAS25 module of the SCALE system. A series of calculations were performed to determine the most reactive fuel and configuration. The most reactive fuel, as demonstrated by the analyses, is the GE12 10x10 assembly. The most reactive credible configuration is an infinite array of flooded casks with minimum assembly-to-assembly pitch and the poison plate gaps located near the center of the basket and at the centerline of the active fuel region.

The NUHOMS®-61BT DSC is analyzed for additional considerations arising from mechanical uncertainties of damaged 7x7 or 8x8 fuel after an accident such as transfer cask drop. In case of a severe accident, rod breakage may be postulated to occur in rods with known pre-existing gross cladding failure. This may result in a more reactive configuration than undamaged fuel therefore a specification limiting the number of known rods with gross cladding damage per fuel assembly is established to be seven (7). Note: an 8x8 array of fuel is also modeled to cover the 8x8 fuel assembly types, therefore it is conservative to limit the number of damaged rods to seven. The maximum number of permissible rods with gross cladding damage was determined by a series of KENO models of a design basis fuel assembly. These models were constructed to evaluate the effects of radial movement of fuel rod pieces (the result of "single-ended" breaks), and axial movement (the result of "double-ended" breaks). Loose fuel pellets or shards may become dislodged if a rod becomes severed, but this will not result in a more reactive state than the cases described below because the fuel assembly is undermoderated by design. The models used to study these limiting breaks are described below.

Single breaks- "free ends" caused by break were assumed to move away from the rest of the assembly. Increasing the rod spacing of the broken rods was found to increase k_{eff}. Conversely, k_{eff} is expected to decrease for local decreases in rod pitch. Rods on the exterior of the fuel assembly were displaced in the models and the assembly was assumed to be pressed in the corner of the fuel cell, thus maximizing the potential rod displacement. Since internal rods can not move as far as rods on the outside of the assembly, they are not limiting. For modeling simplicity, an entire face of 7 rods for the 7x7 array and 8 rods for the 8x8 array were assumed to evenly move away from the remainder of an assembly, as shown in Figure K.6-6. This overpredicts the effect of single rod breaks since the grid spacers of the fuel will limit radial rod displacement over most of the length of the rod.

Double breaks- the effects of pieces of fuel rod migrating axially was investigated by conservatively adding an entire row of fuel rods in the models. Again, the fuel assembly was assumed to be in the worst case position: pressed in the corner of the fuel cell as shown in Figure K.6-7.

The limiting case was the double-ended break. This is not unexpected because the extra row of rods added to the model represents a 14% increase in the fuel loading of the DSC.

K.6.4.1 Calculational Method

K.6.4.1.1 Computer Codes

The CSAS25 control module of SCALE-4.4 [6.1] was used to calculate the effective multiplication factor (k_{eff}) of the fuel in the cask. The CSAS25 control module allows simplified data input to the functional modules BONAMI-S, NITAWL-S, and KENO V.a. These modules process the required cross sections and calculate the k_{eff} of the system. BONAMI-S performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-S applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the k_{eff} of a three-dimensional system. A sufficiently large number of neutron histories are run so that the standard deviation is below 0.0020 for all calculations.

K.6.4.1.2 Physical and Nuclear Data

The physical and nuclear data required for the criticality analysis include the fuel assembly data and cross-section data as described below.

Table K.6-3 lists the pertinent data for criticality analysis with the GE12 10x10 fuel assembly in the NUHOMS®-61BT DSC as loaded in a generic cask described in Section K.6.1.

The criticality analysis used the 44-group cross-section library built into the SCALE system. ORNL used ENDF/B-V data to develop this broad-group library specifically for criticality analysis of a wide variety of thermal systems.

K.6.4.1.3 Bases and Assumptions

The analytical results reported in Section K.2 demonstrate that the cask containment boundary and DSC basket structure do not experience any significant distortion under hypothetical accident conditions. Therefore, for both normal and hypothetical accident conditions the cask geometry is identical except for the neutron shield and skin. As discussed above, the neutron shield and skin are conservatively modeled as water.

The cask was modeled with KENO V.a using the available geometry input. This option allows a model to be constructed that uses regular geometric shapes to define the material boundaries. The following conservative assumptions were also incorporated into the criticality calculations:

1. Omission of grid plates, spacers, and hardware in the fuel assembly.

2. No burnable poisons accounted for in the fuel.

3. Water density at optimum internal and external moderator density.

4. Unirradiated fuel – no credit taken for fissile depletion due to burnup or fission product poisoning.

5. For intact fuel, the lattice average fuel enrichment is modeled as uniform everywhere throughout the assembly. Natural Uranium blankets and axial or radial enrichment zones are modeled as enriched uranium. It is assumed that the fuel assemblies are of uniform enrichment everywhere.

6. For damaged fuel, the lattice average enrichment is modeled as uniform throughout the entire fuel assembly except for the "failed" face rods, which are modeled with the maximum peak pellet enrichment.

7. All fuel rods are assumed to be filled with 100% moderator in the pellet/cladding gap.

8. Only the active fuel length of each assembly type is explicitly modeled. The presence of the plenum materials, end fittings, channel material above and below the active fuel reduce the k_{eff} of the system, therefore; these regions are modeled as water or the reflective boundary conditions. For the cases with reflective boundary conditions, the model is effectively infinitely long.

9. It is assumed that for all Hypothetical Accident Conditions (HAC) cases the neutron shield and stainless steel skin of the cask are stripped away and replaced with moderator.

10. The least material condition (LMC) is assumed for the fuel clad OD, fuel compartment, poison plates and wrappers. This minimizes neutron absorption in the steel sheets and poison plates.

11. The maximum allowed gap between the poison plates in the worst case position is explicitly modeled to maximize k_{eff}.

12. For intact fuel the active fuel region is conservatively assumed to start level with the bottom of the poison plates.

13. Only 90% credit, for poison plates made of a Boron-Aluminum alloy or Boron Carbide/Aluminum Metal Matrix Composite and, 75% credit, for poison plates made with Boral®, is taken for the B10 in the KENO models. (See Section K.9 for justification)

14. Temperature at 20°C (293K).

15. Used 95% theoretical density for fuel although this assumption conservatively increases the total fuel content in the model.

K.6.4.1.4 Determination of k_{eff}.

The criticality calculations were performed with the CSAS25 control module in SCALE-4.4. The Monte Carlo calculations performed with CSAS25 (KENO V.a) used a flat neutron starting distribution. The total number of histories traced for each calculation was approximately 500,000. This number of histories was sufficient to converge the source and produce standard

deviations of less than 0.2% in k_{eff}. The maximum k_{eff} for the calculation was determined with the following formula:

$$k_{eff} = k_{KENO} + 2\sigma_{KENO.}$$

K.6.4.2 Fuel Loading Optimization

A. Determination of the Most Reactive Fuel Lattice

All fuel lattices, with and without channels, listed in Table K.6-3 are evaluated to determine the most reactive fuel assembly type. The lattices are analyzed with water in the fuel pellet cladding annulus and are centered in the fuel compartments. Each lattice is also analyzed with a 0.065, 0.080 and 0.120 inch thick channel to determine the most reactive configuration. The results show that the reactivity change due to the fuel channels is within the statistical uncertainty of the KENO V.a calculations. Finally, this model is used to demonstrate that the use of lattice average enrichment is conservative. Several cases are run to demonstrate that the use of the lattice average enrichment is conservative for intact fuel. Section K.6.6.2 includes a more detailed description of these models.

For this analysis, only the DSC is modeled. The DSC is modeled over the active fuel height of the fuel with water reflectors at the ends (z) and reflective boundary conditions outside the DSC (infinite array in the x-y directions) The DSC model for this evaluation differs from the actual design in the following ways:

- the B10 content in the poison plates is 10% lower for poison plates made of a Boron-Aluminum alloy or Boralyn® and a 25% lower for poison plates made with Boral® or Metamic® than the minimum allowed,
- no gaps between poison plates are modeled,
- the stainless steel basket rails, which hold the basket together, are modeled as water.

In all other respects, the model is the same as that described in Sections K.6.3.1 and K.6.3.2. The sole purpose of this model is to determine the relative reactivity of different fuel lattices in a configuration similar to the actual DSC. The model is more fully discussed in Section K.6.6.2.

A typical input file is included in Section K.6.6.2. The results of these calculations are listed in Table K.6-6. The most reactive fuel lattice evaluated for the DSC design is the GE generation 12 lattice, 10x10 array, without a fuel channel.

B. Determination of the Most Reactive Configuration – Intact Fuel

The fuel-loading configuration of the DSC/cask affects the reactivity of the package. Several series of analyses determined the most reactive configuration for the DSC/cask.

For this analysis, the DSC/cask is modeled. The DSC/cask is modeled over the active fuel height of the fuel with reflective boundary conditions on all sides of the model, this represents and

infinite array in the x-y direction of DSC/casks that are infinite in length. The DSC/cask model for this evaluation differs from the actual design in the following ways:

- only 90% credit for poison plates made of a Boron-Aluminum alloy or Boralyn® and 75% credit for poison plates made with Boral® or Metamic® is taken for the B10 content in the poison plates,
- maximum gaps between poison plates are modeled in their worst case configuration,
- the stainless steel basket rails, which hold the basket together, are modeled as water.

The models are fully described in Section K.6.3.1. The purpose of these models is to determine the most reactive configuration for intact fuel assemblies. A typical input file is included in Section K.6.6.4.

The first series of analyses determined the most reactive fuel assembly-to-assembly pitch. The maximum lattice average fuel enrichment (4.4 wt. % U-235) and a poison plate B10 loading of 0.036 g/cm^2 are used in the model. (Note that the 0.036 g/cm^2 used in the model is 90% of the minimum allowed (0.040 g/cm^2), for poison plates made of a Boron-Aluminum alloy or Boralyn® and, 75% credit for poison plates made with Boral® or Metamic® for a maximum lattice average enrichment of 4.4 wt. % U-235). The results in Table K.6-7 show the most reactive configuration occurs with minimum assembly-to-assembly pitch. The model is similar to the model shown in Table K.6-4 and Figure K.6-2 except that the nominal fuel cell size, nominal poison sheet thickness, fuel clad OD are used and the assemblies are moved within the fuel compartment to vary the assembly-to-assembly pitch.

The second set of analysis evaluates the effect of canister shell thickness on the system reactivity. The model starts with the most reactive assembly-to-assembly pitch (minimum pitch) case above and the canister shell thickness is varied from 0.49 to 0.55 inches. As demonstrated by the results the variation of shell thickness within the tolerance range is statistically insignificant. The nominal shell thickness is used throughout the rest of the analysis except that one additional case is added for the most reactive canister configuration (minimum poison plate thickness and minimum fuel cell size) to demonstrate that the slightly higher result for the maximum shell thickness is indeed a result of the statistics of the calculation.

The third set of analysis evaluates the effect of poison plate thickness on the system reactivity. The model starts with the most reactive assembly-to-assembly pitch (minimum pitch) case above and the poison plate thickness is modeled at 0.3 inches (minimum). The poison plate B10 loading in increased to 0.04724 to account for the reduction in plate thickness to maintain the same areal density. (0.04724 g/cm^3 used in these models is 90% of the minimum allowed (0.040 g/cm^2), for poison plates made of a Boron-Aluminum alloy or Boralyn® and 75% credit for poison plates made with Boral® or Metamic® for a maximum lattice average enrichment of 4.4 wt. % U-235 for a 0.3 inch thick plate). Based on the results of this evaluation the balance of the calculations will use the minimum poison plate thickness because it represents a more reactive condition.

The fourth set of analysis evaluates the sensitivity of the system reactivity on fuel cladding OD. The model starts with the minimum poison plate case above and the fuel cladding thickness is

varied from 0.404 to 0.394 inches. Based on the results of this analysis, it is conservative to model the GE12 10x10 assembly cladding as 0.010 inches less than that reported in Table K.6-7 for the balance of this evaluation.

The fifth set of analysis evaluates the effect of fuel cell size on the system reactivity. The model starts with the most reactive fuel clad OD thickness case above and the canister fuel cell width is varied from 5.8 to 6.1 inches. The results show that the most reactive configuration is with the minimum fuel cell size. One additional run is made to verify that the canister maximum shell thickness does not increase reactivity. The balance of this evaluation will use the minimum cell size because it represents the most reactive configuration.

The second series of analyses determines minimum boron loading in the poison plate as a function of lattice average initial enrichment is evaluated. These models represent the most reactive intact fuel assembly (GE12, 10x10) with a minimum assembly-to-assembly pitch with full internal and external moderator density. The initial lattice average fuel enrichment is varied as well as the B10 density in the poison plates. These cases can be used to specify a minimum B10 poison plate loading as a function of maximum lattice average assembly enrichment. The results are reported in Table K.6-7.

The sixth set of analyses evaluates the effect of internal moderator density on reactivity. The model starts with the most fuel cell width (minimum fuel cell width) case above. The internal moderator is varied from 100 to 0 percent full density. The results in Table K.6-7 confirm that the most reactive condition occurs at full internal moderator density.

The seventh set of analyses evaluates the effect of external moderator density on reactivity. The model uses the most reactive case with internal moderator (full density) density and the external internal moderator is varied from 100 to 0 percent full density. The results in Table K.6-7 show that the system reactivity is not affected by external moderator density. The variation in the results is due entirely to the statistical uncertainties in Keno V.a.

Finally, minimum boron loading in the poison plate as a function of lattice average initial enrichment is evaluated. These models represent the most reactive intact fuel assembly (GE12, 10x10) with a minimum assembly-to-assembly pitch, nominal shell thickness, minimum poison plate thickness, minimum fuel clad OD, minimum fuel cell width with full internal and external moderator density. The initial lattice average fuel enrichment is varied as well as the B10 density in the poison plates. These cases are used to specify a minimum B10 poison plate loading as a function of maximum lattice average assembly enrichment. The results are reported in Table K.6-7.

C. Determination of the Most Reactive Configuration – Damaged Fuel

Five damaged fuel configurations are evaluated using two assembly arrays, 7x7 and 8x8, to demonstrate that a fuel assembly with up to seven fuel rods with gross cladding damage and a peak pellet enrichment of 4.4 wt. % U-235 and a lattice average of 4.0 wt. % U-235 will remain subcritical under all conditions of transfer and storage. These models evaluate the effects of radial movement of fuel rod pieces (the result of "single-ended" breaks), and axial movement

(the result of "double-ended" breaks). The models all include water in the fuel pellet cladding annulus. Section K.6.6.3 includes a more detailed description of these models.

GE 2 7x7 Array: The first two models, Case 1 and Case 2, are used to demonstrate that the difference between reflective and water boundary conditions on the ends has a minimal effect on the system reactivity. The first model, Case 1, is identical to the model used to determine the most reactive configuration for intact fuel, except that 1) the GE12 10x10 assembly is replaced with the GE2 7x7 assembly, and 2) the fuel material is changed from 4.4 wt. % U-235 to 4.0 wt. % U-235 except for the "failed" face row, which is still modeled as 4.4 wt. % U-235. The second model, Case 2, is identical to Case 1 except that the axial boundary conditions are changed from reflective to water. This demonstrates that changing the axial boundary conditions has little, if any effect on the calculated k_{eff}. Cases 4 and 6 determine the effect of moving a single row of seven fuel rods away from the remaining portion of the fuel assembly. As expected, reactivity increases slightly (<1% in k_{eff}) by moving the fuel rods away. Case 8 demonstrates that the most reactive configuration is when the seven fuel rods break in two and move next to the balance of the assembly. Case 8 is extremely conservative in that an entire extra row of fuel is added to the model. Therefore, this case more than bounds the reactivity increase that can possibly occur due to seven fuel rods breaking in two during the postulated accident. Also, note that this "extra" row of fuel rods completely fills the fuel compartment, thereby limiting the number of rods that can move within the fuel compartment.

Another set of runs was performed to determine the effect of sliding the "failed" row of fuel up 12.5 inches above the top of the poison plates. These models are identical to the other models except the model is 12.5" longer with the "failed" fuel extended above the poison.

GE9 8x8 Array: The GE9 8x8 array was chosen to bound all 8x8 arrays licensed herein because it represents the most reactive 8x8 configuration. Case 10 is identical to Case 2 except that the GE9 replaces the GE2 assembly. Cases 12 and 14 determine the effect of moving a single row of eight fuel rods away from the remaining portion of the fuel assembly. As expected the reactivity of the GE9 is unaffected by moving the fuel rods away because the water holes in the center of the assembly control the reactivity of the assembly. Case 16 demonstrates that the most reactive configuration is when the eight fuel rods break in two and move next to the balance of the assembly. Case 16 is extremely conservative in that an entire extra row of fuel is added to the model. Therefore, this case more than bounds the reactivity increase that can possibly occur due to eight fuel rods breaking in two during the postulated accident. Also, note that this "extra" row of fuel rods completely fills the fuel compartment, thereby limiting the number of rods that can move within the fuel compartment.

Finally, as with the 7x7 array, a set of runs was performed to determine the effect of sliding the "failed" row of fuel up 12.5 inches above the top of the poison plates. These models are identical to the other models except the model is 12.5" longer with the "failed" fuel extended above the poison.

For all of the cases above both the cask and DSC are modeled in the radial direction. The cask and DSC are modeled over the active fuel height of the fuel with water reflectors at the ends (z) and reflective boundary conditions outside the DSC (infinite array in the x-y directions) The DSC model for this evaluation differs from the actual design additionally in the following ways:

- only 90% credit for poison plates made of a Boron-Aluminum alloy or Boralyn® and 75% credit for poison plates made with Boral® or Metamic® is taken for the B10 content in the poison plates,
- maximum gaps between poison plates are modeled in their worst case configuration,
- the stainless steel basket rails which hold the basket together are modeled as water,
- Unit 84, and associated arrays and units are added to model the "uncovered" row of fuel above the poison plates.

In all other respects, the model is the same as that described in Sections K.6.3.1 and K.6.3.2. The model is more fully discussed in Section K.6.6.3.

A typical input file is included in Section K.6.6.3. The results of these calculations are listed in Table K.6-8 and Table K.6-9.

K.6.4.3 Criticality Results

Table K.6-10 lists the results that bound all loading, transfer, and storage normal and off-normal conditions. These criticality calculations were performed with CSAS25 of SCALE-4.4. For each case, the result includes (1) the KENO-calculated k_{KENO}; (2) the one sigma uncertainty σ_{KENO}; and (3) the final k_{eff}, which is equal to $k_{KENO} + 2\sigma_{KENO}$. As stated before, the NUHOMS®-61BT system can transfer and store up to 16 damaged and 45 (or more) undamaged BWR fuel assemblies listed in Table K.6-3. Table K.6-10 lists the minimum poison plate B10 loading required as a function of fuel lattice average initial enrichment for intact assemblies and maximum pellet enrichment in the case of damaged fuel.

The criterion for subcriticality is that

$$k_{KENO} + 2\sigma_{KENO} < USL,$$

where USL is the upper subcritical limit established by an analysis of benchmark criticality experiments. From Section 6.5, the minimum USL over the parameter range (in this case, pitch) is 0.9414. From Table K.6-10 for the most reactive case,

$$k_{KENO} + 2\sigma_{KENO} = 0.9340 + 2\ (0.0012) = 0.9364 < 0.9414.$$

K.6.5 Critical Benchmark Experiments

The criticality safety analysis of the NUHOMS®-61BT system used the CSAS25 module of the SCALE system of codes.

The analysis presented herein uses the fresh fuel assumption for criticality analysis. The analysis employed the 44-group ENDF/B-V cross-section library because it has a small bias, as determined by the 125 benchmark calculations described in reference [6.2]. The upper USL-1 was determined using the results of these 125 benchmark calculations.

The benchmark problems used to perform this verification are representative of benchmark arrays of commercial light water reactor (LWR) fuels with the following characteristics:

(1) water moderation

(2) boron neutron absorbers

(3) unirradiated light water reactor type fuel (no fission products or "burnup credit") near room temperature (vs. reactor operating temperature)

(4) close reflection

(5) Uranium Oxide

The 125 uranium oxide experiments were chosen to model a wide range of uranium enrichments, fuel pin pitches, assembly separation, concentration of soluble boron and control elements in order to test the codes ability to accurately calculate k_{eff}. These experiments are discussed in detail in reference [6.2]. The file-input names referred to in the following sub-sections are identical to those used in [6.2].

K.6.5.1 Benchmark Experiments and Applicability

A summary of all of the pertinent parameters for each experiment is included in Table K.6-11 along with the results of each run. The best correlation is observed for fuel assembly separation distance with a correlation of 0.65. All other parameters show much lower correlation ratios indicating no real correlation. All parameters were evaluated for trends and to determine the most conservative USL.

The USL is calculated in accordance to NUREG/CR-6361 [6.3]. USL Method 1 (USL-1) applies a statistical calculation of the bias and its uncertainty plus an administrative margin (0.05) to the linear fit of results of the experimental benchmark data. The basis for the administrative margin is from reference [6.4]. Results from the USL evaluation are presented in Table K.6-12.

The criticality evaluation used the same cross section set, fuel materials and similar material/geometry options that were used in the 125 benchmark calculations as shown in Table K.6-11. The modeling techniques and the applicable parameters listed in Table K.6-13 for the

actual criticality evaluations fall within the range of those addressed by the benchmarks in Table K.6-11.

K.6.5.2 Results of the Benchmark Calculations

The results from the comparisons of physical parameters of each of the fuel assembly types to the applicable USL value are presented in Table K.6-13. The minimum value of the USL was determined to be 0.9414 based on comparisons to the limiting assembly parameters as shown in Table K.6-13.

K.6.6 Appendix

K.6.6.1 References

6.1 Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluations for Workstations and Personal Computers," NUREG/CR-0200, Revision 6, ORNL/NUREG/CSD-2/V2/R6.

6.2 Transnuclear West Calculation No. SCE-01.0602, "Verification and Validation Document: SCALE 4.4 PC; CSAS25 For Uranium Oxide and Uranium Plutonium Mixed Oxide (MOX) Fuel," Revision 0.

6.3 U.S. Nuclear Regulatory Commission, "Criticality Benchmark Guide for Light-Water-Reactor fuel in Transportation and Storage Packages," NUREG/CR-6361, Published March 1997, ORNL-TM-13211.

6.4 U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems," NUREG-1536, Published January 1997.

6.5 U.S. Nuclear Regulating Commission, Office of the Nuclear Materials Safety and Safeguards, "Safety Evaluation Report, Addition of the NUHOMS®-61BT Dry Shielded Canister and Additional Fuel Types," September 17, 2001.

K.6.6.2 Most Reactive Fuel Analysis

The models used to determine the most reactive fuel, are not based on the models used to perform the rest of the analysis. These models are simplified models of the basket and DSC only. Each model represents a different fuel assembly type or condition, such as fuel with fuel channels or variable pin enrichment. Each Unit in the KENO V.a model has a length equal to the active fuel height of the assembly modeled (See Table K.6-3) with water boundary conditions on the ends and reflective boundary conditions on the sides. Figure K.6-3 is an annotated radial plot of the KENO V.a model (with the GE5 assembly type) used to determine the most reactive fuel type. The only difference between this model and the rest of the most reactive fuel models is the assembly layout and model height.

Figure K.6-4 is a graphical depiction of the fuel assembly layout for each assembly type, including a map of the variable enrichment case. A representative input is included below. The example input is for the GE5 fuel type with a variable rod enrichment. The fuel assembly pin by pin layouts for the variable enrichment cases are shown in Figure K.6-5.

Example Input Listing:

```
=csas25
61B Confirmatory Fuel Enrichment Analysis with GE5 8x8, Jack
Boshoven 12/28/00
```

```
44groupndf5 latticecell
uo2     1 0.95 293 92235 2.33 92238 97.67 end
zirc2   2 1.0  293 end
h2o     3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304   5 1.0  293 end
h2o     6 1.0  293 end
h2o     7 1.0  293 end
b-10    8 den=0.046 1.0 293 end
al      8 0.9  293 end
uo2     9 0.95 293 92235 3.01 92238 96.99 end
uo2    10 0.95 293 92235 3.57 92238 96.43 end
uo2    11 0.95 293 92235 4.85 92238 95.15 end
end comp
squarepitch 1.6256  1.0414 11 3 1.22682 2 1.06426 6 end
more data res=9  cylinder 0.5207 dan(9)=0.18804820
          res=10 cylinder 0.5207 dan(10)=0.18804820
          res=1  cylinder 0.5207 dan(1)=0.18804820
end more data
Keno Title Card
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=yes
end param
read geom
unit 1     com='Fuel Rod w/2.33 wt%'
cylinder  1   1  0.5207        381.00        0.0
cylinder  6   1  0.53213       381.00        0.0
cylinder  2   1  0.61341       381.00        0.0
cuboid    3   1  4p0.8128      381.00        0.0
unit 2     com='GE 8x8 Center Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 3     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566      381.00        0.0
unit 4     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566      381.00        0.0
unit 5     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 6     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566      381.00        0.0
unit 7     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
```

```
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  7.9629 -8.3566 2p8.3566       381.00          0.0
unit 8      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  4p8.3566      381.00         0.0
unit 9      com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  2p8.3566        7.9629 -8.3566 381.00         0.0
unit 10     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  7.9629 -8.3566 7.9629 -8.3566 381.00         0.0
unit 11     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  8.3566 -7.9629 7.9629 -8.3566 381.00         0.0
unit 12     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  4p8.3566      381.00         0.0
unit 13     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  2p8.3566 8.3566 -7.9629       381.00          0.0
unit 14     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  7.9629 -8.3566 8.3566 -7.9629 381.00         0.0
unit 15     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  7.9629 -8.3566 2p8.3566       381.00          0.0
unit 16     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  8.3566 -7.9629 8.3566 -7.9629 381.00         0.0
unit 17     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  8.3566 -7.9629 2p8.3566       381.00          0.0
unit 18     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1  4p7.62        381.00         0.0
cuboid     5    1  4p7.9629      381.00         0.0
cuboid     8    1  8.3566 -7.9629 8.3566 -7.9629 381.00         0.0
```

```
unit 19    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629      381.00         0.0
unit 20    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00         0.0
unit 21    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566      381.00         0.0
unit 22    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  4p8.3566      381.00        0.0
unit 23    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566      381.00         0.0
unit 24    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00         0.0
unit 25    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566       7.9629 -8.3566 381.00         0.0
unit 26    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00         0.0
unit 27    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00         0.0
unit 28    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629      381.00         0.0
unit 29    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00         0.0
unit 30    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
```

```
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00        0.0
unit 31    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00        0.0
unit 32    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00        0.0
unit 33    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00        0.0
unit 34    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629        381.00        0.0
unit 35    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00        0.0
unit 36    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00        0.0
unit 37    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00        0.0
unit 38    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9629      381.00        0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00        0.0
unit 39   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 40  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 41  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
```

```
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 42  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 43   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 44  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 45  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 46  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 47   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 48  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 49  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 50  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 51   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 52  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62       381.00        0.0
cuboid    5   1  4p7.9248     381.00        0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 53  com='GE 8x8 Assembly'
```

```
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 54  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00        0.0
cuboid    5   1  4p7.9248      381.00        0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 55  com='center 9x9 array'
array 2 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00        0.0
cuboid    8   1  4p25.7302    381.00        0.0
unit 56  com='right 9x9 array'
array 3 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00        0.0
unit 57  com='top 9x9 array'
array 4 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00        0.0
unit 58  com='left 9x9 array'
array 5 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00        0.0
unit 59  com='bottom 9x9 array'
array 6 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00        0.0
unit 60  com='upper right 2x2 array'
array 7 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00        0.0
unit 61  com='upper left 2x2 array'
array 8 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00        0.0
unit 62  com='lower right 2x2 array'
array 9 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00        0.0
unit 63  com='lower right 2x2 array'
array 10 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00        0.0
unit 64  com='0.31" poison plate'
cuboid    8   1  2p16.51 2p0.3937 381.00    0.0
unit 65  com='0.31" poison plate'
cuboid    8   1  2p0.3937 2p16.51 381.00    0.0
unit 66  com='water hole'
cylinder  3  1  0.67437   381.00    0.0
cylinder  2  1  0.75057   381.00    0.0
cuboid    3  1  4P0.8128  381.00    0.0
unit 67    com='Fuel Rod w/3.01 wt%'
cylinder  9   1  0.5207       381.00        0.0
cylinder  6   1  0.53213      381.00        0.0
cylinder  2   1  0.61341      381.00        0.0
cuboid    3   1  4p0.8128     381.00        0.0
unit 68    com='Fuel Rod w/3.57 wt%'
cylinder 10   1  0.5207       381.00        0.0
cylinder  6   1  0.53213      381.00        0.0
cylinder  2   1  0.61341      381.00        0.0
cuboid    3   1  4p0.8128     381.00        0.0
unit 69    com='Fuel Rod w/4.85 wt%'
cylinder 11   1  0.5207       381.00        0.0
```

```
cylinder  6   1  0.53213       381.00         0.0
cylinder  2   1  0.61341       381.00         0.0
cuboid    3   1  4p0.8128      381.00         0.0
global unit 70
cylinder  3   1  84.757        381.00         0.0
    hole 55   0.0       0.0      0.0
    hole 56   50.673    0.0      0.0
    hole 57   0.0       50.673   0.0
    hole 58  -50.673    0.0      0.0
    hole 59   0.0      -50.673   0.0
    hole 60   42.2404   42.2404 0.0
    hole 61  -42.2404   42.2404 0.0
    hole 62  -42.2404 -42.2404 0.0
    hole 63   42.2404 -42.2404 0.0
    hole 64   42.2404   25.3366 0.0
    hole 64  -42.2404   25.3366 0.0
    hole 64  -42.2404 -25.3366 0.0
    hole 64   42.2404 -25.3366 0.0
    hole 65   25.3366   42.2404 0.0
    hole 65  -25.3366   42.2404 0.0
    hole 65  -25.3366 -42.2404 0.0
    hole 65   25.3366 -42.2404 0.0
cylinder  5   1  86.027        381.00         0.0
cuboid    7   1  4p86.03       381.00         0.0
end geom
read array
   com='GE 8x8 fuel assembly slice, sd, fuel regions'
   ara=1       nux=8       nuy=8       nuz=1
   fill
       67 68 68 68 68 68 67  1
       68 69 69 69 69 69 68 67
       69 69 69 69 69 69 69 68
       69 69 69 66 69 69 69 68
       69 69 69 69 66 69 69 68
       69 69 69 69 69 69 69 68
       69 69 69 69 69 69 69 68
       68 69 69 69 69 69 68 67
   end fill
   com='Center 9x9 Array of Fuel'
   ara=2       nux=3       nuy=3       nuz=1
   fill
        18 19 20
         6  2  3
        11  9 10
   end fill
   com='Right 9x9 Array of Fuel'
   ara=3       nux=3       nuy=3       nuz=1
   fill
        27 28 29
         4  5  3
        30 31 32
   end fill
   com='Top 9x9 Array of Fuel'
   ara=4       nux=3       nuy=3       nuz=1
   fill
        16 13 14
        17 12 15
```

```
          11  9 10
     end fill
     com='Left 9x9 Array of Fuel'
     ara=5      nux=3      nuy=3      nuz=1
     fill
          33 34 35
           6  8  7
          36 37 38
     end fill
     com='Bottom 9x9 Array of Fuel'
     ara=6      nux=3      nuy=3      nuz=1
     fill
          18 19 20
          21 22 23
          24 25 26
     end fill
     com='Upper Right 2x2 Array of Fuel'
     ara=7      nux=2      nuy=2      nuz=1
     fill
          39 40
          41 42
     end fill
     com='Upper Left 2x2 Array of Fuel'
     ara=8      nux=2      nuy=2      nuz=1
     fill
          43 44
          45 46
     end fill
     com='Lower Left 2x2 Array of Fuel'
     ara=9      nux=2      nuy=2      nuz=1
     fill
          47 48
          49 50
     end fill
     com='Lower Right 2x2 Array of Fuel'
     ara=10     nux=2      nuy=2      nuz=1
     fill
          51 52
          53 54
     end fill
end array
read bounds
   xyf=specular
   zfc=water
end bounds
read plot
   ttl='cask material plot  - plan view'
   pic=mat
   nch=' fzmcsblxg'
   xul=-87   yul=87    zul=200
   xlr=87    ylr=-87   zlr=200
   uax=1.0    vdn=-1.0
   nax=650
end plot
end data
end
```

K.6.6.3 Damaged Fuel Analysis

The models for the damaged fuel analysis are based on the intact fuel analysis models. Section K.6.3 provides a complete description of the intact fuel model. The following list identifies the major changes made to the intact fuel model.

