A.Alloy X Fuel baskets (ASME Code material)
B. Metamic-HT baskets (Non-Code material)

A. Alloy X Baskets

An alloy X basket is one in which the structural function is rendered by Alloy X (defined below) and the neturon absorption function is rendered by Metamic (classic). As explained in Appendix 1.A, Alloy X (as defined in this FSAR) may be one of the following materials:

- Type 316
- Type 316LN
- Type 304
- Type 304LN

Any stainless steel part in an MPC may be fabricated from any acceptable Alloy X materials listed above. Additional material grades (viz. duplex stainless steel, UNS S31803) are adopted in the Alloy X roster in Appendix 1.A. These duplex steels shall not be used for the fabrication of MPC baskets and internal components. Additional basket material types may be adopted in the Alloy X roster if determined to be acceptable through the §72.48 process.

The Alloy X approach is accomplished by qualifying the MPC for all mechanical, structural, neutronic, radiological, and thermal conditions using material thermophysical properties that are the least favorable for the entire group for the analysis in question. For example, when calculating the rate of heat rejection to the outside environment, the value of thermal conductivity used is the lowest for the candidate material group. Similarly, the stress analysis calculations use the lowest value of the ASME Code allowable stress intensity for the entire group. Stated differently, we have defined a material, which is referred to as Alloy X, whose thermophysical properties, from the MPC design perspective, are the least favorable of the candidate materials.

The evaluation of the candidate Alloy X materials to determine the least favorable properties is provided in Appendix 1.A. The Alloy X approach is conservative because no matter which material is ultimately utilized in the MPC construction, it guarantees that the performance of the MPC will exceed the analytical predictions contained in this document.

In Alloy X baskets, the Metamic neutron absorber panels are completely enclosed in stainless steel sheathing that is stitch welded to the MPC basket cell walls along their entire periphery. The edges of the sheathing are bent toward the cell wall to make the edge weld. Thus, the neutron absorber is contained in a tight, welded pocket enclosure. The shear strength of the pocket weld joint, which is an order of magnitude greater than the weight of a fuel assembly, guarantees that the neutron absorber and its enveloping sheathing pocket will maintain their as-installed position under all loading, storage, and transient evolutions. Finally, the pocket joint detail ensures that fuel assembly insertion or withdrawal into or out of the MPC basket will not lead to a disconnection of the sheathing from the cell wall.

B. Metamic HT Baskets

APPENDIX 1.A: ALLOY X DESCRIPTION

1.A ALLOY X DESCRIPTION

1.A.1 Alloy X Introduction

Alloy X is used within this licensing application to designate a group of stainless steel alloys. Alloy X can be any one of the following alloys:

- Type 316
- Type 316LN
- Type 304
- Type 304LN
- Duplex Stainless Alloy S31803 [1.A.3]

Qualification of structures made of Alloy X is accomplished by using the least favorable mechanical and thermal properties of the entire group for all MPC mechanical, structural, neutronic, radiological, and thermal conditions. The Alloy X approach is conservative because no matter which material is ultimately utilized, the Alloy X approach guarantees that the performance of the MPC will meet or exceed the analytical predictions.

Duplex stainless steels (DSS) are sensitive to the manufacturing processes employed in welding operations. Control of microstructure stability plays a vital role. The intermetallic microstructure is a complex function of the attendant parameters. For example, Cr and Mo promote ferrite and intermetallic phases, whereas N and Ni promote austenite.

During welding the balance between the ferritic and austenitic phases may be disturbed due to ferritization at high temperatures associated with welding operations. Ferrite content over 70% will lead to lower ductility and reduced corrosion resistance. Coarse ferritic grains are harmful for DSS toughness besides of impairing the austenite reformation at the heat affected zone (HAZ) [1.A.5]. The best metallurgical condition for welding is achieved by the most rapid quenching from the annealing temperature that produces a fine grained DSS structure with the required ferrite content (less than 70%).

Besides the austenite-ferrite phase balance, the second major concern with duplex steels and their chemical composition is the formation of detrimental intermetallic phases, precipitating preferentially in the ferrite, at elevated temperatures in the range of approximately 600 - 1750°F reaching an uncertain state of fragility at 887°F [1.A.4] and above. The mechanical (toughness) and corrosion properties of the weld and HAZ are deteriorated due to the presence of intermetallic phases.

Welding of DSS is associated with problems in HAZ which can be loss of corrosion, toughness, or post-weld cracking. The heat input and cooling rates in welding are important as they control ferrite to austenite transformation. Exceedingly low heat input may result in fusion zones and

HAZ which are excessively ferritic (above 70%) [1.A.6]. Exceedingly high heat input increases the danger of forming intermetallic phases [1.A.6]. In both cases the impact toughness and corrosion resistance of the DSS will be seriously affected. Hence, heat input must be 0.6 – 2.6 kJ/mm to retain the phase balance, limit the width of the HAZ, and obtain a sigma phase free product [1.A.5]. Further, cooling rate from the solution annealing temperature must exceed 0.3°C/s to avoid sigma phase and satisfy the generally accepted toughness requirements [1.A.8]. The maximum interpass temperature is limited to 150°C (302°F) [1.A.6].

DSS have chloride stress corrosion cracking (CSCC) resistance significantly greater than that of the austenitic stainless steels, but they are not completely immune. Experimental results indicate that DSS is prone to stress corrosion cracking at temperatures above 100°C [1.A.9]. Poor welding practice, a low pH, presence of Hydrogen in welds, and/or high ferrite (>70%) can contribute to failures at temperatures below 100°C.

Holtec will make sure that this material shall be used *only* if the metal temperature of the MPC shell can be assured to remain below the limit in Table 1.A.6 under all *normal operating* modes [1.A.3]. Likewise, under short term and accident conditions, such as the “inlet duct blockage” scenario, the maximum metal temperature of duplex stainless steel must be held below the limit in Table 1.A.6.

To confirm that the required properties are achieved in production, Holtec will implement a test program to insure that the weldments are tested for the absence of detrimental intermetallic phases. The test program will comply with ASTM A923 and will use metallographic examination, impact testing and corrosion testing to demonstrate the absence of such detrimental phases. The test will be intended to determine the presence or absence of intermetallic phase to the extent that it is detrimental to the toughness and corrosion resistance of the material. The test *shall* be implemented to products during weld procedure qualification as well as during fabrication which will provide the assurance that the weldments are *free* from detrimental intermetallic phases, and *provide* the required corrosion resistance and fracture toughness [1.A.7].

It is noted that DSS material shall not be used for the fabrication of MPC baskets and MPC internal components. For other stainless steels listed as members of Alloy X above, the design temperature limits in Table 2.2.3 remain unmodified. It is also noted that DSS shall be used only in aboveground systems.

This appendix defines the least favorable material properties of Alloy X.

1.A.2 Alloy X Common Material Properties

Several material properties do not vary significantly from one Alloy X constituent to the next. These common material properties are as follows:

- density
- specific heat
- Young's Modulus (Modulus of Elasticity)

- Poisson's Ratio

The comparative values for Modulus of Elasticity at different temperatures are provided in Table 1.A.7. The values utilized for this licensing application are provided in their appropriate chapters.

1.A.3 Alloy X Least Favorable Material Properties

The following material properties vary between the Alloy X constituents:

- Design Stress Intensity (S_m)
- Tensile (Ultimate) Strength (S_u)
- Yield Strength (S_y)
- Coefficient of Thermal Expansion (α)
- Coefficient of Thermal Conductivity (k)

Each of these material properties are provided in the ASME Code Section II [1.A.10]. Tables 1.A.1 through 1.A.5 provide the ASME Code values for each constituent of Alloy X along with the least favorable value utilized in this licensing application. The ASME Code only provides values from -20°F. The design temperature of the MPC is -40°F, below -20°F, as stated in Table 1.2.2. Most of the above-mentioned properties improve as the temperature drops. For this reason, the values at the lowest design temperature for the HI-STORM 100 System have been assumed to be equal to the lowest value stated in the ASME Code. The lone exceptions are the coefficient of thermal expansion and thermal conductivity. As they decrease with decreasing temperature, its value for -40°F is linearly extrapolated from the 70°F value with the slope based on data from 70°F to 100°F.

The Alloy X material properties are the minimum values of the group for the design stress intensity, tensile strength, yield strength, and coefficient of thermal conductivity. Using minimum values of design stress intensity is conservative because lower design stress intensities lead to lower allowables that are based on design stress intensity. Similarly, using minimum values of tensile strength and yield strength is conservative because lower values of tensile strength and yield strength lead to lower allowables that are based on tensile strength and yield strength. When compared to calculated values, these lower allowables result in factors of safety that are conservative for any of the constituent materials of Alloy X. Using the minimum value of thermal conductivity has the effect of reducing the heat rejection rate from the canister which is conservative. The maximum and minimum values are used for the coefficient of thermal expansion of Alloy X. The maximum and minimum coefficients of thermal expansion are used as appropriate in this submittal to support a conservative safety evaluation. However, for any internal interference assessment the actual values of coefficients of thermal expansion from the ASME Code or Table 1.A.4 will be used.

1.A.4 References

[1.A.1] ASME Boiler & Pressure Vessel Code Section II, 1995 ed. with Addenda through 1997.
[1.A.2] ASME Boiler & Pressure Vessel Code Section II, 2013 ed. with Addenda through 2014
[1.A.3] ASME Code Case N-635-1 (2013)

[1.A.4] C. Örnek, D. Engelberg, S. Lyon and T. Ladwein, "Effect of “475°C Embrittlement” on the Corrosion Behaviour of Grade 2205 Duplex Stainless Steel Investigated Using Local Probing Techiques," *Corrosion Management Magazine,* no. 115, pp. 9-11, 2013.
[1.A.5] C.R. Xavier, H.G. Delgado Jr., J.A de Castro, “An Experimental and Numerical Approach for the Welding Effects on the Duplex Stainless Steel Microstructure” – Materials Research Vol. 18(3) pp. 489-502, 2015.
[1.A.6] “Practical guidelines for Fabrication of Duplex Stainless Steels” – International Molybdenum Association, 2014.
[1.A.7] ASTM A923-14, “Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels” – W Conshohocken, PA, ASTM International 2014.
[1.A.8] J. Charles, “Duplex Stainless Steels, A Review After DSS ’07 held in GRADO” – Steel Research International Vol. 79(6) pp. 455-465, 2008.
[1.A.9] A. Leonard, “Review of external stress corrosion cracking of 22%Cr duplex stainless steel, Phase 1 – Operational data acquisition,” – HSE RR 129, Her Majesty's Stationery Office, Norwich, UK, 2003.
[1.A.10] ASME Boiler & Pressure Vessel Code Section II, Part D, 2015.

Table 1.A.1

ALLOY X DESIGN STRESS INTENSITY (S_m) vs. TEMPERATURE

Temp. (°F)	Type 304	Type 304LN	Type 316	Type 316LN	Duplex Stainless Steel S31803 [Notes 3]	Alloy X (minimum of constituent values)
-40	20.0	20.0	20.0	20.0	30.0	20.0
100	20.0	20.0	20.0	20.0	30.0	20.0
200	20.0	20.0	20.0	20.0	30.0	20.0
300	20.0	20.0	20.0	20.0	28.9	20.0
400	18.7	18.7	19.3	18.9	27.8	18.7
500	17.5	17.5	18.0	17.5	27.2	17.5
600	16.4	16.4	17.0	16.5	26.9	16.4
650	16.2	16.2	16.7	16.0	-	16.0
700	16.0	16.0	16.3	15.6	-	15.6
750	15.6	15.6	16.1	15.2	-	15.2
800	15.2	15.2	15.9	14.9	-	14.9

Notes:

1. Source: Table 2A on pages 314, 318, 326, and 330 of [1.A.1] for Type 316/316LN/304/304LN.
2. Units of design stress intensity values are ksi.
3. Design stress intensity values have been derived based on the basis established in Mandatory Appendix 2 page 924 and 925 which essentially states that the stress intensity value at temperature is the minimum of one-third of the tensile strength or two-thirds of the yield strength at temperature.
4. Maximum temperature of use for duplex stainless steel under both long term storage and short term / accident conditions is noted in Table 1.A.6.

Table 1.A.2

ALLOY X TENSILE STRENGTH (S_u) vs. TEMPERATURE

Temp. (^oF)	Type 304	Type 304LN	Type 316	Type 316LN	Duplex Stainless Steel S31803 [Notes 4]	Alloy X (minimum of constituent values)
-40	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	90 (90)	75.0 (70.0)
100	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	90 (90)	75.0 (70.0)
200	71.0 (66.2)	71.0 (66.2)	75.0 (70.0)	75.0 (70.0)	90 (90)	71.0 (66.2)
300	66.0 (61.5)	66.0 (61.5)	73.4 (68.5)	70.9 (66.0)	86.8 (86.8)	66.0 (61.5)
400	64.4 (60.0)	64.4 (60.0)	71.8 (67.0)	67.1 (62.6)	83.5 (83.5)	64.4 (60.0)
500	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	64.6 (60.3)	81.6 (81.6)	63.5 (59.3)
600	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	63.1 (58.9)	80.7 (80.7)	63.1 (58.9)
650	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	62.8 (58.6)	-	62.8 (58.6)
700	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	62.5 (58.4)	-	62.5 (58.4)
750	63.1 (58.9)	63.1 (58.9)	71.4 (66.5)	62.2 (58.1)	-	62.2 (58.1)
800	62.7 (58.5)	62.7 (58.5)	70.9 (66.2)	61.7 (57.6)	-	61.7 (57.6)

Notes:
1. Source: Table U on pages 437, 439, 441, and 443 of [1.A.1] for Type 304/304LN/316/316LN.
2. Units of tensile strength are ksi.
3. The ultimate stress of Alloy X is dependent on the product form of the material (i.e., forging vs. plate). Values in parentheses are based on SA-336 forged materials (type F304, F304LN, F316, and F316LN) or SA-182 forged material (S31803), which are used solely for the one-piece construction MPC lids. All other values correspond to SA-240 plate material
4. Table U on page 521 of [1.A.10] for DSS UNS S31803
5. Maximum temperature of use for duplex stainless steel under both long term storage and short term / accident conditions is noted in Table 1.A.6..

Table 1.A.3

ALLOY X YIELD STRESSES (S_y) vs. TEMPERATURE

Temp. (^oF)	Type 304	Type 304LN	Type 316	Type 316LN	Duplex Stainless Steel S31803 [Notes 3]	Alloy X (minimum of constituent values)
-40	30.0	30.0	30.0	30.0	65.0 (65.0)	30.0
100	30.0	30.0	30.0	30.0	65.0 (65.0)	30.0
200	25.0	25.0	25.8	25.5	57.8 (57.8)	25.0
300	22.5	22.5	23.3	22.9	53.7 (53.7)	22.5
400	20.7	20.7	21.4	21.0	51.2 (51.2)	20.7
500	19.4	19.4	19.9	19.4	49.6 (49.6)	19.4
600	18.2	18.2	18.8	18.3	47.9 (47.9)	18.2
650	17.9	17.9	18.5	17.8	-	17.8
700	17.7	17.7	18.1	17.3	-	17.3
750	17.3	17.3	17.8	16.9	-	16.9
800	16.8	16.8	17.6	16.6	-	16.6

Notes:

1. Source: Table Y-1 on pages 518, 519, 522, 523, 530, 531, 534, and 535 of [1.A.1] for Type 304/304LN/316/316LN.
2. Units of yield stress are ksi.
3. Table Y-1 on page 672 and 673 of [1.A.10] for DSS UNS S31803. Values in parentheses are based on SA-182 forged material (S31803) which is used solely for the one-piece construction MPC lids. All other values correspond to SA-240 plate material.
4. Maximum temperature of use for duplex stainless steel under both long term storage and short term / accident conditions is noted in Table 1.A.6.

Table 1.A.4

ALLOY X COEFFICIENT OF THERMAL EXPANSION
vs. TEMPERATURE

Temp. (°F)	Type 304 and Type 304LN	Type 316 and Type 316LN	Duplex Stainless Steel S31803 [Notes 3]	Alloy X Maximum	Alloy X Minimum
-40	8.55	8.54	6.63	8.55	6.63
100	8.55	8.54	7.1	8.55	7.1
150	8.67	8.64	7.3	8.67	7.3
200	8.79	8.76	7.5	8.79	7.5
250	8.90	8.88	7.6	8.90	7.6
300	9.00	8.97	7.8	9.00	7.8
350	9.10	9.11	7.9	9.11	7.9
400	9.19	9.21	8.0	9.21	8.0
450	9.28	9.32	8.1	9.32	8.1
500	9.37	9.42	8.3	9.42	8.3
550	9.45	9.50	8.4	9.50	8.4
600	9.53	9.60	8.4	9.60	8.4
650	9.61	9.69	-	9.69	9.61
700	9.69	9.76	-	9.76	9.69
750	9.76	9.81	-	9.81	9.76
800	9.82	9.90	-	9.90	9.82

Notes:
1. Source: Table TE-1 on pages 590 and 591 of [1.A.1], for Type 304/304LN/316/316LN.
2. Units of coefficient of thermal expansion are in./in.-°F x 10^{-6}.
3. Table TE-1 on page 753 of [1.A.10] for DSS UNS S31803.
4. Maximum temperature of use for duplex stainless steel under both long term storage and short term / accident conditions is noted in Table 1.A.6.