- Revised Material 1, UO_2 enrichment to 4.0 wt. % U-235.
- Added Material 10, UO_2 with an enrichment of 4.4 wt. % U-235.
- Revised the "squarepitch" card to reflect the 7x7 dimensions.
- Added "`more data res=10 cylinder 0.61849 dan(10)=0.16513124 end more data`" Card to correctly account for resonance and rod shadow effects.
- Revised Array 1 to model the 7x7 assembly rather than the 10x10.
- Revised unit 1 to model the rod/pitch etc. for the 7x7.
- Replaced array 1 with array 42 in Units 11 and 14 to model the "failed" fuel in the 2x2 compartments.
- Replaced array 1 with array 45 in Units 12 and 13 to model the "failed" fuel in the 2x2 compartments.
- Revised Units 32, 33, 46 and 47 to model the rows of rods above the rest of the fuel assembly.
- Revised units 58 and 59 to replace holes 46 and 47 with the revised 48 and 49.
- Replaced arrays 23 and 24 with arrays 2 and 3 in Units 61 and 62 to model the "failed" fuel in the 2x2 compartments above the rest of the assembly.
- Revised unit 79 to replace holes 75 and 76 with the revised 77 and 78.
- Moved Unit 82 to Unit 83.
- Deleted the old Unit 81 (water space for the 10x10 assembly).
- Added Units 81 and 85 to model the row of displaced rods. This unit contains the same materials and geometry as Unit 1, except that the fuel uses material 10 (higher enrichment) and the water cuboid dimensions are adjusted to account for pin spacing.
- Added Unit 82 to model the water spaces next to the moved row of fuel in the array.
- Added Unit 84 to model the portion of the DSC/cask with the moved rows of "failed" fuel rods. (See Figure K.6-8 for cross section of this unit.)

- Arrays 2 through 5, 18, 19, 23, 24, 26, 26, 37, 38, 40 and 41 are revised to model to account for the displaced rods for the single break or to insert the extra row of fuel for the double break cases.

- Arrays 42 through 45 are added to model the "failed" fuel assemblies for use in the units, which define the "failed" fuel cells.

- Finally, Array 21 is modified to add 50 Unit 79's to the front of the array, (12.5 inches uncovered fuel). To model the "failed" rods which can move above the top of the poison plates.

Figure K.6-6 is a cross section of the 7x7 Single Break case. This case models the maximum separation between the sheared rods and remaining assembly. Figure K.6-7 is a cross section of 7x7 Double Break case. Figure K.6-8 is a cross section through unit 79 of the Single Break case with the a single row of fuel rods pushed up. Finally, Figure K.6-9 is a cross section through unit 79 of the Double Break with the two rows of fuel rods pushed up.

The following example input file listing is for 7x7 Double Break case

```
=csas25
61B w/GE 7x7, including 0.125" gaps, Failed Fuel Jack Boshoven
1/11/01
44groupndf5 latticecell
uo2     1 0.95 293 92235 4.0 92238 96.0 end
zirc2   2 1.0  293 end
h2o     3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304   5 1.0  293 end
h2o     6 1.0  293 end
h2o     7 1.0  293 end
b-10    8 den=0.04724 1.0 293 end
al      8 0.9  293 end
pb      9 1.0  293 end
uo2    10 0.95 293 92235 4.4 92238 95.6 end
end comp
squarepitch 1.87452 1.23698 1 3 1.43002 2 1.26746 6 end
more data res=10 cylinder 0.61849 dan(10)=0.16513124
end more data
Same as run ff04.in except add a row of fuel (Double Break)
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=yes
end param
read geom
unit 1      com='Fuel Rod'
cylinder  1   1  0.61849      0.635          0.0
cylinder  6   1  0.63373      0.635          0.0
cylinder  2   1  0.71501      0.635          0.0
cuboid    3   1  4p0.93726    0.635          0.0
unit 2      com='GE 7x7 center center 3x3 Assembly'
array 1 -6.56082 -6.56082 0.0
cuboid    3   1  4p7.366      0.635          0.0
```

```
cuboid    5   1  4p7.6327     0.635         0.0
unit 3      com='GE 7x7 shift left center 3x3 Assembly'
array 1 -7.366   -6.56082 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 4      com='GE 7x7 shift right center 3x3 Assembly'
array 1 -5.75564 -6.56082 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 5      com='GE 7x7 shift center down 3x3 Assembly'
array 1 -6.56082 -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 6      com='GE 7x7 shift center up 3x3 Assembly'
array 1 -6.56082 -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 7      com='GE 7x7 shift left down 3x3 Assembly'
array 1 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 8      com='GE 7x7 shift right down 3x3 Assembly'
array 1 -5.75564 -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 9      com='GE 7x7 shift right up 3x3 Assembly'
array 1 -5.75564 -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 10     com='GE 7x7 shift left up 3x3 Assembly'
array 1 -7.366   -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 11     com='GE 7x7 shift left down 2x2 Assembly'
array 42 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 12     com='GE 7x7 shift right down 2x2 Assembly'
array 43 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 13     com='GE 7x7 shift right up 2x2 Assembly'
array 43 -7.366   -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 14     com='GE 7x7 shift left up 2x2 Assembly'
array 42 -7.366   -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 15     com='horizontal left gap poison 3x3'
cuboid    0   1  0.3175   0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.2654   0.0  2p0.3810  0.635     0.0
unit 16     com='horizontal gap  3x3'
cuboid    0   1 15.2654   0.0  2p0.3810  0.635     0.0
unit 17     com='horizontal left and right gap poison 3x3'
cuboid    0   1  0.15875 0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.10665 0.0  2p0.3810  0.635     0.0
```

```
cuboid    0   1 15.2654  0.0  2p0.3810  0.635     0.0
unit 18    com='horizontal right gap poison 3x3'
cuboid    8   1 14.9479  0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.2654  0.0  2p0.3810  0.635     0.0
unit 19    com='horizontal left gap poison 2'
cuboid    0   1  0.3175  0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 20   com='horizontal gap  3x3'
cuboid    0   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 21    com='horizontal right gap poison 2x2'
cuboid    8   1 14.8717  0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 22    com='vertical top gap poison 3x3'
cuboid    8   1 2p0.3810  14.9479  0.0  0.635     0.0
cuboid    0   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 23    com='vertical gap  3x3'
cuboid    0   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 24    com='vertical bottom gap poison 3x3'
cuboid    0   1 2p0.3810   0.3175  0.0  0.635     0.0
cuboid    8   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 25    com='horizontal center gap poison 3x3'
cuboid    0   1 2p0.3175  2p0.3810      0.635     0.0
cuboid    8   1 2p23.6601 2p0.3810      0.635     0.0
unit 26    com='horizontal gap  3x3'
cuboid    0   1 2p23.6601 2p0.3810      0.635     0.0
unit 27    com='vertical center gap poison 3x3'
cuboid    0   1 2p0.3810  2p0.3175      0.635     0.0
cuboid    8   1 2p0.3810  2p23.6601     0.635     0.0
unit 28    com='vertical gap  3x3'
cuboid    0   1 2p0.3810  2p23.6601     0.635     0.0
unit 30   com='vertical gap  2x2'
cuboid    0   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 31   com='vertical top gap poison 2x2'
cuboid    8   1 2p0.3810 15.10665  0.0  0.635     0.0
cuboid    0   1 2p0.3810 15.72895  0.0  0.635     0.0
cuboid    8   1 2p0.3810 30.8229   0.0  0.635     0.0
cuboid    0   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 32    com='GE 7x7 shift left down 2x2 Assembly'
array 44 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 33    com='GE 7x7 shift right down 2x2 Assembly'
array 45 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 34   com='Upper Right 2x2 w/poison'
array 4   -7.5946 -15.5702 0.0
unit 35   com='Uppwe Left 2x2 w/poison'
array 5   -7.5946 -15.5702 0.0
unit 36   com='3x3 with poison'
array 6   -7.6327 -23.6601 0.0
unit 37   com='3x3 with poison'
array 7   -7.6327 -23.6601 0.0
unit 38   com='3x3 with poison'
array 8   -7.6327 -23.6601 0.0
unit 39   com='3x3 with poison'
array 9   -7.6327 -23.6601 0.0
```

```
unit 40   com='3x3 with poison'
array 10  -7.6327 -23.6601 0.0
unit 41   com='Center 3x3 fuel with poison'
array 11 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 42   com='Right 3x3 fuel with poison'
array 12 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 43   com='Top 3x3 fuel with poison'
array 13 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 44   com='Left 3x3 fuel with poison'
array 14 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 45   com='Bottom 3x3 fuel with poison'
array 15 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 46    com='GE 7x7 shift right up 2x2 Assembly'
array 45 -7.366   -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 47    com='GE 7x7 shift left up 2x2 Assembly'
array 44 -7.366   -5.75564 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 48   com='Lower Left 2x2 fuel with poison'
array 18 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 49   com='Lower Right 2x2 fuel with poison'
array 19 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 50   com='vertical poison between 3x3 compartments'
cuboid    8   1 2p0.3810  2p23.69185  0.635     0.0
cuboid    0   1 2p0.3810  2p23.8506    0.635     0.0
unit 51   com='vertical poison between 3x3 compartments, gap'
cuboid    0   1 2p0.3810  2p23.8506    0.635     0.0
unit 52   com='center horizontal strip of 3x3 arrays'
array 20 -72.3138 -23.8506 0.0
unit 53   com='center horizontal strip of poison'
cuboid    8   1 2p56.1340 2p0.3810    0.635     0.0
unit 54   com='center horizontal strip of poison, gap'
cuboid    0   1 2p56.1340 2p0.3810    0.635     0.0
unit 55   com='top vertical strip of poison'
cuboid    8   1 2p0.3810  15.7607 -15.4432 0.635     0.0
cuboid    0   1 2p0.3810 2p15.7607 0.635     0.0
unit 56   com='top vertical strip of poison gap'
cuboid    0   1 2p0.3810 2p15.7607 0.635     0.0
unit 57   com='top vertical strip of poison'
cuboid    8   1 2p0.3810  15.4432 -15.7607 0.635     0.0
cuboid    0   1 2p0.3810 2p15.7607 0.635     0.0
unit 58   com='poison everywhere'
cylinder  3   1  84.1375      0.635         0.0
    hole 52   0.0       0.0      0.0
    hole 53   0.0      24.2316  0.0
    hole 53   0.0     -24.2316  0.0
    hole 43   0.0      48.4633  0.0
    hole 45   0.0     -48.4633  0.0
```

```
    hole 55  24.2316  40.3734  0.0
    hole 55 -24.2316  40.3734  0.0
    hole 57  24.2316 -40.3734  0.0
    hole 57 -24.2316 -40.3734  0.0
    hole 48  40.3734  40.3734  0.0
    hole 49 -40.3734  40.3734  0.0
    hole 48 -40.3734 -40.3734  0.0
    hole 49  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 59   com='poison inside, gap outside'
cylinder  3   1  84.1375      0.635         0.0
    hole 60   0.0       0.0    0.0
    hole 54   0.0      24.2316  0.0
    hole 54   0.0     -24.2316  0.0
    hole 43   0.0      48.4633  0.0
    hole 45   0.0     -48.4633  0.0
    hole 56  24.2316  40.3734  0.0
    hole 56 -24.2316  40.3734  0.0
    hole 56  24.2316 -40.3734  0.0
    hole 56 -24.2316 -40.3734  0.0
    hole 48  40.3734  40.3734  0.0
    hole 49 -40.3734  40.3734  0.0
    hole 48 -40.3734 -40.3734  0.0
    hole 49  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 60   com='center horizontal strip of 3x3 arrays with gap'
array 22 -72.3138 -23.8506 0.0
unit 61   com='Upper Right 2x2 w/o poison'
array  2  -7.5946 -15.5702 0.0
unit 62   com='Upper Left 2x2 w/o poison'
array  3  -7.5946 -15.5702 0.0
unit 63   com='Upper Right 2x2 w/o poison'
array 25  -7.5946 -15.5702 0.0
unit 64   com='Uppwe Left 2x2 w/o poison'
array 26  -7.5946 -15.5702 0.0
unit 65   com='3x3 with out poison'
array 27  -7.6327 -23.6601 0.0
unit 66   com='3x3 with out poison'
array 28  -7.6327 -23.6601 0.0
unit 67   com='3x3 with out poison'
array 29  -7.6327 -23.6601 0.0
unit 68   com='3x3 with out poison'
array 30  -7.6327 -23.6601 0.0
unit 69   com='3x3 with out poison'
array 31  -7.6327 -23.6601 0.0
unit 70   com='Center 3x3 fuel with out poison'
array 32 -23.6601 -23.6601 0.0
```

```
cuboid    5   1 4p23.8506      0.635         0.0
unit 71   com='Right 3x3 fuel with out poison'
array 33 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 72   com='Top 3x3 fuel with out poison'
array 34 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 73   com='Left 3x3 fuel with out poison'
array 35 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 74   com='Bottom 3x3 fuel with out poison'
array 36 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 75   com='Lower Left 2x2 fuel with out poison'
array 37 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 76   com='Lower Right 2x2 fuel with out poison'
array 38 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 77   com='Lower Left 2x2 fuel with out poison'
array 39 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 78   com='Lower Right 2x2 fuel with out poison'
array 40 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 79   com='gap inside, gap outside'
cylinder  3   1  84.1375      0.635         0.0
    hole 80   0.0       0.0     0.0
    hole 54   0.0      24.2316  0.0
    hole 54   0.0     -24.2316  0.0
    hole 72   0.0      48.4633  0.0
    hole 74   0.0     -48.4633  0.0
    hole 56  24.2316  40.3734  0.0
    hole 56 -24.2316  40.3734  0.0
    hole 56  24.2316 -40.3734  0.0
    hole 56 -24.2316 -40.3734  0.0
    hole 77  40.3734  40.3734  0.0
    hole 78 -40.3734  40.3734  0.0
    hole 77 -40.3734 -40.3734  0.0
    hole 78  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 80   com='center horizontal strip of 3x3 arrays with all gaps'
array 41 -72.3138 -23.8506 0.0
unit 81   com='broken row rod 2cm from assembly'
cylinder  10  1  0.61849      0.635         0.0
cylinder  6   1  0.63373      0.635         0.0
cylinder  2   1  0.71501      0.635         0.0
cuboid    3   1  2p0.74422 2p0.93726    0.635         0.0
unit 82    com='water hole'
cuboid    3   1  4p0.93726    0.635         0.0
global unit 83
array 21 -85.41   -85.41  0.0
```

```
unit 84   com='gap inside, gap outside'
cylinder  3   1  84.1375      0.635         0.0
    hole 56  24.2316  40.3734  0.0
    hole 56 -24.2316  40.3734  0.0
    hole 56  24.2316 -40.3734  0.0
    hole 56 -24.2316 -40.3734  0.0
    hole 75  40.3734  40.3734  0.0
    hole 76 -40.3734  40.3734  0.0
    hole 75 -40.3734 -40.3734  0.0
    hole 76  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 85   com='broken row rod 2cm from assembly'
cylinder  10  1  0.61849      0.635         0.0
cylinder  6   1  0.63373      0.635         0.0
cylinder  2   1  0.71501      0.635         0.0
cuboid    3   1  2p0.74422   2p0.93726     0.635          0.0
end geom
read array
   com='GE 7x7 fuel assembly slice, sd, fuel regions'
   ara=1      nux=7      nuy=7      nuz=1
   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
        1 1 1 1 1 1 1
        1 1 1 1 1 1 1
   end fill
   com='Lower Left 2x2 Array of Fuel w/o poison'
   ara=2     nux=1      nuy=3      nuz=1
   fill
        46
        20
        33
   end fill
   com='Lower Left 2x2 Array of Fuel w/o poison'
   ara=3      nux=1      nuy=3      nuz=1
   fill
        47
        20
        32
   end fill
   com='Lower Left 2x2 Array of Fuel w/poison'
   ara=4      nux=1      nuy=3      nuz=1
   fill
        13
        21
        12
   end fill
   com='Lower Left 2x2 Array of Fuel w/poison'
   ara=5      nux=1      nuy=3      nuz=1
```

```
fill
     14
     19
     11
end fill
com='3x3 Array of Fuel w/poison'
ara=6      nux=1      nuy=5      nuz=1
fill
      9
     18
      4
     18
      8
end fill
com='3x3 Array of Fuel w/poison'
ara=7      nux=1      nuy=5      nuz=1
fill
      6
     17
      2
     17
      5
end fill
com='3x3 Array of Fuel w/poison'
ara=8      nux=1      nuy=5      nuz=1
fill
     10
     15
      3
     15
      7
end fill
com='3x3 Array of Fuel w/poison'
ara=9      nux=5      nuy=1      nuz=1
fill
      9  22   6  22  10
end fill
com='3x3 Array of Fuel w/poison'
ara=10     nux=5      nuy=1      nuz=1
fill
      8  24   5  24   7
end fill
com='Center 3x3 Array of Fuel w/poison'
ara=11     nux=5      nuy=1      nuz=1
fill
     36  27  37  27  38
end fill
com='Right 3x3 Array of Fuel w/poison'
ara=12     nux=5      nuy=1      nuz=1
fill
     38  27  38  27  38
end fill
com='Top 3x3 Array of Fuel w/poison'
ara=13     nux=1      nuy=5      nuz=1
fill
     40
     25
```

```
     40
     25
     40
end fill
com='Left 3x3 Array of Fuel w/poison'
ara=14     nux=5      nuy=1      nuz=1
fill
     36  27  36  27  36
end fill
com='Bottom 3x3 Array of Fuel w/poison'
ara=15     nux=1      nuy=5      nuz=1
fill
     39
     25
     39
     25
     39
end fill
com='Lower Left 2x2 Array of Fuel w/poison'
ara=18     nux=3      nuy=1      nuz=1
fill
     34  31  35
end fill
com='Lower Right 2x2 Array of Fuel w/poison'
ara=19     nux=3      nuy=1      nuz=1
fill
     34  31  35
end fill
com='Center row of 3x3 arrays of Fuel w/poison'
ara=20    nux=5      nuy=1      nuz=1
fill
     44  50  41  50  42
end fill
com='Axail Cask'
ara=21    nux=1      nuy=1      nuz=576
fill
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
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     59
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     79 79 79
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      58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
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      59
      58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
      58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
      59
end fill
com='Center row of 3x3 arrays of Fuel w/poison'
ara=22    nux=5      nuy=1      nuz=1
fill
      44  51  41  51  42
end fill
com='Upper Right 2x2 Array of Fuel w/o poison'
ara=23     nux=1      nuy=3      nuz=1
fill
      11
      20
      14
end fill
com='Upper Left 2x2 Array of Fuel w/o poison'
ara=24     nux=1      nuy=3      nuz=1
fill
      12
      20
      13
end fill
com='Lower Left 2x2 Array of Fuel w/o poison'
ara=25     nux=1      nuy=3      nuz=1
fill
      13
      20
      12
end fill
com='Lower Left 2x2 Array of Fuel w/o poison'
ara=26     nux=1      nuy=3      nuz=1
fill
      14
      20
      11
end fill
com='3x3 Array of Fuel w/o poison'
ara=27     nux=1      nuy=5      nuz=1
```

```
fill
      9
     16
      4
     16
      8
end fill
com='3x3 Array of Fuel w/o poison'
ara=28     nux=1      nuy=5      nuz=1
fill
      6
     16
      2
     16
      5
end fill
com='3x3 Array of Fuel w/o poison'
ara=29     nux=1      nuy=5      nuz=1
fill
     10
     16
      3
     16
      7
end fill
com='3x3 Array of Fuel w/o poison'
ara=30     nux=5      nuy=1      nuz=1
fill
      9  23   6  23  10
end fill
com='3x3 Array of Fuel w/o poison'
ara=31     nux=5      nuy=1      nuz=1
fill
      8  23   5  23   7
end fill
com='Center 3x3 Array of Fuel w/o poison'
ara=32     nux=5      nuy=1      nuz=1
fill
     65  28  66  28  67
end fill
com='Right 3x3 Array of Fuel w/o poison'
ara=33     nux=5      nuy=1      nuz=1
fill
     67  28  67  28  67
end fill
com='Top 3x3 Array of Fuel w/o poison'
ara=34     nux=1      nuy=5      nuz=1
fill
     69
     26
     69
     26
     69
end fill
com='Left 3x3 Array of Fuel w/o poison'
ara=35     nux=5      nuy=1      nuz=1
fill
```

```
     65  28  65  28  65
end fill
com='Bottom 3x3 Array of Fuel w/o poison'
ara=36     nux=1      nuy=5      nuz=1
fill
     68
     26
     68
     26
     68
end fill
com='Lower Left 2x2 Array of Fuel w/o poison'
ara=37     nux=3      nuy=1      nuz=1
fill
     61  30  62
end fill
com='Lower Right 2x2 Array of Fuel w/o poison'
ara=38     nux=3      nuy=1      nuz=1
fill
     61  30  62
end fill
com='Lower Left 2x2 Array of Fuel w/o poison'
ara=39     nux=3      nuy=1      nuz=1
fill
     63  30  64
end fill
com='Lower Right 2x2 Array of Fuel w/o poison'
ara=40     nux=3      nuy=1      nuz=1
fill
     63  30  64
end fill
com='Center row of 3x3 arrays of Fuel w/o poison'
ara=41    nux=5      nuy=1      nuz=1
fill
     73  51  70  51  71
end fill
com='GE 7x7 failed fuel assembly slice, sd, fuel regions'
ara=42     nux=8      nuy=7      nuz=1
fill
     85 85 1 1 1 1 1 1
     85 85 1 1 1 1 1 1
     85 85 1 1 1 1 1 1
     85 85 1 1 1 1 1 1
     85 85 1 1 1 1 1 1
     85 85 1 1 1 1 1 1
     85 85 1 1 1 1 1 1
end fill
com='GE 7x7 failed fuel assembly slice, sd, fuel regions'
ara=43     nux=8      nuy=7      nuz=1
fill
     1 1 1 1 1 1 81 81
     1 1 1 1 1 1 81 81
     1 1 1 1 1 1 81 81
     1 1 1 1 1 1 81 81
     1 1 1 1 1 1 81 81
     1 1 1 1 1 1 81 81
     1 1 1 1 1 1 81 81
```

```
    end fill
    com='GE 7x7 failed fuel assembly slice, sd, fuel regions'
    ara=44      nux=8      nuy=7      nuz=1
    fill
        85 85 82 82 82 82 82 82
        85 85 82 82 82 82 82 82
        85 85 82 82 82 82 82 82
        85 85 82 82 82 82 82 82
        85 85 82 82 82 82 82 82
        85 85 82 82 82 82 82 82
        85 85 82 82 82 82 82 82
    end fill
    com='GE 7x7 failed fuel assembly slice, sd, fuel regions'
    ara=45      nux=8      nuy=7      nuz=1
    fill
         82 82 82 82 82 82 81 81
         82 82 82 82 82 82 81 81
         82 82 82 82 82 82 81 81
         82 82 82 82 82 82 81 81
         82 82 82 82 82 82 81 81
         82 82 82 82 82 82 81 81
         82 82 82 82 82 82 81 81
    end fill
end array
read bounds
    xyf=specular
    zfc=water
end bounds
read plot
    ttl='cask material plot  - plan view all poison'
    pic=mat
    nch=' fzmcsblxg'
    xul=-105  yul=105   zul=53
    xlr=105   ylr=-105  zlr=53
    uax=1.0    vdn=-1.0
    nax=650
end plot
end data
end
```

K.6.6.4 Example CSAS25 Input Deck

```
=csas25
61B w/GE 10x10, including 0.125" gaps, assemblies in Jack Boshoven
1/6/01
44groupndf5 latticecell
uo2     1 0.95 293 92235 4.4 92238 95.6 end
zirc2   2 1.0  293 end
h2o     3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304   5 1.0  293 end
h2o     6 1.0  293 end
h2o     7 1.0  293 end
b-10    8 den=0.04724 1.0 293 end
al      8 0.9  293 end
pb      9 1.0  293 end
end comp
squarepitch 1.2954 0.87630 1 3 1.00076 2 0.89408 6 end
Assemblies pushed to center; clad OD 0.394"; minimum fuel cell width
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=no
end param
read geom
unit 1     com='Fuel Rod'
cylinder  1   1  0.43815     0.635         0.0
cylinder  6   1  0.44704     0.635         0.0
cylinder  2   1  0.50038     0.635         0.0
cuboid    3   1  4p0.6477    0.635         0.0
unit 2     com='GE 10x10 center center 3x3 Assembly'
array 1 -6.47700 -6.47700 0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
unit 3     com='GE 10x10 shift left center 3x3 Assembly'
array 1 -7.366   -6.47700 0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
unit 4     com='GE 10x10 shift right center 3x3 Assembly'
array 1 -5.58810 -6.47700 0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
unit 5     com='GE 10x10 shift center down 3x3 Assembly'
array 1 -6.47700 -7.366   0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
unit 6     com='GE 10x10 shift center up 3x3 Assembly'
array 1 -6.47700 -5.58810 0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
unit 7     com='GE 10x10 shift left down 3x3 Assembly'
array 1 -7.366   -7.366   0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
unit 8     com='GE 10x10 shift right down 3x3 Assembly'
array 1 -5.58810 -7.366   0.0
cuboid    3   1  4p7.366     0.635         0.0
cuboid    5   1  4p7.6327    0.635         0.0
```

```
unit 9     com='GE 10x10 shift right up 3x3 Assembly'
array 1 -5.58810 -5.58810 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 10    com='GE 10x10 shift left up 3x3 Assembly'
array 1 -7.366   -5.58810 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.6327     0.635         0.0
unit 11    com='GE 10x10 shift left down 2x2 Assembly'
array 1 -7.366   -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 12    com='GE 10x10 shift right down 2x2 Assembly'
array 1 -5.58810 -7.366   0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 13    com='GE 10x10 shift right up 2x2 Assembly'
array 1 -5.58810 -5.58810 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 14    com='GE 10x10 shift left up 2x2 Assembly'
array 1 -7.366   -5.58810 0.0
cuboid    3   1  4p7.366      0.635         0.0
cuboid    5   1  4p7.5946     0.635         0.0
unit 15    com='horizontal left gap poison 3x3'
cuboid    0   1  0.3175  0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.2654  0.0  2p0.3810  0.635     0.0
unit 16    com='horizontal gap  3x3'
cuboid    0   1 15.2654  0.0  2p0.3810  0.635     0.0
unit 17    com='horizontal left and right gap poison 3x3'
cuboid    0   1  0.15875 0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.09395 0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.2654  0.0  2p0.3810  0.635     0.0
unit 18    com='horizontal right gap poison 3x3'
cuboid    8   1 14.9479  0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.2654  0.0  2p0.3810  0.635     0.0
unit 19    com='horizontal left gap poison 2'
cuboid    0   1  0.3175  0.0  2p0.3810  0.635     0.0
cuboid    8   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 20   com='horizontal gap  3x3'
cuboid    0   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 21    com='horizontal right gap poison 2x2'
cuboid    8   1 14.8717  0.0  2p0.3810  0.635     0.0
cuboid    0   1 15.1892  0.0  2p0.3810  0.635     0.0
unit 22    com='vertical top gap poison 3x3'
cuboid    8   1 2p0.3810  14.9479  0.0  0.635     0.0
cuboid    0   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 23    com='vertical gap  3x3'
cuboid    0   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 24    com='vertical bottom gap poison 3x3'
cuboid    0   1 2p0.3810   0.3175  0.0  0.635     0.0
cuboid    8   1 2p0.3810  15.2654  0.0  0.635     0.0
unit 25    com='horizontal center gap poison 3x3'
cuboid    0   1 2p0.3175  2p0.3810      0.635     0.0
cuboid    8   1 2p23.6601 2p0.3810      0.635     0.0
unit 26    com='horizontal gap  3x3'
cuboid    0   1 2p23.6601 2p0.3810      0.635     0.0
```

```
unit 27    com='vertical center gap poison 3x3'
cuboid    0   1 2p0.3810  2p0.3175      0.635     0.0
cuboid    8   1 2p0.3810  2p23.6601     0.635     0.0
unit 28    com='vertical gap  3x3'
cuboid    0   1 2p0.3810  2p23.6601     0.635     0.0
unit 29    com='vertical bottom gap poison 2x2'
cuboid    0   1 2p0.3810  0.3175   0.0  0.635     0.0
cuboid    8   1 2p0.3810 15.41145  0.0  0.635     0.0
cuboid    0   1 2p0.3810 16.04645  0.0  0.635     0.0
cuboid    8   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 30   com='vertical gap  2x2'
cuboid    0   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 31   com='vertical top gap poison 2x2'
cuboid    8   1 2p0.3810 15.09395  0.0  0.635     0.0
cuboid    0   1 2p0.3810 15.72895  0.0  0.635     0.0
cuboid    8   1 2p0.3810 30.8229   0.0  0.635     0.0
cuboid    0   1 2p0.3810 31.1404   0.0  0.635     0.0
unit 32   com='Upper Right 2x2 w/poison'
array 2   -7.5946 -15.5702 0.0
unit 33   com='Upper Left 2x2 w/poison'
array 3   -7.5946 -15.5702 0.0
unit 34   com='Upper Right 2x2 w/poison'
array 4   -7.5946 -15.5702 0.0
unit 35   com='Uppwe Left 2x2 w/poison'
array 5   -7.5946 -15.5702 0.0
unit 36   com='3x3 with poison'
array 6   -7.6327 -23.6601 0.0
unit 37   com='3x3 with poison'
array 7   -7.6327 -23.6601 0.0
unit 38   com='3x3 with poison'
array 8   -7.6327 -23.6601 0.0
unit 39   com='3x3 with poison'
array 9   -7.6327 -23.6601 0.0
unit 40   com='3x3 with poison'
array 10  -7.6327 -23.6601 0.0
unit 41   com='Center 3x3 fuel with poison'
array 11 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635        0.0
unit 42   com='Right 3x3 fuel with poison'
array 12 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635        0.0
unit 43   com='Top 3x3 fuel with poison'
array 13 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635        0.0
unit 44   com='Left 3x3 fuel with poison'
array 14 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635        0.0
unit 45   com='Bottom 3x3 fuel with poison'
array 15 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635        0.0
unit 46   com='Upper Right 2x2 fuel with poison'
array 16 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635        0.0
unit 47   com='Upper Left 2x2 fuel with poison'
array 17 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635        0.0
unit 48   com='Lower Left 2x2 fuel with poison'
```

```
array 18 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 49   com='Lower Right 2x2 fuel with poison'
array 19 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 50   com='vertical poison between 3x3 compartments'
cuboid    8   1 2p0.3810  2p23.69185  0.635     0.0
cuboid    0   1 2p0.3810  2p23.8506    0.635     0.0
unit 51   com='vertical poison between 3x3 compartments, gap'
cuboid    0   1 2p0.3810  2p23.8506    0.635     0.0
unit 52   com='center horizontal strip of 3x3 arrays'
array 20 -72.3138 -23.8506 0.0
unit 53   com='center horizontal strip of poison'
cuboid    8   1 2p56.2102 2p0.3810    0.635     0.0
unit 54   com='center horizontal strip of poison, gap'
cuboid    0   1 2p56.2102 2p0.3810    0.635     0.0
unit 55   com='top vertical strip of poison'
cuboid    8   1 2p0.3810  15.7607 -15.4432 0.635     0.0
cuboid    0   1 2p0.3810 2p15.7607 0.635     0.0
unit 56   com='top vertical strip of poison gap'
cuboid    0   1 2p0.3810 2p15.7607 0.635     0.0
unit 57   com='top vertical strip of poison'
cuboid    8   1 2p0.3810  15.4432 -15.7607 0.635     0.0
cuboid    0   1 2p0.3810 2p15.7607 0.635     0.0
unit 58   com='poison everywhere'
cylinder  3   1  84.1375      0.635         0.0
    hole 52   0.0       0.0     0.0
    hole 53   0.0      24.2316  0.0
    hole 53   0.0     -24.2316  0.0
    hole 43   0.0      48.4633  0.0
    hole 45   0.0     -48.4633  0.0
    hole 55  24.2316  40.3734  0.0
    hole 55 -24.2316  40.3734  0.0
    hole 57  24.2316 -40.3734  0.0
    hole 57 -24.2316 -40.3734  0.0
    hole 46  40.3734  40.3734  0.0
    hole 47 -40.3734  40.3734  0.0
    hole 48 -40.3734 -40.3734  0.0
    hole 49  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 59   com='poison inside, gap outside'
cylinder  3   1  84.1375      0.635         0.0
    hole 60   0.0       0.0     0.0
    hole 54   0.0      24.2316  0.0
    hole 54   0.0     -24.2316  0.0
    hole 43   0.0      48.4633  0.0
    hole 45   0.0     -48.4633  0.0
    hole 56  24.2316  40.3734  0.0
    hole 56 -24.2316  40.3734  0.0
    hole 56  24.2316 -40.3734  0.0
    hole 56 -24.2316 -40.3734  0.0
    hole 46  40.3734  40.3734  0.0
```

```
    hole 47 -40.3734  40.3734  0.0
    hole 48 -40.3734 -40.3734  0.0
    hole 49  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 60   com='center horizontal strip of 3x3 arrays with gap'
array 22 -72.3138 -23.8506 0.0
unit 61   com='Upper Right 2x2 w/o poison'
array 23  -7.5946 -15.5702 0.0
unit 62   com='Upper Left 2x2 w/o poison'
array 24  -7.5946 -15.5702 0.0
unit 63   com='Upper Right 2x2 w/o poison'
array 25  -7.5946 -15.5702 0.0
unit 64   com='Uppwe Left 2x2 w/o poison'
array 26  -7.5946 -15.5702 0.0
unit 65   com='3x3 with out poison'
array 27  -7.6327 -23.6601 0.0
unit 66   com='3x3 with out poison'
array 28  -7.6327 -23.6601 0.0
unit 67   com='3x3 with out poison'
array 29  -7.6327 -23.6601 0.0
unit 68   com='3x3 with out poison'
array 30  -7.6327 -23.6601 0.0
unit 69   com='3x3 with out poison'
array 31  -7.6327 -23.6601 0.0
unit 70   com='Center 3x3 fuel with out poison'
array 32 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 71   com='Right 3x3 fuel with out poison'
array 33 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 72   com='Top 3x3 fuel with out poison'
array 34 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 73   com='Left 3x3 fuel with out poison'
array 35 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 74   com='Bottom 3x3 fuel with out poison'
array 36 -23.6601 -23.6601 0.0
cuboid    5   1 4p23.8506      0.635         0.0
unit 75   com='Upper Right 2x2 fuel with out poison'
array 37 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 76   com='Upper Left 2x2 fuel with out poison'
array 38 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 77   com='Lower Left 2x2 fuel with out poison'
array 39 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 78   com='Lower Right 2x2 fuel with out poison'
array 40 -15.5702 -15.5702 0.0
cuboid    5   1 4p15.7607     0.635         0.0
unit 79   com='gap inside, gap outside'
```

```
cylinder  3   1  84.1375      0.635         0.0
    hole 80   0.0       0.0     0.0
    hole 54   0.0      24.2316  0.0
    hole 54   0.0     -24.2316  0.0
    hole 72   0.0      48.4633  0.0
    hole 74   0.0     -48.4633  0.0
    hole 56  24.2316  40.3734  0.0
    hole 56 -24.2316  40.3734  0.0
    hole 56  24.2316 -40.3734  0.0
    hole 56 -24.2316 -40.3734  0.0
    hole 75  40.3734  40.3734  0.0
    hole 76 -40.3734  40.3734  0.0
    hole 77 -40.3734 -40.3734  0.0
    hole 78  40.3734 -40.3734  0.0
cylinder  5   1  85.4075      0.635         0.0
cylinder  3   1  86.36        0.635         0.0
cylinder  5   1  89.535       0.635         0.0
cylinder  9   1  97.79        0.635         0.0
cylinder  5   1 104.14        0.635         0.0
cuboid    7   1 4p104.15      0.635         0.0
unit 80   com='center horizontal strip of 3x3 arrays with all gaps'
array 41 -72.3138 -23.8506 0.0
unit 81  com='water hole'
cuboid    3  1  4P0.6477      0.635         0.0
global unit 82
array 21 -85.41   -85.41  0.0
end geom
read array
   com='GE 10x10 fuel assembly slice, sd, fuel regions'
   ara=1      nux=10     nuy=10     nuz=1
   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 81 81  1  1  1  1  1
        1  1  1 81 81  1  1  1  1  1
        1  1  1  1  1 81 81  1  1  1
        1  1  1  1  1 81 81  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
   com='Upper Right 2x2 Array of Fuel w/poison'
   ara=2      nux=1      nuy=3      nuz=1
   fill
        11
        19
        11
   end fill
   com='Upper Left 2x2 Array of Fuel w/poison'
   ara=3      nux=1      nuy=3      nuz=1
   fill
        12
        21
        12
   end fill
   com='Lower Left 2x2 Array of Fuel w/poison'
```

```
ara=4       nux=1       nuy=3       nuz=1
fill
     13
     21
     13
end fill
com='Lower Left 2x2 Array of Fuel w/poison'
ara=5       nux=1       nuy=3       nuz=1
fill
     14
     19
     14
end fill
com='3x3 Array of Fuel w/poison'
ara=6       nux=1       nuy=5       nuz=1
fill
      9
     18
      4
     18
      8
end fill
com='3x3 Array of Fuel w/poison'
ara=7       nux=1       nuy=5       nuz=1
fill
      6
     17
      2
     17
      5
end fill
com='3x3 Array of Fuel w/poison'
ara=8       nux=1       nuy=5       nuz=1
fill
     10
     15
      3
     15
      7
end fill
com='3x3 Array of Fuel w/poison'
ara=9       nux=5       nuy=1       nuz=1
fill
      9  22   6  22  10
end fill
com='3x3 Array of Fuel w/poison'
ara=10      nux=5       nuy=1       nuz=1
fill
      8  24   5  24   7
end fill
com='Center 3x3 Array of Fuel w/poison'
ara=11      nux=5       nuy=1       nuz=1
fill
     36  27  37  27  38
end fill
com='Right 3x3 Array of Fuel w/poison'
ara=12      nux=5       nuy=1       nuz=1
```

```
fill
     38  27  38  27  38
end fill
com='Top 3x3 Array of Fuel w/poison'
ara=13     nux=1      nuy=5      nuz=1
fill
     40
     25
     40
     25
     40
end fill
com='Left 3x3 Array of Fuel w/poison'
ara=14     nux=5      nuy=1      nuz=1
fill
     36  27  36  27  36
end fill
com='Bottom 3x3 Array of Fuel w/poison'
ara=15     nux=1      nuy=5      nuz=1
fill
     39
     25
     39
     25
     39
end fill
com='Upper Right 2x2 Array of Fuel w/poison'
ara=16     nux=3      nuy=1      nuz=1
fill
     32  29  32
end fill
com='Upper Left 2x2 Array of Fuel w/poison'
ara=17     nux=3      nuy=1      nuz=1
fill
     33  29  33
end fill
com='Lower Left 2x2 Array of Fuel w/poison'
ara=18     nux=3      nuy=1      nuz=1
fill
     34  31  34
end fill
com='Lower Right 2x2 Array of Fuel w/poison'
ara=19     nux=3      nuy=1      nuz=1
fill
     35  31  35
end fill
com='Center row of 3x3 arrays of Fuel w/poison'
ara=20    nux=5      nuy=1      nuz=1
fill
     44  50  41  50  42
end fill
com='Axail Cask'
ara=21    nux=1      nuy=1      nuz=576
fill
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     59
```

```
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     59
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
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     59
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
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     59
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     79 79 79
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
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     59
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     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     59
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58 58
     59
end fill
com='Center row of 3x3 arrays of Fuel w/poison'
ara=22   nux=5     nuy=1     nuz=1
fill
     44  51  41  51  42
end fill
com='Upper Right 2x2 Array of Fuel w/o poison'
ara=23    nux=1     nuy=3     nuz=1
fill
     11
     20
     11
end fill
com='Upper Left 2x2 Array of Fuel w/o poison'
ara=24    nux=1     nuy=3     nuz=1
fill
     12
     20
```

```
     12
end fill
com='Lower Left 2x2 Array of Fuel w/o poison'
ara=25     nux=1      nuy=3      nuz=1
fill
     13
     20
     13
end fill
com='Lower Left 2x2 Array of Fuel w/o poison'
ara=26     nux=1      nuy=3      nuz=1
fill
     14
     20
     14
end fill
com='3x3 Array of Fuel w/o poison'
ara=27     nux=1      nuy=5      nuz=1
fill
      9
     16
      4
     16
      8
end fill
com='3x3 Array of Fuel w/o poison'
ara=28     nux=1      nuy=5      nuz=1
fill
      6
     16
      2
     16
      5
end fill
com='3x3 Array of Fuel w/o poison'
ara=29     nux=1      nuy=5      nuz=1
fill
     10
     16
      3
     16
      7
end fill
com='3x3 Array of Fuel w/o poison'
ara=30     nux=5      nuy=1      nuz=1
fill
      9  23   6  23  10
end fill
com='3x3 Array of Fuel w/o poison'
ara=31     nux=5      nuy=1      nuz=1
fill
      8  23   5  23   7
end fill
com='Center 3x3 Array of Fuel w/o poison'
ara=32     nux=5      nuy=1      nuz=1
fill
     65  28  66  28  67
```

```
      end fill
      com='Right 3x3 Array of Fuel w/o poison'
      ara=33     nux=5      nuy=1      nuz=1
      fill
           67  28  67  28  67
      end fill
      com='Top 3x3 Array of Fuel w/o poison'
      ara=34     nux=1      nuy=5      nuz=1
      fill
           69
           26
           69
           26
           69
      end fill
      com='Left 3x3 Array of Fuel w/o poison'
      ara=35     nux=5      nuy=1      nuz=1
      fill
           65  28  65  28  65
      end fill
      com='Bottom 3x3 Array of Fuel w/o poison'
      ara=36     nux=1      nuy=5      nuz=1
      fill
           68
           26
           68
           26
           68
      end fill
      com='Upper Right 2x2 Array of Fuel w/o poison'
      ara=37     nux=3      nuy=1      nuz=1
      fill
           61  30  61
      end fill
      com='Upper Left 2x2 Array of Fuel w/o poison'
      ara=38     nux=3      nuy=1      nuz=1
      fill
           62  30  62
      end fill
      com='Lower Left 2x2 Array of Fuel w/o poison'
      ara=39     nux=3      nuy=1      nuz=1
      fill
           63  30  63
      end fill
      com='Lower Right 2x2 Array of Fuel w/o poison'
      ara=40     nux=3      nuy=1      nuz=1
      fill
           64  30  64
      end fill
      com='Center row of 3x3 arrays of Fuel w/o poison'
      ara=41    nux=5      nuy=1      nuz=1
      fill
           73  51  70  51  71
      end fill
   end array
   read bounds
      xyf=specular
```

```
   zfc=specular
end bounds
read plot
   ttl='cask material plot  - plan view all poison'
   pic=mat
   nch=' fzmcsblxg'
   xul=-105  yul=105   zul=20
   xlr=105   ylr=-105  zlr=20
   uax=1.0    vdn=-1.0
   nax=650
end plot
end data
end
```

Table K.6-1
Minimum B10 Content in the Neutron Poison Plates

Maximum Lattice Average Enrichment (wt% U-235)	Minimum B10 Content Boral® or Metamic® (g/cm^2)	Minimum B10 Content Boron-Aluminum Alloy or Boralyn® (g/cm^2)	B10 Content Used in Criticality Evaluation(1) (g/cm^2)
3.7	0.025	0.021	0.019
4.1	0.038	0.032	0.029
4.4	0.048	0.040	0.036
For Failed Fuel			
4.0(2)	0.048	0.040	0.036

(1) 90% B10 credit for Boron-Aluminum alloy or Boralyn®. 75% B10 credit for Boral® or Metamic®.

(2) Maximum Peak Pellet Enrichment 4.4 wt% U-235.

Table K.6-2
Authorized Contents for NUHOMS®-61BT System

Assembly Type (1)	Array
Intact Fuel	
General Electric 7x7 /GE2	7x7
General Electric 7x7 /GE3	7x7
General Electric 8x8 /GE4	8x8
General Electric 8x8 /GE5	8x8
General Electric 8x8 /GE-Pres	8x8
General Electric 8x8 /GE-Barrier	8x8
General Electric 8x8 /GE8 Type I	8x8
General Electric 8x8 /GE8 Type II	8x8
General Electric 8x8 /GE9	8x8
General Electric 8x8 /GE10	8x8
General Electric 9x9 /GE11	9x9
General Electric 9x9 /GE13	9x9
General Electric 10x10 /GE12	10x10
Damaged Fuel with up to 7 damaged rods per assembly	
General Electric 7x7 /GE2	7x7
General Electric 7x7 /GE3	7x7
General Electric 8x8 /GE4	8x8
General Electric 8x8 /GE5	8x8
General Electric 8x8 /GE-Pres	8x8
General Electric 8x8 /GE-Barrier	8x8
General Electric 8x8 /GE8 Type I	8x8
General Electric 8x8 /GE8 Type II	8x8
General Electric 8x8 /GE9	8x8
General Electric 8x8 /GE10	8x8

(1) Reload fuel from other manufactures with the same parameters as thos listed in Table K.6-3 are also considered as authorized contents.

Table K.6-3
Parameters for BWR Assemblies

Manufacturer[(1)]	Array	Version	Active Fuel Length (in)	Number Fuel Rods per Assembly	Pitch (in)	Fuel Pellet OD (in)
GE	7x7	GE2	144	49	0.738	0.487
GE	7x7	GE3	144	49	0.738	0.487
GE	8x8	GE4	146	63	0.640	0.416
GE	8x8	GE5	150	62	0.640	0.410
GE	8x8	GE-Pres	150	62	0.640	0.410
GE	8x8	GE-Barrier	150	62	0.640	0.410
GE	8x8	GE8 Type I	150	62	0.640	0.410
GE	8x8	GE8 Type II	150	60	0.640	0.410
GE	8x8	GE9	150	60	0.640	0.411
GE	8x8	GE10	150	60	0.640	0.411
GE	9x9	GE11	146-Full 90-Partial	66-Full 8-Partial	0.566	0.376
GE	9x9	GE13	146-Full 90-Partial	66-Full 8-Partial	0.566	0.376
GE	10x10	GE12	150-Full 93-Partial	78-Full 14-Partial	0.510	0.345

Manufacturer [(1)]	Array	Version	Clad Thickness (in)	Clad OD (in)	Water Rod OD (in)	Water Rod ID (in)
GE	7x7	GE2	0.032	0.563	NA	NA
GE	7x7	GE3	0.032	0.563	NA	NA
GE	8x8	GE4	0.034	0.493	0.591	0.531
GE	8x8	GE5	0.032	0.483	0.591	0.531
GE	8x8	GE-Pres	0.032	0.483	0.591	0.531
GE	8x8	GE-Barrier	0.032	0.483	0.591	0.531
GE	8x8	GE8 Type I	0.032	0.483	0.591	0.531
GE	8x8	GE8 Type II	0.032	0.483	2@0.591 2@0.483	2@0.531 2@0.419
GE	8x8	GE9	0.032	0.483	1.34	1.26
GE	8x8	GE10	0.032	0.483	1.34	1.26
GE	9x9	GE11	0.028	0.440	0.98	0.92
GE	9x9	GE13	0.028	0.440	0.98	0.92
GE	10x10	GE12	0.026	0.404	0.98	0.92

(1) Reload fuel from other manufacturers with these parameters are also acceptable.

Table K.6-4
Axial Layout of the KENO V.a Model of Cask and DSC

Number of Times Unit is Repeated	Unit Number	Description (Reflective Boundary Conditions on All Sides)
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
3	79	0.75 inches of Fuel w/out poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
1	59	0.25 inches of Fuel w/poison in the compartments but no poison between the compartments
40	58	10 Inches of Fuel w/ poison in the compartments and between the compartments
365.76	Total Length of Model, cm	
144	Total Length of Model, cm	

Table K.6-5
Material Property Data

Material	Density g/cm³	Element	Weight %	Atom Density (atoms/b-cm)
UO_2 (Enrichment - 4.4 wt%)	10.41	U-235	3.88	1.0347E-03
		U-238	84.26	2.2197E-02
		O	11.86	4.6464E-02
UO_2 (Enrichment - 4.1 wt%)	10.41	U-235	3.61	9.6415E-04
		U-238	84.53	2.2267E-02
		O	11.86	4.6462E-02
UO_2 (Enrichment - 3.7 wt%)	10.41	U-235	3.26	8.7010E-04
		U-238	84.88	2.2360E-02
		O	11.86	4.6460E-02
Zircaloy-2	6.56	Zr	98.250	4.2550E-02
		Sn	1.450	4.8254E-04
		Fe	0.135	9.5501E-05
		Cr	0.100	7.5978E-05
		Ni	0.055	3.7023E-05
		Hf	0.010	2.2133E-06
Water	0.9982	H	11.1	6.6769E-02
		O	88.9	3.3385E-02
Carbon Steel	7.8212	Fe	99	8.3498E-02
		C	1	3.9250E-03
Stainless Steel (SS304)	7.94	C	0.080	3.1877E-04
		Si	1.000	1.7025E-03
		P	0.045	6.9468E-05
		Cr	19.000	1.7473E-02
		Mn	2.000	1.7407E-03
		Fe	68.375	5.8545E-02
		Ni	9.500	7.7402E-03
Lead	11.344	Pb	100.000	3.2969E-02
Aluminum - Boron Poison Plate (0.040 g/cm² B-10)	2.479	B-10	1.906	2.8412E-03
		Al	98.094	5.4276E-02
Aluminum - Boron Poison Plate (0.032 g/cm² B-10)	2.470	B-10	1.531	2.2734E-03
		Al	98.469	5.4276E-02
Aluminum - Boron Poison Plate (0.021 g/cm² B-10)	2.457	B-10	1.010	1.4916E-03
		Al	98.990	5.4276E-02

Table K.6-6
Most Reactive Fuel Type

Manufacturer	Array	Version	k_{KENO}	1σ	k_{eff}
GE	7x7	GE2, GE3	0.9037	0.0012	0.9061
GE	7x7 0.120 channel	GE2, GE3	0.9033	0.0015	0.9063
GE	7x7 0.080 channel	GE2, GE3	0.9028	0.0012	0.9052
GE	7x7 0.065 channel	GE2, GE3	0.9043	0.0013	0.9069
GE	8x8	GE4	0.8951	0.0013	0.8977
GE	8x8 0.120 channel	GE4	0.8927	0.0013	0.8953
GE	8x8 0.080 channel	GE4	0.8930	0.0013	0.8956
GE	8x8 0.065 channel	GE4	0.8940	0.0012	0.8964
GE	8x8	GE5 GE-Pres GE-Barrier GE8 Type I GE8 Type II	0.9009	0.0011	0.9031
GE	8x8 0.120 channel	GE5	0.9015	0.0012	0.9039
GE	8x8 0.080 channel	GE5	0.9027	0.0013	0.9053
GE	8x8 0.065 channel	GE5	0.9012	0.0011	0.9034
GE	8x8	GE8 Type II	0.9020	0.0012	0.9044
GE	8x8 0.120 channel	GE8 Type II	0.9054	0.0014	0.9082
GE	8x8 0.080 channel	GE8 Type II	0.9043	0.0014	0.9071
GE	8x8 0.065 channel	GE8 Type II	0.9023	0.0013	0.9049
GE	8x8	GE9, GE10	0.9043	0.0013	0.9069
GE	8x8 0.120 channel	GE9, GE10	0.9062	0.0013	0.9088
GE	8x8 0.080 channel	GE9, GE10	0.9054	0.0011	0.9076
GE	8x8 0.065 channel	GE9, GE10	0.9052	0.0014	0.9080
GE	9x9	GE11, GE13	0.9042	0.0014	0.9070
GE	9x9 0.120 channel	GE11, GE13	0.9025	0.0014	0.9053
GE	9x9 0.080 channel	GE11, GE13	0.9066	0.0012	0.9090
GE	9x9 0.065 channel	GE11, GE13	0.9040	0.0013	0.9066
GE	10x10	GE12	0.9095	0.0013	0.9121
GE	10x10 0.120 channel	GE12	0.9094	0.0010	0.9114
GE	10x10 0.080 channel	GE12	0.9092	0.0013	0.9118
GE	10x10 0.065 channel	GE12	0.9076	0.0011	0.9098
GE	7x7 w/variable enrichment	GE2, GE3	0.8947	0.0012	0.8971
GE	8x8 w/variable enrichment	GE5	0.8951	0.0011	0.8973
GE	8x8 w/variable enrichment	GE9	0.9008	0.0013	0.9034

Table K.6-7
Most Reactive Configuration – Intact Fuel

Model Description	k_{KENO}	1σ	k_{eff}
Assembly-to-Assembly Pitch Evaluation			
Maximum Assembly-to-Assembly Pitch	0.8710	0.0013	0.8736
Assemblies Centered in Sleeves	0.9110	0.0012	0.9134
Minimum Assembly-to-Assembly Pitch	0.9110	0.0014	0.9138
Canister Shell Variation Evaluation			
Minimum Shell Thickness	0.9125	0.0012	0.9149
Nominal Shell Thickness	0.9110	0.0014	0.9138
Maximum Shell Thickness	0.9141	0.0011	0.9163
Poison Thickness Evaluation			
Nominal PoisonThickness (0.31 inches)	0.9110	0.0014	0.9138
Minimum Poison Thickness (0.3 inches)	0.9163	0.0012	0.9187
Fuel Cladding O.D. Evaluation			
Fuel Clad OD = 0.404 inches	0.9163	0.0012	0.9187
Fuel Clad OD = 0.402 inches	0.9157	0.0010	0.9177
Fuel Cald OD = 0.400 inches	0.9183	0.0011	0.9205
Fuel Clad OD = 0.398 inches	0.9201	0.0013	0.9227
Fuel Clad OD = 0.396 inches	0.9222	0.0012	0.9246
Fuel Clad OD = 0.394 inches	0.9229	0.0012	0.9253
Fuel Cell Width Evaluation			
Maximum Fuel Cell Width	0.9194	0.0011	0.9216
Nominal Fuel Cell Width	0.9229	0.0012	0.9253
Minimum Fuel Cell Width	0.9349	0.0011	0.9371
Minimum Fuel Cell Width with Maximum Shell Thickness	0.9326	0.0014	0.9354
Internal Moderator Density Evaluation			
Internal Moderator at 100% TD	0.9349	0.0011	0.9371
Internal Moderator at 90% TD	0.9079	0.0013	0.9105
Internal Moderator at 80% TD	0.8772	0.0013	0.8798
Internal Moderator at 70% TD	0.8401	0.0012	0.8425
Internal Moderator at 60% TD	0.7980	0.0010	0.8000
Internal Moderator at 50% TD	0.7466	0.0010	0.7486
Internal Moderator at 40% TD	0.6862	0.0010	0.6882
Internal Moderator at 30% TD	0.6236	0.0008	0.6252
Internal Moderator at 20% TD	0.5628	0.0010	0.5648
Internal Moderator at 10% TD	0.5078	0.0006	0.5090
Internal Moderator at 0% TD	0.4364	0.0004	0.4372
External Moderator Density Evaluation			
External Moderator at 100% TD	0.9349	0.0011	0.9371
External Moderator at 90% TD	0.9340	0.0011	0.9362
External Moderator at 80% TD	0.9324	0.0012	0.9348
External Moderator at 70% TD	0.9365	0.0011	0.9387
External Moderator at 60% TD	0.9363	0.0011	0.9385
External Moderator at 50% TD	0.9336	0.0011	0.9358
External Moderator at 40% TD	0.9345	0.0011	0.9367
External Moderator at 30% TD	0.9332	0.0013	0.9358
External Moderator at 20% TD	0.9332	0.0012	0.9356
External Moderator at 10% TD	0.9321	0.0013	0.9347
External Moderator at 0% TD	0.9321	0.0012	0.9345
Minimum Boron-10 Loading as a Function of Maximum Lattice Average Enrichment			
4.4 wt% U-235; 0.040 g/cm^2 B-10	0.9349	0.0011	0.9371
4.1 wt% U-235; 0.032 g/cm^2 B-10	0.9336	0.0011	0.9358
3.7 wt% U-235; 0.021 g/cm^2 B-10	0.9343	0.0013	0.9369

Table K.6-8
Most Reactive 7x7 Configuration – Damaged Fuel

Case #	Model Description	k_{KENO}	1σ	k_{eff}
Case 1	GE2 7x7 Infinite Long Model - Intact Fuel with 6x7 array of 4.0 % enriched rods and a single row (1x7) of 4.4%	0.8969	0.0012	0.8993
Case 2	Same as Case 1 except a Finite Model - Intact Fuel	0.8952	0.0011	0.8974
Case 3	Same as Case 2 except the high enriched row of seven rods moved up 12.75" above the top of the poison plates.	0.8965	0.0012	0.8989
Case 4	Same as Case 2 except a single row of fuel rods moves halfway between the rest of the fuel assembly and the edge of the fuel sleeve. - "single break"	0.8938	0.0013	0.8964
Case 5	Same as Case 4 except the high enriched row of seven rods moved up 12.5" above the top of the poison plates.	0.8956	0.0011	0.8978
Case 6	Same as Case 4 except a single row of fuel rods moves all the way to the edge of the fuel sleeve. - "single break"	0.8990	0.0014	0.9018
Case 7	Same as Case 6 except the high enriched row of seven rods moved up 12.5" above the top of the poison plates.	0.8994	0.0011	0.9016
Case 8	Same as Case 4 except an eigth row of fuel is added to the fuel sleeve - "double break"	0.8989	0.0010	0.9009
Case 9	Same as Case 8 except the high enriched row of seven rods moved up 12.5" above the top of the poison plates.	0.8988	0.0012	0.9012

Table K.6-9
Most Reactive 8x8 Configuration – Damaged Fuel

Case #	Model Description	k_{KENO}	1σ	k_{eff}
Case 10	GE9 8x8 Finite Model - Intact Fuel	0.8934	0.0011	0.8956
Case 11	Same as Case 10 except the high enriched row of seven rods moved up 12.75" above the top of the poison	0.8939	0.0012	0.8963
Case 12	Same as Case 10 except a single row of fuel rods moves halfway between the rest of the fuel assembly and the edge of the fuel sleeve. - "single break"	0.8962	0.0013	0.8988
Case 13	Same as Case 12 except the high enriched row of seven rods moved up 12.5" above the top of the poison plates.	0.8947	0.0013	0.8973
Case 14	Same as Case 12 except a single row of fuel rods moves all the way to the edge of the fuel sleeve. - "single break"	0.8964	0.0011	0.8986
Case 15	Same as Case 14 except the high enriched row of seven rods moved up 12.5" above the top of the poison plates.	0.8975	0.0011	0.8997
Case 16	Same as Case 12 except an eigth row of fuel is added to the fuel sleeve - "double break"	0.8979	0.0012	0.9003
Case 17	Same as Case 16 except the high enriched row of seven rods moved up 12.5" above the top of the poison plates.	0.9011	0.0012	0.9035

Table K.6-10
Criticality Results

Model Description	k_{KENO}	1σ	k_{eff}
Regulatory Requirements			
Dry Storage (Bounded by infinite array of undamaged casks)	0.4364	0.0004	0.4372
Normal Conditions (Wet Loading)	0.4364	0.0004	0.4372
Off-Normal Conditions (damaged transfer cask while fuel still wet)	0.9365	0.0011	0.9387
Minimum Boron-10 Loading as a Function of Maximum Lattice Average Enrichment			
4.4 wt% U-235; 0.040 g/cm^2 B-10	0.9349	0.0011	0.9371
4.1 wt% U-235; 0.032 g/cm^2 B-10	0.9336	0.0011	0.9358
3.7 wt% U-235; 0.021 g/cm^2 B-10	0.9343	0.0013	0.9369
Damaged Fuel with up to 7 damaged rods			
Maximum pellet enrichment of 4.4 wt% U-235; 0.040 g/cm^2 B-10	0.9011	0.0012	0.9035