Table 1.A.5

ALLOY X THERMAL CONDUCTIVITY vs. TEMPERATURE

Temp. (°F)	Type 304 and Type 304LN	Type 316 and Type 316LN	Duplex Stainless Steel S31803 [Notes 3]	Alloy X (minimum of constituent values)
-40	8.23	6.96	7.83	6.96
70	8.6	7.7	8.2	7.7
100	8.7	7.9	8.3	7.9
150	9.0	8.2	8.6	8.2
200	9.3	8.4	8.8	8.4
250	9.6	8.7	9.1	8.7
300	9.8	9.0	9.3	9.0
350	10.1	9.2	9.5	9.2
400	10.4	9.5	9.8	9.5
450	10.6	9.8	10.0	9.8
500	10.9	10.0	10.2	10.0
550	11.1	10.3	10.5	10.3
600	11.3	10.5	10.7	10.5
650	11.6	10.7	-	10.7
700	11.8	11.0	-	11.0
750	12.0	11.2	-	11.2
800	12.2	11.5	-	11.5

Notes:
1. Source: Table TCD on page 606 of [1.A.1] for Type 304/304LN/316/316LN.
2. Units of thermal conductivity are Btu/hr-ft-°F.
3. Table TCD on page 773 of [1.A.10] for DSS UNS S31803.
4. Maximum temperature of use for duplex stainless steel under both long term storage and short term / accident conditions is noted in Table 1.A.6.

Table 1.A.6

DUPLEX STAINLESS STEEL TEMPERATURE LIMITS†

Parameter	Value
Long Term, Normal Condition Design Temperature Limits (Long-Term Events) (^{o} F)	550
Short-Term Events, Off-Normal, and Accident Condition Temperature Limits (^{o} F)	600

† These temperature limits take precedence over those in Table 2.2.3

Table 1.A.7

ALLOY X MODULI OF ELASTICITY (E) vs. TEMPERATURE

Temp. (Deg. F)	Moduli of Elasticity (E)	
	Austenitic stainless steels (304, 304LN, 316, 316LN)	Duplex stainless steel (UNS S31803)
-40	28.82	29.78
100	28.14	28.82
150	27.87	28.51
200	27.6	28.2
250	27.3	27.85
300	27.0	27.5
350	26.75	27.25
400	26.5	27.0
450	26.15	26.7
500	25.8	26.4
550	25.55	26.2
600	25.3	26.0
650	25.05	-
700	24.8	-
750	24.45	-
800	24.1	-

Definitions:

E = Young's Modulus (psi x 10^6)

Notes:

1. Source for E values of austenitic stainless steels is material group G in Table TM-1 of [3.3.1].
2. Source for E values of duplex stainless steel is material group H in Table TM-1 of [1.A.10].

FIGURES 1.A.1 through 1.A.5
INTENTIONALLY DELETED

Table 1.III.1
Key Parameters for MPC-68M

	BWR
MPC internal environment Helium fill (99.995% fill helium purity) (heat load ≤ 28.19 kW) (heat load >28.19 kW) Quarter Symmetric Heat Load (QSHL)	(all pressure ranges are at a reference temperature of 70°F) ≥ 29.3 psig and ≤ 48.5 psig OR 0.1218 +/-10% g-moles/liter ≥ 45.5 psig and ≤ 48.5 psig ≥ 43.5 psig and ≤ 46.5 psig
B_4C content in Metamic-HT (wt. %)	As specified on drawing in Section 1.5

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Minimum Cooling Time:	3 years (Intact ZR Clad Fuel) 8 years (Intact SS Clad Fuel)	-	Section 2.19
Max. Fuel Assembly Weight: (including non-fuel hardware and DFC, as applicable)	1,720 lb. for fuel assemblies that do not require fuel spacers, otherwise 1,680 lb.	-	Section 2.1.9
Max. Fuel Assembly Length: (Unirradiated Nominal)	176.8 in.	-	Section 2.1.9
Max. Fuel Assembly Width (Unirradiated Nominal)	8.54 in.	-	Section 2.1.9
BWR Fuel Assemblies:			
Type	Various	-	Sections 2.1.9 and 6.2
Max. Burnup	65,000 MWD/MTU	-	Section 2.1.9
Max. Enrichment	Varies by fuel design	-	Section 2.1.9, Table 2.1.4
Max. Decay Heat/ MPC†.	36.9 kW 42.8 kW (MPC-68M)	-	Section 4.4
Minimum Cooling Time:	2 years (Intact ZR Clad Fuel) 8 years (Intact SS Clad Fuel)		Section 2.1.9
Max. Fuel Assembly Weight:			
w/channels and DFC, as applicable	830 lb. (intact fuel)	-	Section 2.1.9
Max. Fuel Assembly Length (Unirradiated Nominal)	176.5in.	-	Section 2.1.9
Max. Fuel Assembly Width (Unirradiated Nominal)	5.85 in.	-	Section 2.1.9
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperatures	See Tables 2.0.2 and 2.0.3	ANSI/ANS 57.9	Section 2.2.1.4
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2

2.1.9.1.3
Burnup Limits as a Function of Cooling Time for ZR-Clad Fuel

The maximum allowable ZR-clad fuel assembly average burnup varies with the following parameters, based on the shielding analysis in Chapter 5:

- Minimum required fuel assembly cooling time
- Maximum allowable fuel assembly decay heat
- Minimum fuel assembly average enrichment

The calculation described in this section is used to determine the maximum allowable fuel assembly burnup for minimum cooling times between 2 and 40 years, using maximum decay heat and minimum enrichment as input values. This calculation may be used to create multiple burnup versus cooling time tables for a particular fuel assembly array/class and different minimum enrichments. The allowable maximum burnup for a specific fuel assembly may be calculated based on the assembly's particular enrichment and cooling time.

(i) Choose a fuel assembly minimum enrichment, E_{235}.

(ii) Calculate the maximum allowable fuel assembly average burnup for a minimum cooling time between 2 and 40 years using the equation below:

$$Bu = (A \times q) + (B \times q^2) + (C \times q^3) + [D \times (E_{235})^2] + (E \times q \times E_{235}) + (F \times q^2 \times E_{235}) + G$$

Equation j

Where:

Bu = Maximum allowable assembly average burnup (MWD/MTU)

q = Maximum allowable decay heat per fuel storage location determined in Section 2.1.9.1.1 or 2.1.9.1.2 (kW)

E_{235} = Minimum fuel assembly average enrichment (wt. % ^{235}U)
(e.g., for 4.05 wt. %, use 4.05)

A through G = Coefficients from Tables 2.1.28 or 2.1.29 for the applicable fuel assembly array/class and minimum cooling time.

2.1.9.1.4 Other Considerations

In computing the allowable maximum fuel storage location decay heats and fuel assembly average burnups, the following requirements apply:

Table 2.1.28
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 14X14A
(Page 1 of 8)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	8716.89	1454.67	-91.96	-168.45	2047.50	-209.91	-738.51
2.25	10917.50	1441.49	-112.76	-162.14	2274.96	-266.46	-788.45
2.5	13452.90	1258.44	-119.69	-154.08	2491.83	-329.35	-760.18
2.75	16326.90	847.56	-100.72	-146.46	2680.07	-390.55	-727.50
3.0	19310.30	276.56	-59.30	-139.52	2851.81	-452.00	-614.85
4.0	33007.90	-4711.82	663.64	-117.16	3291.32	-622.31	-338.63
5.0	46306.70	-12448.80	2292.51	-113.20	3504.56	-662.41	-73.12
6.0	57461.80	-20693.50	4405.17	-121.14	3633.52	-614.82	1.66
7.0	66450.10	-28314.10	6635.00	-129.61	3706.00	-510.84	-113.74
8.0	73652.70	-34919.90	8759.36	-136.91	3752.43	-391.36	-311.56
9.0	79378.80	-40316.60	10606.30	-141.55	3784.66	-280.29	-485.97
10.0	84125.10	-44860.80	12239.70	-143.00	3777.62	-152.58	-635.70
11.0	88066.60	-48540.60	13594.30	-142.74	3758.54	-33.78	-726.86
12.0	91416.80	-51619.90	14789.00	-141.31	3742.31	64.80	-833.14
13.0	94657.90	-54579.30	15916.70	-137.14	3652.04	215.05	-967.41
14.0	97332.40	-56854.80	16823.50	-133.83	3610.21	315.79	-959.48
15.0	99866.10	-58816.70	17560.80	-128.68	3529.41	430.14	-991.32
16.0	102093.00	-60412.40	18171.30	-124.64	3469.67	535.07	-1078.73
17.0	104419.00	-62150.90	18846.80	-118.62	3363.97	674.13	-1092.27
18.0	106439.00	-63357.20	19259.50	-114.31	3300.43	769.38	-1137.26
19.0	108613.00	-64655.80	19660.70	-107.71	3182.61	904.63	-1084.05
20.0	110475.00	-65506.20	19883.50	-103.32	3125.81	988.08	-1062.86
22.0	114223.00	-66854.40	19969.00	-91.34	2899.19	1260.81	-1076.58
24.0	117822.00	-67556.70	19641.80	-79.56	2684.32	1499.23	-1011.23
26.0	121396.00	-67752.70	18783.80	-68.61	2465.91	1753.65	-940.82
28.0	125040.00	-67445.30	17353.90	-55.51	2184.99	2059.27	-883.36
30.0	128075.00	-65562.60	14994.70	-45.58	2003.10	2244.12	-819.25
35.0	136419.00	-58633.40	6027.48	-15.81	1354.94	2757.84	-687.83
40.0	144776.00	-48670.50	-4898.54	5.02	1019.97	2652.57	-507.64

Table 2.1.28
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 14X14B
(Page 2 of 8)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	7962.04	1332.84	-83.96	-165.28	1836.65	-176.15	-859.65
2.25	10055.50	1296.32	-100.51	-156.80	2012.11	-217.67	-907.11
2.5	12332.50	1153.20	-110.56	-149.42	2185.46	-264.52	-845.06
2.75	15072.80	715.71	-82.42	-140.68	2336.22	-310.64	-833.26
3.0	18034.30	64.77	-24.88	-130.87	2450.80	-348.00	-857.34
4.0	30007.50	-4046.37	538.96	-110.22	2792.92	-469.98	-371.81
5.0	41033.00	-9824.17	1644.13	-108.10	2979.87	-509.22	122.91
6.0	50398.10	-16082.00	3115.79	-113.75	3084.72	-485.25	117.44
7.0	57782.60	-21657.00	4602.39	-121.19	3161.16	-433.49	-112.57
8.0	63670.20	-26431.00	6006.16	-127.70	3227.81	-382.20	-74.84
9.0	68390.50	-30359.70	7246.09	-131.82	3277.23	-336.08	-200.60
10.0	72284.50	-33630.50	8335.68	-132.71	3293.15	-279.98	-291.73
11.0	75584.30	-36387.10	9298.07	-132.38	3295.07	-227.50	-340.65
12.0	78425.20	-38681.30	10125.90	-130.36	3283.13	-176.12	-462.22
13.0	80928.60	-40624.70	10848.10	-127.28	3259.89	-127.73	-563.09
14.0	83136.90	-42279.70	11500.20	-124.50	3249.69	-97.40	-565.79
15.0	85398.00	-44023.70	12192.30	-119.64	3186.24	-30.11	-665.54
16.0	87257.50	-45137.70	12617.40	-113.94	3127.01	22.40	-678.95
17.0	89196.20	-46520.30	13209.90	-110.27	3091.45	63.17	-713.69
18.0	90991.80	-47570.50	13623.80	-104.55	3008.16	136.69	-772.63
19.0	92591.90	-48339.00	13957.70	-99.63	2967.34	161.34	-697.42
20.0	94285.30	-49165.00	14265.20	-93.25	2875.59	235.94	-721.92
22.0	97593.80	-50692.00	14904.40	-82.77	2745.24	324.79	-695.61
24.0	100677.00	-51565.30	15201.30	-71.53	2596.73	409.91	-701.93
26.0	103715.00	-52185.40	15380.80	-60.88	2445.30	499.31	-581.96
28.0	106669.00	-52197.30	15136.20	-49.42	2276.34	582.57	-547.22
30.0	109832.00	-52431.30	15114.20	-38.14	2103.73	641.34	-544.99
35.0	116933.00	-49435.10	12742.20	-10.82	1691.80	667.30	-388.35
40.0	123932.00	-43775.70	9268.80	15.25	1356.03	327.73	-339.10

Table 2.1.28
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 14X14C
(Page 3 of 8)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	7910.49	1566.52	-112.06	-173.92	1975.67	-202.57	-1582.61
2.25	10090.40	1516.08	-132.53	-164.22	2144.71	-245.91	-1586.24
2.5	12672.30	1230.85	-127.98	-154.40	2293.68	-288.88	-1526.05
2.75	15404.70	785.48	-103.88	-146.02	2435.58	-333.58	-1526.92
3.0	18263.20	174.52	-57.73	-138.13	2539.97	-369.83	-1372.54
4.0	30052.40	-3931.93	484.14	-116.91	2815.30	-467.36	-710.84
5.0	40995.00	-9796.91	1583.72	-113.09	2900.21	-451.56	-204.87
6.0	49804.50	-15620.10	2905.31	-119.64	2970.21	-399.85	-228.44
7.0	56671.50	-20724.30	4228.04	-129.87	3058.54	-347.83	-244.26
8.0	62114.70	-24957.40	5410.68	-135.49	3080.42	-267.82	-216.83
9.0	66532.70	-28492.00	6458.64	-138.92	3102.21	-196.64	-343.21
10.0	70257.00	-31538.30	7424.54	-139.96	3109.64	-131.37	-466.58
11.0	73240.40	-33856.10	8182.60	-139.49	3113.36	-77.52	-528.62
12.0	75830.10	-35829.20	8857.54	-137.30	3097.43	-23.81	-597.83
13.0	78304.00	-37697.30	9499.38	-132.64	3034.49	60.52	-690.28
14.0	80401.00	-39162.40	10022.20	-129.04	3004.11	112.39	-819.41
15.0	82413.50	-40565.20	10547.80	-125.00	2972.01	159.60	-815.35
16.0	84138.60	-41575.10	10920.50	-121.03	2935.91	206.01	-844.59
17.0	85994.20	-42654.40	11295.20	-113.82	2848.12	279.72	-924.47
18.0	87721.10	-43657.50	11664.00	-108.56	2775.07	353.35	-960.97
19.0	89122.20	-44109.80	11806.40	-103.94	2740.54	384.66	-864.21
20.0	90678.60	-44723.70	11996.00	-97.44	2648.86	459.77	-907.84
22.0	93894.70	-46071.00	12444.30	-85.57	2487.47	593.03	-912.09
24.0	96742.60	-46597.20	12482.60	-75.19	2358.14	688.79	-833.76
26.0	99697.50	-47055.90	12472.30	-63.23	2185.39	810.10	-803.84
28.0	102343.00	-46639.70	11970.90	-52.13	2038.03	893.63	-704.66
30.0	105173.00	-46148.00	11326.10	-41.21	1856.73	1002.71	-620.51
35.0	111963.00	-42828.60	8640.91	-13.96	1473.64	1063.44	-455.86
40.0	118574.00	-36526.50	4330.66	12.00	1111.29	892.32	-351.40

Table 2.1.28
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 15x15A/B/C
(Page 4 of 8)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	6771.99	897.63	-45.95	-155.96	1478.91	-112.57	-571.21
2.25	8543.84	862.70	-53.16	-148.35	1638.47	-142.90	-603.00
2.5	10454.10	757.88	-56.51	-143.91	1802.08	-178.39	-613.38
2.75	12589.40	536.75	-50.58	-136.31	1939.28	-212.48	-598.75
3.0	15043.50	106.18	-18.51	-127.37	2049.65	-242.76	-584.58
4.0	25256.40	-2809.40	320.40	-108.47	2382.23	-339.78	-246.30
5.0	34995.70	-7157.77	1037.70	-104.27	2547.85	-373.57	64.26
6.0	43079.90	-11755.40	1968.81	-110.42	2669.55	-367.08	207.73
7.0	49495.50	-15880.10	2915.99	-117.70	2745.06	-335.00	79.17
8.0	54674.20	-19541.50	3863.26	-124.97	2823.26	-307.52	-139.52
9.0	58746.90	-22465.30	4666.71	-128.88	2870.36	-274.05	-284.74
10.0	62159.00	-24900.00	5358.04	-129.81	2882.28	-231.65	-307.41
11.0	64980.00	-26916.40	5974.92	-128.99	2890.02	-197.70	-320.91
12.0	67449.80	-28657.30	6533.20	-126.96	2889.14	-168.72	-358.64
13.0	69587.80	-30096.10	7005.49	-125.03	2881.70	-138.49	-417.57
14.0	71617.00	-31412.90	7443.05	-120.37	2839.04	-95.47	-497.72
15.0	73320.90	-32442.90	7811.27	-117.59	2836.73	-78.55	-582.44
16.0	75078.70	-33504.10	8184.69	-111.70	2773.08	-28.70	-569.58
17.0	76605.90	-34256.30	8446.38	-106.43	2722.31	10.58	-648.37
18.0	78201.90	-35135.30	8779.71	-102.00	2687.99	34.04	-637.10
19.0	79683.00	-35825.50	9024.65	-96.68	2626.60	78.21	-644.17
20.0	81040.00	-36264.40	9175.96	-90.42	2571.71	105.53	-621.79
22.0	83842.80	-37347.80	9582.93	-79.77	2452.81	179.87	-678.83
24.0	86457.20	-37934.30	9779.99	-69.09	2348.63	223.29	-555.43
26.0	89143.70	-38488.40	9965.70	-58.22	2222.80	276.21	-541.65
28.0	91552.10	-38289.80	9775.89	-47.03	2083.59	328.54	-483.47
30.0	93976.80	-37775.30	9380.97	-35.17	1933.91	367.06	-412.13
35.0	99743.70	-35109.80	7937.17	-10.10	1701.23	242.55	-292.95
40.0	105747.00	-30710.40	5734.70	16.14	1409.70	-19.63	-330.25