Table K.6-11
Benchmarking Results

Run ID	U Enrich. Wt%	Pu Enrich. Wt%	Pitch (cm)	H_2O/fuel volume	Separation of assemblies (cm)	AEG	k_{eff}	1σ
B1645SO1	2.46		1.41	1.015		32.8194	0.9967	0.0009
B1645SO2	2.46		1.41	1.015		32.7584	1.0002	0.0011
BW1231B1	4.02		1.511	1.139		31.1427	0.9966	0.0012
BW1231B2	4.02		1.511	1.139		29.8854	0.9972	0.0009
BW1273M	2.46		1.511	1.376		32.2106	0.9965	0.0009
BW1484A1	2.46		1.636	1.841	1.636	34.5304	0.9962	0.0010
BW1484A2	2.46		1.636	1.841	4.908	35.1629	0.9931	0.0010
BW1484B1	2.46		1.636	1.841		33.9421	0.9979	0.0010
BW1484B2	2.46		1.636	1.841	1.636	34.5820	0.9955	0.0012
BW1484B3	2.46		1.636	1.841	4.908	35.2609	0.9969	0.0011
BW1484C1	2.46		1.636	1.841	1.636	34.6463	0.9931	0.0011
BW1484C2	2.46		1.636	1.841	4.908	35.2422	0.9939	0.0012
BW1484S1	2.46		1.636	1.841	1.636	34.5105	1.0001	0.0010
BW1484S2	2.46		1.636	1.841	1.636	34.5569	0.9992	0.0010
BW1484SL	2.46		1.636	1.841	6.544	35.4151	0.9935	0.0011
BW1645S1	2.46		1.209	0.383	1.778	30.1040	0.9990	0.0010
BW1645S2	2.46		1.209	0.383	1.778	29.9961	1.0037	0.0011
BW1810A	2.46		1.636	1.841		33.9465	0.9984	0.0008
BW1810B	2.46		1.636	1.841		33.9631	0.9984	0.0009
BW1810C	2.46		1.636	1.841		33.1569	0.9992	0.0010
BW1810D	2.46		1.636	1.841		33.0821	0.9985	0.0013
BW1810E	2.46		1.636	1.841		33.1600	0.9988	0.0009
BW1810F	2.46		1.636	1.841		33.9556	1.0031	0.0011
BW1810G	2.46		1.636	1.841		32.9409	0.9973	0.0011
BW1810H	2.46		1.636	1.841		32.9420	0.9972	0.0011
BW1810I	2.46		1.636	1.841		33.9655	1.0037	0.0009
BW1810J	2.46		1.636	1.841		33.1403	0.9983	0.0011
DSN399-1	4.74		1.6	3.807	1.8	33.9520	1.0036	0.0015
DSN399-2	4.74		1.6	3.807	5.8	34.4207	0.9989	0.0016
DSN399-3	4.74		1.6	3.807		35.3140	1.0024	0.0015
DSN399-4	4.74		1.6	3.807		35.3784	0.9977	0.0013
EPRU65	2.35		1.562	1.196		33.9106	0.9960	0.0011
EPRU65B	2.35		1.562	1.196		33.4013	0.9993	0.0012
EPRU75	2.35		1.905	2.408		35.8671	0.9958	0.0010
EPRU75B	2.35		1.905	2.408		35.3043	0.9996	0.0010
EPRU87	2.35		2.21	3.687		36.6129	1.0007	0.0011
EPRU87B	2.35		2.21	3.687		36.3499	1.0007	0.0011
NSE71SQ	4.74		1.26	1.823		33.7610	0.9979	0.0012
NSE71W1	4.74		1.26	1.823		34.0129	0.9988	0.0013
NSE71W2	4.74		1.26	1.823		36.3037	0.9957	0.0010
P2438BA	2.35		2.032	2.918	5.05	36.2277	0.9979	0.0013
P2438SLG	2.35		2.032	2.918	8.39	36.2889	0.9986	0.0012
P2438SS	2.35		2.032	2.918	6.88	36.2705	0.9974	0.0011
P2438ZR	2.35		2.032	2.918	8.79	36.2840	0.9987	0.0010
P2615BA	4.31		2.54	3.883	6.72	35.7286	1.0019	0.0014
P2615SS	4.31		2.54	3.883	8.58	35.7495	0.9952	0.0015
P2615ZR	4.31		2.54	3.883	10.92	35.7700	0.9977	0.0014
P2827L1	2.35		2.032	2.918	13.27	36.2526	1.0057	0.0011
P2827L2	2.35		2.032	2.918	11.25	36.2908	0.9999	0.0012

Table K.6-11
Benchmarking Results, continued

Run ID	U Enrich. Wt%	Pu Enrich. Wt%	Pitch (cm)	H_2O/fuel volume	Separation of assemblies (cm)	AEG	k_{eff}	1σ
P2827L3	4.31		2.54	3.883	20.78	35.6766	1.0092	0.0012
P2827L4	4.31		2.54	3.883	19.04	35.7131	1.0073	0.0012
P2827SLG	2.35		2.032	2.918	8.31	36.3037	0.9957	0.0010
P3314BA	4.31		1.892	1.6	2.83	33.1881	0.9988	0.0012
P3314BC	4.31		1.892	1.6	2.83	33.2284	0.9992	0.0012
P3314BF1	4.31		1.892	1.6	2.83	33.2505	1.0037	0.0013
P3314BF2	4.31		1.892	1.6	2.83	33.2184	1.0009	0.0013
P3314BS1	2.35		1.684	1.6	3.86	34.8594	0.9956	0.0013
P3314BS2	2.35		1.684	1.6	3.46	34.8356	0.9949	0.0010
P3314BS3	4.31		1.892	1.6	7.23	33.4247	0.9970	0.0013
P3314BS4	4.31		1.892	1.6	6.63	33.4162	0.9998	0.0012
P3314SLG	4.31		1.892	1.6	2.83	34.0198	0.9974	0.0012
P3314SS1	4.31		1.892	1.6	2.83	33.9601	0.9999	0.0012
P3314SS2	4.31		1.892	1.6	2.83	33.7755	1.0022	0.0012
P3314SS3	4.31		1.892	1.6	2.83	33.8904	0.9992	0.0013
P3314SS4	4.31		1.892	1.6	2.83	33.7625	0.9958	0.0011
P3314SS5	2.35		1.684	1.6	7.8	34.9531	0.9949	0.0013
P3314SS6	4.31		1.892	1.6	10.52	33.5333	1.0020	0.0011
P3314W1	4.31		1.892	1.6		34.3994	1.0024	0.0013
P3314W2	2.35		1.684	1.6		35.2167	0.9969	0.0011
P3314ZR	4.31		1.892	1.6	2.83	33.9954	0.9971	0.0013
P3602BB	4.31		1.892	1.6	8.3	33.3221	1.0029	0.0013
P3602BS1	2.35		1.684	1.6	4.8	34.7750	1.0027	0.0012
P3602BS2	4.31		1.892	1.6	9.83	33.3679	1.0039	0.0012
P3602N11	2.35		1.684	1.6	8.98	34.7438	1.0023	0.0012
P3602N12	2.35		1.684	1.6	9.58	34.8391	1.0030	0.0012
P3602N13	2.35		1.684	1.6	9.66	34.9337	1.0013	0.0012
P3602N14	2.35		1.684	1.6	8.54	35.0282	0.9974	0.0013
P3602N21	2.35		2.032	2.918	11.2	36.2821	0.9987	0.0011
P3602N22	2.35		2.032	2.918	10.36	36.1896	1.0025	0.0011
P3602N31	4.31		1.892	1.6	14.87	33.2094	1.0057	0.0013
P3602N32	4.31		1.892	1.6	15.74	33.3067	1.0093	0.0012
P3602N33	4.31		1.892	1.6	15.87	33.4174	1.0107	0.0012
P3602N34	4.31		1.892	1.6	15.84	33.4683	1.0045	0.0013
P3602N35	4.31		1.892	1.6	15.45	33.5185	1.0013	0.0012
P3602N36	4.31		1.892	1.6	13.82	33.5855	1.0004	0.0014
P3602N41	4.31		2.54	3.883	12.89	35.5276	1.0109	0.0013
P3602N42	4.31		2.54	3.883	14.12	35.6695	1.0071	0.0014
P3602N43	4.31		2.54	3.883	12.44	35.7542	1.0053	0.0015
P3602SS1	2.35		1.684	1.6	8.28	34.8701	1.0025	0.0013
P3602SS2	4.31		1.892	1.6	13.75	33.4202	1.0035	0.0012
P3926L1	2.35		1.684	1.6	10.06	34.8519	1.0000	0.0011
P3926L2	2.35		1.684	1.6	10.11	34.9324	1.0017	0.0011
P3926L3	2.35		1.684	1.6	8.5	35.0641	0.9949	0.0012
P3926L4	4.31		1.892	1.6	17.74	33.3243	1.0074	0.0014
P3926L5	4.31		1.892	1.6	18.18	33.4074	1.0057	0.0013
P3926L6	4.31		1.892	1.6	17.43	33.5246	1.0046	0.0013
P3926SL1	2.35		1.684	1.6	6.59	33.4737	0.9995	0.0012
P3926SL2	4.31		1.892	1.6	12.79	33.5776	1.0007	0.0012

Table K.6-11
Benchmarking Results, continued

Run ID	U Enrich. Wt%	Pu Enrich. Wt%	Pitch (cm)	H_2O/fuel volume	Separation of assemblies (cm)	AEG	k_{eff}	1σ
P4267B1	4.31		1.8901	1.59		31.8075	0.9990	0.0010
P4267B2	4.31		0.89	1.59		31.5323	1.0033	0.0010
P4267B3	4.31		1.715	1.09		30.9905	1.0050	0.0011
P4267B4	4.31		1.715	1.09		30.5061	0.9996	0.0011
P4267B5	4.31		1.715	1.09		30.1011	1.0004	0.0011
P4267SL1	4.31		1.89	1.59		33.4737	0.9995	0.0012
P4267SL2	4.31		1.715	1.09		31.9460	0.9988	0.0016
P62FT231	4.31		1.891	1.6	5.19	32.9196	1.0012	0.0013
P71F14F3	4.31		1.891	1.6	5.19	32.8237	1.0009	0.0014
P71F14V3	4.31		1.891	1.6	5.19	32.8597	0.9972	0.0014
P71F14V5	4.31		1.891	1.6	5.19	32.8609	0.9993	0.0013
P71F214R	4.31		1.891	1.6	5.19	32.8778	0.9969	0.0012
PAT80L1	4.74		1.6	3.807	4.9	35.0253	1.0012	0.0012
PAT80L2	4.74		1.6	3.807	4.9	35.1136	0.9993	0.0015
PAT80SS1	4.74		1.6	3.807	4.9	35.0045	0.9988	0.0013
PAT80SS2	4.74		1.6	3.807	4.9	35.1072	0.9960	0.0013
W3269A	5.7		1.422	1.93		33.1480	0.9988	0.0012
W3269B1	3.7		1.105	1.432		32.4055	0.9961	0.0011
W3269B2	3.7		1.105	1.432		32.3921	0.9963	0.0011
W3269B3	3.7		1.105	1.432		32.2363	0.9944	0.0011
W3269C	2.72		1.524	1.494		33.7727	0.9989	0.0012
W3269SL1	2.72		1.524	1.494		33.3850	0.9981	0.0014
W3269SL2	5.7		1.422	1.93		33.0910	1.0005	0.0013
W3269W1	2.72		1.524	1.494		33.5114	0.9966	0.0014
W3269W2	5.7		1.422	1.93		33.1680	1.0014	0.0014
W3385SL1	5.74		1.422	1.932		33.2387	1.0009	0.0012
W3385SL2	5.74		2.012	5.067		35.8818	0.9997	0.0013
EPRI70UN	0.71	2	1.778	1.2		31.6775	0.9983	0.0012
EPRI70B	0.71	2	1.778	1.2		30.9021	1.0009	0.0012
EPRI87UN	0.71	2	2.2098	2.53		33.3230	1.0096	0.0011
EPRI87B	0.71	2	2.2098	2.53		31.6775	0.9983	0.0012
EPRI99UN	0.71	2	2.5146	3.64		35.1817	1.0063	0.0011
EPRI99B	0.71	2	2.5146	3.64		34.4098	1.0095	0.0011
SAXTON52	0.71	6.6	1.3208	1.68		30.2980	1.0020	0.0014
SAXTON56	0.71	6.6	1.4224	2.16		31.4724	1.0010	0.0014
SAXTON56B	0.71	6.6	1.4224	2.16		31.0038	0.9994	0.0013
SAXTN735	0.71	6.6	1.8669	4.7		34.1848	1.0007	0.0016
SATN792	0.71	6.6	2.01168	5.67		34.6401	1.0026	0.0013
SAXTN104	0.71	6.6	2.6416	10.75		35.8333	1.0054	0.0014
Correlation	0.31	-0.26	0.43	0.25	0.65	-0.01	N/A	N/A

Table K.6-12
USL-1 Results

Parameter	Range of applicability	USL-1
U Enrichment (wt. % U-235)	2.4 2.8 3.3 3.8 – 5.7	0.9424 0.9430 0.9435 0.9438
Pu Enrichment (wt. % Pu)	2.0 – 6.6	0.9417
Fuel Rod Pitch (cm)	0.89 1.1 1.4 1.6 1.9 – 2.6	0.9396 0.9408 0.9421 0.9433 0.9439
Water/Fuel Volume Ratio	0.38 1.9 3.3 – 11	0.9414 0.9425 0.9426
Assembly Separation (cm)	1.6 4.4 7.1 9.8 – 21	0.9410 0.9425 0.9440 0.9441
Average Energy Group Causing Fission (AEG)	30 – 37	0.9433

Table K.6-13
USL Determination for Criticality Analysis

Parameter	Value from Limiting Analysis	Bounding USL-1
U Enrichment (wt% U-235)	3.7 - 4.4	0.9438
Fuel Rod Pitch (cm)	1.875	0.9433
Water/Fuel Ratio	1.6	**0.9414**
Assembly Separation (cm)	16.56	0.9441
Average Energy Group Causing Fission (AEG)	~33	0.9433

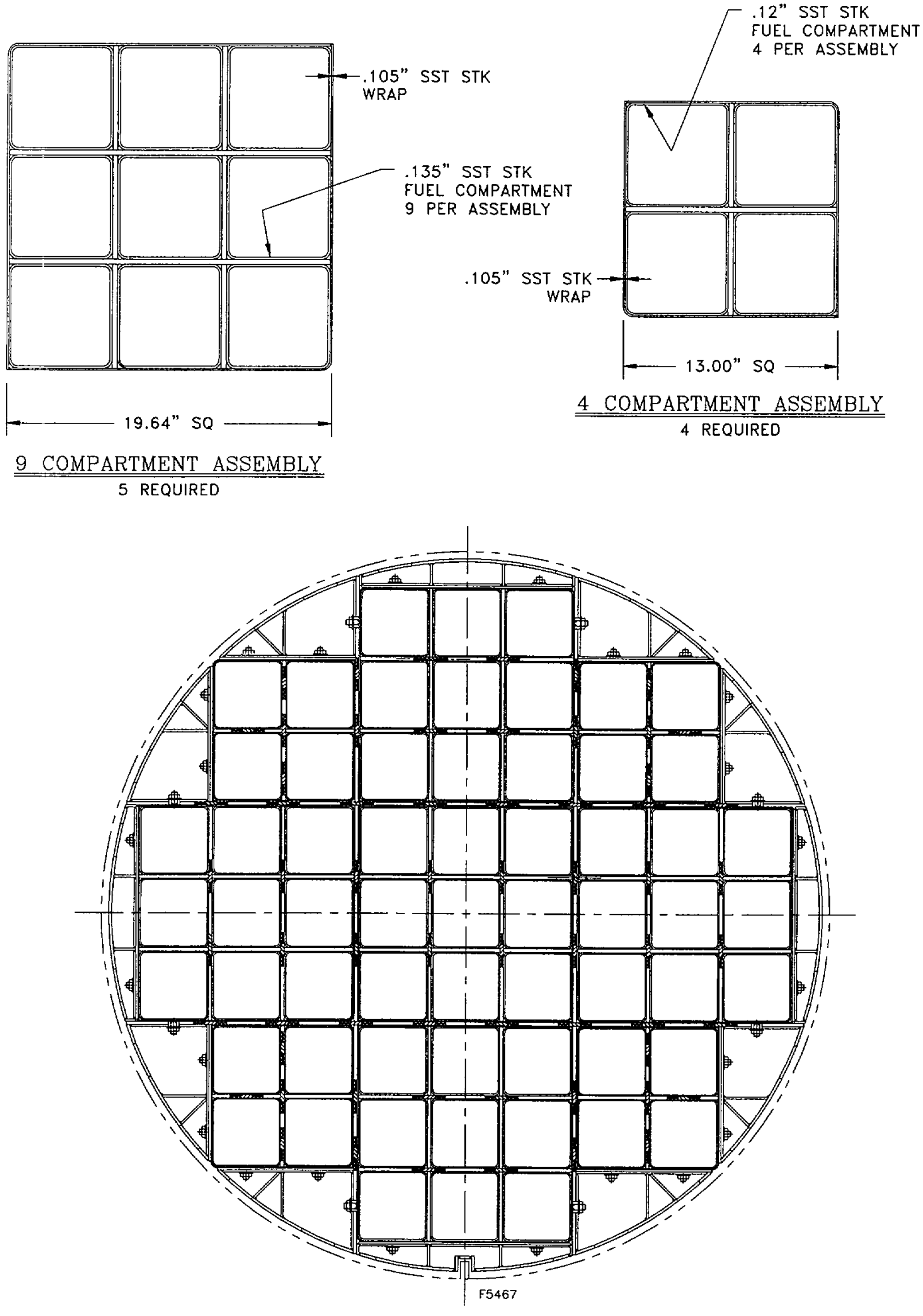
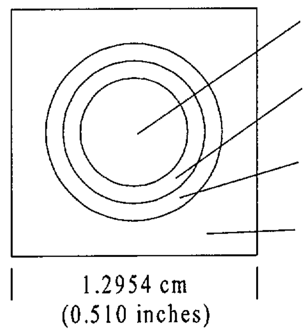
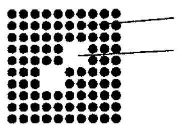


Figure K.6-1
NUHOMS®-61BT DSC Axial Cross Section

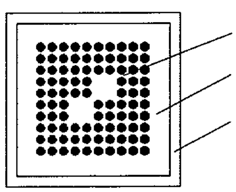
Unit 1 GE 10x10 Fuel Rod



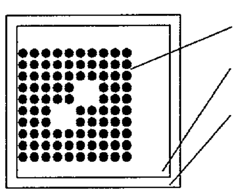
Array 1 GE 10x10 Fuel Assembly made up by a 10x10 array of Units 1 (fuel) and 81 (Water Holes)



Unit 2 GE 10x10 Fuel Assembly Centered in a Fuel Compartment for a 3x3 Compartment



Unit 3 GE 10x10 Fuel Assembly Shifted to the Left in a Fuel Compartment for a 3x3 Compartment



Unit 4 GE 10x10 Fuel Assembly Shifted to the Right in a Fuel Compartment for a 3x3 Compartment

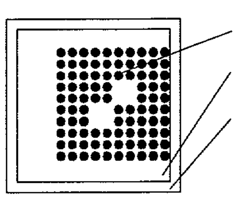
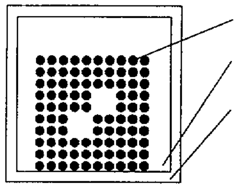


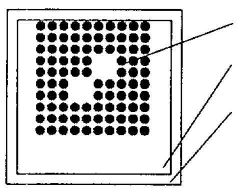
Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model

PART 1 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

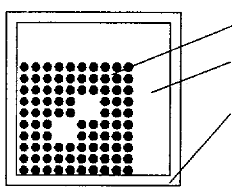
Unit 5 GE 10x10 Fuel Assembly Shifted Down in a Fuel Compartment for a 3x3 Compartment



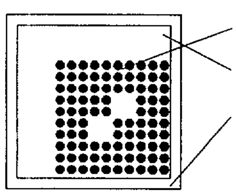
Unit 6 GE 10x10 Fuel Assembly Shifted Up in a Fuel Compartment for a 3x3 Compartment



Unit 7 GE 10x10 Fuel Assembly Shifted to the Lower Left in a Fuel Compartment for a 3x3 Compartment



Unit 8 GE 10x10 Fuel Assembly Shifted to the Lower Right in a Fuel Compartment for a 3x3 Compartment



Unit 9 GE 10x10 Fuel Assembly Shifted to the Upper Right in a Fuel Compartment for a 3x3 Compartment

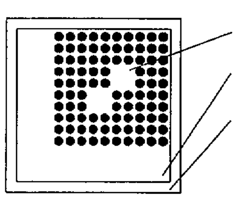
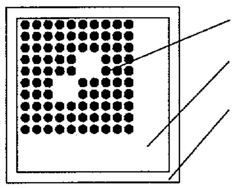
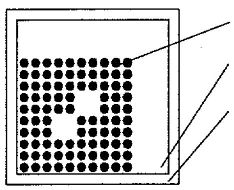


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 2 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

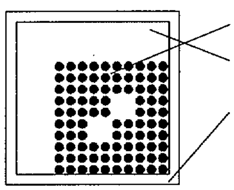
Unit 10 GE 10x10 Fuel Assembly Shifted to the Upper Left in a Fuel Compartment for a 3x3 Compartment



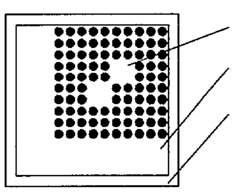
Unit 11 GE 10x10 Fuel Assembly Shifted to the Lower Left in a Fuel Compartment for a 2x2 Compartment



Unit 12 GE 10x10 Fuel Assembly Shifted to the Lower Right in a Fuel Compartment for a 2x2 Compartment



Unit 13 GE 10x10 Fuel Assembly Shifted to the Upper Right in a Fuel Compartment for a 2x2 Compartment



Unit 14 GE 10x10 Fuel Assembly Shifted to the Upper Left in a Fuel Compartment for a 2x2 Compartment

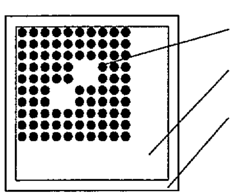


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 3 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

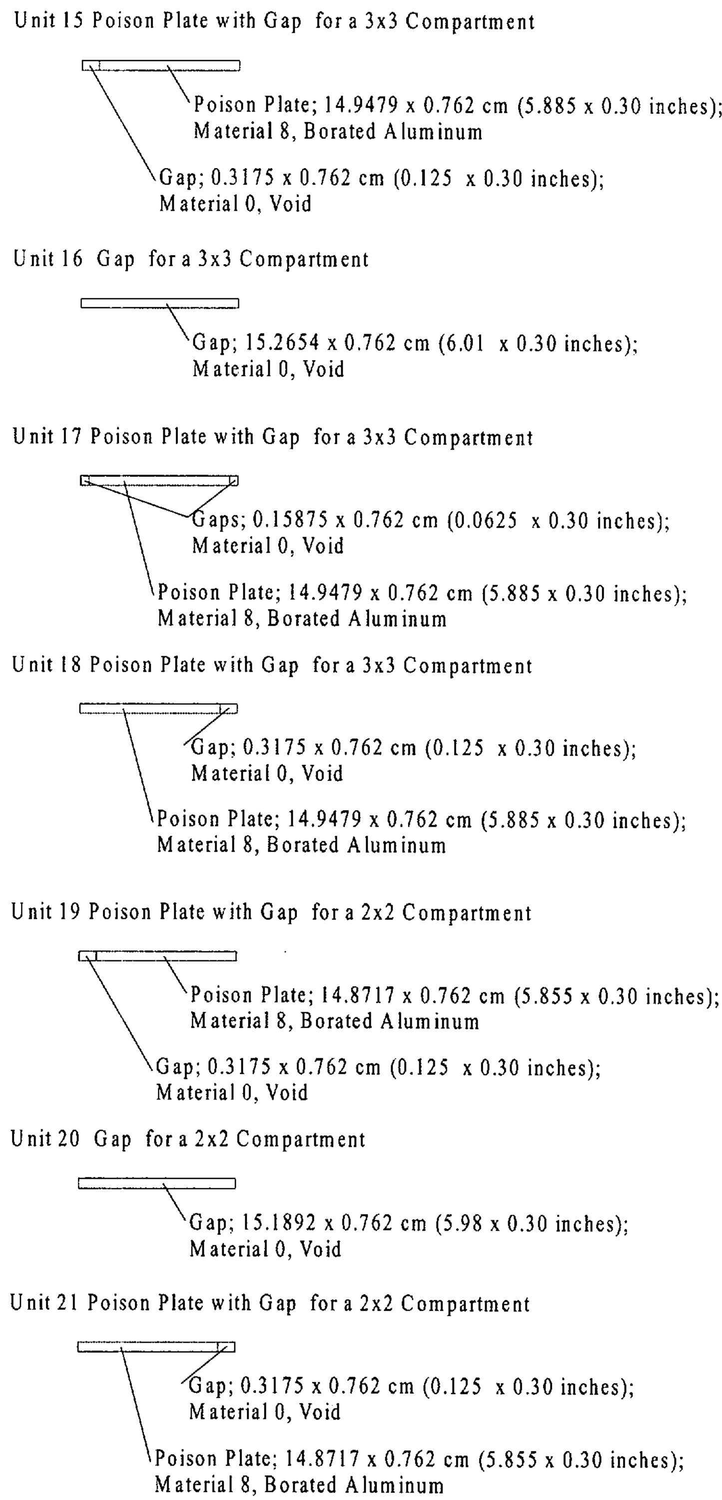
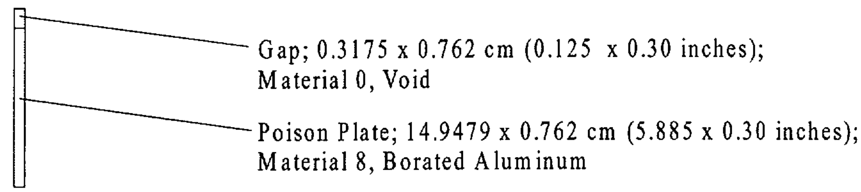
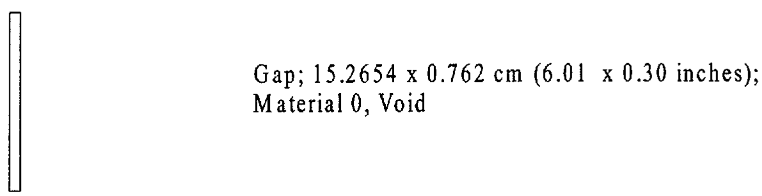


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 4 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

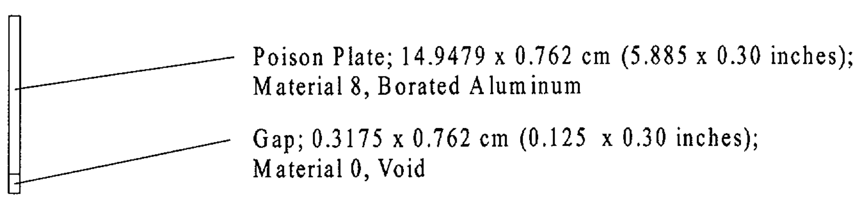
Unit 22 Poison Plate with Gap for a 3x3 Compartment



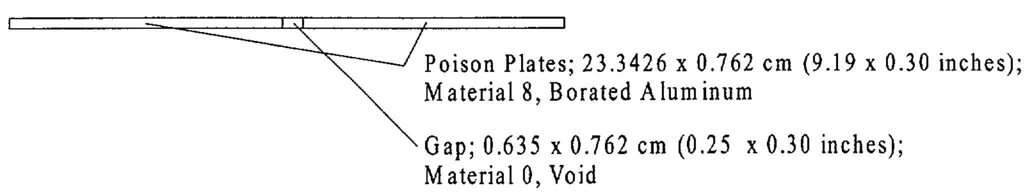
Unit 23 Gap for a 3x3 Compartment



Unit 24 Poison Plate with Gap for a 3x3 Compartment



Unit 25 Poison Plates with Gap for a 3x3 Compartment



Unit 26 Long Gap for a 3x3 Compartment

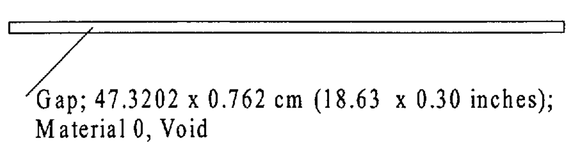
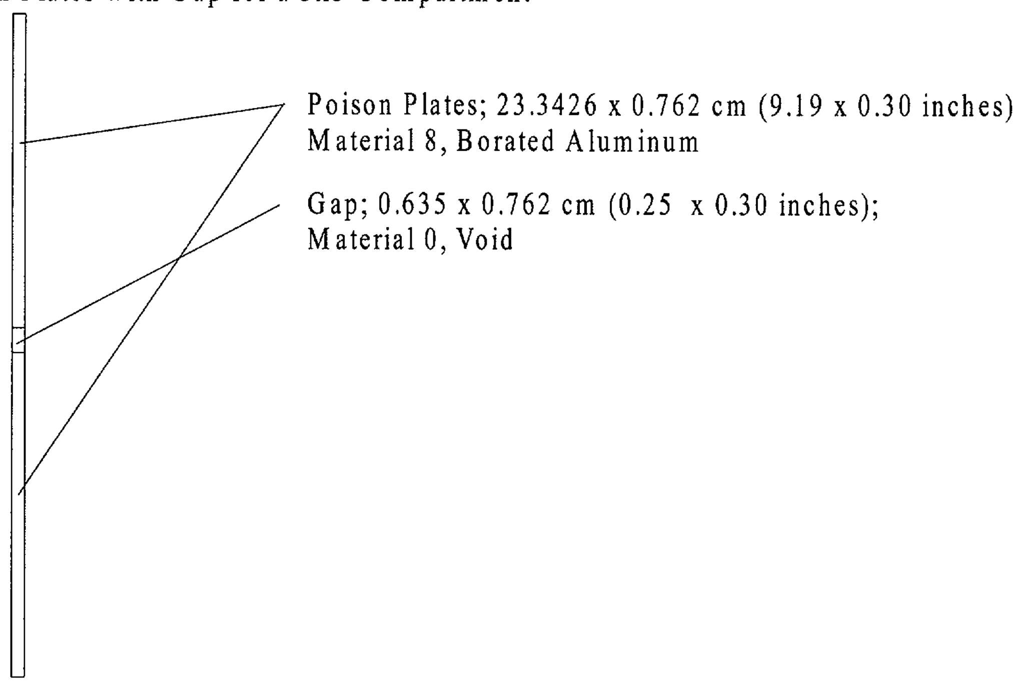


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 5 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 27 Poison Plates with Gap for a 3x3 Compartment