Table 2.1.28
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 15x15D/E/F/H/I
(Page 5 of 8)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	6290.79	883.39	-49.29	-150.42	1348.67	-93.23	-194.84
2.25	7850.16	906.09	-62.37	-145.85	1507.07	-121.33	-234.20
2.5	9917.64	729.63	-57.61	-138.51	1649.34	-150.19	-389.61
2.75	12039.70	498.88	-50.28	-132.19	1776.46	-179.02	-384.86
3.0	14308.20	140.88	-27.37	-126.11	1896.47	-208.80	-424.35
4.0	24246.40	-2585.64	274.38	-105.96	2197.31	-292.15	-98.88
5.0	33660.00	-6672.88	931.23	-104.57	2380.99	-330.06	323.27
6.0	41534.90	-11039.20	1790.84	-111.20	2485.37	-318.04	436.06
7.0	47737.40	-14940.00	2668.46	-119.75	2572.84	-293.94	394.87
8.0	52510.40	-18097.60	3446.19	-126.75	2647.38	-274.16	310.51
9.0	56484.50	-20845.30	4162.00	-129.08	2662.71	-225.75	158.84
10.0	59692.00	-23093.90	4799.05	-130.53	2692.07	-199.57	18.86
11.0	62307.70	-24865.90	5320.34	-130.34	2710.88	-176.52	-96.66
12.0	64497.20	-26247.00	5725.38	-127.89	2691.98	-137.42	-152.99
13.0	66473.70	-27479.90	6111.71	-124.64	2678.39	-110.34	-220.62
14.0	68322.50	-28605.10	6471.87	-120.12	2648.26	-78.83	-317.16
15.0	69880.10	-29416.90	6732.96	-115.83	2620.06	-52.26	-351.02
16.0	71504.30	-30337.40	7046.36	-110.89	2583.27	-22.60	-386.91
17.0	72938.30	-31008.00	7269.02	-105.81	2541.55	5.22	-421.21
18.0	74306.50	-31601.90	7471.26	-100.67	2498.95	31.67	-421.69
19.0	75649.10	-32149.50	7661.36	-95.47	2449.77	61.38	-439.23
20.0	76868.40	-32525.30	7793.09	-90.99	2421.09	73.14	-450.75
22.0	79592.40	-33604.00	8197.86	-78.90	2293.07	142.14	-486.11
24.0	81996.10	-34015.70	8295.91	-67.98	2173.93	196.55	-435.49
26.0	84232.50	-34067.60	8271.85	-57.61	2083.11	215.81	-374.64
28.0	86620.60	-34049.50	8171.94	-45.82	1954.61	249.73	-400.41
30.0	88983.60	-33826.80	8026.95	-34.27	1835.41	255.33	-353.18
35.0	94579.10	-31817.80	7120.43	-8.81	1596.94	131.34	-263.56
40.0	100058.00	-27653.80	5318.64	17.12	1355.45	-187.62	-273.88

Table 2.1.28 (Page 6 of 8)
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 16x16A

Cooling Time (years)	A	B	C	D	E	F	G
2.0	7213.94	1062.48	-60.18	-163.16	1632.73	-137.39	-660.90
2.25	9068.86	1052.65	-73.90	-157.12	1812.61	-174.53	-682.57
2.5	11282.40	881.74	-74.10	-149.28	1970.43	-212.23	-710.99
2.75	13602.30	625.18	-68.06	-143.44	2124.68	-253.65	-734.52
3.0	16226.30	143.97	-32.51	-136.73	2255.52	-291.73	-699.79
4.0	27528.60	-3346.42	393.54	-115.66	2587.71	-397.43	-273.55
5.0	38357.70	-8605.59	1312.06	-110.58	2719.25	-409.35	60.77
6.0	47353.00	-14184.20	2511.45	-117.96	2810.98	-373.58	26.38
7.0	54492.70	-19227.40	3751.22	-126.74	2889.14	-321.58	-84.61
8.0	60159.30	-23487.00	4884.62	-133.44	2918.29	-242.53	-126.66
9.0	64663.30	-26994.20	5900.01	-137.02	2946.64	-181.25	-285.69
10.0	68346.00	-29851.40	6755.60	-138.49	2958.18	-120.30	-384.11
11.0	71361.10	-32184.10	7502.54	-138.40	2964.72	-68.91	-497.04
12.0	74014.20	-34136.30	8127.59	-135.73	2938.32	-7.78	-627.98
13.0	76326.40	-35820.10	8697.58	-132.72	2908.57	49.64	-715.32
14.0	78450.30	-37288.70	9197.21	-128.85	2871.70	104.32	-771.96
15.0	80439.10	-38636.00	9667.15	-124.14	2815.86	168.64	-851.14
16.0	82142.00	-39610.20	10013.20	-120.20	2790.66	203.72	-859.48
17.0	83886.70	-40590.10	10336.30	-114.04	2714.78	270.50	-870.62
18.0	85580.90	-41545.60	10677.80	-108.53	2648.66	332.69	-921.15
19.0	87028.10	-42030.60	10787.80	-102.57	2576.39	390.15	-880.17
20.0	88490.60	-42584.60	10956.70	-97.67	2529.96	430.91	-912.08
22.0	91586.50	-43770.60	11272.60	-85.21	2343.82	579.90	-878.01
24.0	94293.80	-44158.40	11248.70	-74.44	2224.40	656.22	-824.58
26.0	97086.50	-44420.30	11078.90	-62.82	2045.62	784.53	-737.98
28.0	99965.10	-44515.00	10777.60	-51.29	1871.32	897.77	-719.30
30.0	102352.00	-43418.60	9831.79	-40.46	1725.50	957.49	-626.62
35.0	109039.00	-40353.50	7075.81	-12.07	1286.03	1106.60	-531.72
40.0	115345.00	-34020.20	2448.15	13.49	928.92	963.44	-395.64

Table 2.1.28
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 17x17A, 16x16B/C
(Page 7 of 8)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	7482.84	749.18	-32.06	-153.69	1490.54	-111.64	-301.94
2.25	9138.06	783.14	-45.73	-148.43	1678.27	-147.42	-271.38
2.5	11115.90	682.88	-49.46	-143.38	1855.10	-184.65	-248.90
2.75	13492.40	392.81	-34.32	-137.63	2018.42	-224.60	-364.95
3.0	15985.10	3.54	-9.05	-128.84	2149.50	-260.42	-263.00
4.0	27326.30	-3316.13	388.73	-110.89	2545.62	-376.10	-60.44
5.0	38630.20	-8729.17	1335.65	-109.86	2754.84	-407.49	244.70
6.0	48364.20	-14788.30	2652.90	-117.55	2878.88	-375.72	252.15
7.0	56144.10	-20415.70	4068.96	-128.12	2970.68	-312.43	-145.42
8.0	62319.20	-25122.10	5332.37	-133.94	2986.20	-212.65	-192.32
9.0	67097.40	-28916.30	6441.26	-139.07	3028.70	-142.12	-304.90
10.0	71141.80	-32210.80	7461.17	-140.60	3037.68	-63.75	-484.40
11.0	74293.50	-34623.40	8214.63	-140.16	3026.35	11.71	-567.89
12.0	77101.60	-36783.10	8922.19	-138.37	3008.48	83.17	-677.97
13.0	79705.10	-38760.90	9576.13	-134.21	2949.33	173.71	-820.83
14.0	81840.20	-40208.40	10063.30	-130.61	2915.99	236.79	-867.80
15.0	83845.30	-41560.10	10535.80	-126.12	2867.51	306.60	-940.08
16.0	85751.10	-42671.70	10876.60	-120.77	2799.15	386.28	-990.12
17.0	87613.20	-43744.30	11214.60	-114.75	2722.88	466.15	-1028.96
18.0	89198.60	-44487.50	11451.40	-110.00	2673.61	522.32	-974.28
19.0	90843.80	-45204.50	11637.70	-103.89	2591.93	602.99	-1048.14
20.0	92361.20	-45701.20	11710.50	-98.45	2507.40	689.65	-1034.50
22.0	95455.20	-46715.70	11886.10	-86.86	2353.10	835.28	-1006.44
24.0	98319.40	-46988.20	11622.80	-74.63	2169.86	995.06	-941.81
26.0	101240.00	-47039.80	11136.00	-62.32	1971.79	1168.97	-907.73
28.0	103863.00	-46243.10	10186.30	-51.51	1822.28	1270.39	-758.20
30.0	106638.00	-45299.90	9011.04	-39.38	1598.42	1447.93	-698.69
35.0	113059.00	-40056.10	4113.55	-12.17	1169.02	1660.44	-557.52
40.0	119131.00	-30799.70	-3521.78	14.35	791.94	1564.09	-401.82

Table 2.1.28 (Page 8 of 8)
PWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 17x17B/C

Cooling Time (years)	A	B	C	D	E	F	G
2.0	6766.33	744.89	-33.96	-154.11	1387.05	-99.30	-455.94
2.25	8406.78	735.84	-42.13	-148.76	1546.40	-127.76	-412.22
2.5	10326.00	618.40	-42.67	-140.84	1696.17	-158.83	-428.21
2.75	12425.70	400.95	-35.11	-134.79	1833.92	-190.65	-448.69
3.0	14787.40	16.36	-8.09	-128.41	1953.16	-221.24	-426.08
4.0	25076.00	-2855.35	319.19	-107.73	2268.19	-307.82	-118.54
5.0	34842.80	-7144.52	1015.11	-107.42	2457.65	-342.14	294.08
6.0	43259.40	-11920.40	1970.81	-113.08	2547.52	-316.78	82.08
7.0	49884.40	-16230.60	2962.56	-122.92	2650.94	-291.11	127.95
8.0	55105.20	-19804.80	3845.74	-128.64	2682.52	-232.47	-61.87
9.0	59268.90	-22820.00	4674.45	-133.56	2742.72	-203.91	-265.03
10.0	62653.20	-25227.80	5347.65	-134.19	2744.28	-150.34	-229.28
11.0	65528.50	-27328.80	5990.85	-134.07	2759.67	-117.12	-349.73
12.0	67925.00	-28930.10	6470.25	-131.66	2738.04	-69.75	-467.93
13.0	70014.00	-30295.30	6903.21	-128.41	2714.49	-27.74	-580.42
14.0	71939.40	-31542.90	7318.09	-124.70	2688.09	8.93	-630.83
15.0	73678.50	-32578.30	7669.57	-120.41	2659.19	41.04	-637.54
16.0	75313.80	-33488.20	7973.96	-115.46	2610.74	86.53	-708.01
17.0	76870.20	-34276.40	8238.11	-110.15	2563.22	123.29	-739.52
18.0	78338.30	-34971.50	8477.60	-104.26	2505.00	166.49	-731.14
19.0	79849.90	-35703.80	8726.57	-99.14	2447.13	211.29	-756.38
20.0	81109.20	-36047.10	8827.48	-93.99	2404.21	235.46	-751.74
22.0	83793.40	-36898.90	9088.73	-82.74	2281.57	313.80	-704.73
24.0	86424.70	-37453.70	9205.18	-70.11	2134.35	393.96	-654.44
26.0	88971.30	-37671.00	9134.01	-58.64	1983.82	478.46	-659.93
28.0	91497.60	-37723.60	9032.79	-47.61	1861.20	520.75	-564.47
30.0	93706.20	-36961.70	8512.11	-37.17	1743.83	543.52	-523.93
35.0	99798.50	-34670.70	6911.55	-9.53	1376.43	593.61	-406.67
40.0	105384.00	-29185.20	3708.34	16.92	1086.25	354.06	-343.59

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 7x7B, 10x10F
(Page 1 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	15761.10	10171.40	-1983.74	-180.41	4533.44	-1035.69	-1020.71
2.25	20683.90	10100.50	-2362.96	-171.37	4924.21	-1259.16	-1149.28
2.5	25710.50	9847.51	-2788.08	-162.18	5329.88	-1548.05	-1048.31
2.75	31858.60	7767.18	-2661.83	-154.93	5675.76	-1804.31	-992.87
3.0	38703.40	4333.22	-2101.88	-144.94	5898.42	-1990.59	-1030.87
4.0	65948.40	-16991.70	3924.57	-118.43	6390.16	-2406.62	-614.30
5.0	90881.20	-47264.90	16771.40	-112.75	6498.93	-2241.12	-192.49
6.0	111776.00	-79261.50	33399.20	-115.32	6416.04	-1620.07	-84.57
7.0	127348.00	-107023.00	50534.70	-139.25	6848.43	-1458.29	-14.89
8.0	140072.00	-130028.00	65223.10	-144.93	6836.24	-857.79	-99.75
9.0	150749.00	-150213.00	79005.50	-147.77	6773.51	-231.87	-331.15
10.0	158943.00	-167178.00	92612.70	-164.66	7287.36	-461.83	-382.12
11.0	165714.00	-179168.00	101557.00	-164.07	7241.92	-45.10	-521.50
12.0	171975.00	-190727.00	110548.00	-161.09	7166.19	380.43	-589.16
13.0	177624.00	-200947.00	118921.00	-158.82	7131.17	664.17	-667.75
14.0	182802.00	-210117.00	126526.00	-154.60	7016.50	1083.45	-747.88
15.0	186884.00	-214518.00	128584.00	-147.82	6809.36	1591.41	-783.35
16.0	191316.00	-221293.00	134071.00	-142.04	6646.92	2019.29	-841.16
17.0	195369.00	-231600.00	147624.00	-158.43	7404.40	946.55	-820.02
18.0	199404.00	-236224.00	150408.00	-148.69	7053.70	1655.35	-883.27
19.0	203726.00	-243272.00	157476.00	-143.31	6936.71	1903.09	-895.71
20.0	206861.00	-245479.00	159023.00	-137.13	6829.41	2091.47	-903.40
22.0	213325.00	-250875.00	163825.00	-127.55	6623.17	2500.20	-800.98
24.0	220063.00	-255065.00	166460.00	-114.40	6330.37	2896.83	-803.85
26.0	226903.00	-262541.00	177379.00	-115.77	6627.51	2189.72	-651.65
28.0	234964.00	-270961.00	187677.00	-102.37	6255.46	2595.08	-735.34
30.0	241796.00	-272482.00	188002.00	-88.80	5779.54	3315.93	-731.24
35.0	257457.00	-265751.00	183333.00	-71.68	5676.93	1648.24	-511.23
40.0	282525.00	-292276.00	240288.00	-43.47	4948.25	152.96	-833.96

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 8x8B
(Page 2 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	15913.80	11664.70	-2480.99	-179.56	4694.73	-1100.00	-1003.87
2.25	20652.00	12023.80	-3025.66	-174.12	5204.92	-1412.29	-979.17
2.5	26986.10	10399.30	-3032.60	-163.94	5594.88	-1694.85	-1213.71
2.75	33074.30	8670.65	-3129.69	-156.84	5959.94	-1975.74	-1054.90
3.0	39987.50	5388.94	-2722.03	-146.15	6189.85	-2184.18	-1039.58
4.0	68821.60	-18071.10	4016.97	-119.21	6655.64	-2578.72	-677.77
5.0	95032.70	-50959.00	18228.50	-113.67	6737.08	-2341.46	-253.74
6.0	117864.00	-88879.60	39468.80	-128.75	6937.68	-1918.61	-203.01
7.0	133919.00	-117151.00	56431.30	-139.69	6960.80	-1212.83	-123.38
8.0	147621.00	-142952.00	73246.80	-143.67	6879.18	-441.73	-342.11
9.0	158036.00	-165478.00	90946.70	-167.32	7480.35	-551.45	-378.22
10.0	166796.00	-181378.00	101771.00	-165.98	7346.03	114.50	-504.04
11.0	174312.00	-195869.00	112810.00	-165.26	7291.07	642.48	-648.03
12.0	180736.00	-207916.00	122412.00	-163.34	7243.01	1055.04	-742.81
13.0	187002.00	-219945.00	132127.00	-159.70	7084.08	1641.84	-903.88
14.0	192382.00	-229413.00	139613.00	-156.32	7001.62	2085.84	-972.60
15.0	196087.00	-233618.00	142299.00	-151.48	6860.06	2570.55	-883.73
16.0	202268.00	-249608.00	159974.00	-162.80	7359.57	1999.93	-1048.13
17.0	206376.00	-256109.00	166401.00	-159.20	7309.03	2257.68	-1062.93
18.0	209117.00	-255071.00	162389.00	-151.82	7125.28	2596.49	-891.61
19.0	213124.00	-261295.00	168674.00	-146.82	7004.96	2966.11	-951.40
20.0	217047.00	-267281.00	175609.00	-141.96	6943.62	3118.99	-1012.59
22.0	223569.00	-268761.00	171389.00	-127.42	6436.52	4175.11	-877.23
24.0	233533.00	-291046.00	200512.00	-131.73	6830.33	3613.57	-988.74
26.0	238557.00	-284966.00	188216.00	-118.63	6424.02	4316.86	-862.50
28.0	245385.00	-285588.00	185055.00	-105.51	6116.61	4651.69	-844.39
30.0	254559.00	-295608.00	196106.00	-100.36	6027.39	4465.31	-886.90
35.0	272231.00	-295589.00	203313.00	-71.05	5259.94	4464.18	-744.47
40.0	290782.00	-286198.00	204311.00	-50.38	4868.38	2364.75	-614.59