Unit 28 Long Gap for a 3x3 Compartment

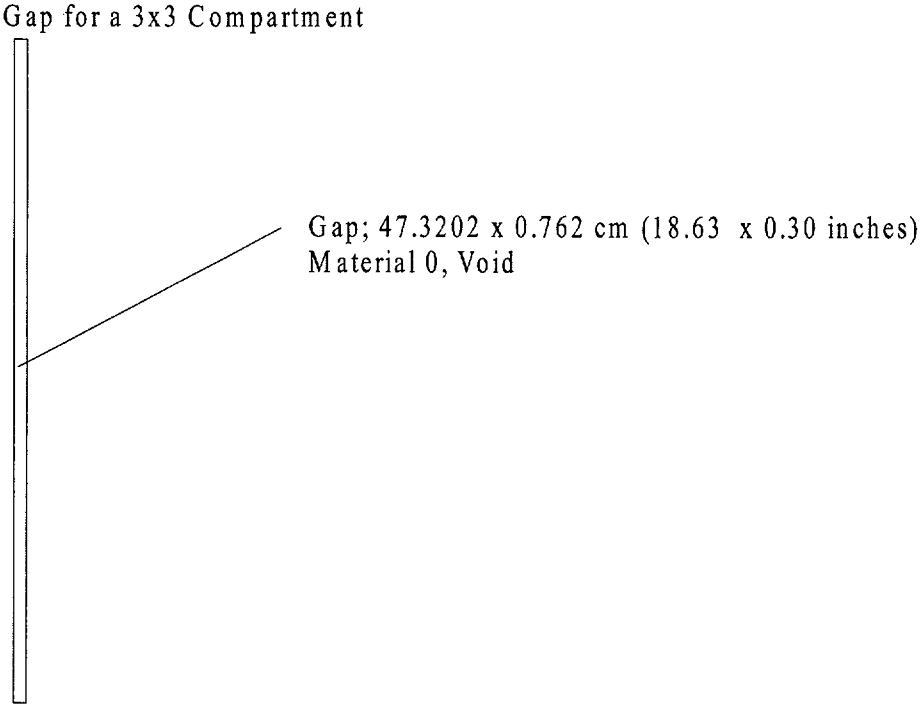
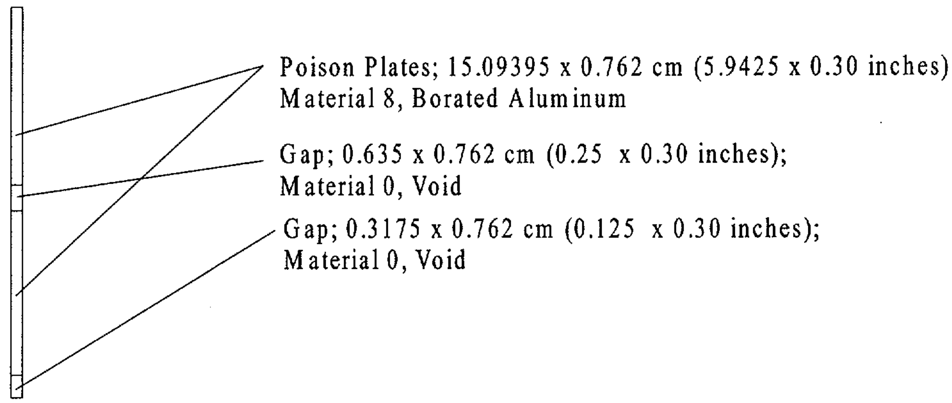
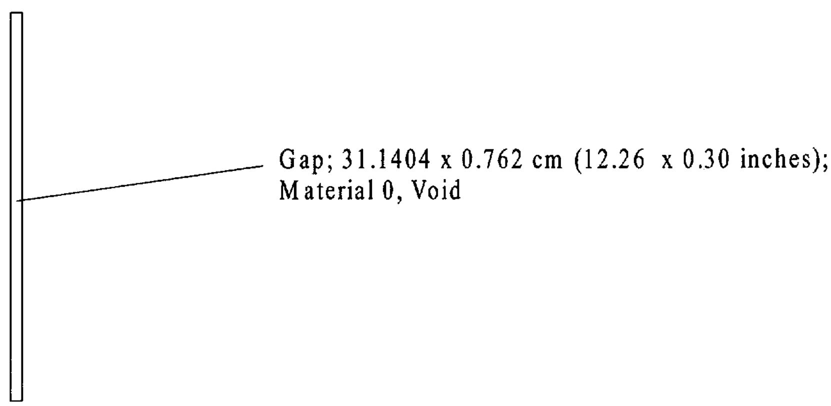


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 6 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 29 Poison Plates with Gap for a 2x2 Compartment



Unit 30 Gap for a 2x2 Compartment



Unit 31 Poison Plates with Gap for a 2x2 Compartment

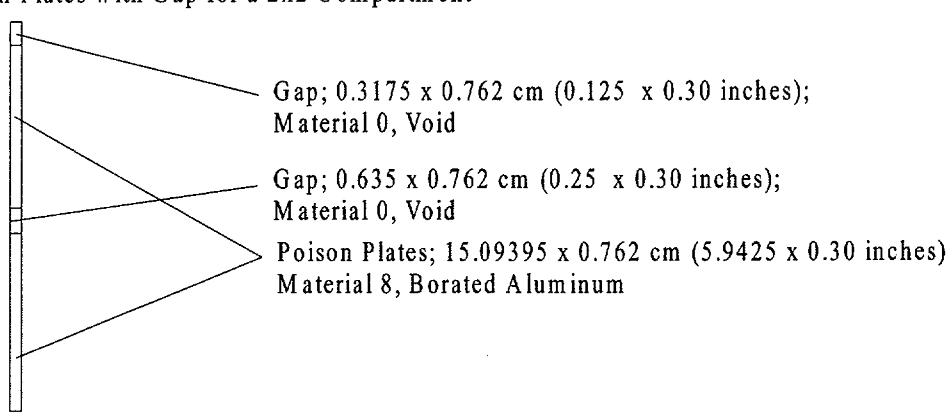
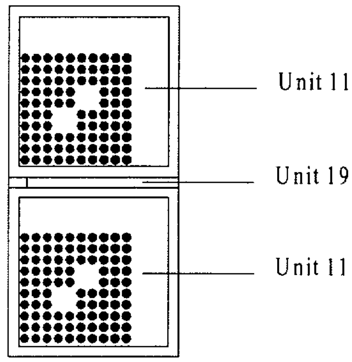
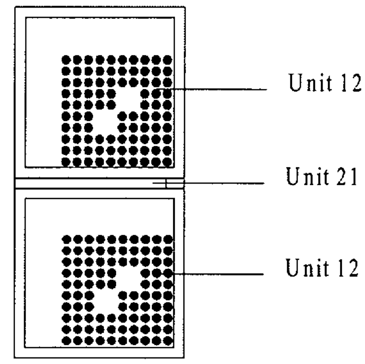


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 7 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

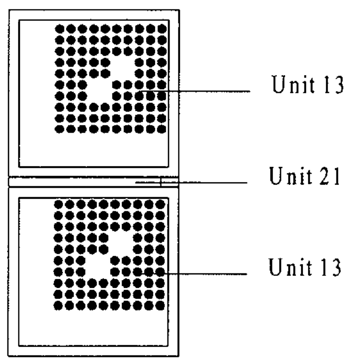
Unit 32, Array 2 - 2x2 with Poison



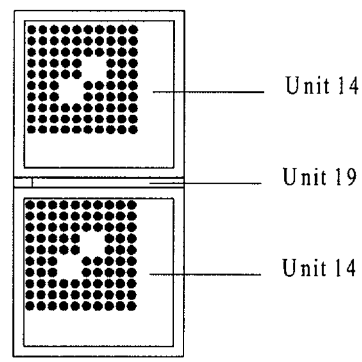
Unit 33, Array 3 - 2x2 with Poison



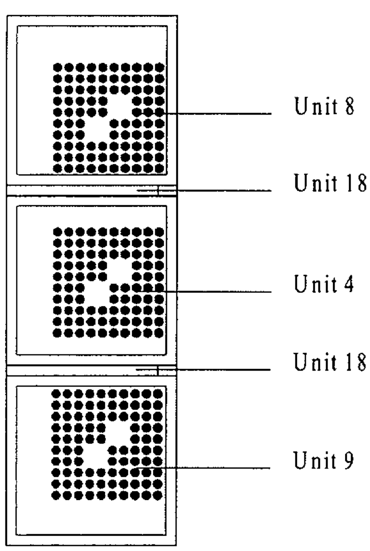
Unit 34, Array 4 - 2x2 with Poison



Unit 35, Array 5 - 2x2 with Poison



Unit 36, Array 6 - 3x3 with Poison



Unit 37, Array 7 - 3x3 with Poison

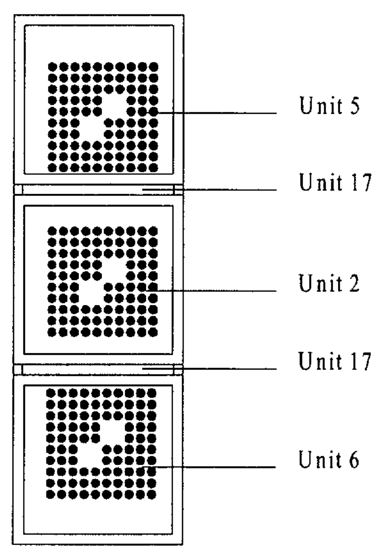


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 8 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

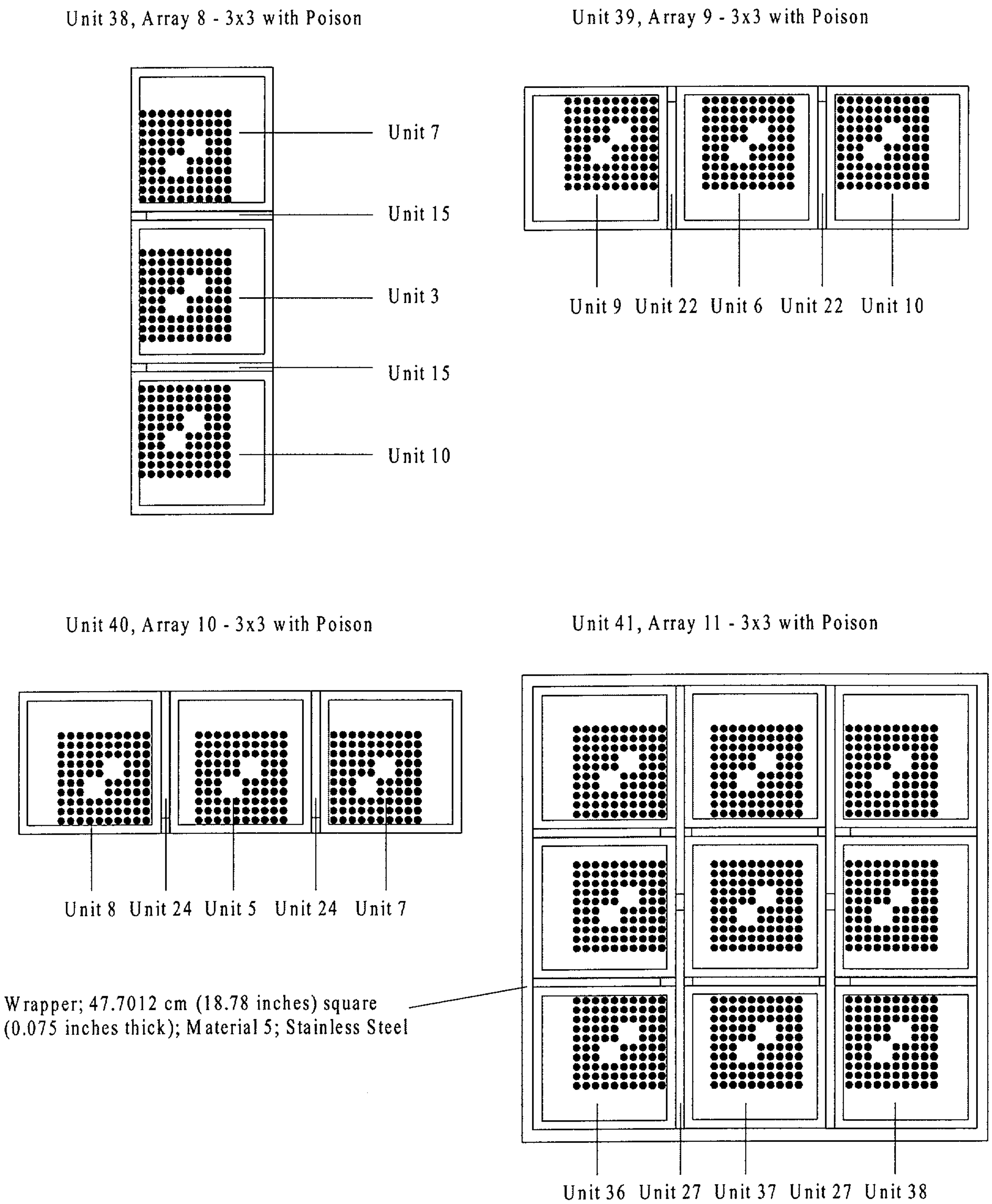


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 9 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

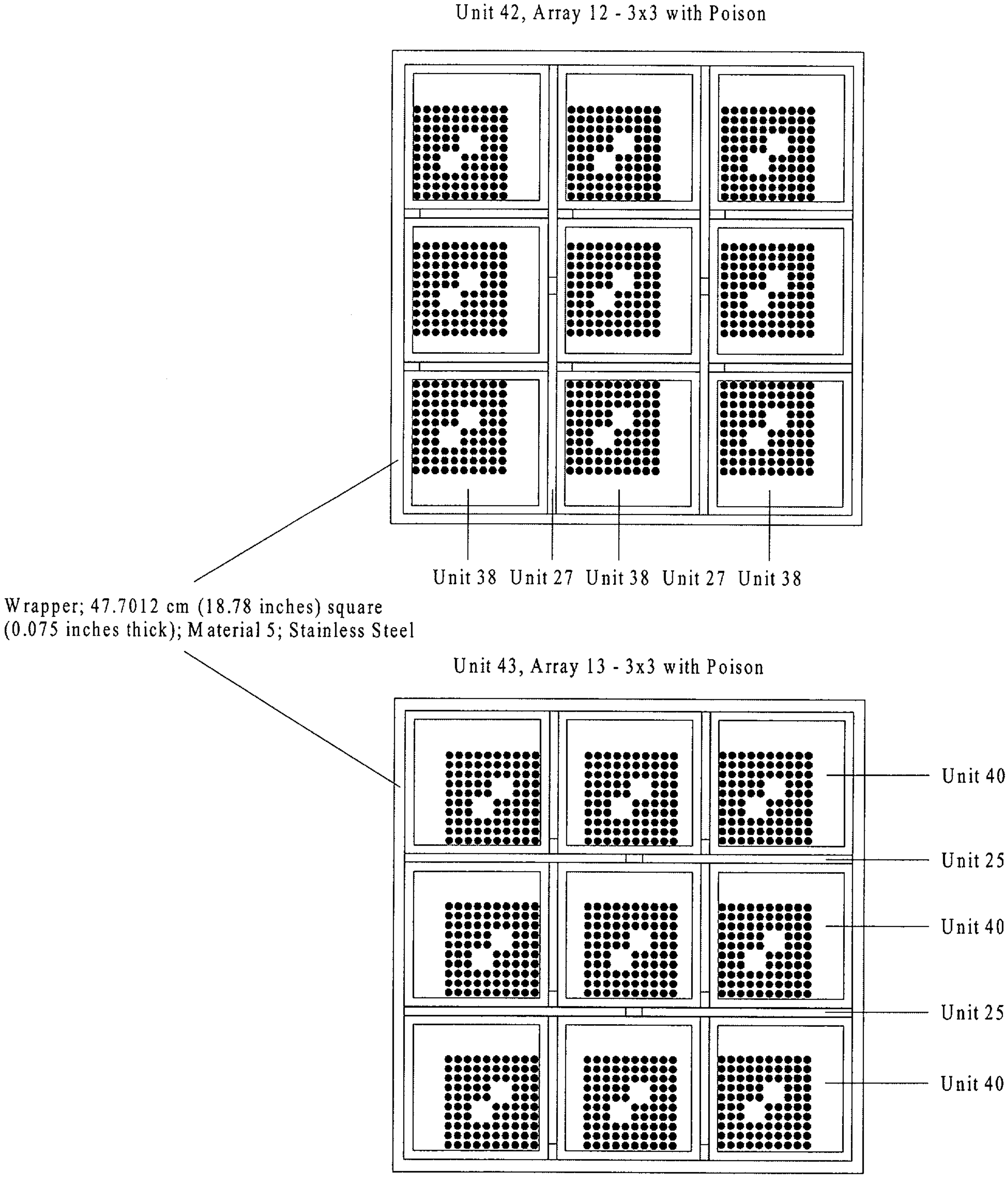


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 10 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

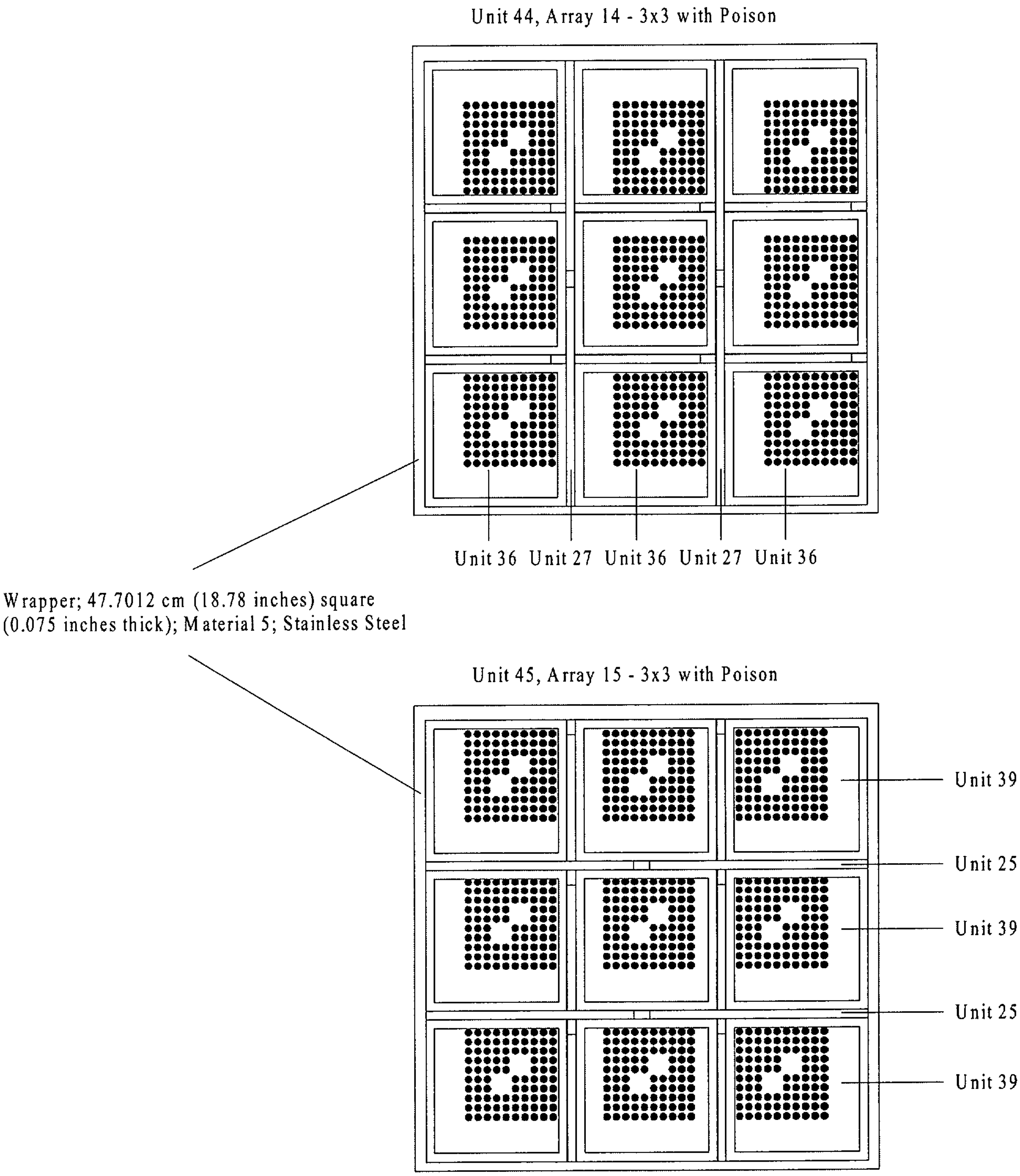


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 11 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

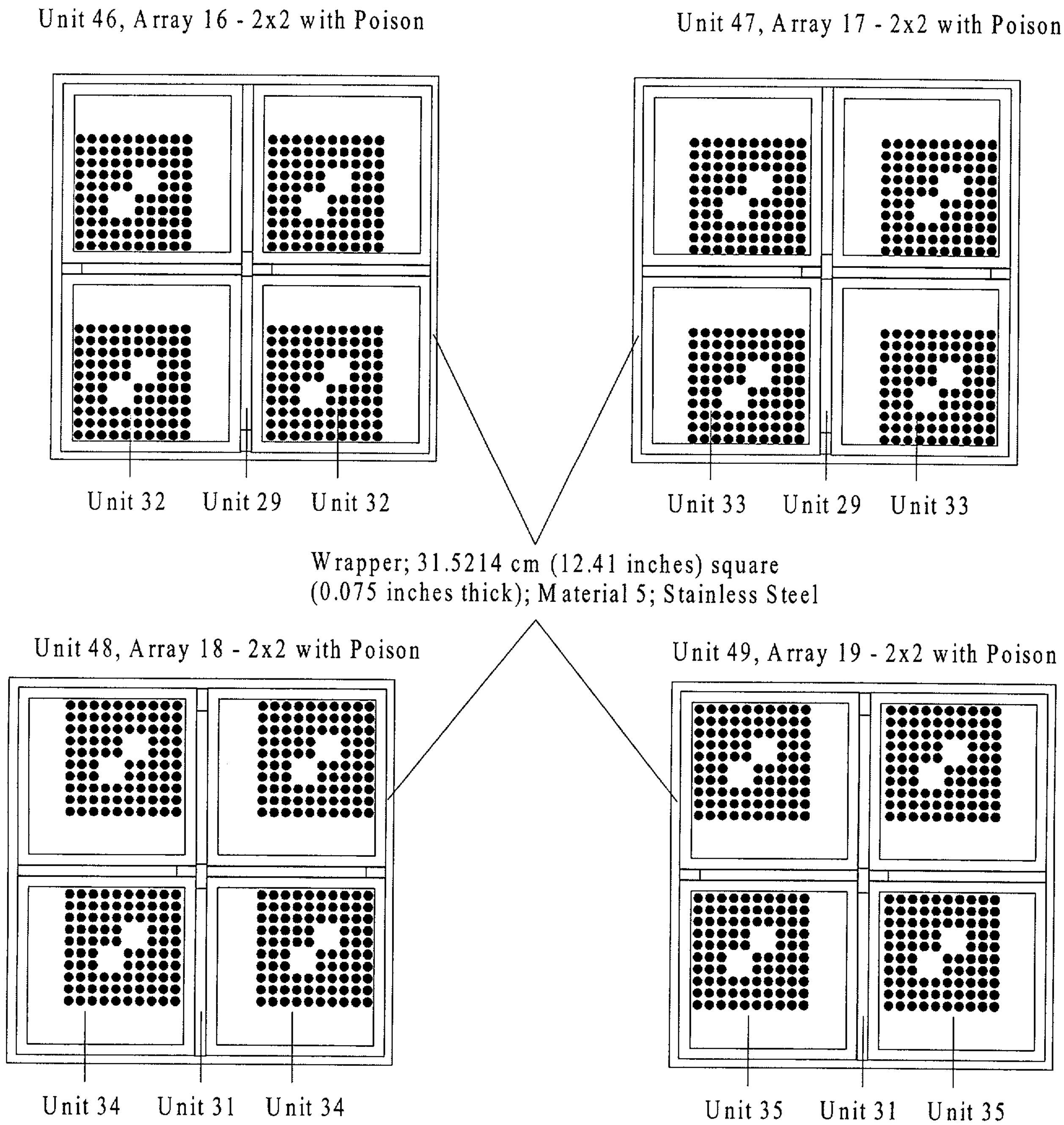
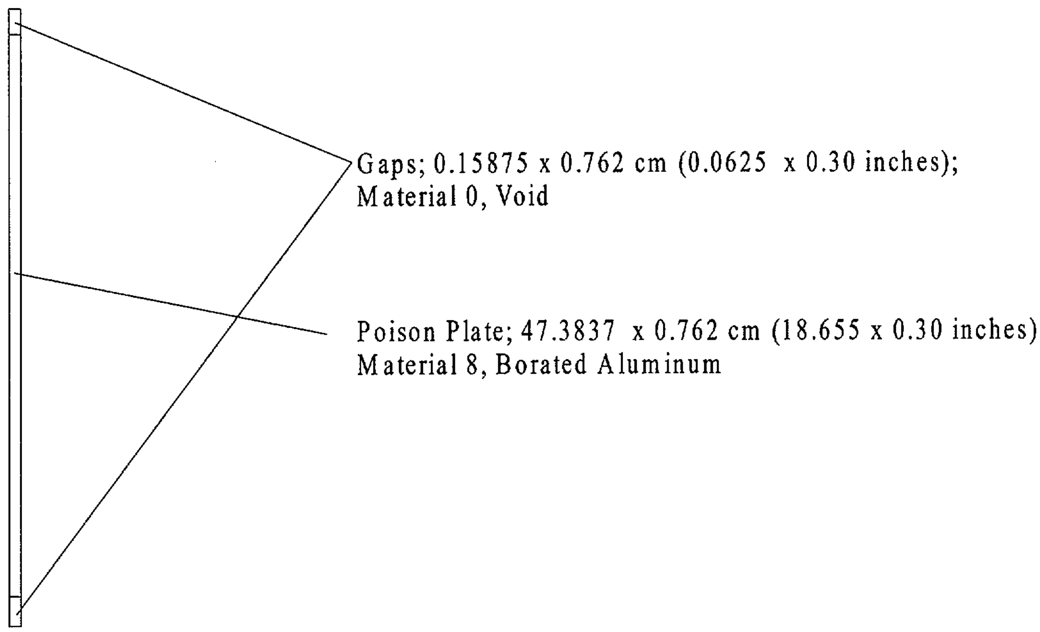


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 12 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 50, Poison Plates for 3x3 with Gaps - Outside



Unit 51, Short Gap for 3x3 - Outside

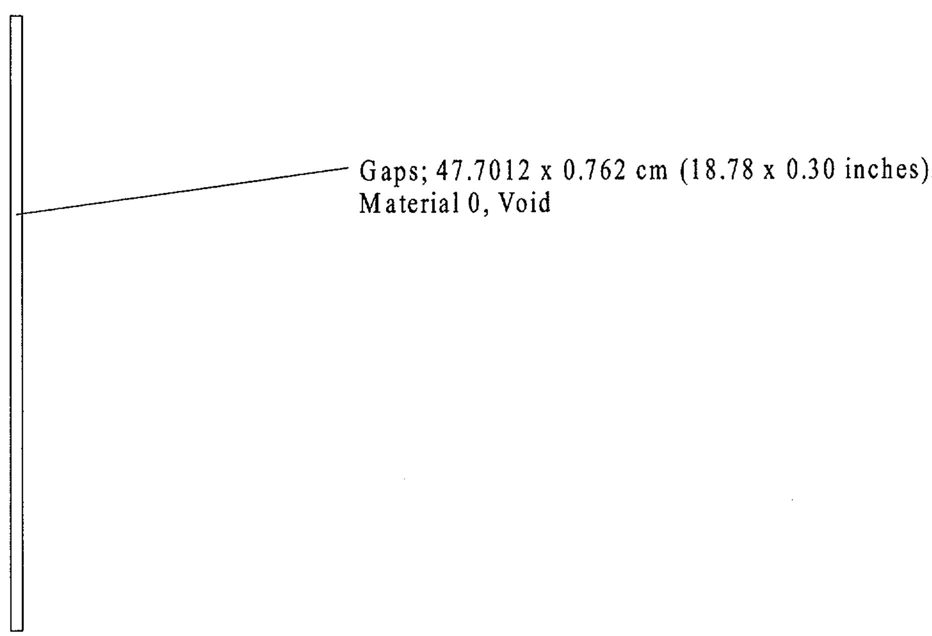
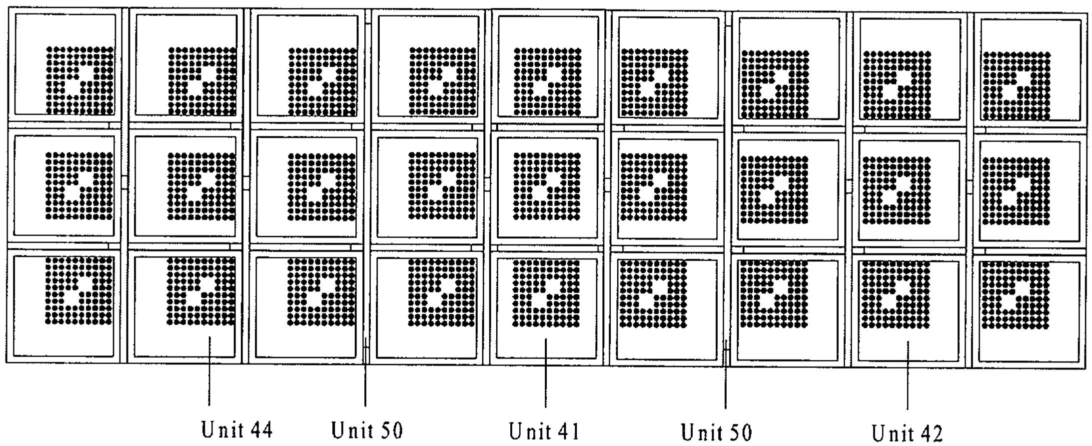


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 13 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 52, Array 20 - Row of 3x3 Compartments with Poison



Unit 53 Long Horizontal Poison Plates

Poison Plate; 112.4204 x 0.762 cm (44.26 x 0.30 inches);
Material 8, Borated Aluminum

Unit 54 Long Horizontal Gaps

Gap; 112.4204 x 0.762 cm (44.26 x 0.30 inches);
Material 0, Void

Unit 55 Poison Plates with Gap

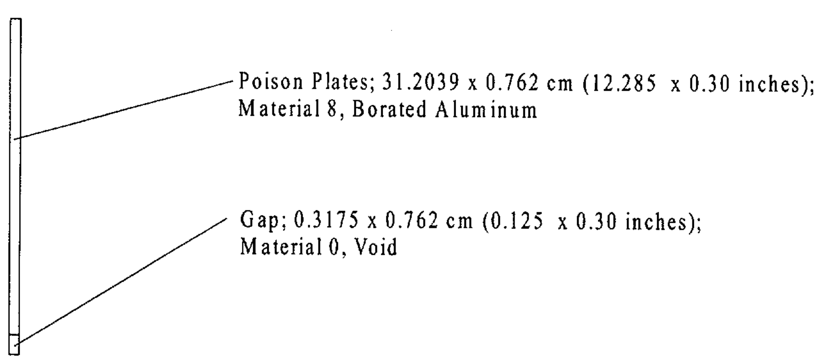
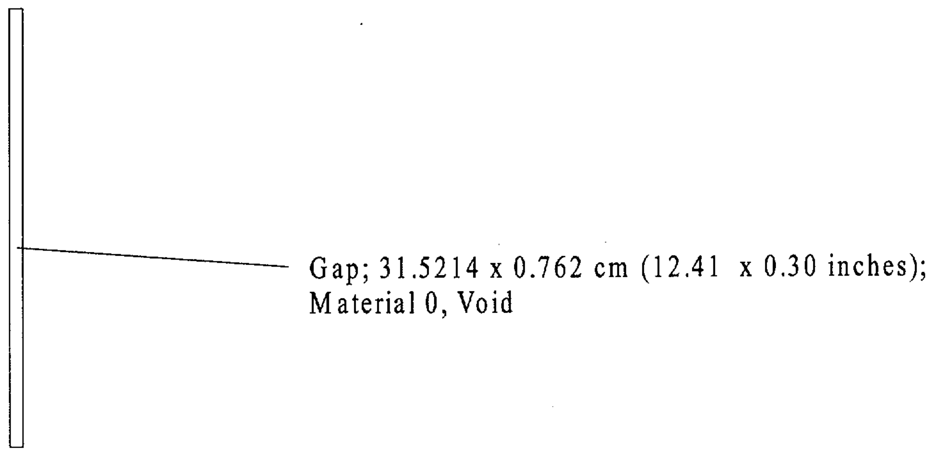


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 14 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 56 Gap