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 8x8C/D/E
(Page 3 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	16663.00	10889.80	-2211.52	-182.17	4831.25	-1175.27	-1260.49
2.25	21598.90	10980.20	-2691.18	-176.65	5300.72	-1453.46	-1219.04
2.5	27348.40	10071.30	-2967.33	-165.41	5680.31	-1735.86	-1252.79
2.75	33467.10	8232.39	-2999.52	-158.56	6061.56	-2033.93	-1086.98
3.0	40382.30	4849.42	-2525.53	-148.53	6314.10	-2257.89	-1075.95
4.0	68954.10	-18263.30	4048.93	-123.13	6850.62	-2734.70	-652.59
5.0	96324.30	-53730.10	19778.60	-114.90	6841.59	-2381.30	-353.71
6.0	118229.00	-89906.60	39997.30	-134.45	7190.60	-2120.86	-143.41
7.0	134948.00	-119919.00	58227.10	-143.18	7200.03	-1397.69	-170.37
8.0	149092.00	-147517.00	76590.50	-149.16	7110.00	-528.97	-313.19
9.0	159771.00	-170139.00	93968.00	-170.19	7649.69	-595.38	-403.04
10.0	168715.00	-187828.00	107088.00	-172.19	7651.82	-46.57	-555.81
11.0	176169.00	-201821.00	117349.00	-170.83	7550.84	552.84	-651.76
12.0	182662.00	-214445.00	127628.00	-169.36	7519.56	997.32	-756.73
13.0	189114.00	-227085.00	137699.00	-166.11	7388.07	1583.27	-844.97
14.0	195273.00	-239345.00	148361.00	-160.79	7228.22	2124.28	-1017.11
15.0	199939.00	-249862.00	159949.00	-174.10	7782.47	1566.35	-1026.32
16.0	204899.00	-258274.00	166856.00	-167.77	7534.06	2227.05	-1070.51
17.0	209356.00	-265290.00	173458.00	-161.96	7463.49	2386.89	-1040.14
18.0	213546.00	-272476.00	180667.00	-158.41	7387.49	2763.66	-1098.37
19.0	217506.00	-277100.00	183949.00	-150.21	7155.18	3240.82	-1107.07
20.0	219837.00	-275266.00	179705.00	-145.05	7009.96	3638.55	-1007.16
22.0	228092.00	-285272.00	186688.00	-133.55	6672.08	4473.64	-1122.87
24.0	237213.00	-304032.00	211958.00	-136.95	7000.92	4086.48	-1049.61
26.0	242060.00	-297359.00	199620.00	-125.83	6734.22	4465.79	-972.10
28.0	249432.00	-299622.00	196900.00	-111.26	6222.03	5440.43	-914.71
30.0	263307.00	-334844.00	247655.00	-111.83	6452.32	4775.31	-1191.53
35.0	273393.00	-291765.00	178985.00	-83.84	5736.80	4650.87	-621.35
40.0	293153.00	-283353.00	175255.00	-57.06	4937.79	3684.27	-559.25

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 9x9A
(Page 4 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	16564.30	12063.20	-2586.67	-184.87	4976.49	-1228.06	-894.91
2.25	22071.80	11834.70	-3015.91	-174.88	5443.22	-1518.94	-1014.33
2.5	27866.60	10993.50	-3286.54	-168.71	5965.88	-1909.06	-1027.88
2.75	34375.10	9004.62	-3367.62	-158.97	6305.05	-2182.06	-933.24
3.0	41566.50	5392.11	-2800.23	-149.79	6613.45	-2462.36	-904.38
4.0	72006.50	-20264.40	4921.01	-123.85	7211.86	-3004.62	-603.22
5.0	100197.00	-57315.80	21669.60	-118.72	7356.33	-2796.24	-243.52
6.0	124367.00	-99348.10	46264.80	-136.71	7648.05	-2394.38	-67.58
7.0	143009.00	-134740.00	68824.10	-143.35	7544.90	-1403.30	-173.80
8.0	157479.00	-165996.00	92255.30	-168.05	8114.30	-1315.88	-266.71
9.0	169636.00	-191379.00	110928.00	-172.50	8069.55	-500.37	-450.57
10.0	179282.00	-211202.00	125969.00	-172.12	7976.57	283.36	-617.13
11.0	187512.00	-228637.00	140325.00	-172.16	7928.03	894.69	-760.39
12.0	195321.00	-245580.00	154682.00	-170.38	7824.20	1596.02	-863.97
13.0	202110.00	-263050.00	173293.00	-187.18	8470.09	1003.55	-953.17
14.0	208171.00	-274758.00	183332.00	-179.75	8249.83	1717.21	-1103.07
15.0	213590.00	-284590.00	191650.00	-175.64	8098.33	2289.04	-1165.13
16.0	218091.00	-292503.00	199557.00	-171.84	8035.82	2659.38	-1119.03
17.0	223491.00	-302449.00	208733.00	-164.92	7833.36	3192.21	-1255.80
18.0	226523.00	-304524.00	209895.00	-162.71	7829.04	3410.57	-1091.33
19.0	231702.00	-312496.00	215730.00	-153.73	7552.13	4052.91	-1189.12
20.0	236531.00	-324776.00	232293.00	-164.72	8073.05	3368.73	-1233.57
22.0	244888.00	-335452.00	241932.00	-150.44	7566.26	4642.58	-1160.69
24.0	252171.00	-340795.00	244542.00	-141.18	7321.23	5355.16	-1142.40
26.0	259438.00	-343494.00	244340.00	-129.66	7094.56	5645.82	-1119.92
28.0	268823.00	-359239.00	266068.00	-130.16	7204.93	5605.85	-1064.30
30.0	277221.00	-363922.00	268930.00	-116.96	6799.84	6219.78	-1037.79
35.0	294285.00	-351643.00	245914.00	-99.35	6404.25	5923.44	-713.23
40.0	324174.00	-389397.00	319233.00	-77.68	5933.52	3992.56	-1188.62

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 9x9B
(Page 5 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	17186.80	11657.20	-2441.58	-183.45	5049.98	-1246.51	-1156.40
2.25	21800.20	12295.50	-3074.77	-180.94	5660.86	-1631.58	-1064.82
2.5	28010.00	11198.70	-3349.88	-169.84	6074.18	-1943.73	-1220.46
2.75	34607.80	9092.75	-3327.98	-161.55	6476.70	-2279.47	-1090.70
3.0	41425.40	6300.12	-3202.59	-151.95	6782.84	-2566.85	-1000.46
4.0	71942.80	-18734.90	3920.65	-125.38	7367.52	-3119.27	-631.75
5.0	101151.00	-57291.00	21182.10	-118.05	7377.24	-2721.50	-361.88
6.0	125823.00	-99944.80	45636.60	-136.47	7588.00	-2124.69	-262.67
7.0	144638.00	-135378.00	67687.60	-143.88	7447.72	-995.76	-340.94
8.0	159872.00	-168383.00	91921.20	-168.66	7933.70	-673.04	-395.74
9.0	172305.00	-194121.00	110332.00	-172.16	7831.09	301.31	-634.37
10.0	181683.00	-213140.00	124418.00	-173.36	7740.03	1165.16	-753.12
11.0	190922.00	-232977.00	140095.00	-171.28	7581.53	2053.29	-1027.00
12.0	198213.00	-248066.00	152236.00	-170.70	7492.96	2781.03	-1087.99
13.0	205947.00	-268590.00	173240.00	-187.42	8096.44	2390.78	-1199.48
14.0	211867.00	-280583.00	184192.00	-183.14	8023.23	2903.27	-1325.04
15.0	217071.00	-289407.00	190649.00	-177.77	7760.30	3819.17	-1355.68
16.0	221340.00	-294404.00	193178.00	-173.59	7653.54	4235.81	-1282.26
17.0	227205.00	-306489.00	204027.00	-164.96	7309.81	5290.73	-1440.44
18.0	231085.00	-310612.00	206608.00	-160.03	7176.88	5715.32	-1383.11
19.0	236345.00	-320398.00	215697.00	-153.84	7020.00	6284.82	-1522.44
20.0	240125.00	-328538.00	227545.00	-170.25	7836.24	5008.11	-1382.77
22.0	245672.00	-325279.00	216287.00	-158.18	7517.98	5919.63	-1187.15
24.0	256479.00	-345503.00	236771.00	-144.07	6970.57	7508.12	-1317.75
26.0	260950.00	-331434.00	205388.00	-130.57	6497.58	8638.70	-1076.78
28.0	269984.00	-343628.00	218366.00	-134.58	6861.68	8165.52	-1062.58
30.0	278259.00	-348285.00	221391.00	-123.31	6538.19	8720.28	-1076.88
35.0	297697.00	-344053.00	202586.00	-105.06	6094.38	9194.58	-852.15
40.0	331243.00	-401432.00	313358.00	-81.82	5561.33	7636.50	-1470.42

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 9x9C/D
(Page 6 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	16691.80	11823.60	-2447.14	-185.99	5008.36	-1243.90	-1059.30
2.25	21740.60	12301.10	-3136.66	-173.22	5422.51	-1511.79	-1061.56
2.5	27709.70	11300.00	-3398.46	-167.10	5898.90	-1850.17	-1171.40
2.75	33988.10	9774.59	-3696.16	-158.15	6268.38	-2155.04	-974.14
3.0	41117.20	6515.41	-3381.03	-148.32	6548.78	-2413.74	-948.98
4.0	71428.60	-18297.80	3576.44	-123.51	7125.21	-2923.50	-632.21
5.0	100397.00	-56458.80	20611.70	-115.75	7125.58	-2528.06	-313.97
6.0	124283.00	-97234.10	43750.10	-135.36	7393.89	-2038.45	-178.07
7.0	142677.00	-131502.00	64937.90	-142.42	7276.64	-994.67	-255.89
8.0	158111.00	-164750.00	89150.00	-165.13	7682.79	-614.18	-382.56
9.0	169539.00	-187815.00	105688.00	-170.16	7701.54	95.21	-536.66
10.0	179168.00	-207560.00	120407.00	-172.05	7615.14	907.40	-757.15
11.0	187428.00	-224318.00	133228.00	-170.11	7472.64	1710.47	-885.30
12.0	195546.00	-241540.00	147050.00	-166.19	7281.30	2560.85	-1135.94
13.0	202256.00	-258699.00	164971.00	-182.40	7906.42	2044.37	-1182.19
14.0	207838.00	-268927.00	173192.00	-178.93	7770.91	2703.98	-1224.09
15.0	213979.00	-281611.00	184781.00	-172.75	7552.21	3409.13	-1276.86
16.0	217809.00	-285839.00	187221.00	-168.56	7458.11	3805.42	-1317.69
17.0	223749.00	-297214.00	196642.00	-160.86	7141.47	4676.19	-1362.21
18.0	226075.00	-295937.00	193130.00	-157.66	7127.19	4895.03	-1291.13
19.0	230997.00	-304670.00	201281.00	-150.53	6907.85	5558.32	-1353.07
20.0	238022.00	-324930.00	227066.00	-158.32	7284.25	5103.45	-1464.16
22.0	243676.00	-322706.00	217208.00	-147.77	6978.74	5979.30	-1239.05
24.0	251683.00	-332524.00	227486.00	-137.48	6744.91	6651.45	-1261.39
26.0	256408.00	-321812.00	204514.00	-125.79	6394.39	7373.18	-1135.32
28.0	264537.00	-330729.00	215269.00	-131.03	6864.20	6415.84	-1014.55
30.0	273958.00	-341208.00	225146.00	-115.29	6196.43	7947.39	-1073.39
35.0	292385.00	-333153.00	204415.00	-98.00	5956.86	7222.98	-860.79
40.0	329247.00	-419504.00	371883.00	-71.42	4943.73	7633.01	-1618.27

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 9x9E/F
(Page 7 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	16854.60	11084.70	-2322.04	-181.73	4769.99	-1147.12	-810.29
2.25	21630.80	11546.20	-2940.96	-172.49	5228.13	-1436.00	-839.61
2.5	27849.90	10029.20	-2985.66	-164.15	5650.51	-1736.59	-1040.92
2.75	34540.60	7548.11	-2786.62	-154.38	5990.92	-2013.50	-935.15
3.0	41307.10	4337.80	-2362.16	-146.82	6295.85	-2275.82	-884.96
4.0	70768.40	-20480.20	5197.61	-121.39	6876.47	-2797.83	-537.40
5.0	98180.80	-56583.30	21720.10	-115.24	7004.63	-2612.66	-168.15
6.0	120573.00	-94683.40	43765.30	-134.45	7390.91	-2400.88	20.85
7.0	138493.00	-128353.00	65326.00	-141.23	7368.45	-1657.87	2.12
8.0	151304.00	-154813.00	84923.70	-165.48	7997.42	-1799.73	-3.75
9.0	162835.00	-178601.00	102770.00	-169.20	8012.87	-1222.27	-178.21
10.0	173089.00	-200396.00	119704.00	-169.43	7906.04	-489.94	-481.35
11.0	180227.00	-213998.00	130552.00	-169.48	7924.61	-143.28	-537.04
12.0	188058.00	-230819.00	144797.00	-165.45	7782.15	482.35	-705.69
13.0	193490.00	-240795.00	153382.00	-163.80	7756.04	834.76	-753.66
14.0	199338.00	-255751.00	170303.00	-178.59	8424.78	16.81	-795.55
15.0	204471.00	-264530.00	177215.00	-172.61	8186.47	708.91	-873.25
16.0	209807.00	-275635.00	189071.00	-167.97	8087.71	1042.99	-936.73
17.0	214452.00	-282609.00	194830.00	-159.86	7819.12	1616.41	-906.17
18.0	217197.00	-283928.00	195786.00	-157.56	7869.81	1568.69	-890.15
19.0	221266.00	-288837.00	199363.00	-149.64	7592.40	2213.50	-965.82
20.0	225737.00	-295774.00	205279.00	-143.23	7337.40	2875.11	-876.23
22.0	234598.00	-314227.00	231133.00	-148.51	7825.76	2021.35	-879.15
24.0	242046.00	-320606.00	235951.00	-134.75	7367.58	2926.98	-913.50
26.0	247960.00	-318479.00	229552.00	-123.51	7133.33	3171.11	-783.22
28.0	261521.00	-352854.00	278305.00	-120.41	7120.21	3024.72	-1121.44
30.0	264913.00	-340198.00	263913.00	-111.92	6968.28	2888.33	-788.23
35.0	288082.00	-360268.00	293412.00	-86.40	6220.44	2894.70	-961.02
40.0	298948.00	-303570.00	215523.00	-55.72	5417.82	785.23	-415.39

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 9X9G
(Page 8 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	18157.70	12664.10	-2736.69	-182.35	5344.31	-1383.11	-916.79
2.25	23646.70	12752.10	-3248.16	-178.95	5971.94	-1793.73	-925.78
2.5	29660.10	12309.80	-3821.64	-169.21	6473.09	-2183.65	-879.92
2.75	36525.80	10358.80	-3962.11	-162.46	6968.29	-2613.38	-863.49
3.0	44006.40	7030.85	-3698.49	-153.38	7336.54	-2971.63	-809.92
4.0	77288.30	-21207.50	4543.15	-125.70	8058.78	-3705.78	-537.87
5.0	110686.00	-69960.20	29062.30	-130.54	8442.77	-3626.36	-336.85
6.0	137786.00	-118830.00	58088.00	-136.52	8339.36	-2532.48	-201.40
7.0	160795.00	-169293.00	94340.50	-161.16	8672.27	-1671.25	-379.07
8.0	177763.00	-207034.00	122389.00	-170.18	8619.96	-400.24	-562.99
9.0	193108.00	-243101.00	150849.00	-171.94	8368.05	1156.18	-881.11
10.0	205042.00	-275555.00	181997.00	-195.35	9071.69	1098.87	-1083.51
11.0	215280.00	-300568.00	204362.00	-194.55	8934.09	2200.13	-1266.10
12.0	223585.00	-319189.00	220301.00	-191.69	8775.21	3201.84	-1325.62
13.0	230947.00	-335777.00	234994.00	-189.96	8659.97	4110.52	-1472.39
14.0	239135.00	-355478.00	253619.00	-183.93	8406.36	5194.67	-1726.13
15.0	245572.00	-374776.00	278406.00	-203.34	9278.36	4194.86	-1666.34
16.0	251881.00	-387322.00	288544.00	-193.80	8836.24	5557.89	-1689.56
17.0	257861.00	-401610.00	304798.00	-189.68	8737.81	6220.47	-1840.71
18.0	262232.00	-408488.00	311370.00	-185.11	8602.16	6925.67	-1728.75
19.0	265329.00	-406025.00	301388.00	-178.52	8347.70	7730.36	-1689.95
20.0	271234.00	-419055.00	315509.00	-171.72	8067.36	8751.47	-1705.40
22.0	283895.00	-451199.00	356261.00	-175.40	8389.72	8926.87	-1890.66
24.0	288388.00	-437401.00	323902.00	-164.80	8075.31	9968.86	-1575.02
26.0	299757.00	-459004.00	349014.00	-154.15	7793.16	11086.10	-1690.60
28.0	312233.00	-487890.00	389532.00	-156.41	8001.62	11248.70	-1695.28
30.0	317451.00	-470929.00	352843.00	-144.12	7616.90	12129.50	-1519.49
35.0	340908.00	-472938.00	320383.00	-126.33	6958.19	14189.40	-1265.87
40.0	355826.00	-406707.00	181832.00	-109.88	6567.54	13350.90	-690.33

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 10x10A/B/G
(Page 9 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	16284.00	11316.60	-2373.42	-183.95	4757.49	-1129.72	-908.53
2.25	21494.10	11161.90	-2738.06	-174.87	5233.98	-1435.08	-1029.88
2.5	27378.90	10122.70	-3001.13	-163.37	5590.72	-1687.18	-1133.76
2.75	33997.50	7667.21	-2796.85	-154.59	5934.47	-1960.21	-1063.93
3.0	40669.30	4604.85	-2427.68	-146.64	6233.46	-2224.40	-1023.08
4.0	69456.60	-19048.60	4510.80	-121.07	6769.53	-2693.26	-595.32
5.0	96363.50	-53810.50	20060.80	-115.15	6852.01	-2455.28	-235.29
6.0	118075.00	-89649.00	40101.30	-135.03	7207.34	-2199.03	-31.82
7.0	135465.00	-121448.00	59891.00	-141.81	7176.22	-1464.52	-84.35
8.0	149172.00	-147759.00	77477.10	-146.29	7123.94	-720.75	-270.69
9.0	160098.00	-171854.00	96698.30	-168.49	7716.07	-861.33	-341.94
10.0	168703.00	-188210.00	108590.00	-170.65	7707.01	-369.98	-413.26
11.0	176895.00	-205123.00	122221.00	-167.56	7590.63	267.07	-597.28
12.0	183500.00	-217775.00	132403.00	-165.29	7503.92	748.16	-696.44
13.0	189527.00	-229054.00	141757.00	-162.77	7481.92	1050.96	-848.98
14.0	195892.00	-241671.00	152138.00	-155.37	7192.81	1854.09	-983.23
15.0	199561.00	-249322.00	161820.00	-172.75	7962.69	824.80	-863.19
16.0	204447.00	-258563.00	171271.00	-167.33	7839.02	1163.01	-928.77
17.0	209187.00	-266807.00	178586.00	-160.49	7588.94	1870.46	-983.28
18.0	212908.00	-270532.00	180865.00	-155.48	7487.99	2077.63	-955.84
19.0	216478.00	-274912.00	185127.00	-150.92	7417.63	2302.50	-949.30
20.0	219761.00	-276790.00	185299.00	-144.53	7207.71	2794.21	-860.04
22.0	230330.00	-297894.00	208958.00	-142.95	7317.84	2710.62	-1141.54
24.0	235204.00	-296597.00	207242.00	-136.96	7299.78	2658.68	-881.02
26.0	243035.00	-302622.00	210474.00	-120.72	6753.85	3686.66	-891.14
28.0	250446.00	-307503.00	216130.00	-107.51	6366.92	4185.55	-863.84
30.0	265199.00	-348982.00	280458.00	-107.22	6539.80	3562.03	-1192.36
35.0	273468.00	-298369.00	203934.00	-79.97	5875.23	3082.40	-627.85
40.0	292898.00	-285148.00	187876.00	-50.41	4835.07	2436.15	-509.94

Table 2.1.29
BWR FUEL ASSEMBLY COOLING TIME-DEPLETION COEFFICIENTS
(ZR-CLAD FUEL)
ARRAY/CLASS 10x10C
(Page 10 of 10)

Cooling Time (years)	A	B	C	D	E	F	G
2.0	17325.30	11490.30	-2423.96	-183.30	5030.60	-1243.75	-1042.41
2.25	22130.00	11951.30	-2993.28	-179.73	5638.45	-1641.98	-1049.38
2.5	28141.40	10893.00	-3249.42	-171.97	6092.80	-1970.42	-1042.25
2.75	35001.90	8485.77	-3132.08	-161.49	6464.02	-2288.54	-1064.03
3.0	41817.40	5588.18	-2935.15	-152.37	6778.27	-2580.33	-960.42
4.0	72503.80	-20126.90	4676.40	-126.12	7389.26	-3161.51	-598.75
5.0	101686.00	-58844.80	22172.30	-118.88	7430.83	-2824.08	-314.90
6.0	125964.00	-100714.00	46115.40	-137.38	7670.65	-2280.40	-139.13
7.0	145279.00	-138063.00	69971.00	-145.81	7593.29	-1239.47	-240.17
8.0	160736.00	-171770.00	94922.90	-169.48	8074.18	-936.98	-413.14
9.0	173109.00	-198050.00	114195.00	-173.24	7952.04	107.22	-587.69
10.0	183348.00	-219689.00	130706.00	-174.38	7886.25	887.26	-747.19
11.0	192349.00	-239413.00	146643.00	-173.03	7738.68	1801.89	-960.79
12.0	198722.00	-251849.00	156661.00	-174.40	7779.41	2247.21	-1024.32
13.0	206317.00	-271870.00	177242.00	-191.21	8405.58	1825.60	-1138.70
14.0	212647.00	-284224.00	187282.00	-183.63	8103.28	2759.09	-1219.61
15.0	218920.00	-297923.00	200391.00	-179.50	7978.82	3335.37	-1313.57
16.0	223379.00	-304963.00	206476.00	-175.76	7922.23	3689.54	-1328.16
17.0	228676.00	-314595.00	214380.00	-168.29	7569.76	4728.35	-1384.57
18.0	233175.00	-321606.00	220636.00	-164.63	7582.84	4872.65	-1394.73
19.0	238334.00	-334048.00	236292.00	-170.69	7886.97	4618.40	-1403.78
20.0	242429.00	-340497.00	242818.00	-172.36	8094.92	4434.37	-1437.97
22.0	251428.00	-353397.00	253878.00	-156.59	7500.41	6060.21	-1412.04
24.0	257957.00	-354461.00	249954.00	-147.71	7305.10	6634.39	-1346.94
26.0	272010.00	-391459.00	299301.00	-145.25	7227.25	7258.81	-1619.05
28.0	273995.00	-368436.00	261102.00	-136.90	7071.78	7562.48	-1159.20
30.0	279666.00	-356857.00	232864.00	-125.34	6696.43	8273.08	-973.58
35.0	297242.00	-340805.00	191056.00	-108.66	6404.77	8127.91	-777.55
40.0	330405.00	-398218.00	299749.00	-84.01	5531.03	7980.06	-1232.79

Table 2.2.3
DESIGN TEMPERATURES

Component	Long Term, Normal Condition Design Temperature Limits (Long-Term Events) (^{o} F)	Off-Normal and Accident Condition Temperature Limits (Short-Term Events)* (^{o} F)	30-Day Accident Condition Temperature Limits (^{o} F)†
MPC shell	500‡	775‡	572
MPC basket	725	950	752
MPC Neutron Absorber	800	1000	752
MPC lid	550‡	775‡	572
MPC closure ring	400‡	775‡	572
MPC baseplate	400‡	775‡	572
HI-TRAC inner shell	400	800	-
HI-TRAC pool lid/transfer lid	350	800	-
HI-TRAC top lid	400	800	-
HI-TRAC top flange	400	700	-
HI-TRAC pool lid seals	350	N/A	-
HI-TRAC bottom lid bolts	350	800	-
HI-TRAC bottom flange	350	800	-
HI-TRAC top lid neutron shielding	300	350	-
HI-TRAC radial neutron shield	307	N/A	-
HI-TRAC radial lead gamma shield	350	600	-
Remainder of HI-TRAC	350	800	-
Fuel Cladding	752	752 or 1058 (Short Term Operations)§ 1058 (Off-Normal and Accident Conditions)	752
Overpack concrete	300*	572 (local temperature)	450 (local temperature)
Overpack Lid Top and Bottom Plate	450	800	450
Remainder of overpack steel structure	350	800	450

* For accident conditions that involve heating of the steel structures and no mechanical loading (such as the blocked air duct accident), the permissible metal temperature of the steel parts is defined by Table 1A of ASME Section II (Part D) for Section III, Class 3 materials as 700^{O}F. For the ISFSI fire event, the maximum temperature limit for ASME Section 1 equipment is appropriate (850^{O}F in Code Table 1A).
† 30-day accident event is defined as a 100% blocked vent condition at threshold heat loads defined in Section 4.6.
‡ Temperature limits in Table 1.A.6 shall take precedence if duplex stainless steels are used for the fabrication of confinement boundary components as described in Appendix 1.A
§ Normal short term operations includes MPC drying and onsite transport per Reference [2.0.8]. The 1058^{o}F temperature limit applies to MPCs containing all moderate burnup fuel as discussed in Reference [2.0.9]. The limit for MPCs containing one or more high burnup fuel assemblies is 752^{o}F. See also Section 4.3.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Confinement	Shell	A	ASME Section III; Subsection NB	Alloy X [5]	See Appendix 1.A	NA	NA
Confinement	Baseplate	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Confinement	Lid (One-piece design and top portion of optional two-piece design)	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Confinement	Closure Ring	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Confinement	Port Cover Plates	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Basket Cell Plates	A	ASME Section III; Subsection NG core support structures (NG-1121)	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Neutron Absorber	A	Non-code	NA	NA	NA	Aluminum/SS
Shielding	Drain and Vent Shield Block	C	Non-code	Alloy X	See Appendix 1.A	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A. It is also noted that duplex stainless steel shall not be used for the fabrication of MPC baskets and internal components..
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength $\geq$ 75 ksi, yield strength $\geq$ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Shielding	Plugs for Drilled Holes	NITS	Non-code	SA 193B8 (or equivalent)	See Appendix 1.A	NA	NA
Shielding	Bottom portion of optional two-piece MPC lid design	B	Non-code	Alloy X or Carbon Steel	See Appendix 1.A for Alloy X, Table 3.3.6 for Carbon Steel	Stainless Steel coating when using Carbon Steel	Stainless Steel when using Carbon Steel
Structural Integrity	Upper Fuel Spacer Column	B	ASME Section III; Subsection NG (only for stress analysis)	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Sheathing	A	Non-code	Alloy X	See Appendix 1.A	Aluminum/SS	NA
Structural Integrity	Shims	NITS	Non-code (shims, welded directly to angle or parallel plate basket supports, are ASME Section II)	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Basket Supports (Angled	A	ASME Section III;	Alloy X	See Appendix 1.A	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A. It is also noted that duplex stainless steel shall not be used for the fabrication of MPC baskets and internal components..
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength ≥ 75 ksi, yield strength ≥ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC (1,2)

Primary Function	Component (3)	Safety Class (4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
	Plate or Parallel Plates with connecting end shim)		Subsection NG internal structures (NG-1122)				
Structural Form	Basket Supports (Flat Plates)	NITS	Non-Code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug	C	NUREG-0612	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug Baseplate	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Upper Fuel Spacer Bolt	NITS	Non-code	A193-B8 (or equiv.)	Per ASME Section II	NA	NA
Structural Integrity	Upper Fuel Spacer End Plate	B	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lower Fuel Spacer Column	B	ASME Section III; Subsection NG (only for stress analysis)	Stainless Steel. See Note 6	See Appendix 1.A	NA	NA
Structural Integrity	Lower Fuel Spacer End Plate	B	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Vent Shield Block Spacer	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Operations	Vent and Drain Tube	C	Non-code	S/S	Per ASME Section	Thread area	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A. It is also noted that duplex stainless steel shall not be used for the fabrication of MPC baskets and internal components..
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength $\geq$ 75 ksi, yield strength $\geq$ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC (1,2)

Primary Function	Component (3)	Safety Class (4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
					II	surface hardened	
Operations	Vent & Drain Cap	C	Non-code	S/S	Per ASME Section II	NA	NA
Operations	Vent & Drain Cap Seal Washer	NITS	Non-code	Aluminum	NA	NA	Aluminum/SS
Operations	Vent & Drain Cap Seal Washer Bolt	NITS	Non-code	Aluminum	NA	NA	NA
Operations	Reducer	NITS	Non-code	Alloy X	See Appendix 1.A	NA	NA
Operations	Drain Line	NITS	Non-code	Alloy X	See Appendix 1.A	NA	NA
Operations	Damaged Fuel Container	C	ASME Section III; Subsection NG	S/S (Primarily 304 S/S)	See Appendix 1.A	NA	NA
Operations	Drain Line Guide Tube	NITS	Non-code	S/S	NA	NA	NA
Operations	Vent and Drain Tube, Optional	C	Non-code	S/S	Per ASME Section II	Thread area surface hardened	N/A
Operations	Threaded Disc, Plug Adjustment	C	Non-code	S/S	Per ASME Section II	N/A	N/A
Operations	Vent and Drain Plug	C	Non-code	Aluminum	N/A	N/A	N/A
Operations	Thread Shield Cap	NITS	Non-code	Aluminum	N/A	N/A	N/A

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A. It is also noted that duplex stainless steel shall not be used for the fabrication of MPC baskets and internal components..
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength ≥ 75 ksi, yield strength ≥ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Operations	Retaining Ring	NITS	Non-code	S/S	N/A	N/A	N/A

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A. It is also noted that duplex stainless steel shall not be used for the fabrication of MPC baskets and internal components..
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength $\geq$ 75 ksi, yield strength $\geq$ 30 ksi and chemical properties per ASTM A554.

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.
MPC	NB-2121	Provides permitted material specification for pressure-retaining material, which must conform to Section II, Part D, Tables 2A and 2B	Certain duplex stainless steels are not included in Section II, Part D, Tables 2A and 2B. UNS S31803 duplex stainless steel alloy is evaluated in the HI-STORM 100 FSAR and meet the required design criteria for use in the HI-STORM 100 system per ASME Code Case N-635-1. Appendix 1.A provides the required property data for the necessary safety analysis.
MPC, MPC basket assembly, HI-STORM overpack, and HI-TRAC transfer cask	NB-3100 NG-3100 NF-3100	Provides requirements for determining design loading conditions, such as pressure, temperature, and mechanical loads.	These requirements are not applicable. The HI-STORM FSAR, serving as the Design Specification, establishes the service conditions and load combinations for the storage system.

non-mechanistic). The basis for the lateral deflection limit in the active fuel region, θ, is provided in [2.III.6.1] as

$$\theta = \frac{\delta}{w}$$

where δ is defined as the maximum total deflection sustained by the basket panels under the loading event and *w* is the nominal inside (width) dimension of the storage cell. The limiting value of θ is provided in Table 2.III.4. The above deflection-based criterion has been used previously in the HI-STAR 180 Transportation Package [2.III.6.2] to qualify similar Metamic-HT fuel baskets.

ii. Thermal

The design and operation of the HI-STORM 100 System with the MPC-68M must meet the intent of the review guidance contained in ISG-11, Revision 3 [2.0.8] as described in Subsection 2.0.1.

All applicable material design temperature limits in Section 2.2 and 4.3 continue to apply to the MPC-68M. Temperature limits of MPC-68M fuel basket and basket shim materials are specified in Table 4.III.2.

The MPC-68M is designed for both uniform and regionalized fuel loading strategies as described in Subsection 2.0.1. The regions for the MPC-68M are given in Table 2.III.1. Additionally, ta quarter-summetric heat load pattern has been defined for MPC-68M as shown in Figure 2.III.1. The same temperature limits apply to this configuration.

iii. Shielding

Same as Subsection 2.0.1.

iv. Criticality

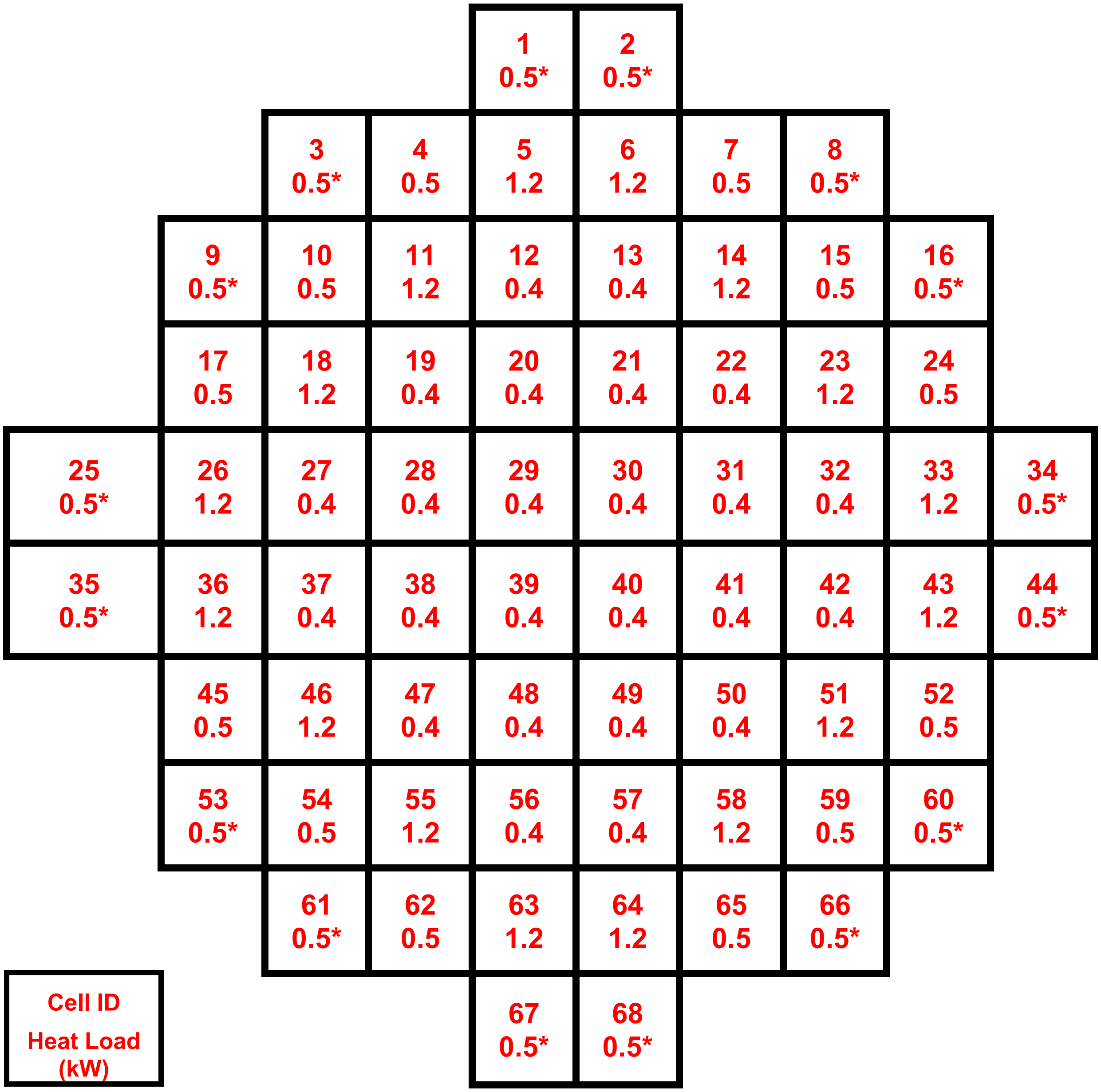
Same as Subsection 2.0.1 with the clarifications herein.