Unit 57 Poison Plates with Gap

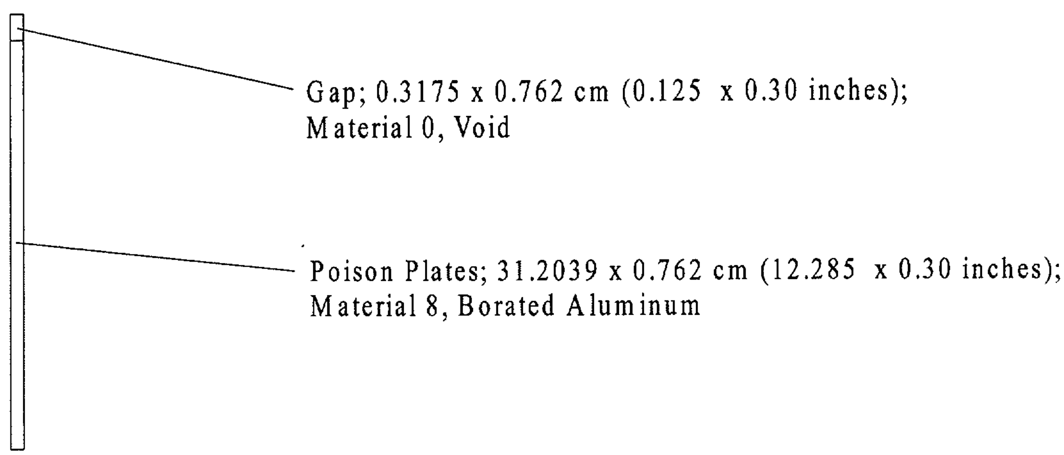


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 15 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 58 DSC/Cask Layer with Poison

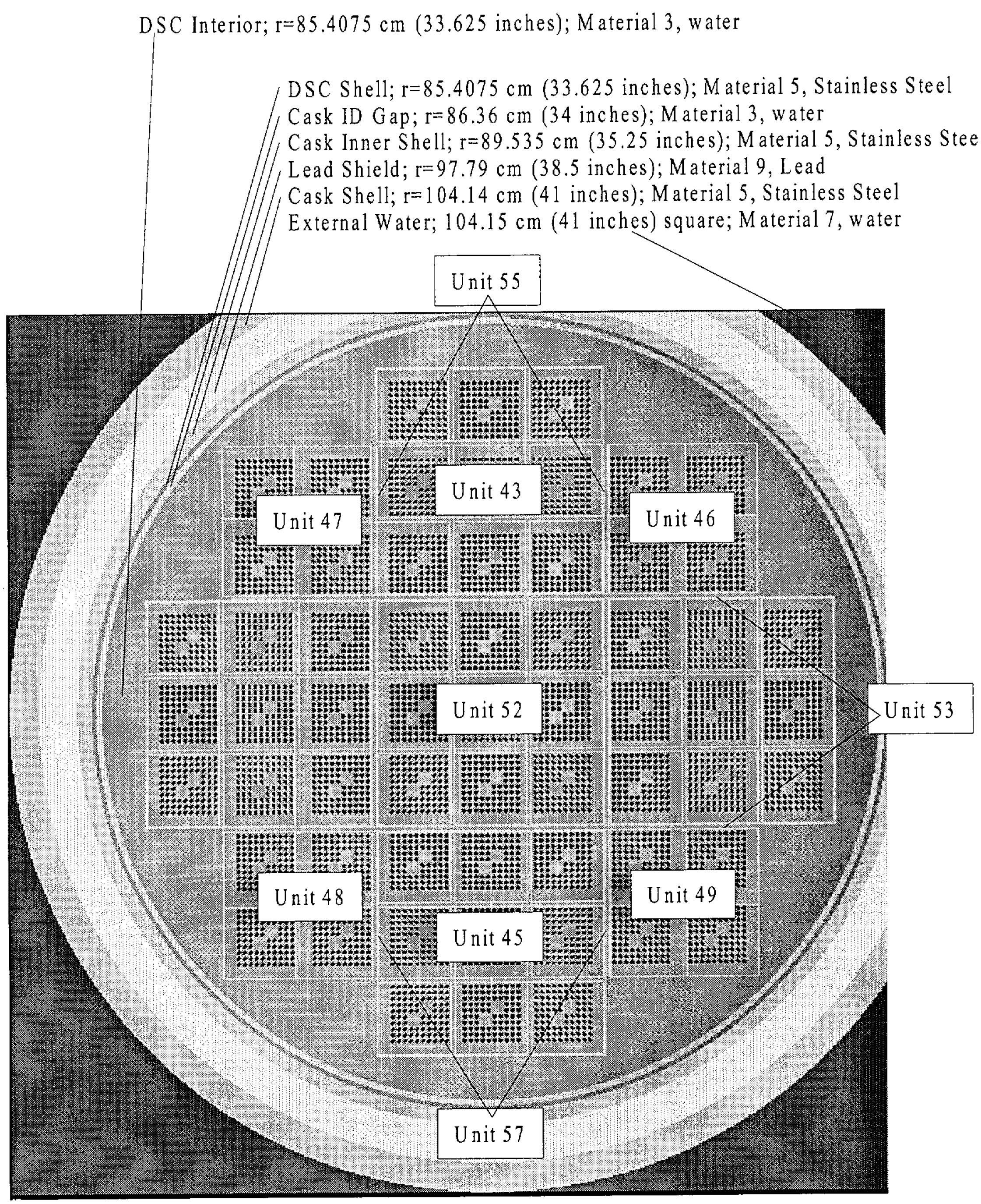


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 16 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 59 models the portion of the DSC that has poison in side the 3x3 and 2x2 compartments, but no poison between the compartments. Therefore, Unit 59 is identical to Unit 58 except:

Unit 52 is replaced with Unit 60,

Unit 53 is replaced with Unit 54,

Units 55 and 57 are replaced with Unit 56

Unit 60, (Array 22) is identical to Unit 52 except that Unit 50 is replaced with Unit 51 as compared to Array 20.

Unit 61, (Array 23) is identical to Unit 32 except that Unit 19 is replaced with Unit 20 as compared to Array 2.

Unit 62, (Array 24) is identical to Unit 33 except that Unit 21 is replaced with Unit 20 as compared to Array 3.

Unit 63, (Array 25) is identical to Unit 34 except that Unit 21 is replaced with Unit 20 as compared to Array 4.

Unit 64, (Array 26) is identical to Unit 35 except that Unit 19 is replaced with Unit 20 as compared to Array 5.

Unit 65, (Array 27) is identical to Unit 36 except that Unit 18 is replaced with Unit 16 as compared to Array 6.

Unit 66, (Array 28) is identical to Unit 37 except that Unit 17 is replaced with Unit 16 as compared to Array 7.

Unit 67, (Array 29) is identical to Unit 38 except that Unit 15 is replaced with Unit 16 as compared to Array 8.

Unit 68, (Array 30) is identical to Unit 39 except that Unit 22 is replaced with Unit 23 as compared to Array 9.

Unit 69, (Array 31) is identical to Unit 40 except that Unit 24 is replaced with Unit 23 as compared to Array 10.

Unit 70, (Array 32) is identical to Unit 41 except that Unit 27 is replaced with Unit 28 as compared to Array 11.

Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 17 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 71, (Array 33) is identical to Unit 42 except that Unit 27 is replaced with Unit 28 as compared to Array 12.

Unit 72, (Array 34) is identical to Unit 43 except that Unit 25 is replaced with Unit 26 as compared to Array 13.

Unit 73, (Array 35) is identical to Unit 44 except that Unit 27 is replaced with Unit 28 as compared to Array 14.

Unit 74, (Array 36) is identical to Unit 45 except that Unit 25 is replaced with Unit 26 as compared to Array 15.

Unit 75, (Array 37) is identical to Unit 46 except that
Unit 32 is replaced with Unit 61 and
Unit 29 is replaced with Unit 30 as compared to Array 16.

Unit 76, (Array 38) is identical to Unit 47 except that
Unit 33 is replaced with Unit 62 and
Unit 29 is replaced with Unit 30 as compared to Array 17.

Unit 77, (Array 39) is identical to Unit 48 except that
Unit 34 is replaced with Unit 63 and
Unit 31 is replaced with Unit 30 as compared to Array 18.

Unit 78, (Array 40) is identical to Unit 49 except that
Unit 35 is replaced with Unit 64 and
Unit 31 is replaced with Unit 30 as compared to Array 19.

Unit 79, models the portion of the DSC that has no inside the compartments, and no poison between the compartments. Therefore, Unit 79 is identical to Unit 59 except:

Unit 60 is replaced with Unit 80,
Unit 43 is replaced with Unit 72,
Unit 43 is replaced with Unit 74,
Unit 45 is replaced with Unit 74,
Unit 46 is replaced with Unit 75,
Unit 47 is replaced with Unit 76,
Unit 48 is replaced with Unit 77, and
Unit 49 is replaced with Unit 78.

Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 18 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

Unit 80, (Array 41) is identical to Unit 60 except that:
Unit 44 is replaced with Unit 73,
Unit 41 is replaced with Unit 70, and
Unit 42 is replaced with Unit 71 as compared to Array 22.

Unit 81 GE 10x10 Water "Hole" in Fuel

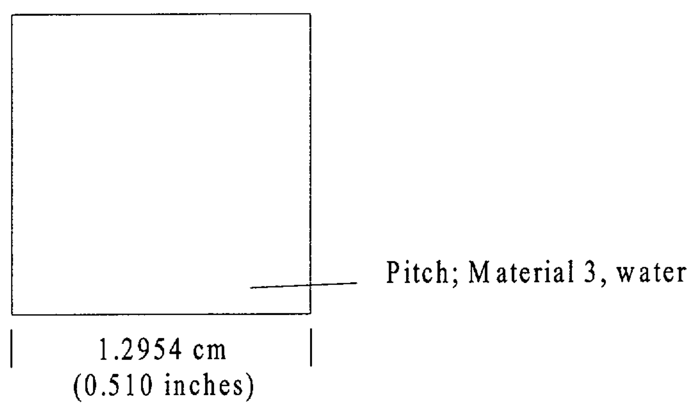


Figure K.6-2
KENO V.a Units and Radial Cross Sections of the Model
PART 19 OF 19 - (ALL UNITS 0.635 CM (0.25 INCHES) HIGH)

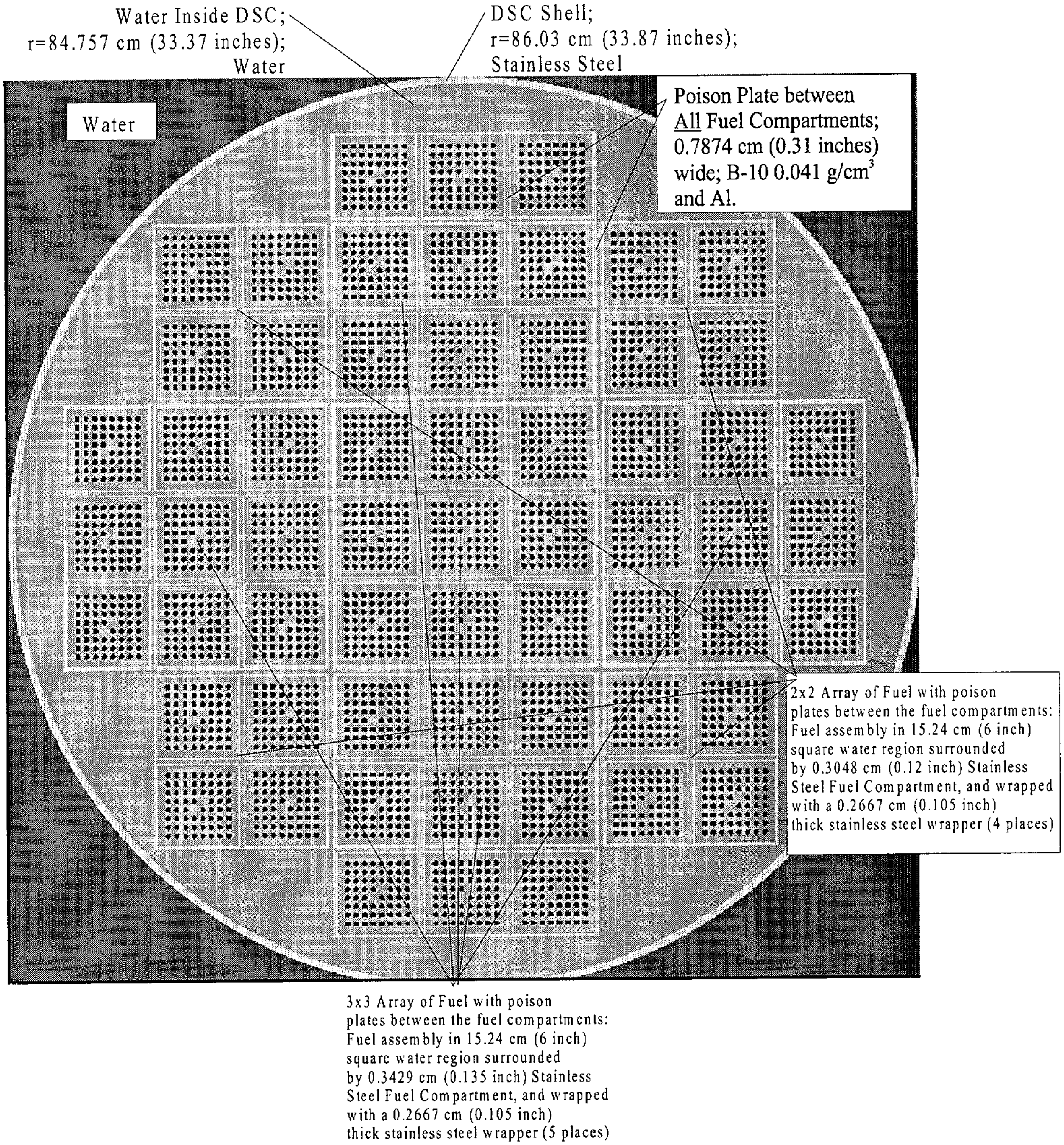


Figure K.6-3
Representative KENO V.a Model Cross Section – Most Reactive Fuel

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
1	1	1	1	1	1	1
1	1	1	1	1	1	1

GE2 - 7x7 Array
1 = Fuel Rod

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	66	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	1

GE4 - 8x8 Array
1 = Fuel Rod
66 = Water Rod

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	66	1	1	1	1
1	1	1	1	66	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

GE5 - 8x8 Array
1 = Fuel Rod
66 = Water Rod

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	67	66	1	1	1
1	1	1	66	67	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

GE8 - 8x8 Array
1 = Fuel Rod
66 = Water Rod 1
67 = Water Rod 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	66	66	1	1	1
1	1	1	66	66	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

GE9 - 8x8 Array
1 = Fuel Rod
66 = Water Hole

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	66	66	1	1	1	1
1	1	1	66	66	66	1	1	1
1	1	1	1	66	66	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

GE11 - 9x9 Array
1 = Fuel Rod
66 = Water Hole

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	66	66	1	1	1	1	1
1	1	1	66	66	1	1	1	1	1
1	1	1	1	1	66	66	1	1	1
1	1	1	1	1	66	66	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

GE12 - 10x10 Array
1 = Fuel Rod
66 = Water Hole

Figure K.6-4
Fuel Assembly Layouts

68	67	67	67	68	68	69
67	1	1	1	1	67	68
1	1	1	1	1	1	68
1	1	1	1	1	1	67
1	1	1	1	1	1	67
67	1	1	1	1	1	67
67	67	1	1	1	67	68

GE2 - 7x7 Array
(Case GE2var)
1 = Fuel Rod w/ 5.15 wt%
67 = Fuel Rod w/3.41 wt%
68 = Fuel Rod w/2.97 wt%
69 = Fuel Rod w/2.34 wt%

67	68	68	68	68	68	67	1
68	69	69	69	69	69	68	67
69	69	69	69	69	69	69	68
69	69	69	w	69	69	69	68
69	69	69	69	w	69	69	68
69	69	69	69	69	69	69	68
69	69	69	69	69	69	69	68
68	69	69	69	69	69	68	67

GE5 - 8x8 Array
(Case GE5var)
1 = Fuel Rod w/ 2.33 wt%
67 = Fuel Rod w/3.01 wt%
68 = Fuel Rod w/3.57 wt%
69 = Fuel Rod w/4.85 wt%
w = Water Rod

71	70	69	69	69	68	74	1
69	72	70	72	72	71	69	74
72	69	72	72	72	72	71	68
72	72	73	w	w	72	72	69
72	69	72	w	w	72	72	69
72	72	72	72	73	72	70	69
69	69	72	69	72	69	72	70
71	69	72	72	72	72	69	71

GE9 - 8x8 Array
(Case GE9var)
1 = Fuel Rod w/ 2.02 wt%
68 = Fuel Rod w/4.03 wt%
69 = Fuel Rod w/4.29 wt%
70= Fuel Rod w/ 3.78 wt%
71 = Fuel Rod w/3.03 wt%
72 = Fuel Rod w/4.98 wt%
73 = Fuel Rod w/4.54 wt%
74 = Fuel Rod w/3.28 wt%
w = Water Rod

Figure K.6-5
Variable Enrichment Fuel Assembly Layouts

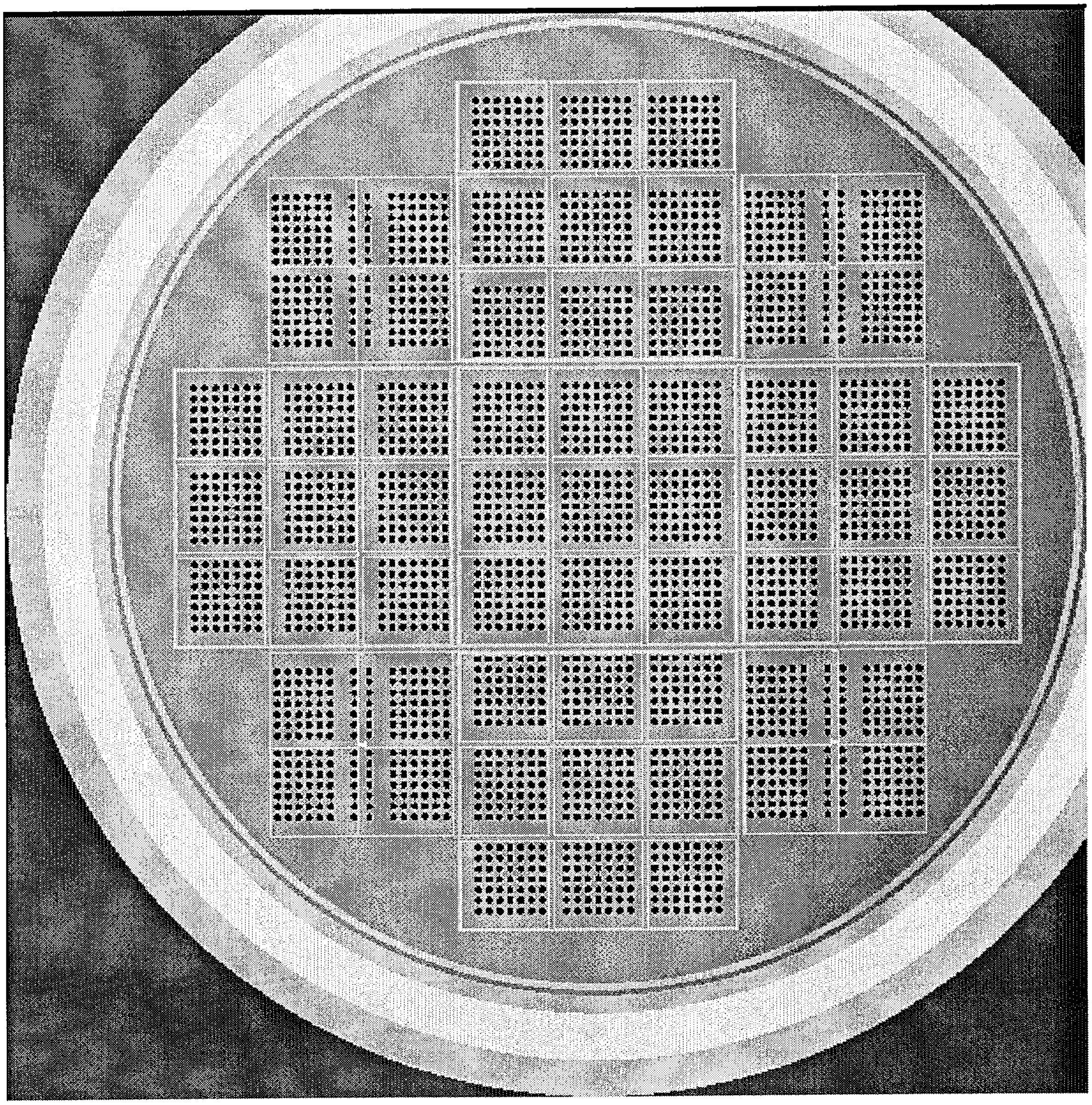


Figure K.6-6
Single Break Case – Maximum Separation

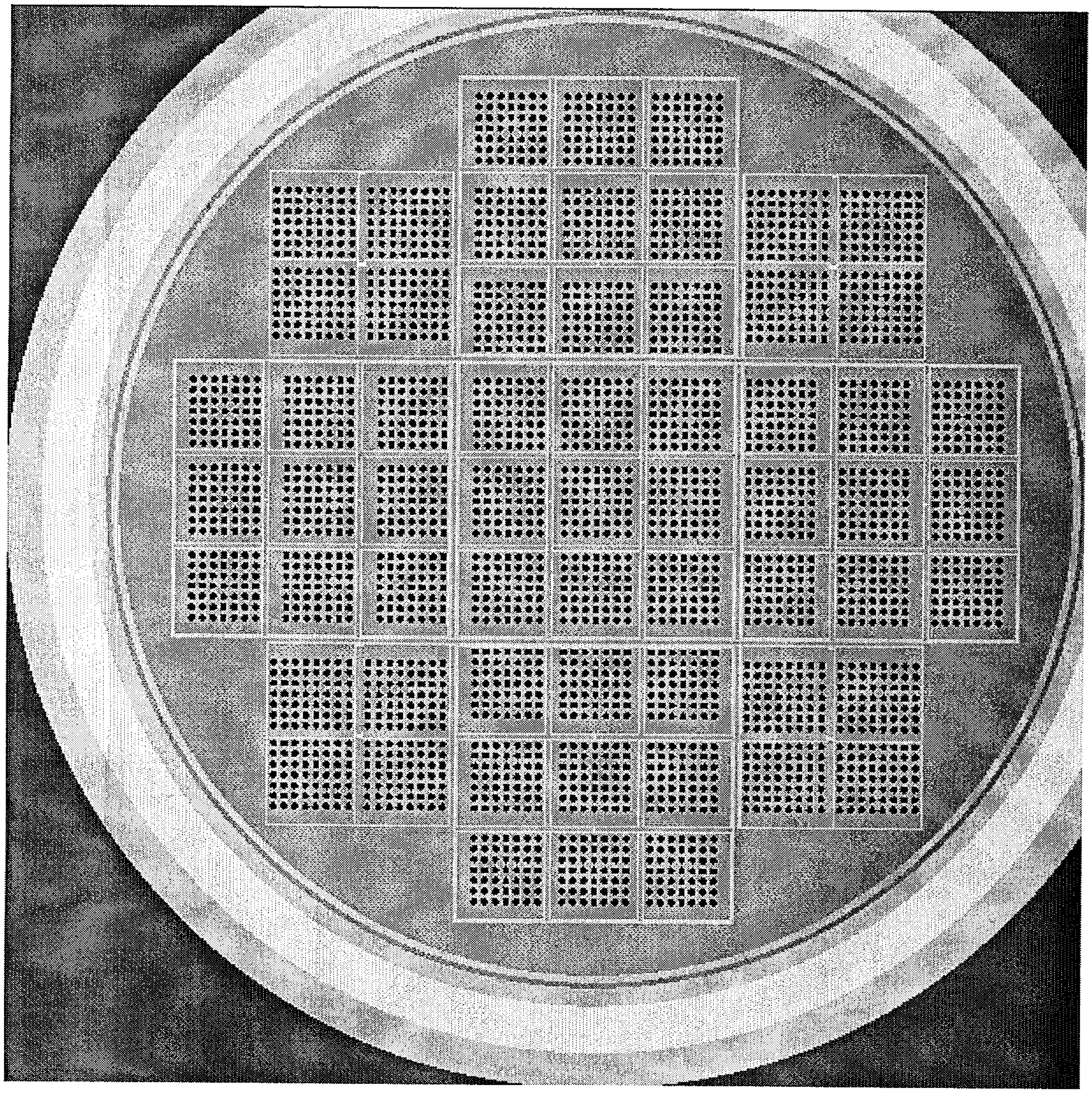


Figure K.6-7
Double Break Case

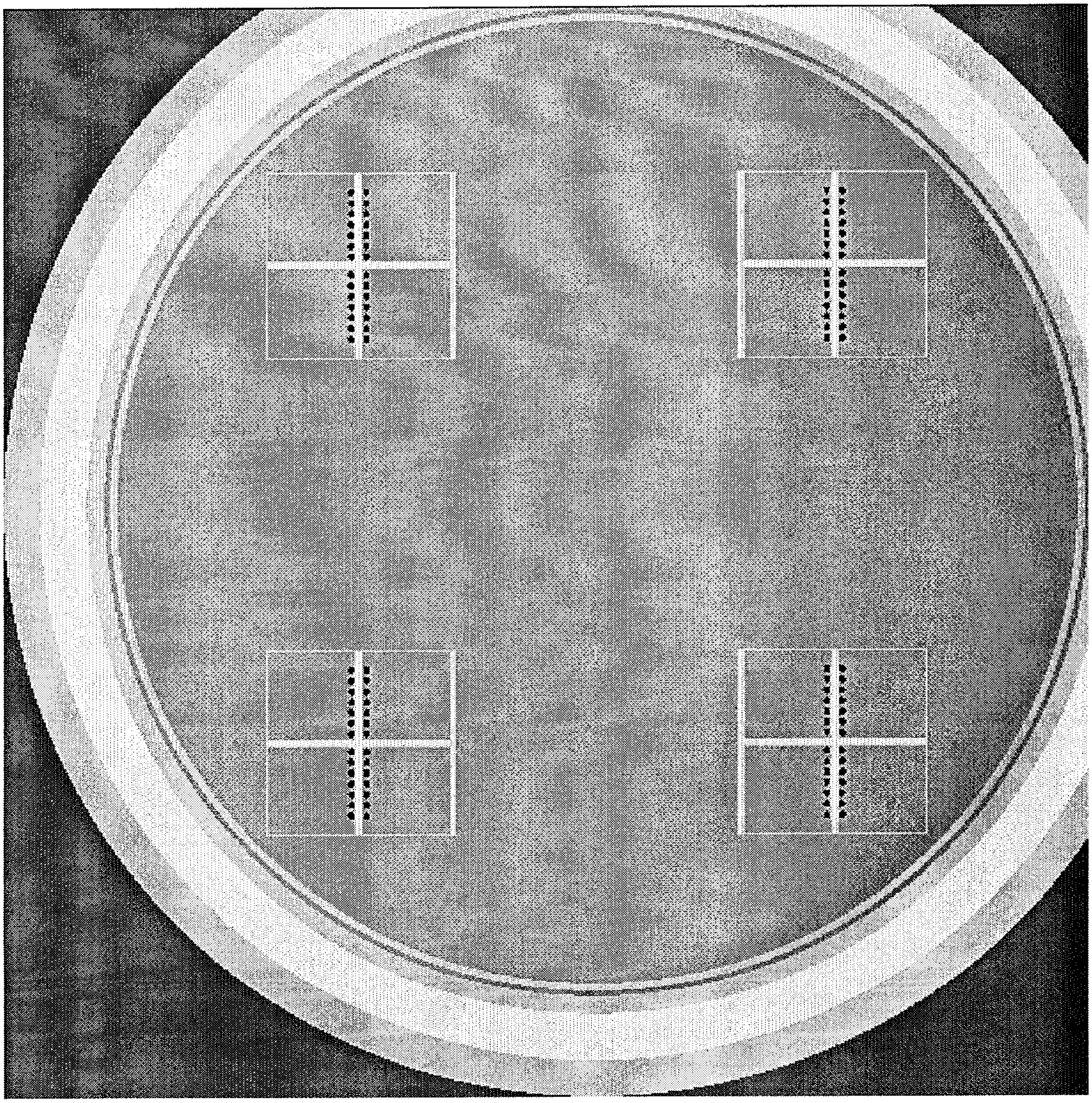


Figure K.6-8
Single Break Case – Above Poison Plates

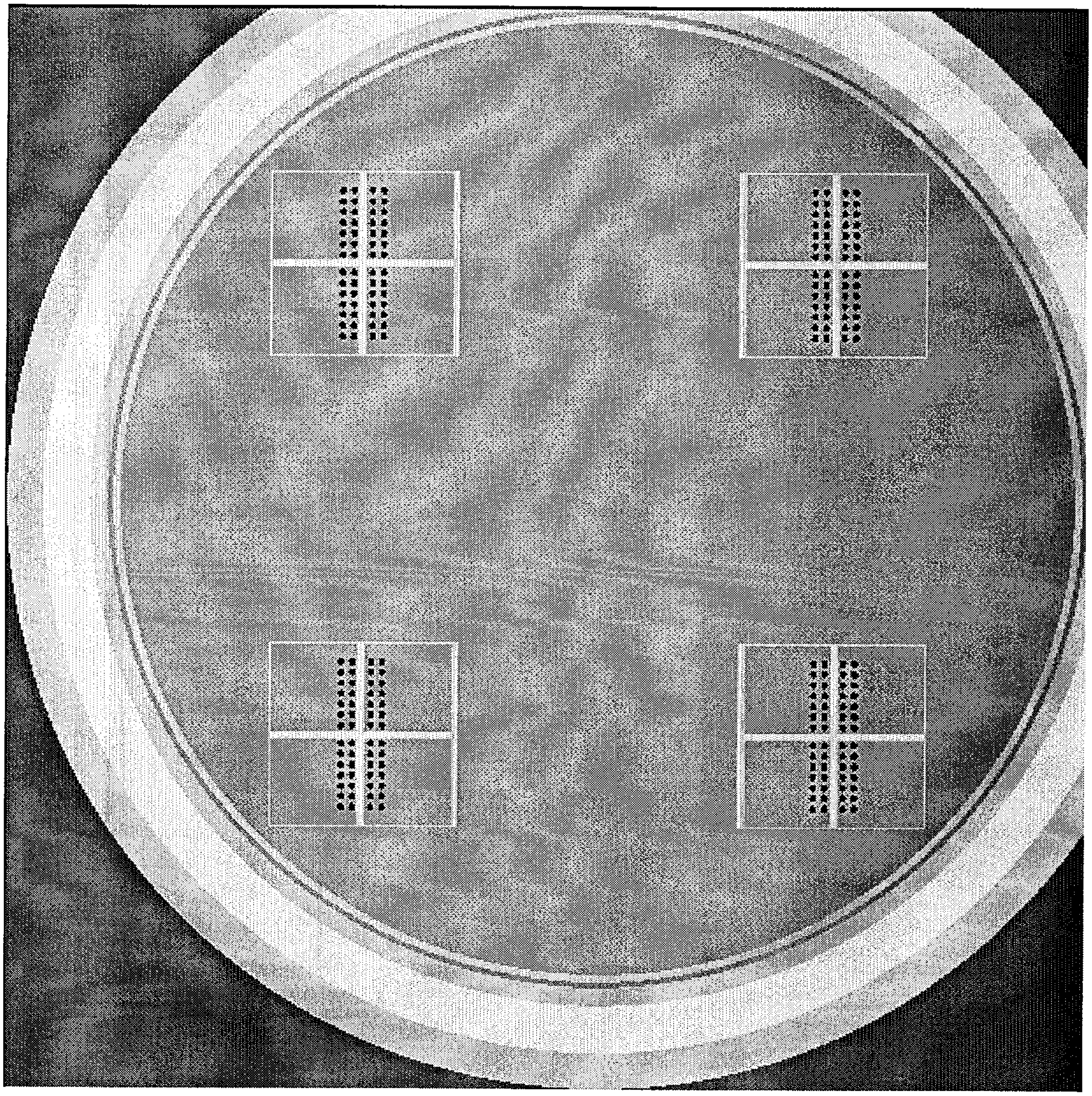


Figure K.6-9
Double Break Case – Above Poison Plate

K.7 Confinement

Confinement of all radioactive materials in the NUHOMS®-61BT system is provided by the NUHOMS®-61BT DSC which is designed and tested to meet the leak tight criteria [7.1].

As discussed in Section 7.2.2, the release of airborne radioactive material is addressed for three phases of system operation: fuel handling in the spent fuel pool, drying and sealing of the DSC, and DSC transfer and storage. Potential airborne releases from irradiated fuel assemblies in the spent fuel pool are discussed in the plant's existing 10CFR50 license.

DSC drying and sealing operations are performed using procedures which prohibit airborne leakage. During these operations, all vent lines are routed to the existing radwaste systems of the plant. Once the DSC is dried and sealed, there are no design basis accidents, which could result in a breach of the DSC and the airborne release of radioactivity. Design provisions to preclude the release of gaseous fission products as a result of accident conditions are discussed in Section 8.2.9.

During transfer of the sealed DSC and subsequent storage in the HSM, the only postulated mechanism for the release of airborne radioactive material is the dispersion of non-fixed surface contamination on the DSC exterior. By filling the cask/DSC annulus with demineralized water, placing an inflatable seal over the annulus, and utilizing procedures which require examination of the annulus surfaces for smearable contamination, the contamination limits on the DSC can be kept below the permissible level for off-site shipments of fuel. Therefore, there is no possibility of significant radionuclide release from the DSC exterior surface during transfer or storage.

K.7.1 Confinement Boundary

Once inside the DSC, the SFAs are confined by the DSC shell and by multiple barriers at each end of the DSC. For intact fuel, the fuel cladding is the first barrier for confinement of radioactive materials. The fuel cladding is protected by maintaining the cladding temperatures during storage below those levels, which may cause degradation of the cladding. In addition, the SFAs are stored in an inert atmosphere to prevent degradation of the fuel, specifically cladding rupture due to oxidation and its resulting volumetric expansion of the fuel. Thus, a helium atmosphere for the DSC is incorporated in the design to protect the fuel cladding integrity by inhibiting the ingress of oxygen into the DSC cavity.

Helium is known to leak through valves, mechanical seals, and escape through very small passages because of its small atomic diameter and because it is an inert element and exists in a monatomic species. Negligible leakage rates can be achieved with careful design of vessel closures. Helium will not, to any practical extent, diffuse through stainless steel. For this reason, the DSC has been designed as a redundant weld-sealed containment pressure vessel with no mechanical or electrical penetrations.

For damaged fuel assemblies, top and bottom caps are provided to contain fuel debris such as broken rods, loose pellets and/or pieces of cladding in the fuel compartment. The end caps fit snugly into the top and bottom of the fuel compartment. They are held in place by the fuel compartments and the inner bottom cover plate and the top shield plug during transfer and storage. The end caps have multiple 1/8-inch through holes to permit unrestricted flooding and draining of the fuel cells.

K.7.1.1 Confinement Vessel

The confinement vessel is provided by the NUHOMS®-61BT DSC. The DSC is designed to provide confinement of all radionuclides under normal and accident conditions. The DSC is designed, fabricated and tested in accordance with the applicable requirements of the ASME Boiler and Pressure Vessel Code, Division 1, Section III, Subsection NB [7.2] with exceptions as discussed in Section K.3.1.2.3. The shell and inner and outer bottom cover plates are delivered to the site as an assembly. The shell and the inner bottom cover plate, which provide the confinement boundary as shown in Figure K.3-1, are tested to meet the leak tight criteria as defined in Reference 7.1 at the fabricator. The pneumatic pressure test and leak test are performed on the finished shell and the inner cover plate during fabrication. The outer bottom cover plate provides redundant confinement boundary. The root and final layer closure welds for this redundant boundary are inspected using dye penetrant inspection methods in accordance with requirements of the ASME code[7.2].

Once the fuel assemblies are loaded in the DSC, the heavy shield plug is installed to provide radiation shielding to minimize radiation exposure to workers during DSC closure operations. The inner top cover plate is welded into place along with the vent and siphon port cover plates. These welds represent the first level of closure for the DSC. Finally, the outer top cover plate is welded into place to form the redundant confinement boundary of the DSC. The inner plate is

tested using the test port in the outer top cover plate to meet the leak tight criteria [7.1]. The test port is then threaded into the outer top cover plate and seal welded in place. The root, mid and final layer closure welds for this redundant boundary are inspected using dye penetrant inspection methods in accordance with requirements of the ASME code [7.2].

K.7.1.2 Confinement Penetrations

The DSC pressure boundary contains two penetrations (vent and siphon ports) for draining, vacuum drying and backfilling the DSC cavity. The vent and siphon ports are closed with welded cover plates and the outer top cover plate provides the redundant closure. The outer cover plate has a single penetration used for leak testing the closure welds. This test port is threaded into the outer top cover plate and seal welded in place after testing to complete the redundant closure. The DSC has no bolted closures or mechanical seals. The final confinement boundary contains no external penetrations.

K.7.1.3 Seals and Welds

The DSC cylindrical shell is fabricated from rolled ASME stainless steel plate that is joined with full penetration 100% radiographed welds. All top and bottom end closure welds are multiple-layer welds. This effectively eliminates a pinhole leak which might occur in a single pass weld, since the chance of pinholes being in alignment on successive weld passes is not credible. Furthermore, the DSC cover plates are sealed by separate, redundant closure welds. All the DSC pressure boundary welds are inspected according to the appropriate articles of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB. These criteria insure that the weld filler metal is as sound as the parent metal of the pressure vessel. There are no bolted closures or mechanical seals.

K.7.1.4 Closure

All top end closure welds are multiple-layer welds. This effectively eliminates a pinhole leak which might occur in a single pass weld, since the chance of pinholes being in alignment on successive weld passes is not credible. Furthermore, the DSC cover plates are sealed by separate, redundant closure welds. Finally, the inner closure welds are tested to the leak tight criteria [7.1]. There are no bolted closures or mechanical seals.

K.7.2 Requirements for Normal Conditions of Storage

K.7.2.1 Release of Radioactive Material

The NUHOMS®-61BT DSC is designed, fabricated and tested to meet the leak tight criteria [7.1]. Therefore, there is no release of radioactive material under normal conditions of storage. As noted in acceptance criteria IV-4 of [7.3], a closure monitoring system is not required. The confinement boundary ensures that the inert fill gas does not leak or diffuse through the weld or parent material of the DSC. The continued effectiveness of the confinement boundary is demonstrated by the (a) daily visual inspections of the HSM inlets and outlets (b) daily monitoring of the HSM thermal performance (c) and the use of radiation monitors (typically TLDs) on the ISFSI boundary fence. A breach of the confinement boundary would result in an increase in the measured dose at the ISFSI fence. If an increase were detected, steps would be initiated to enable the licensee to take corrective actions to maintain safe storage conditions.

K.7.2.2 Pressurization of Confinement Vessel

The maximum internal pressures in the NUHOMS®-61BT DSC during transfer and storage are calculated in Section K.4.4.4 to be 1.61 atm (9.0 psig) and 1.48 atm (7.0 psig), respectively. The maximum internal pressures during off-normal conditions are 1.68 atm (10 psig) and 1.78 atm (11.5 psig) during storage and transfer, respectively. These pressures are below the design pressures of the DSC as shown in Section K.4.4.

K.7.3 Confinement Requirements for Hypothetical Accident Conditions

K.7.3.1 Fission Gas Products

The analysis presented in Section K.3 demonstrates that the confinement boundary (pressure boundary) is not compromised following hypothetical accident conditions. Therefore, there is no need to calculate the fission gas products available for release.

K.7.3.2 Release of Contents

The NUHOMS®-61BT DSC is designed and tested to meet the leak tight criteria [7.1]. The analysis presented in Section K.3 demonstrates that the confinement boundary (pressure boundary) is not compromised following hypothetical accident conditions. Therefore, there is no release of radioactive material under hypothetical accident conditions of storage.

K.7.4 References

7.1 "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," ANSI N14.5-1997, American National Standards Institute, Inc., New York, New York, 1997.

7.2 ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, 1998, including 1999 addenda.

7.3 Interim Staff Guidance (ISG)-5, Revision 1, Confinement Evaluation.

K.8 Operating Systems

This Chapter presents the operating procedures for the standardized NUHOMS®-61BT system described in previous chapters and shown on the drawings in Section K.1.5. The procedures include preparation of the DSC and fuel loading, closure of the DSC, transport to the ISFSI, DSC transfer into the HSM, monitoring operations, and DSC retrieval from the HSM. The standardized NUHOMS® transfer equipment, and the existing plant systems and equipment are used to accomplish these operations. Procedures are delineated here to describe how these operations are to be performed and are not intended to be limiting. Standard fuel and cask handling operations performed under the plant's 10CFR50 operating license are described in less detail. Existing operational procedures may be revised by the licensee and new ones may be developed according to the requirements of the plant, provided that the limiting conditions of operation specified in Technical Specifications, Functional and Operating Limits of NUHOMS® CoC are not exceeded.

The following sections outline the typical operating procedures for the standardized NUHOMS® system. These generic NUHOMS® procedures have been developed to minimize the amount of time required to complete the subject operations, to minimize personnel exposure, and to assure that all operations required for DSC loading, closure, transfer, and storage are performed safely. Plant specific ISFSI procedures are to be developed by each licensee in accordance with the requirements of 10CFR72.24 (h) and the guidance of Regulatory Guide 3.61 (8.1). The generic procedures presented here are provided as a guide for the preparation of plant specific procedures and serve to point out how the NUHOMS® system operations are to be accomplished. They are not intended to be limiting, in that the licensee may judge that alternate acceptable means are available to accomplish the same operational objective.

K.8.1 Procedures for Loading the Cask

Process flow diagrams for the NUHOMS® system operation are presented Figure K.8.1-1 and Figure K.8.2-1. The location of the various operations may vary with individual plant requirements. The following steps describe the recommended generic operating procedures for the standardized NUHOMS® system.

K.8.1.1 Preparation of the Transfer Cask and DSC

1. Prior to placement in dry storage, the candidate intact and damaged fuel assemblies shall be evaluated (by plant records or other means) to verify that they meet the physical, thermal and radiological criteria specified in Technical Specification 1.2.1.

2. Prior to being placed in service, the transfer cask is to be cleaned or decontaminated as necessary to insure a surface contamination level of less than those specified in Technical Specification 1.2.12.

3. Place the transfer cask in the vertical position in the cask decon area using the cask handling crane and the transfer cask lifting yoke.

4. Place scaffolding around the cask so that the top cover plate and surface of the cask are easily accessible to personnel.

5. Remove the transfer cask top cover plate and examine the cask cavity for any physical damage and ready the cask for service.

6. Examine the DSC for any physical damage which might have occurred since the receipt inspection was performed. The DSC is to be cleaned and any loose debris removed.

7. Using a crane, lower the DSC into the cask cavity by the internal lifting lugs and rotate the DSC to match the cask and DSC alignment marks.

8. Fill the cask-DSC annulus with clean, demineralized water. Place the inflatable seal into the upper cask liner recess and seal the cask-DSC annulus by pressurizing the seal with compressed air.

9. If damaged fuel assemblies are to be included in a specific loading campaign, place required number of bottom end caps provided (up to a maximum of 16) into the bottom of 2x2 compartments of a Type C basket.

10. Fill the DSC cavity with water from the fuel pool or an equivalent source which meets the requirements of Technical Specification 1.2.15. For BWR fuel, demineralized water may be used.

    Note: A TC/DSC annulus pressurization tank filled with water from the fuel pool as described above is connected to the top vent port of the TC via a hose to provide a positive head above the level of water in the TC/DSC annulus. This is an optional arrangement, which provides additional assurance that contaminated water from the fuel pool will not enter the TC/DSC annulus, provided a positive head is maintained at all times.

11. Using the fuel/reactor building main hook and the cask lifting yoke, position the cask lifting yoke above the DSC top shield plug and attach the four designated cable assemblies between the yoke and the DSC top shield plug. Adjust the turnbuckles on the cable assemblies as necessary to level the shield plug. If not already done, test fit the DSC top shield plug onto the DSC.

12. Place the DSC top shield plug, with the cable assemblies attached and disconnect from the yoke. Position the cask lifting yoke above the transfer cask and engage the cask lifting trunnions.

13. Visually inspect the yoke lifting hooks to insure that they are properly positioned and engaged on the cask lifting trunnions.

14. Visually inspect the yoke lifting hooks to insure that they are properly positioned and engaged on the cask lifting trunnions.

15. Connect the vacuum drying system (VDS) or optional liquid pump to the siphon port of the DSC and position the connecting hose such that the hose will not interfere with loading (yoke, fuel, shield plug, rigging, etc.). A rotometer must be installed at a suitable location as part of this connection.

16. Move the scaffolding away from the cask as necessary.

17. Lift the cask just far enough to allow the weight of the cask to be distributed onto the yoke lifting hooks. Reinspect the lifting hooks to insure that they are properly positioned on the cask trunnions.

18. Optionally, secure a sheet of suitable material to the bottom of the transfer cask to minimize the potential for ground-in contamination. This may also be done prior to initial placement of the cask in the decon area.

19. Prior to the cask being lifted into the fuel pool, the water level in the pool should be adjusted as necessary to accommodate the cask/DSC volume. If the water placed in the DSC cavity was obtained from the fuel pool, a level adjustment may not be necessary.

K.8.1.2 DSC Fuel Loading

1. Lift the cask/DSC and position it over the cask loading area of the spent fuel pool in accordance with the plant's 10CFR50 cask handling procedures.

2. Lower the cask into the fuel pool until the bottom of the cask is at the height of the fuel pool surface. As the cask is lowered into the pool, spray the exterior surface of the cask with demineralized water.

3. Place the cask in the location of the fuel pool designated as the cask loading area.

4. Disengage the lifting yoke from the cask lifting trunnions and move the yoke and the top shield plug clear of the cask. Spray the lifting yoke and top shield plug with clean demineralized water if it is raised out of the fuel pool.

5. Move a candidate fuel assembly from a fuel rack in accordance with the plant's 10CFR50 fuel handling procedures.

6. Prior to insertion of a spent fuel assembly into the DSC, the identity of the assembly is to be verified by two individuals using an underwater video camera or other means. Read and record the fuel assembly identification number from the fuel assembly and check this identification number against the DSC loading plan which indicates which fuel assemblies are acceptable for dry storage.

7. Position the fuel assembly for insertion into the selected DSC storage cell and load the fuel assembly. Repeat Steps 5 through 7 for each SFA loaded into the DSC. If loading damaged fuel assemblies, place top end caps over each damaged fuel assembly placed into the basket. A maximum of 16 damaged fuel assemblies may be loaded into the 2x2 compartments of a Type C basket. After the DSC has been fully loaded, check and record the identity and location of each fuel assembly in the DSC.

8. After all the SFAs have been placed into the DSC and their identities verified, place the hold down ring and position the lifting yoke and the top shield plug and lower the shield plug onto the DSC.

   CAUTION: Verify that all the lifting height restrictions as a function of temperature specified in Technical Specification 1.2.13 can be met in the following steps which involve lifting of the transfer cask.

9. Visually verify that the top shield plug is properly seated onto the DSC.

10. Position the lifting yoke with the cask trunnions and verify that it is properly engaged.

11. Raise the transfer cask to the pool surface. Prior to raising the top of the cask above the water surface, stop vertical movement.

12. Inspect the top shield plug to verify that it is properly seated onto the DSC. If not, lower the cask and reposition the top shield plug. Repeat Steps 11 and 12 as necessary.

13. Continue to raise the cask from the pool and spray the exposed portion of the cask with demineralized water until the top region of the cask is accessible.

14. Drain any excess water from the top of the DSC shield plug back to the fuel pool.

15. Drain approximately 1100 gallons of water (as indicated on the rotometer) from the DSC back into the fuel pool or other suitable location using the VDS or optional liquid pump.

16. Lift the cask from the fuel pool. As the cask is raised from the pool, continue to spray the cask with demineralized water.

17. Move the transfer cask with loaded DSC to the cask decon area.

18. Replace the approximate 1100 gallons of water removed (as indicated on the rotometer) from the DSC with demineralized water or spent fuel pool water. Fill the neutron shield with demineralized water.

19. Install TC seismic restraints if required by Technical Specification 1.2.16 (required only on plant specific basis).

K.8.1.3 DSC Drying and Backfilling

1. Check the radiation levels along the perimeter of the cask. The cask exterior surface should be decontaminated as necessary in accordance with the limits specified in Technical Specification 1.2.12. Temporary shielding may be installed as necessary to minimize personnel exposure.

2. Place scaffolding around the cask so that any point on the surface of the cask is easily accessible to personnel.

3. Disengage the rigging cables from the top shield plug and remove the eyebolts. Disengage the lifting yoke from the trunnions and position it clear of the cask.

4. Decontaminate the exposed surfaces of the DSC shell perimeter and remove the inflatable cask/DSC annulus seal.

5. Connect the cask drain line to the cask, open the cask cavity drain port and allow water from the annulus to drain out until the water level is approximately twelve inches below the top edge of the DSC shell. Take swipes around the outer surface of the DSC shell and check for smearable contamination in accordance with the Technical Specification 1.2.12 limits.

6. Drain approximately 1100 gallons of water (as indicated on a rotometer) from the DSC back into the fuel pool or other suitable location using the VDS or an optional liquid pump.

7. Disconnect hose from the DSC siphon port.

8. Install the automatic welding machine onto the inner top cover plate and place the inner top cover plate with the automatic welding machine onto the DSC. Verify proper fit-up of the inner top cover plate with the DSC shell.

9. Check radiation levels along surface of the inner top cover plate. Temporary shielding may be installed as necessary to minimize personnel exposure.

10. Insert a ¼ inch tygon tubing of sufficient length through the vent port such that it terminates just below the DSC shield plug. Connect the tygon tubing to a hydrogen

monitor to allow continuous monitoring of the hydrogen atmosphere in the DSC cavity during welding of the inner cover plate.

11. Cover the cask/DSC annulus to prevent debris and weld splatter from entering the annulus.

12. Ready the automatic welding machine and tack weld the inner top cover plate to the DSC shell. Install the inner top cover plate weldment and remove the automatic welding machine.

    CAUTION: Continuously monitor the hydrogen concentration in the DSC cavity using the tygon tube arrangement described in step 9 during the inner top cover plate cutting/welding operations. Verify that the measured hydrogen concentration does not exceed a safety limit of 2.4% (8.4). If this limit is exceeded, stop all welding operations and purge the DSC cavity with 2-3 psig helium (or any other inert medium) via the ¼" tygon tubing to reduce the hydrogen concentration safely below the 2.4% limit.

13. Perform dye penetrant weld examination of the inner top cover plate weld in accordance with the Technical Specification 1.2.5 requirements.

14. Place the strongback so that it sits on the inner top cover plate and is oriented such that:

    - the DSC siphon and vent ports are accessible;

    - the strongback stud holes line up with the TC lid bolt holes.

15. Lubricate the studs and, using a crossing pattern, adjust the strongback studs to snug tight ensuring approximately even pressure on the cover plate.

16. Connect the VDS to the DSC siphon and vent ports.

17. Install temporary shielding to minimize personnel exposure throughout the subsequent welding operations as required.

18. Engage the compressed air, nitrogen or helium supply and open the valve on the vent port and allow compressed gas to force the water from the DSC cavity through the siphon port.

19. Once the water stops flowing from the DSC, close the DSC siphon port and disengage the gas source.

20. Open the cask drain port valve and remove the remaining water from the cask/DSC annulus. (This step may be performed after completion of the vacuum drying procedure).

21. Connect the hose from the vent port and the siphon port to the intake of the vacuum pump. Connect a hose from the discharge side of the VDS to the plant's radioactive waste system or spent fuel pool. Connect the VDS to a helium source.

22. Open the valve on the suction side of the pump, start the VDS and draw a vacuum on the DSC cavity. The cavity pressure should be reduced in steps of approximately 100 mm Hg, 50 mm Hg, 25 mm Hg, 15 mm Hg, 10 mm Hg, 5 mm Hg, and 3 mm Hg. After pumping down to each level, the pump is valved off and the cavity pressure monitored. The cavity pressure will rise as water and other volatiles in the cavity evaporate. When the cavity pressure stabilizes, the pump is valved in to complete the vacuum drying process. It may be necessary to repeat some steps, depending on the rate and extent of the pressure increase. Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg or less as specified in Technical Specification 1.2.2. A time limit of 96 hours for duration of the vacuum drying exists per Technical Specification 1.2.17 to ensure that the 61BT DSC basket structure does not exceed 800°F.

23. Open the valve to the vent port and allow the helium to flow into the DSC cavity.

24. Pressurize the DSC with helium to about 24 psia not to exceed 34 psia.

25. Helium leak test the inner top cover plate weld for leakage in accordance with ANSI N14.5 to a sensitivity of 1 X 10^{-5} atm cm^3/sec.

26. If a leak is found, repair the weld, repressurize the DSC and repeat the helium leak test.

27. Once no leaks are detected, depressurize the DSC cavity by releasing the helium through the VDS to the plant's spent fuel pool or radioactive waste system.

28. Re-evacuate the DSC cavity using the VDS. The cavity pressure should be reduced in steps of approximately 10 mm Hg, 5 mm Hg, and 3 mm Hg. After pumping down to each level, the pump is valved off and the cavity pressure is monitored. When the cavity pressure stabilizes, the pump is valved in to continue the vacuum drying process. Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg or less in accordance with Technical Specification 1.2.2 limits.

29. Open the valve on the vent port and allow helium to flow into the DSC cavity to pressurize the DSC to about 17.2 psia in accordance with Technical Specification 1.2.3a limits.

30. Close the valves on the helium source.

31. Remove the Strongback, decontaminate as necessary, and store.

K.8.1.4 DSC Sealing Operations

1. Disconnect the VDS from the DSC. Seal weld the prefabricated plugs over the vent and siphon ports and perform a dye penetrant weld examination in accordance with the Technical Specification 1.2.5 requirements.

2. Install the automatic welding machine onto the outer top cover plate and place the outer top cover plate with the automatic welding system onto the DSC. Verify proper fit up of the outer top cover plate with the DSC shell.

3. Tack weld the outer top cover plate to the DSC shell. Place the outer top cover plate weld root pass.

4. Helium leak test the inner top cover plate and vent/siphon port plate welds using the leak test port in the outer top cover plate in accordance with Technical Specification 1.2.4a limits.

5. If a leak is found, remove the outer cover plate root pass, the vent and siphon port plugs and repair the inner cover plate welds. Then install the Strongback and repeat procedure steps from K.8.1.3 step 22.

6. Perform dye penetrant examination of the root pass weld. Weld out the outer top cover plate to the DSC shell and perform dye penetrant examination on the weld surface in accordance with the Technical Specification 1.2.5 requirements.

7. Seal weld the prefabricated plug over the outer cover plate test port and perform dye penetrant weld examinations in accordance with Technical Specification 1.2.5 requirement.

8. Remove the automatic welding machine from the DSC. Rig the cask top cover plate and lower the cover plate onto the transfer cask.

9. Bolt the cask cover plate into place, tightening the bolts to the required torque in a star pattern.

K.8.1.5 Transfer Cask Downending and Transport to ISFSI

NOTE:

Alternate Procedure for Downending of Transfer Cask: Some plants have limited floor hatch openings above the cask/trailer/skid, which limit crane travel (within the hatch opening) that would be needed in order to downend the TC with the trailer/skid in a stationary position. For these situations, alternate procedures are to be developed on a plant-specific basis, with detailed steps for downending.

1. Drain the neutron shield to an acceptable location.

2. Re-attach the transfer cask lifting yoke to the crane hook, as necessary. Ready the transport trailer and cask support skid for service.

3. Move the scaffolding away from the cask as necessary. Engage the lifting yoke and lift the cask over the cask support skid on the transport trailer.

4. The transport trailer should be positioned so that cask support skid is accessible to the crane with the trailer supported on the vertical jacks.

5. Position the cask lower trunnions onto the transfer trailer support skid pillow blocks.

6. Move the crane forward while simultaneously lowering the cask until the cask upper trunnions are just above the support skid upper trunnion pillow blocks.

7. Inspect the positioning of the cask to insure that the cask and trunnion pillow blocks are properly aligned.

8. Lower the cask onto the skid until the weight of the cask is distributed to the trunnion pillow blocks.

9. Inspect the trunnions to insure that they are properly seated onto the skid and install the trunnion tower closure plates.

10. Fill the neutron shield.

11. Remove the bottom ram access cover plate from the cask. Install the two-piece temporary neutron/gamma shield plug to cover the bottom ram access. Install the ram trunnion support frame on the bottom of the transfer cask. (The temporary shield plug and ram trunnion support frame are not required with integral ram/trailer.)

K.8.1.6 DSC Transfer to the HSM

1. Prior to transporting the cask to the ISFSI or prior to positioning the transfer cask at the HSM designated for storage, remove the HSM door using a porta-crane, inspect the cavity of the HSM, removing any debris and ready the HSM to receive a DSC. The doors on adjacent HSMs should remain in place.

2. Inspect the HSM air inlet and outlets to ensure that they are clear of debris. Inspect the screens on the air inlet and outlets for damage.

CAUTION: Verify that the requirements of Technical Specification 1.2.14, "TC/DSC Transfer Operations at High Ambient Temperatures" are met prior to next step.

3. Using a suitable heavy haul tractor, transport the cask from the plant's fuel/reactor building to the ISFSI along the designated transfer route.

4. Once at the ISFSI, position the transport trailer to within a few feet of the HSM.

5. Check the position of the trailer to ensure the centerline of the HSM and cask approximately coincide. If the trailer is not properly oriented, reposition the trailer, as necessary.

6. Using a porta-crane, unbolt and remove the cask top cover plate.

7. Back the cask to within a few inches of the HSM, set the trailer brakes and disengage the tractor. Drive the tractor clear of the trailer. Extend the transfer trailer vertical jacks.

8. Connect the skid positioning system hydraulic power unit to the positioning system via the hose connector panel on the trailer, and power it up. Remove the skid tie-down bolts and use the skid positioning system to bring the cask into approximate vertical and horizontal alignment with the HSM. Using optical survey equipment and the alignment marks on the cask and the HSM, adjust the position of the cask until it is properly aligned with the HSM.

9. Using the skid positioning system, fully insert the cask into the HSM access opening docking collar.

10. Secure the cask trunnions to the front wall embedments of the HSM using the cask restraints.

11. After the cask is docked with the HSM, verify the alignment of the transfer cask using the optical survey equipment.

12. Position the hydraulic ram behind the cask in approximate horizontal alignment with the cask and level the ram. Remove either the bottom ram access cover plate or the outer plug of the two-piece temporary shield plug. Power up the ram hydraulic power supply and extend the ram through the bottom cask opening into the DSC grapple ring.

13. Activate the hydraulic cylinder on the ram grapple and engage the grapple arms with the DSC grapple ring.

14. Recheck all alignment marks in accordance with the Technical Specification 1.2.9 limits and ready all systems for DSC transfer.

15. Activate the hydraulic ram to initiate insertion of the DSC into the HSM. Stop the ram when the DSC reaches the support rail stops at the back of the module.

16. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.

17. Retract and disengage the hydraulic ram system from the cask and move it clear of the cask. Remove the cask restraints from the HSM.

18. Using the skid positioning system, disengage the cask from the HSM access opening. Insert the inner tube of the DSC axial retainer.

19. Install the HSM door using a portable crane and secure it in place.

20. Replace the transfer cask top cover plate. Secure the skid to the trailer, retract the vertical jacks and disconnect the skid positioning system.

21. Tow the trailer and cask to the designated equipment storage area. Return the remaining transfer equipment to the storage area.

22. Close and lock the ISFSI access gate and activate the ISFSI security measures.

K.8.1.7 Monitoring Operations

1. Perform routine security surveillance in accordance with the licensee's ISFSI security plan.

2. Perform a daily visual surveillance of the HSM air inlets and outlets to insure that no debris is obstructing the HSM vents in accordance with Technical Specification 1.3.1 requirements.

3. Perform a temperature measurement of the thermal performance, for each HSM, on a daily basis in accordance with Technical Specification 1.3.2 requirements.