Criticality control is maintained by the geometric spacing of the fuel assemblies and spatially distributed B-10 isotope in the Metamic-HT. No soluble boron is required in the MPC-68M water. The minimum specified boron concentration in the Metamic-HT purchasing specification must be met in every lot of the material manufactured. No credit is taken for burnup. Enrichment limits are delineated in Table 2.III.2.

v. Confinement

Same as Subsection 2.0.1

vi. Operations



* Note: This figure provides per cell allowable heat loads for MPC-68M with all UNDAMAGED FUEL assemblies. For MPC-68M with DAMAGED FUEL and/or FUEL DEBRIS stored in this location (in a DFC), the per cell allowable heat load of the cell is limited to 0.35 kW.

Figure 2.III.1
Per Cell Allowable Heat Loads (kW) for Quarter-Symmetric Pattern - MPC-68M

Symbol	Description	Notes
Q	Secondary membrane plus bending stress	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by pressure, mechanical loads, or differential thermal expansion.
F	Peak stress	Increment added to primary or secondary stress by a concentration (notch), or, certain thermal stresses that may cause fatigue but not distortion. This value is not used in the tables.

It is shown that there is no interference between component parts due to free thermal expansion. Therefore, P_e does not develop within any HI-STORM 100 component.

It is recognized that the planar temperature distribution in the fuel basket and the overpack under the maximum heat load condition is the highest at the cask center and drops monotonically, reaching its lowest value at the outside surface. Strictly speaking, the allowable stresses/stress intensities at any location in the basket, the enclosure vessel, or the overpack should be based on the coincident metal temperature under the specific operating condition. However, in the interest of conservatism, reference temperatures are established for each component, which are upper bounds on the metal temperature for each situational condition. Table 3.1.17 provides the reference temperatures for the fuel basket and the MPC canister utilizing Tables 3.1.6 through 3.1.16, and provides conservative numerical limits for the stresses and stress intensities for all loading cases. Reference temperatures for the MPC baseplate and the MPC lid are 400 degrees F and 550 degrees F, respectively, as specified in Table 2.2.3.

Finally, the lifting attachments or the interfacing lifting points in the HI-STORM 100 Overpack and HI-TRAC casks and the multi-purpose canisters, must meet the requirements of NUREG-0612 and/or Regulatory Guide 3.61 as described in Subsection 3.4.4 and Tables 2.0.1, 2.0.2, and 2.0.3 under a normal handling condition (Load Case 01 in Table 3.1.5). The load combination D+H in Table 3.1.5 is equivalent to 1.15D. This is further explained in Subsection 3.4.3.

The region around the trunnions is part of the NF structure in HI-STORM 100 and HI-TRAC and NB pressure boundary in the MPC, and as such, must satisfy the applicable stress (or stress intensity) limits for the load combination. In addition to meeting the applicable Code limits, it is further required that the primary stress required to maintain equilibrium at the defined trunnion/mother structure interface must not exceed the material yield stress at three times the handling condition load (1.15D). This criterion, mandated by Regulatory Guide 3.61, Section 3.4.3, insures that a large safety factor exists on non-local section yielding at the trunnion/mother structure interface that would lead to unacceptable section displacement and rotation.

3.1.2.3 Brittle Fracture

The MPC canister and basket are constructed from a series of stainless steels termed Alloy X. Austenitic stainless steels do not undergo a ductile-to-brittle transition (DBT) in the operating temperature range of the HI-STORM 100 System. Therefore, brittle fracture is not a concern for

the MPC components fabricated using austenitic stainless steel. Such an assertion cannot be made a' priori for the MPC confinement boundary components fabricated using duplex stainless steel grade of Alloy X, or for the HI-STORM storage overpack and the HI-TRAC transfer cask that contain ferritic steel parts.

The use of duplex stainless steel grade of Alloy X material is limited to the MPC confinement boundary components and shall be restricted to the maximum temperatures specified in Table 1.A.6 as the material may suffer from precipitation of brittle micro-constituents above 600°F.

The duplex stainless steel material undergoes DBT below the temperature of -40°F/-40°C [3.1.4] (which is equal to the Lowest Service Temperature (LST) of MPC). In addition, Holtec Position Paper DS-213 [9.1.6] demonstrates that crack propagation in MPC lid-to-shell weld is not credible for austenitic and duplex stainless steel grades of Alloy X. Therefore, brittle fracture is not a concern for the MPC confinement boundary components fabricated using duplex stainless steel grade of Alloy X as well.

In general, the impact testing requirements for the HI-STORM overpack and the HI-TRAC transfer cask are a function of two parameters: the LST and the normal stress level. The significance of these two parameters, as they relate to impact testing of the overpack and the transfer cask, is discussed below.

In normal storage mode, the LST of the HI-STORM storage overpack structural members may reach -40°F in the limiting condition wherein the spent nuclear fuel (SNF) in the contained MPCs emits no (or negligible) heat and the ambient temperature is at -40°F (design minimum per Chapter 2: Principal Design Criteria). During the HI-STORM handling operations, the applicable lowest service temperature is 0°F (which is the threshold ambient temperature below which lifting and handling of the HI-STORM 100 Overpack or the HI-TRAC cask is not permitted by the Technical Specification). Therefore, two distinct LSTs are applicable to load bearing metal parts within the HI-STORM 100 Overpack and the HI-TRAC cask; namely,

LST = 0°F for the HI-STORM overpack during handling operations and for the HI-TRAC transfer cask during all normal operating conditions.

LST = -40°F for the HI-STORM overpack during all non-handling operations (i.e., normal storage mode).

Parts used to lift the overpack or the transfer cask, which include the anchor block in the HI-STORM 100 overpack, and the pocket trunnions, the lifting trunnions and the lifting trunnion block in HI-TRAC, will henceforth be referred to as "significant-to-handling" (STH) parts. The applicable design code for these elements of the structure is ANSI N14.6. All other parts of the overpack and the transfer cask will be referred to as "NF" components. It is important to ensure that all materials designated as "NF" or "STH" parts possess sufficient fracture toughness to preclude brittle fracture. For the STH parts, the necessary level of protection against brittle fracture is deemed to exist if the NDT (nil ductility transition) temperature of the part is at least 40° below the LST. Therefore, the required NDT temperature for all STH parts is -40°F.

TABLE 3.1.13

DESIGN, LEVELS A AND B: STRESS INTENSITY

Code:	**ASME NB**
Material:	**Alloy X**
Service Conditions:	**Design, Levels A and B**
Item:	**Stress Intensity**

Temp. (Deg. F)	Classification and Numerical Value					
	S_m	P_m†	P_L†	$P_L + P_b$†	P_L+ P_b+Q††	P_e††
-20 to 100	20.0	20.0	30.0	30.0	60.0	60.0
200	20.0	20.0	30.0	30.0	60.0	60.0
300	20.0	20.0	30.0	30.0	60.0	60.0
400	18.7	18.7	28.1	28.1	56.1	56.1
500	17.5	17.5	26.3	26.3	52.5	52.5
600	16.4	16.4	24.6	24.6	49.2	49.2
650	16.0	16.0	24.0	24.0	48.0	48.0
700	15.6	15.6	23.4	23.4	46.8	46.8
750	15.2	15.2	22.8	22.8	45.6	45.6
800	14.9	14.9	22.4	22.4	44.7	44.7

Notes:

1. S_m = Stress intensity values per Table 2A of ASME II, Part D for austenitic stainless steels of Alloy X and Appendix 1.A for duplex stainless steel of Alloy X.
2. Alloy X S_m values are the lowest values for each of the candidate materials at temperature.
3. Stress classification per NB-3220.
4. Limits on values are presented in Table 2.2.10.
5. P_m, P_L, P_b, Q, and P_e are defined in Table 3.1.6.

† Evaluation required for Design condition only.

†† Evaluation required for Levels A, B conditions only. P_e not applicable to vessels.

TABLE 3.1.15

DESIGN, LEVELS A AND B: STRESS INTENSITY

Code: ASME NG
Material: Alloy X
Service Conditions: Design, Levels A and B
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)				
	S_m	P_m	P_m+P_b	P_m+P_b +Q	P_e
-20 to 100	20.0	20.0	30.0	60.0	60.0
200	20.0	20.0	30.0	60.0	60.0
300	20.0	20.0	30.0	60.0	60.0
400	18.7	18.7	28.1	56.1	56.1
500	17.5	17.5	26.3	52.5	52.5
600	16.4	16.4	24.6	49.2	49.2
650	16.0	16.0	24.0	48.0	48.0
700	15.6	15.6	23.4	46.8	46.8
750	15.2	15.2	22.8	45.6	45.6
800	14.9	14.9	22.4	44.7	44.7

Notes:

1. S_m = Stress intensity values per Table 2A of ASME, Section II, Part D for austenitic stainless steels of Alloy X and Appendix 1.A for duplex stainless steel of Alloy X.
2. Alloy X S_m values are the lowest values for each of the candidate materials at temperature.
3. Classifications per NG-3220.
4. Limits on values are presented in Table 2.2.11.
5. P_m, P_b, Q, and P_e are defined in Table 3.1.6.

3.3 MECHANICAL PROPERTIES OF MATERIALS

Table 2.2.6 provides a comprehensive listing of materials of construction, applicable code, and ITS designation for all functional parts in the HI-STORM 100 System. This section provides the mechanical properties used in the structural evaluation. The properties include yield stress, ultimate stress, modulus of elasticity, Poisson's ratio, weight density, and coefficient of thermal expansion. Values are presented for a range of temperatures which envelopes the maximum and minimum temperatures under all service conditions discussed in the preceding section where structural analysis is performed.

The materials selected for use in the MPC, HI-STORM 100 Overpack, and HI-TRAC transfer cask are presented in the Bills-of-Material in Section 1.5. In this chapter, the materials are divided into two categories, structural and nonstructural. Structural materials are materials that act as load bearing members and are, therefore, significant in the stress evaluations. Materials that do not support mechanical loads are considered nonstructural. For example, the HI-TRAC inner shell is a structural material, while the lead between the inner and outer shell is a nonstructural material. For nonstructural materials, the only property that is used in the structural analysis is weight density. In local deformation analysis, however, such as the study of penetration from a tornado-borne missile, the properties of lead in HI-TRAC and plain concrete in HI-STORM 100 are included.

3.3.1 Structural Materials

3.3.1.1 Alloy X

A hypothetical material termed Alloy X is defined for all MPC structural components. The material properties of Alloy X are the least favorable values from the set of candidate alloys. The purpose of a least favorable material definition is to ensure that all structural analyses are conservative, regardless of the actual MPC material. For example, when evaluating the stresses in the MPC, it is conservative to work with the minimum values for yield strength and ultimate strength. This guarantees that the material used for fabrication of the MPC will be of equal or greater strength than the hypothetical material used in the analysis. In the structural evaluation, the only property for which it is not always conservative to use the set of minimum values is the coefficient of thermal expansion. Two sets of values for the coefficient of thermal expansion are specified, a minimum set and a maximum set. For each analysis, the set of coefficients, minimum or maximum that causes the more severe load on the cask system is used.

Table 3.3.1 lists the numerical values for the material properties of Alloy X versus temperature. These values, taken from the ASME Code, Section II, Part D [3.3.1] and Appendix 1.A, are used in all structural analyses. A minimum requirement on yield strength is set for MPC Lids in Table 3.3.1, to ensure that the lid internal threads have enough capacity under the lifted load as mandated by NUREG-0612. The maximum temperatures in some MPC components may exceed the long term normal allowable temperature limits during short term loading operations, off-normal events, or storage accident events. However, it is ensured that the maximum temperature of austenitic stainless steel grades of Alloy X used for or within the confinement boundary does

not exceed 1000°F under any condition and the maximum temperature of duplex stainless steel (UNS S31803) grade of Alloy X used for the confinement boundary does not exceed 600°F under any condition. As shown in ASME Code Case N-47-33 (Class 1 Components in Elevated Temperature Service, 1995 Code Cases, Nuclear Components), the strength properties of austenitic stainless steels do not change due to exposure to 1000°F temperature for up to 10,000 hours. In addition, per ASME Code Case N-635-1 (Use of 22Cr-5Ni-3Mo-N (Alloy UNS S31803) Forgings, Plate, Bar, Welded and Seamless Pipe, and/or Tube, Fittings, and Fusion Welded Pipe with Additional of Filler Metal, Classes 1, 2, and 3, Section III, Division 1), the maximum permissible temperature for duplex stainless steel grade of Alloy X is 600°F. Therefore, there is no significant effect on mechanical properties of the confinement or basket material during the short time duration loading. It is noted that duplex stainless steel material shall not be used for the fabrication of MPC baskets and MPC internal components. A further description of Alloy X, including the materials from which it is derived, is provided in Appendix 1.A.

Two properties of Alloy X that are not included in Table 3.3.1 are weight density and Poisson's ratio. These properties are assumed constant for all structural analyses, regardless of temperature. The values used are shown in the table below.

PROPERTY	VALUE
Weight Density (lb/in^3)	0.290
Poisson's Ratio	0.30

3.3.1.2 Carbon Steel, Low-Alloy and Nickel Alloy Steel

The carbon steels used in the structural qualification of the HI-STORM 100 System are SA516 Grade 70, SA515 Grade 70, and SA36. The nickel alloy and low alloy steels are SA203-E and SA350-LF3, respectively. These steels are not constituents of Alloy X. The material properties of SA516 Grade 70 and SA515 Grade 70 are shown in Tables 3.3.2. The material properties of SA203-E and SA350-LF3 are given in Table 3.3.3. The material properties of SA36 are shown in Table 3.3.6.

Two properties of these steels that are not included in Tables 3.3.2, 3.3.3 and 3.3.6 are weight density and Poisson's ratio. These properties are assumed constant for all structural analyses. The values used are shown in the table below.

PROPERTY	VALUE
Weight Density (lb/in^3)	0.283
Poisson's Ratio	0.30

3.3.1.3 Bolting Materials

TABLE 3.3.1
ALLOY X MATERIAL PROPERTIES

Temp. (Deg. F)	Alloy X				
	S_y ‡	S_u †	α_{min}	α_{max}	E
-40	30.0 (33.0)	75.0 (70.0)	8.54	8.55	28.82
100	30.0 (33.0)	75.0 (70.0)	8.54	8.55	28.14
150	27.5 (30.25)	73.0 (68.1)	8.64	8.67	27.87
200	25.0 (27.5)	71.0 (66.2)	8.76	8.79	27.6
250	23.75 (26.12)	68.5 (63.85)	8.88	8.9	27.3
300	22.5 (24.75)	66.0 (61.5)	8.97	9.0	27.0
350	21.6 (23.76)	65.2 (60.75)	9.10	9.11	26.75
400	20.7 (22.77)	64.4 (60.0)	9.19	9.21	26.5
450	20.05 (22.06)	64.0 (59.65)	9.28	9.32	26.15
500	19.4 (21.34)	63.5 (59.3)	9.37	9.42	25.8
550	18.8 (20.68)	63.3 (59.1)	9.45	9.50	25.55
600	18.2 (20.02)	63.1 (58.9)	9.53	9.6	25.3
650	17.8 (19.58)	62.8 (58.6)	9.61	9.69	25.05
700	17.3 (19.03)	62.5 (58.4)	9.69	9.76	24.8
750	16.9 (18.59)	62.2 (58.1)	9.76	9.81	24.45
800	16.6 (18.26)	61.7 (57.6)	9.82	9.90	24.1

Definitions:

S_y = Yield Stress (ksi)

α = Mean Coefficient of thermal expansion (in./in. per degree F x 10^{-6})

S_u = Ultimate Stress (ksi)

E = Young's Modulus (psi x 10^6)

Notes:

1. Source for S_y values is Table Y-1 of [3.3.1] for austenitic stainless steels of Alloy X and Appendix 1.A for duplex stainless steel of Alloy X.
2. Source for S_u values is Table U of [3.3.1] for austenitic stainless steels of Alloy X and Appendix 1.A for duplex stainless steel of Alloy X.
3. Source for α_{min} and α_{max} values is Table TE-1 of [3.3.1] for austenitic stainless steels of Alloy X. Values

‡ Values in the parentheses correspond to yield stress of MPC Lids which are 10% greater than the minimum yield stress values tabulated in Table 1.A.3. These higher values are only credited for the stress analysis of the MPC Lid lifting holes.