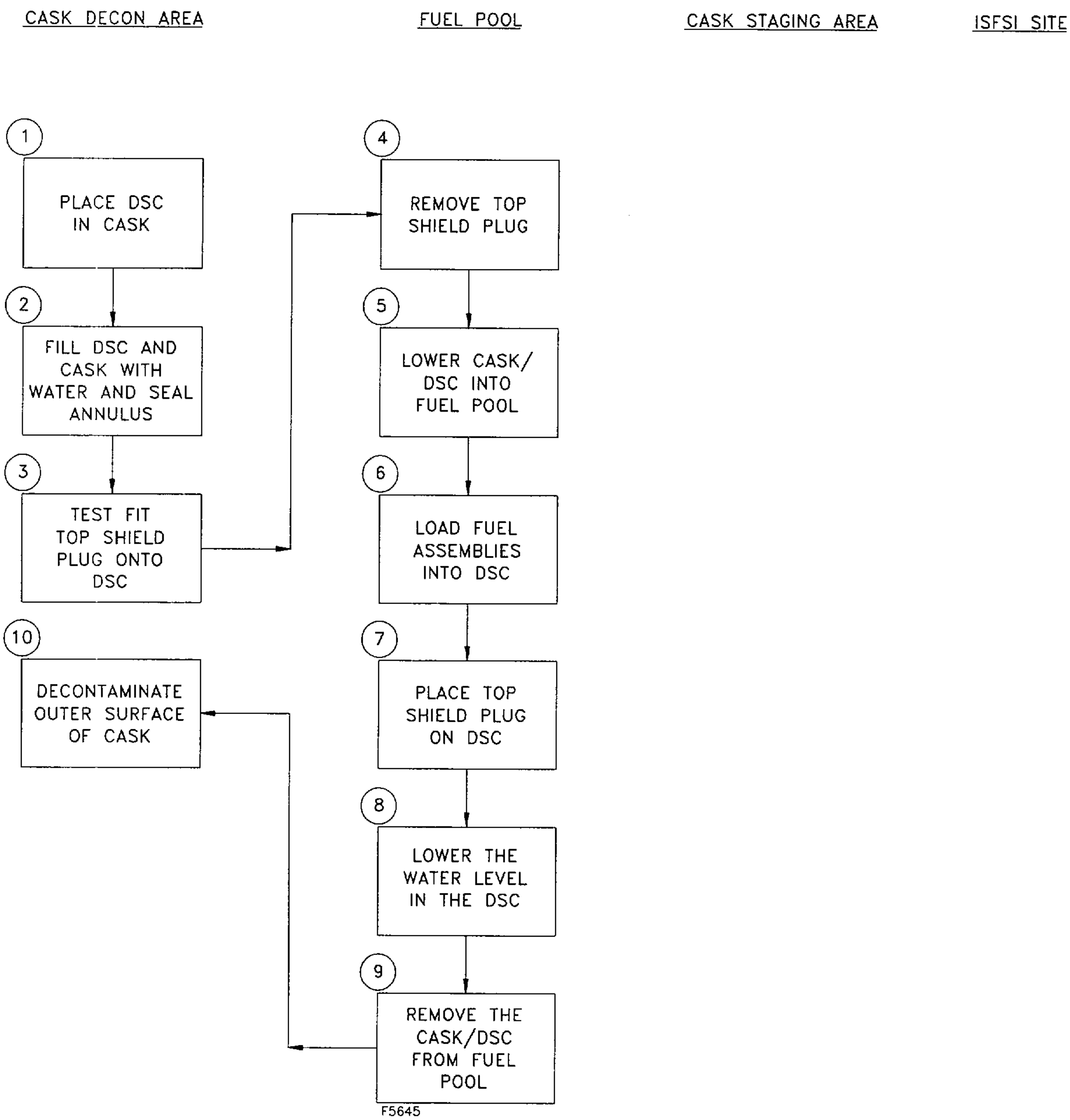


Figure K.8.1-1
NUHOMS® System Loading Operations Flow Chart

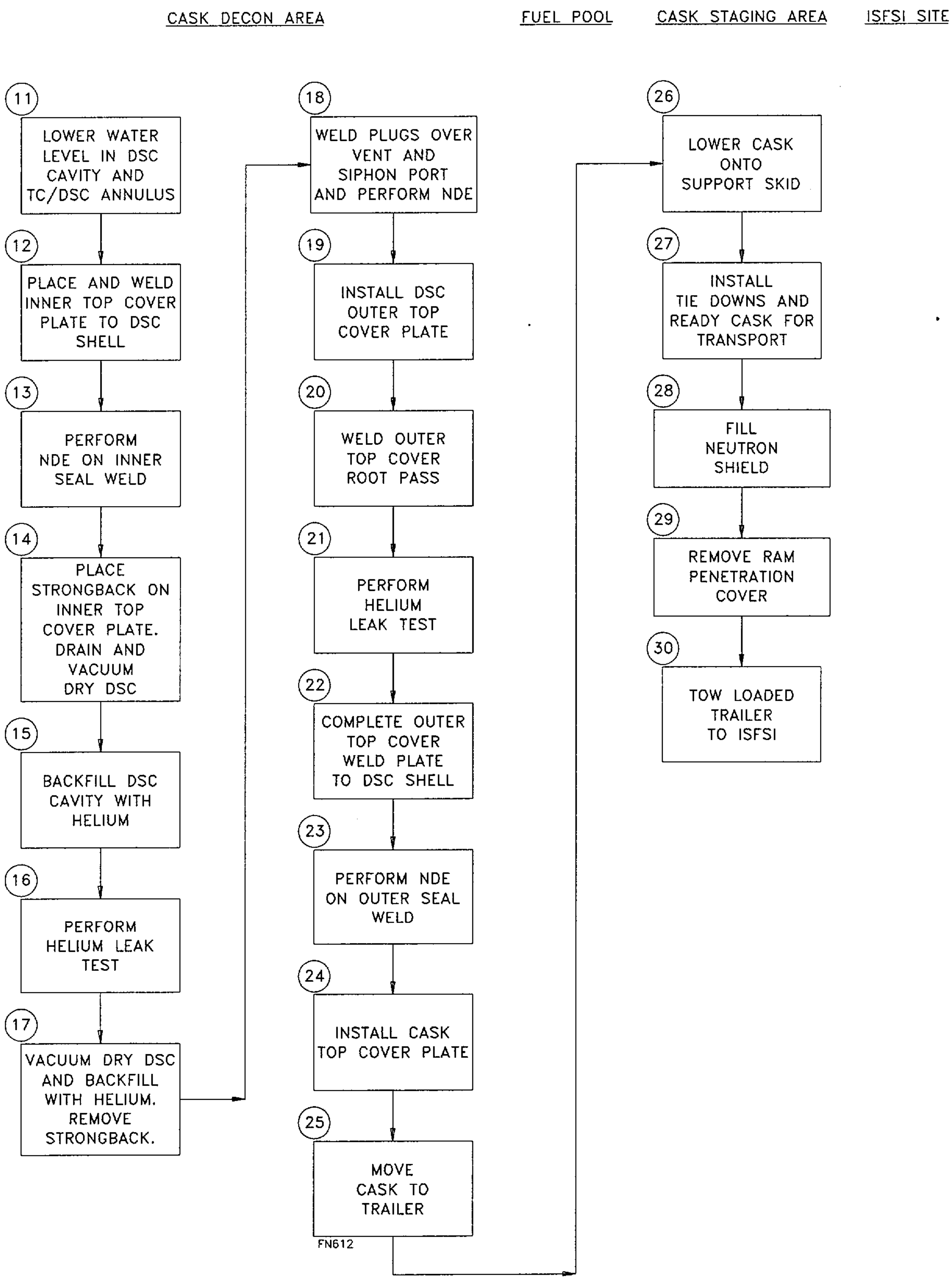


Figure K.8.1-1
NUHOMS® System Loading Operations Flow Chart
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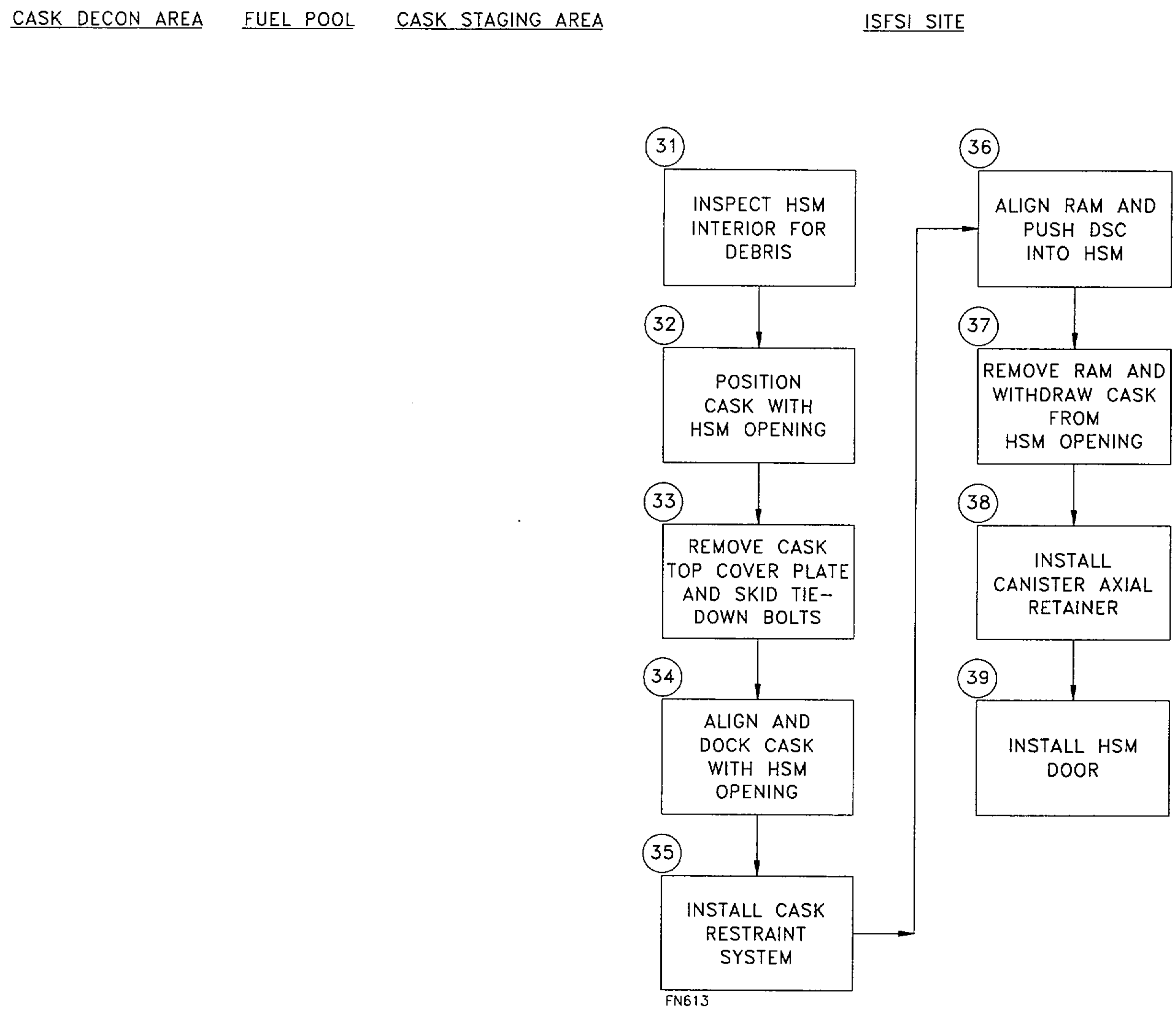

Figure K.8.1-1
NUHOMS® System Loading Operations Flow Chart
(concluded)

K.8.2 Procedures for Unloading the Cask

K.8.2.1 DSC Retrieval from the HSM

1. Ready the transfer cask, transport trailer, and support skid for service and tow the trailer to the HSM.

2. Back the trailer to within a few inches of the HSM and remove the cask top cover plate.

3. Remove the HSM door using a porta-crane. Remove the inner tube of the DSC axial retainer.

4. Using the skid positioning system, align the cask with the HSM and position the skid until the cask is docked with the HSM access opening.

5. Using optical survey equipment, verify alignment of the cask with respect to the HSM. Install the cask restraints.

6. Install and align the hydraulic ram with the cask.

7. Extend the ram through the cask into the HSM until it is inserted in the DSC grapple ring.

8. Activate the arms on the ram grapple mechanism with the DSC grapple ring.

9. Retract ram and pull the DSC into the cask.

10. Retract the ram grapple arms.

11. Disengage the ram from the cask.

12. Remove the cask restraints.

13. Using the skid positioning system, disengage the cask from the HSM.

14. Install the cask top cover plate and ready the trailer for transport.

15. Replace the door on the HSM.

K.8.2.2 Removal of Fuel from the DSC

When the DSC has been removed from the HSM, there are several potential options for off-site shipment of the fuel. It is preferred to ship the DSC intact to a reprocessing facility, monitored retrievable storage facility or permanent geologic repository in a compatible shipping cask licensed under 10CFR71.

If it becomes necessary to remove fuel from the DSC prior to off-site shipment, there are two basic options available at the ISFSI or reactor site. The fuel assemblies could be removed and reloaded into a shipping cask using dry transfer techniques, or if the applicant so desires, the initial fuel loading sequence could be reversed and the plant's spent fuel pool utilized. Procedures for unloading the DSC in a fuel pool are presented here. However, wet or dry unloading procedures are essentially identical to those of DSC loading through the DSC weld removal (beginning of preparation to placement of the cask in the fuel pool). Prior to opening the DSC, the following operations are to be performed.

1. The cask may now be transported to the cask handling area inside the plant's fuel/reactor building.

2. Position and ready the trailer for access by the crane and install the ram access penetration cover plate.

3. Attach the lifting yoke to the crane hook.

4. Engage the lifting yoke with the trunnions of the cask.

5. Visually inspect the yoke lifting hooks to insure that they are properly aligned and engaged onto the cask trunnions.

6. Drain water from the neutron shield.

7. Lift the cask approximately one inch off the trunnion supports. Visually inspect the yoke lifting hooks to insure that they are properly positioned on the trunnions.

8. Move the crane backward in a horizontal motion while simultaneously raising the crane hook vertically and lift the cask off the trailer. Move the cask to the cask decon area.

9. Lower the cask into the cask decon area in the vertical position.

10. Wash the cask to remove any dirt which may have accumulated on the cask during the DSC loading and transfer operations.

11. Place scaffolding around the cask so that any point on the surface of the cask is easily accessible to handling personnel.

12. Unbolt the cask top cover plate.

13. Connect the rigging cables to the cask top cover plate and lift the cover plate from the cask. Set the cask cover plate aside and disconnect the lid lifting cables.

14. Install temporary shielding to reduce personnel exposure as required. Fill the cask/DSC annulus with clean demineralized water and seal the annulus.

The process of DSC unloading is similar to that used for DSC loading. DSC opening operations described below are to be carefully controlled in accordance with plant procedures. This operation is to be performed under the site's standard health physics guidelines for welding, grinding, and handling of potentially highly contaminated equipment. These are to include the use of prudent housekeeping measures and monitoring of airborne particulates. Procedures may require personnel to perform the work using respirators or supplied air.

If fuel needs to be removed from the DSC, either at the end of service life or for inspection after an accident, precautions must be taken against the potential for the presence of damaged or oxidized fuel and to prevent radiological exposure to personnel during this operation. A sampling of the atmosphere within the DSC will be taken prior to inspection or removal of fuel.

If the work is performed outside the fuel/reactor building, a tent may be constructed over the work area, which may be kept under a negative pressure to control airborne particulates. Any radioactive gas release will be Kr-85, which is not readily captured. Whether the krypton is vented through the plant stack or allowed to be released directly depends on the plant operating requirements.

Following opening of the DSC, the cask and DSC are filled with water prior to lowering the top of cask below the surface of the fuel pool to prevent a sudden inrush of pool water. Cask placement into the pool is performed in the usual manner. Fuel unloading procedures will be governed by the plant operating license under 10CFR50. The generic procedures for these operations are as follows:

15. Locate the DSC siphon and vent port using the indications on the top cover plate. Place a portable drill press on the top of the DSC. Position the drill with the siphon port.

16. Place an exhaust hood or tent over the DSC, if necessary. The exhaust should be filtered or routed to the site radwaste system.

17. Drill a hole through the DSC top cover plate to expose the siphon port quick connect.

18. Drill a second hole through the top cover plate to expose the vent port quick connect.

19. Obtain a sample of the DSC atmosphere, if necessary (e.g., at the end of service life). Fill the DSC with water from the fuel pool through the siphon port with the vent port open and routed to the plant's off-gas system.

    CAUTION:

    (a) The water fill rate must be regulated during this reflooding operation to ensure that the DSC vent pressure does not exceed 20.0 psig.

    (b) Provide for continuous hydrogen monitoring of the DSC cavity atmosphere during all subsequent cutting operations to ensure that a safety limit of 2.4% is not exceeded (8.4). Purge with 2-3 psig helium (or any other inert medium) as necessary to maintain the hydrogen concentration safely below this limit.

20. Place welding blankets around the cask and scaffolding.

21. Using plasma arc-gouging, a mechanical cutting system or other suitable means, remove the seal weld from the outer top cover plate and DSC shell. A fire watch should be placed on the scaffolding with the welder, as appropriate. The exhaust system should be operating at all times.

22. The material or waste from the cutting or grinding process should be treated and handled in accordance with the plant's low level waste procedures unless determined otherwise.

23. Remove the top of the tent, if necessary.

24. Remove the exhaust hood, if necessary.

25. Remove the DSC outer top cover plate.

26. Reinstall tent and temporary shielding, as required. Remove the seal weld from the inner top cover plate to the DSC shell in the same manner as the top cover plate. Remove the inner top cover plate. Remove any remaining excess material on the inside shell surface by grinding.

27. Clean the cask surface of dirt and any debris which may be on the cask surface as a result of the weld removal operation. Any other procedures which are required for the operation of the cask should take place at this point as necessary.

28. Engage the yoke onto the trunnions, install eyebolts into the top shield plug and connect the rigging cables to the eyebolts.

29. Visually inspect the lifting hooks or the yoke to insure that they are properly positioned on the trunnions.

30. Drain approximately 1100 gallons of water from the DSC.

31. The cask should be lifted just far enough to allow the weight of the transfer cask to be distributed onto the yoke lifting hooks. Inspect the lifting hooks to insure that they are properly positioned on the trunnions.

32. Install suitable protective material onto the bottom of the transfer cask to minimize cask contamination. Move the cask to the fuel pool.

33. Prior to lowering the cask into the pool, adjust the pool water level, if necessary, to accommodate the volume of water which will be displaced by the cask during the operation.

34. Lower the cask into the fuel pool leaving the top surface of the cask approximately one foot above the surface of the pool water.

35. Fill the DSC with pool water.

36. Position the cask over the cask loading area in the fuel pool

37. Lower the cask into the pool. As the cask is being lowered, the exterior surface of the cask should be sprayed with clean demineralized water.

38. Disengage the lifting yoke from the cask and lift the top shield plug from the DSC.

39. Remove the holddown ring. If the DSC contains damaged fuel assemblies, remove the top end caps. Remove the fuel from the DSC and place the fuel into the spent fuel racks.

40. Lower the top shield plug onto the DSC.

41. Visually verify that the top shield plug is properly positioned onto the DSC.

42. Engage the lifting yoke onto the cask trunnions.

43. Visually verify that the yoke lifting hooks are properly engaged with the cask trunnions.

44. Lift the cask by a small amount and verify that the lifting hooks are properly engaged with the trunnions.

45. Lift the cask to the pool surface. Prior to raising the top of the cask to the water surface, stop vertical movement and inspect the top shield plug to ensure that it is properly positioned.

46. Spray the exposed portion of the cask with demineralized water.

47. Visually inspect the top shield plug of the DSC to insure that it is properly seated onto the cask. If the top shield plug is not properly seated, lower the cask back to the fuel pool and reposition the plug.

48. Drain any excess water from the top of the top shield plug into the fuel pool.

49. Lift the cask from the pool. As the cask is rising out of the pool, spray the cask with demineralized water.

50. Move the cask to the cask decon area.

51. Check radiation levels around the perimeter of the cask. The cask exterior surface should be decontaminated if necessary.

52. Place scaffolding around the cask so that any point along the surface of the cask is easily accessible to personnel.

53. Ready the DSC vacuum drying system (VDS).

54. Connect the VDS to the vent port with the system open to atmosphere. Also connect the VDS to the siphon port and connect the other end of the system to the liquid pump. The pump discharge should be routed to the plant radwaste system or the spent fuel pool.

55. Open the valves on the vent port and siphon port of the VDS.

56. Activate the liquid pump.

57. Once the water stops flowing out of the DSC, deactivate the pump.

58. Close the valves on the VDS.

59. Disconnect the VDS from the vent and siphon ports.

60. The top cover plates may be welded into place as required.

61. Decontaminate the DSC, as necessary, and handle in accordance with low-level waste procedures. Alternatively, the DSC may be repaired for reuse.

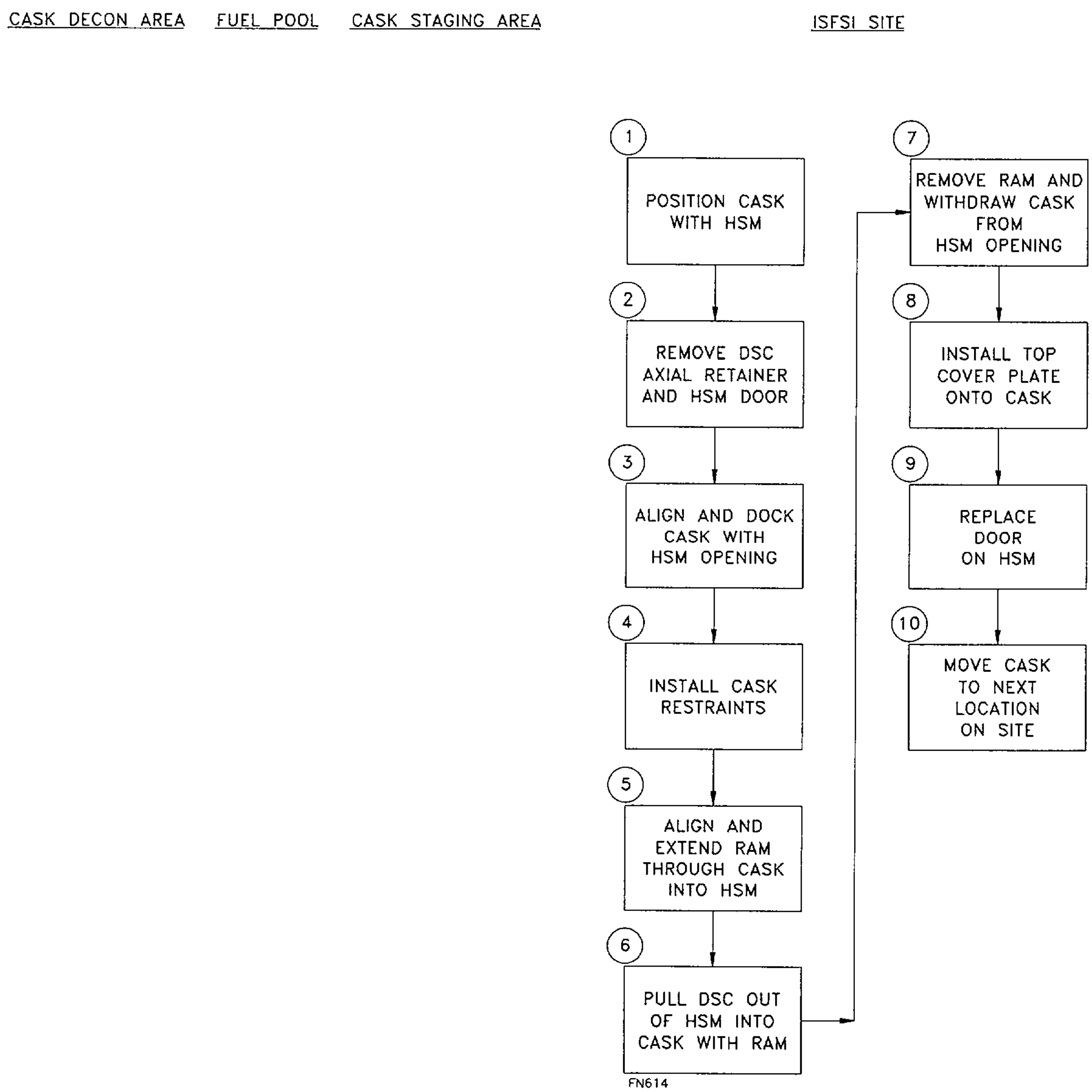

Figure K.8.2-1
NUHOMS® System Retrieval Operations Flow Chart

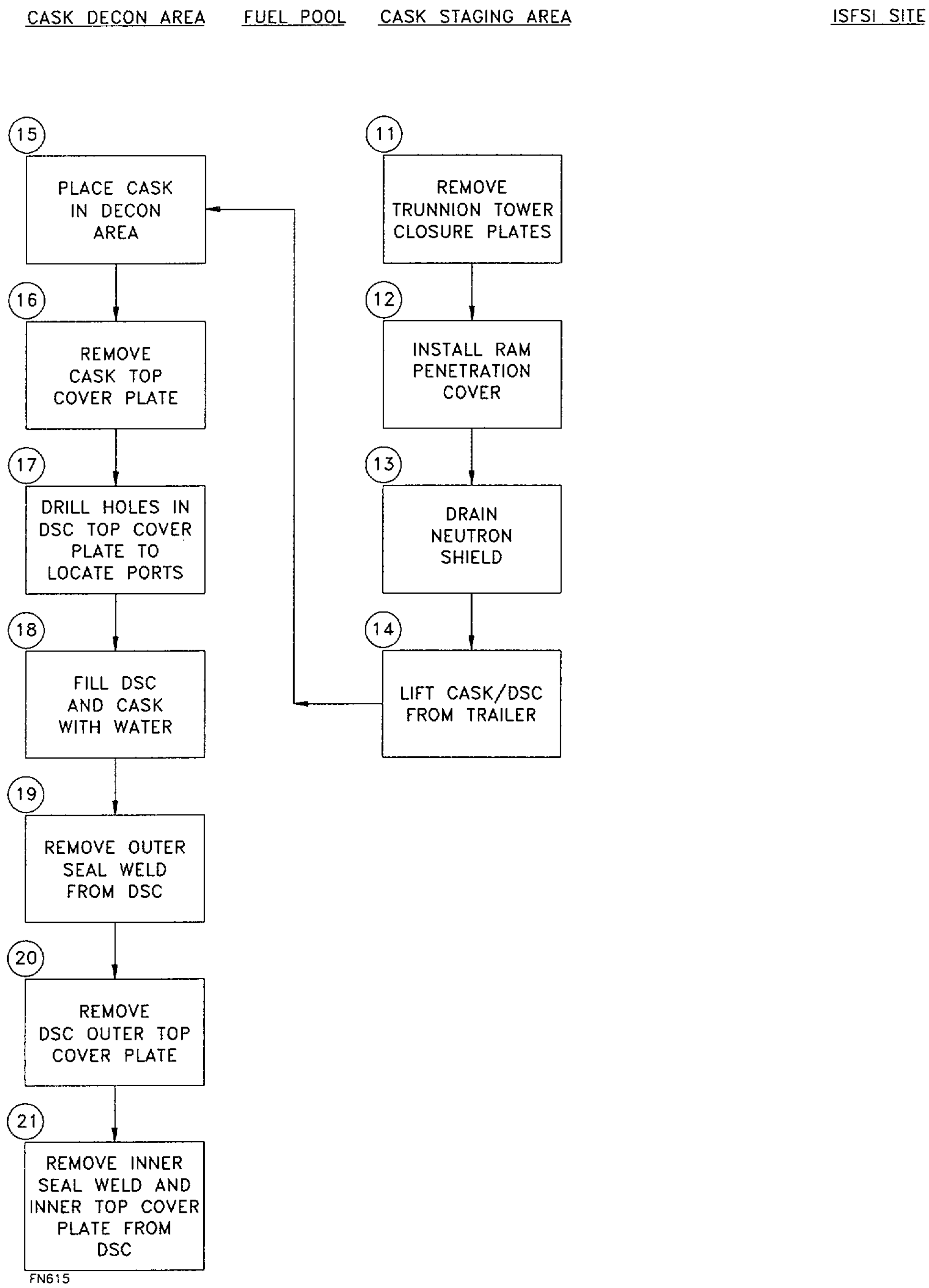

Figure K.8.2-1
NUHOMS® System Retrieval Operations Flow Chart

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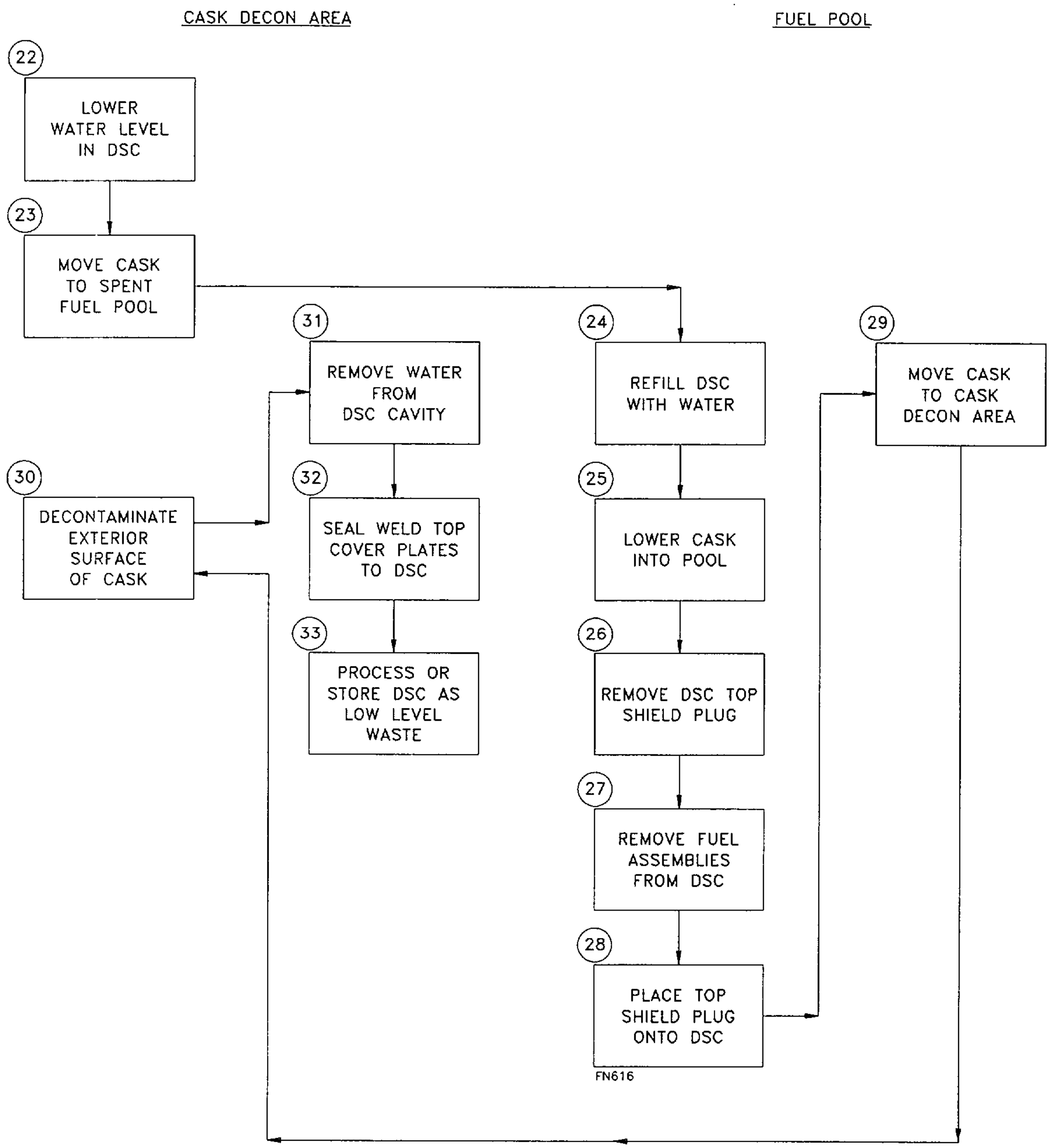

Figure K.8.2-1
NUHOMS® System Retrieval Operations Flow Chart

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K.8.3 Identification of Subjects for Safety Analysis

No change.

K.8.4 Fuel Handling Systems

No change.

K.8.5 Other Operating Systems

No change.

K.8.6 Operation Support System

No change.

K.8.7 Control Room and/or Control Areas

No change.

K.8.8 Analytical Sampling

No change.

K.8.9 References

8.1 U.S. Nuclear Regulatory Commission, "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Container," Regulatory Guide 3.61 (February 1989).

8.2 Deleted.

8.3 Deleted.

8.4 U. S. Nuclear Regulatory Commission, Office of the Nuclear Material Safety and Safeguards, "Safety Evaluation of VECTRA Technologies' Response to Nuclear Regulatory Commission Bulletin 96-04 for the NUHOMS®-24P and NUHOMS®–7P.

8.5 U. S. Nuclear Regulatory Commission Bulletin 96-04, "Chemical, Galvanic or Other Reactions in Spent Fuel Storage and Transportation Casks," July 5, 1996.