† The ultimate stress of Alloy X is dependent on the product form of the material (i.e., forging vs. plate). Values in parentheses are based on SA-336 forged materials (type F304, F304LN, F316, and F316LN), which are used solely for the one-piece construction MPC lids. All other values correspond to SA-240 plate material.

of α for duplex stainless steel grade of Alloy X can be obtained from Appendix 1.A.

4. Source for E values is material group G in Table TM-1 of [3.3.1] for austenitic stainless steels of Alloy X and Appendix 1.A for duplex stainless steel of Alloy X.
5. Minimum values of S_y, S_u and E from all candidate Alloy X materials are listed.
6. Duplex stainless steel grade of Alloy X is only used in fabrication of MPC confinement boundary components and its use is limited to 600 ^{o}F per Appendix 1.A.

3.8 REFERENCES

[3.1.1] NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," United States Nuclear Regulatory Commission.

[3.1.2] ANSI N14.6-1993, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10000 Pounds (4500 kg) or More for Nuclear Materials," American National Standards Institute, Inc.

[3.1.3] D. Burgreen, "Design Methods for Power Plant Structures", Arcturus Publishers, 1975.

[3.1.4] "Practical Guidelines for the Fabrication of Duplex Stainless Steels", International Molybdenum Association (IMOA), London, UK – ISBN: 978-1-907470-00-4, Second Edition, 2009.

[3.1.5] Deleted.

[3.1.6] Aerospace Structural Metals Handbook, Manson.

[3.3.1] ASME Boiler & Pressure Vessel Code, Section II, Part D, 1995.

[3.3.2] American Concrete Institute, "Building Code Requirements for Structural Plain Concrete (ACI 318.1-89) (Revised 1992) and Commentary - ACI 318.1R-89 (Revised 1992)".

[3.3.3] American Concrete Institute, "Code Requirements for Nuclear Safety Related Structures" (ACI-349-85) and Commentary (ACI-349R-85)(For anchored casks, the requirements on the design of the steel embedment are ACI-349-97, including Appendix B and the Commentary (ACI-349R-97)).

[3.3.5] J.H. Evans, "Structural Analysis of Shipping Casks, Volume 8, Experimental Study of Stress-Strain Properties of Lead Under Specified Impact Conditions", ORNL/TM-1312, Vol. 8, ORNL, Oak Ridge, TN, August, 1970.

[3.4.1] ANSYS 5.3, ANSYS, Inc., 1996 (Current usage of ANSYS includes Versions up thru 7.0, 2003).

[3.4.2] ASME Boiler & Pressure Vessel Code, Section III, Subsection NF, 1995.

[3.4.3] ASME Boiler & Pressure Vessel Code, Section III, Appendices, 1995.

[3.4.4] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB, 1995.

[3.4.5] "Evaluation of Bounding Explosion Pressure Limits for HI-STORM 100", Holtec Report HI-2063635, Revision 0.

free from condensation and gross environmental contaminants. The cleanliness requirements and inspections during fabrication and fuel loading operations also ensure that the MPC has minimal surface debris and impurities.

Tests on Metamic-HT

Extensive tests [1.III] have been conducted to establish material properties of Metamic-HT including its corrosion-resistance characteristics. The Metamic-HT specimens were used for corrosion testing in demineralized water and in 2000 ppm boric acid solution. The tests concluded that the Metamic-HT panels will sustain no discernible degradation due to corrosion when subjected to the severe thermal and aqueous environment that exists around a fuel basket during fuel loading or unloading conditions.

Aluminum Alloy

Aluminum alloy used in the fuel basket shims are hard anodized to achieve the desired emissivity specified in Supplement 4.III. The anodizing is an electrolytic passivation process used to increase the thickness of the natural oxide layer on the surface of metal parts. Anodizing increases corrosion resistance and wear resistance of the material surface. There is no mechanistic process for the basket shims with hard anodized surface to react with borated water or demineralized water during fuel loading operation. Under the long-term storage condition, the basket shims are exposed to dry and inert helium with no potential for reaction.

Finally, to ensure safe fuel loading operation, the operating procedure described in Chapter 8 provides for the monitoring of hydrogen gas in the area around the MPC lid prior to and during welding or cutting activities. Although the aluminum surfaces (Metamic-HT fuel basket and aluminum basket shims) are anodized, there is still a potential for generation of hydrogen in minute amounts when immersed in spent fuel pool water for an extended period. Accordingly, as a defense-in-depth measure, the lid welding procedure requires purging the space below the MPC lid prior to and during welding or cutting operation to eliminate any potential for formation of any combustible mixture of hydrogen and oxygen. Following the completion of the MPC lid welding and hydrostatic testing, the MPC-68M is drained and dried. After the completion of the drying operation, there is no credible mechanism for any combustible gases to be generated within the MPC-68M.

3.III.4.2 Positive Closure

Same as in Subsection 3.4.2.

3.III.4.3 Lifting Attachment Points

The structural analyses of the lifting attachment points in Subsection 3.4.3 (including all paragraphs) are bounding for the MPC-68M for the following reasons:

During a non-mechanistic tip-over event, the fuel assemblies exert a lateral force on the fuel basket panels as the overpack impacts the ground and decelerates. The lateral force causes the fuel basket panels to deflect potentially affecting the spacing between stored fuel assemblies. To maintain the fuel in a subcritical configuration, a deflection limit for the fuel basket panels is set in Subsection 2.III.0.1, which is supported by the criticality safety analysis in Supplement 6.III. Here a finite element analysis is performed using ANSYS to demonstrate that the maximum lateral deflection in the fuel basket panels under a bounding deceleration of 60g is less than the limit specified in Section 2.III.0.1. The 60g input deceleration is bounding because it exceeds the design basis deceleration limit of 45g for the non-mechanistic tip over of the HI-STORM storage overpack (see Subsection 3.III.4.10) and for the horizontal drop of the HI-TRAC transfer cask (see Subsection 3.4.9), and it matches the design basis lateral deceleration limit of 60g for the HI-STAR transport cask [1.1.3] for future considerations. The analysis methodology presented in this subsection is identical to the methodology used in [2.III.6.2] to qualify the F-37 fuel basket.

As shown in Figure 3.III.1, a representative slice of the MPC-68M fuel basket, consisting of a smaller end section and a full section, is modeled in detail including the contained fuel assemblies and supporting basket shims. The fuel basket panels are modeled with SOLSH190 solid shell elements. The basket shims and each fuel assembly are modeled with SOLID45 solid elements. The mass density assigned to the fuel assemblies corresponds to the maximum BWR fuel assembly weight per Table 2.1.22, except at the 16 cell locations along the basket perimeter where Damaged Fuel Containers are permitted. At these 16 locations, the mass density corresponds to the maximum weight of a BWR fuel assembly plus DFC per Table 2.1.22. Standard contact pairs using CONTA173/TARGE170 elements are defined at the interfaces of fuel assembly/basket panel, shim/basket panel, and between stacked basket panels including all the intersecting slot locations. At the perimeter corners, the intersecting basket panels are bonded together in the finite element model, and the strength properties of the corner most elements are then adjusted depending on whether there is a full length weld at that location. At corner locations that are not welded full length (see licensing drawing in Section 1.5), the elastic modulus of the corner elements is reduced to 1% of the MGV in Table 1.III.2 to effectively eliminate the joint's shear and moment carrying capacity. The fuel basket material model is implemented with true stress-true strain multi-linear isotropic hardening plasticity model. An elastic material model is used for the basket shims since no plastic deformation is expected. To accommodate large plastic deformation in the fuel basket panels, sufficiently small element sizes (< 0.40 in) are used and 9 integration points through the thickness are specified. A sensitivity study was performed in [2.III.6.2] to confirm that the panel stresses and displacements obtained using solid shell elements are converged and comparable to those obtained using 5 solid elements through the thickness of the panel.

The 60g deceleration is applied to the model with the basket in the so-called 0º orientation (see Figure 3.III.5). This orientation is chosen for analysis because it maximizes the lateral load on a single basket panel, which in turn maximizes the lateral deflection of the panel. In the 0º orientation, the amplified weight of each stored fuel assembly (during the 60g impact event) bears entirely on one basket panel. Conversely, in the 45º orientation, the amplified weight of each stored fuel assembly is equally supported by two basket panels. The difference in loading between these two basket orientations is pictorially shown in Figure 3.III.5, where "m" denotes

temperature of 375ºC, which bounds the computed metal temperatures anywhere in the fuel basket (see Table 4.III.3). The critical buckling stress for a pin-ended bar is:

$$\sigma_{cr} = (\pi)^2 \frac{E}{12(1-\nu^2)} \left(\frac{h}{a}\right)^2$$

where h is the plate thickness, a is the unsupported plate length, E is the Young's Modulus of Metamic-HT at 375ºC, ν is Poisson's Ratio (use 0.3 for this calculation)

From the drawings in Section 1.5, h = 0.40 in, a = 6.05 in, and E = 6,125 ksi (Table 1.III.2). Then, the classical critical buckling stress is computed as 24.199 ksi, which exceeds the yield strength of the material (9.425 ksi) at 375ºC. This demonstrates that basket plate instability by elastic buckling is not possible.

3.III.4.5 Cold

Same as in Subsection 3.4.5.

3.III.4.6 HI-STORM 100 Kinematic Stability under Flood Condition (Load Case A in Table 3.1.1)

The stability evaluation of the HI-STORM 100 overpack under flood conditions in Subsection 3.4.6 bounds the scenario of a loaded MPC-68M inside a HI-STORM overpack. The previous analysis is bounding because it uses as input the empty weight of the HI-STORM overpack (i.e., no MPC inside) combined with the maximum CG height from Table 3.2.3.

3.III.4.7 Seismic Event and Explosion

Since there are no physical changes to the HI-STORM overpacks and the MPC-68M reduces the CG height of the loaded HI-STORM overpacks, relative to those analyzed in Chapter 3, the seismic event and explosion analyses presented in Subsection 3.4.7 (including all paragraphs) bound the scenario of a loaded MPC-68M inside a HI-STORM overpack.

3.III.4.8 Tornado Wind and Missile Impact (Load Case B in Table 3.1.1 and Load Case 04 in Table 3.1.5)

The results for the post-impact response of the HI-STORM 100 overpack in Subsection 3.4.8 for the combination of tornado missile plus either steady tornado wind or instantaneous tornado pressure drop bound the results for a loaded MPC-68M inside a HI-STORM overpack. The results are bounding because they are calculated assuming a lower bound weight for the loaded HI-STORM and an upper bound CG height (as compared to a loaded MPC-68M inside a HI-STORM).

Same as in Subsection 3.4.11 (including all paragraphs).

3.III.4.12 MPC Service Life

Same as in Subsection 3.4.12 and with the following supplementary information provided herein.

3.III.4.12.1 Metamic-HT Considerations

Metamic-HT has been extensively tested as indicated in Supplement 1.III. Testing has included extensive tests for creep, irradiation and corrosion to ensure long-term fuel basket performance under normal conditions of storage. The Metamic-HT is also not susceptible to structural fatigue and brittle fracture under long term conditions of storage. Corrosion is discussed further in Subsection 3.III.4.1. Creep and boron depletion are further discussed below.

i) Fuel Basket Creep

The Metamic sourcebook contains data on the testing to determine the creep characteristics of the Metamic-HT under both unirradiated and irradiated conditions. A creep equation to estimate a bounding estimate of total creep as a function of stress and temperature is also provided. The creep equation developed from this test provides a conservative prediction of accumulated creep strain by direct comparison to measured creep in unirradiated and irradiated coupons.

The creep equation for Metamic-HT that bounds *all* measured data (tests run for 20,000 hours) is of the classical exponential form in stress and temperature [1.III.3], which is written symbolically as $\varepsilon = f(\sigma,T)$.

Creep in the MPC-68M fuel basket will not be a reactivity modifier because the basket is arrayed in the vertical orientation. The lateral loading of the fuel basket walls is insignificant and hence no mechanistic means for the basket panels to undergo lateral deformation from creep exists, even if the panel material were susceptible to creep.

The creep effect would tend to shorten the fuel basket under the self-weight of the basket. An illustrative calculation of the cumulative reduction of the basket length is presented below to demonstrate the insignificant role of creep in the MPC-68M fuel basket.

The in-plane compressive stress, σ, at height x in the basket panel is given by

$$\sigma = \rho(H-x) \qquad (3.III.1)$$

where:
ρ = weight density of Metamic-HT
H = height of the fuel basket

Using the above stress equation, the total creep shrinkage, δ, is given by

$$\delta = \int_{o}^{H} f(\sigma, T)dx \qquad (3.III.2)$$

where:
T = panel's metal temperature (conservatively assumed to be 375°C for a period of 60 years)
H = height of the basket (conservatively assumed to be 200 inches)

Using the creep equation (provided in [1.III.3]) and performing the above integration numerically yields δ = 0.138 inch. In other words, the computed shrinkage of the basket is less than 0.069% of its original length. Therefore, it is concluded that for the vertical storage configuration the creep effects of the MPC-68M fuel basket are insignificant due to absence of any meaningful loads on the panels. Therefore, creep in the Metamic-HT fuel basket is not a matter of safety concern.

ii) Fuel Basket Boron Depletion

The similarities between Metamic-HT and Metamic (classic) neutron absorbers and their exposure to the same long-term conditions of storage in the HI-STORM 100 system provide a logical basis to expect negligible neutron absorber boron depletion in Metamic-HT. However, to assure criticality safety during worst case design basis conditions over the 40-year design life, the analysis discussed in Subsection 6.III demonstrates that the boron depletion in the Metamic-HT is negligible over a 50-year duration. Thus, sufficient levels of boron are present in the fuel basket to maintain criticality safety over the 40-year design life of the MPC.

3.III.4.12.2 Basket Shim Considerations:

i) Basket Shim Creep

Like the fuel basket, the basket shims are not subject to any significant loading during storage. The ability of the basket shims (made of a creep resistant aluminum alloy) has been evaluated and qualified in Docket No. 71-9325 [2.III.6.2] for transport applications where the stress level (in horizontal configuration) is significant. Therefore, in light of the minuscule stress levels from self-weight in long-term storage, creep is ruled out as a viable concern for the basket shims.

ii) Basket Shim Corrosion

Basket shim corrosion is discussed in Subsection 3.III.4.1.

3.III.4.13 <u>Design and Service Life</u>

Same as in Subsection 3.4.13.

3.III.5 <u>FUEL RODS</u>

Same as in Section 3.5.

TABLE 3.III.4
MAXIMUM DISPLACEMENT IN MPC-68M FUEL BASKET

Maximum Lateral Displacement in Fuel Basket Panel, θ (dimensionless) (Note 1)	Maximum Allowable Value of θ (from Table 2.III.4)	Safety Factor
1.008×10^{-3}	0.005	4.96

Notes:

1. See Subsection 2.III.0.1 for definition of θ.

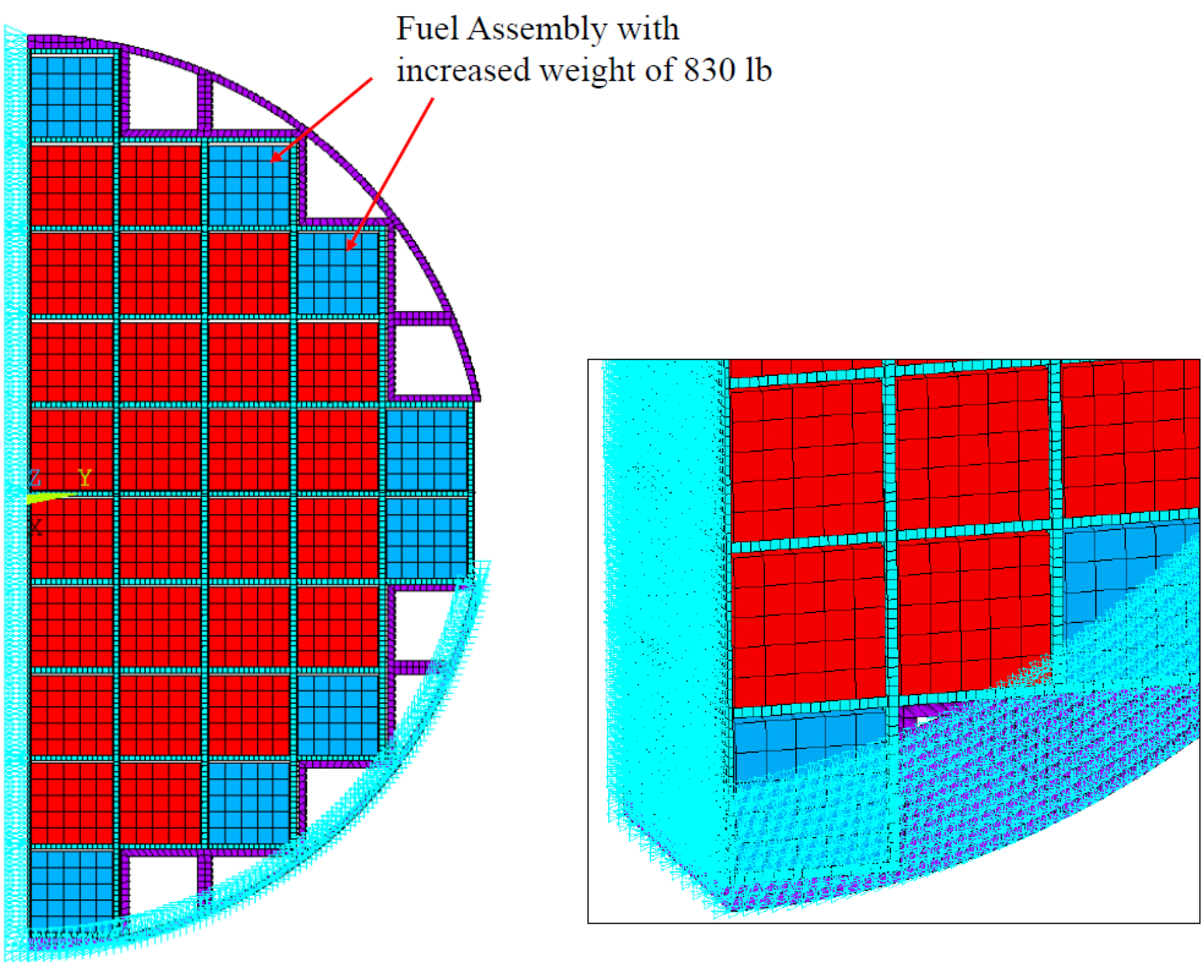


FIGURE 3.III.1: FINITE ELEMENT MODEL OF MPC-68M FUEL BASKET

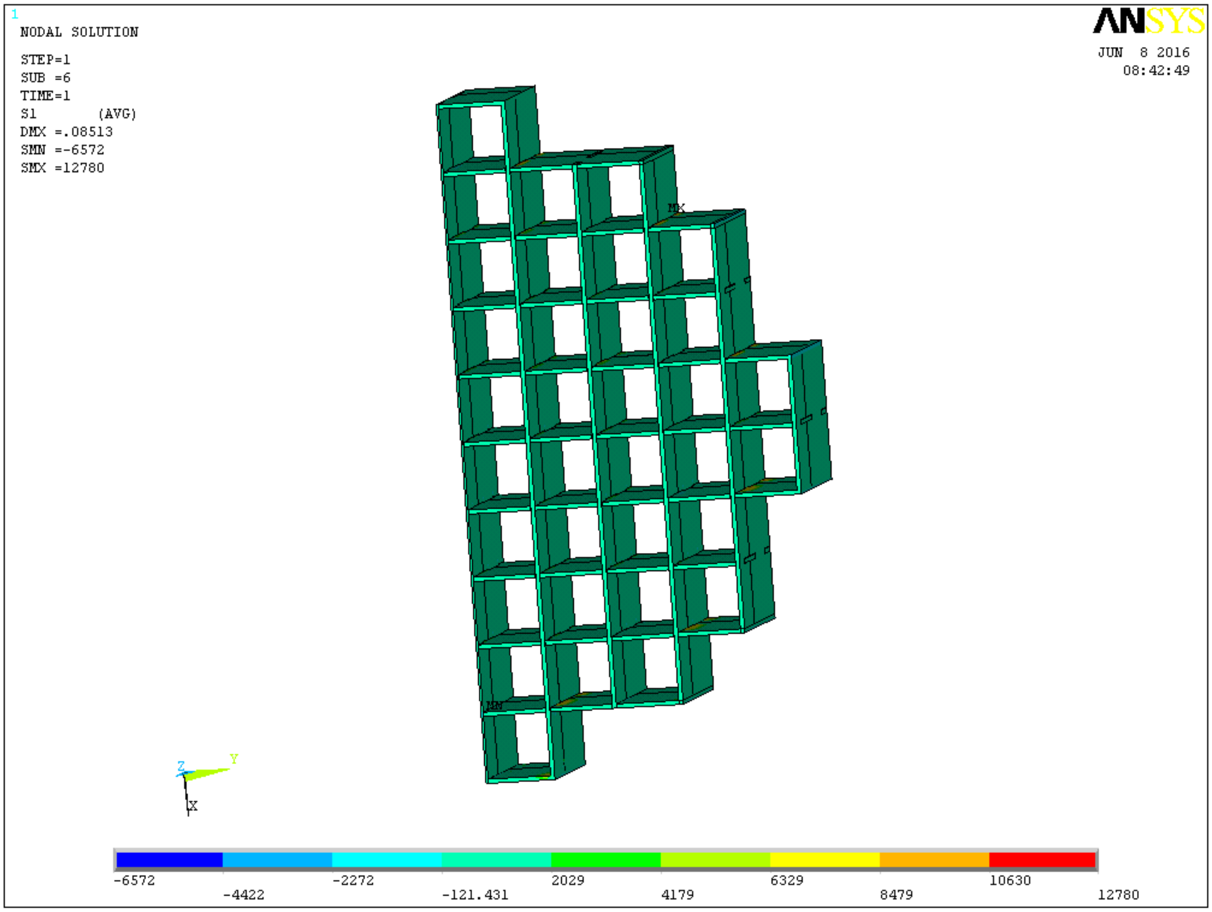


FIGURE 3.III.2: TRUE STRESS DISTRIBUTION IN MPC-68M FUEL BASKET UNDER 60G LOAD

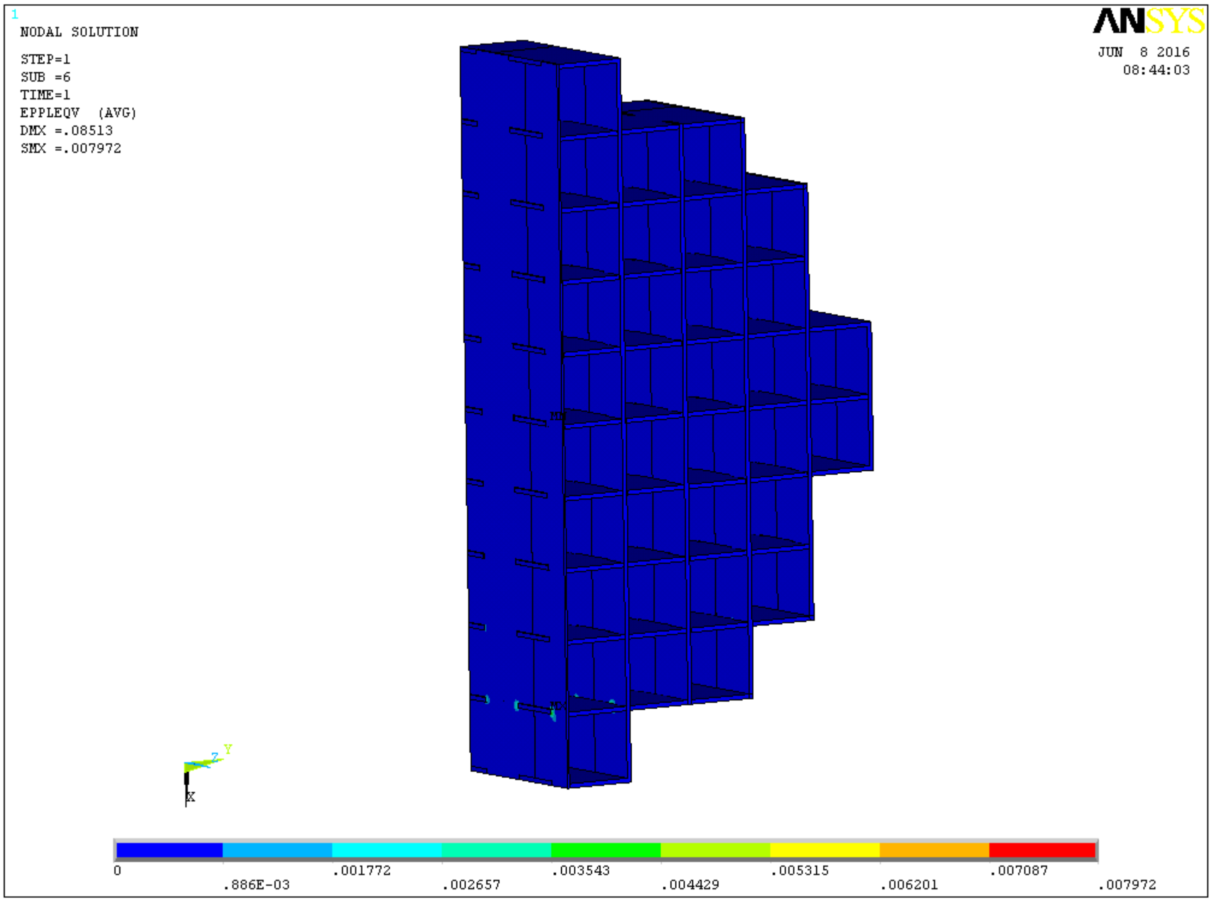


FIGURE 3.III.3: PLASTIC STRAIN DISTRIBUTION IN MPC-68M FUEL BASKET UNDER 60g LOAD

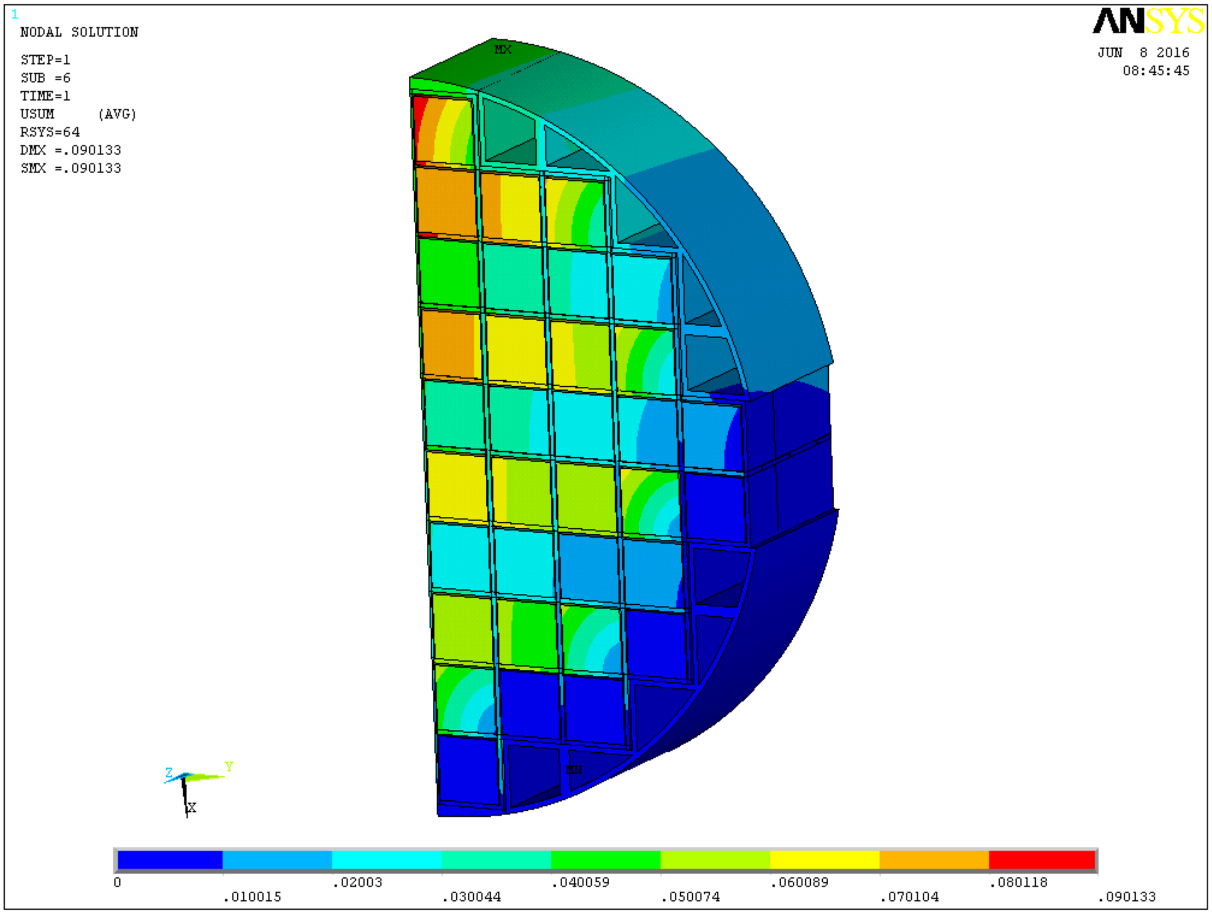


FIGURE 3.III.4: DISPLACEMENT CONTOUR IN MPC-68M FUEL BASKET UNDER 60g LOAD

Table 4.2.2

SUMMARY OF HI-STORM SYSTEM MATERIALS
THERMAL CONDUCTIVITY DATA

Material	At 200°F (Btu/ft-hr-°F)	At 450°F (Btu/ft-hr-°F)	At 700°F (Btu/ft-hr-°F)	At 1000°F (Btu/ft-hr-°F)
Helium	0.0976	0.1289	0.1575	0.1890
Air*	0.0173	0.0225	0.0272	0.0336
Alloy X***	8.4	9.8	11.0	12.4
Carbon Steel	24.4	23.9	22.4	20.0
Concrete**	1.05	1.05	1.05	1.05
Lead	19.4	17.9	16.9	N/A
Water	0.392	0.368	N/A	N/A

* At lower temperatures, Air conductivity is between 0.0139 Btu/ft-hr-°F at 32°F and 0.0176 Btu/ft-hr-°F at 212°F.

** Conservatively assumed to be constant for the entire range of temperatures.

*** Individual thermal conductivities of the alloys that comprise the Alloy X materials are reported in Appendix 1.A. Lowerbound Alloy X thermal conductivity is tabulated herein.

Table 4.2.3

SUMMARY OF FUEL ELEMENT COMPONENTS
THERMAL CONDUCTIVITY DATA

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

* Lowest values of conductivity used in the thermal analyses for conservatism.

4.4.2 [deleted]

4.4.3 Test Model

The HI-STORM thermal analysis is performed on the FLUENT [4.1.2] Computational Fluid Dynamics (CFD) program. To ensure a high degree of confidence in the HI-STORM thermal evaluations, the FLUENT code is benchmarked using data from tests conducted with casks loaded with irradiated SNF ([4.1.3],[4.1.7]). The benchmark work is archived in QA validated Holtec reports ([4.1.5],[4.1.6]).These evaluations show that the FLUENT solutions are conservative in all cases. In view of these considerations, additional experimental verification of the thermal design is not necessary.

4.4.4 Maximum and Minimum Temperatures

4.4.4.1 Maximum Temperatures

The 3-D model from the previous subsection is used to determine temperature distributions under long-term normal storage conditions for an array of cases covering PWR and BWR fuel storage in uniform and regionalized loading configurations. For this purpose one bounding MPC design in each of the two fuel classes – MPC-68 for BWR and MPC-32 for PWR – are analyzed and results obtained and summarized in this subsection. For a bounding evaluation the MPCs are assumed to be emplaced in a limiting overpack (HI-STORM 100S Version B).

The HI-STORM 100S Version B is the limiting overpack by virtue of the inlet and outlet vents design. Compared to two other overpack designs (i.e., HI-STORM 100 and HI-STORM 100S), the HI-STORM 100S Version B has smaller inlet and outlet vents. Thus Version B vent airflow resistances are bounding. Also, the HI-STORM 100S Version B is the shortest of the overpacks. This reduces the chimney height which minimizes the driving head for air flow. Because the HI-STORM 100S Version B will have the least cooling air flow, it will yield bounding results.

A cross-reference of HI-STORM thermal analyses is provided in Table 4.4.5. Under regionalized loading, an array of runs covering a range of regionalized storage configurations specified in Chapter 2 (X=0.5 to X=3) are analyzed. The results are graphed in Figures 4.4.6 and 4.4.7 for PWR and BWR fuel storage respectively. Based on this array of runs the fuel storage condition corresponding to X = 0.5 is determined to be limiting for both PWR and BWR MPCs. Accordingly HI-STORM MPC and overpack temperatures are reported for this storage condition in Tables 4.4.6 and 4.4.7.

Damaged fuel is canestirezed in damaged fuel containers (DFCs) before long-term storage. Each MPC type has designated locations for placement of DFCs, as described in Chapter 2. Particularly, the DFCs are placed for storage in basket peripheral locations. The presence of DFCs impedes helium flow through it. However, since the DFCs are placed in the cold peripheral locations, they do not control the peak cladding temperature. Moreover, as a substantial fraction of basket cells are occupied by intact fuel, the overall effect of DFC fuel storage on the heat dissipation from the basket

is small. To account for its impact, a heat load penalty described in Tables 4.4.3 and 4.4.4 is placed on the DFC locations under both uniform and regionalized heat load patterns.

It should be noted that the 3-D FLUENT cask model incorporates the effective conductivity of the fuel assembly submodell. Therefore the FLUENT models report the peak temperature in the fuel storage cells Thus, as the fuel assembly models include the fuel pellets, the FLUENT calculated peak temperatures are actually peak pellet centerline temperatures which bound the peak cladding temperatures with a margin.

The following observations can be derived by inspecting the temperature field obtained from the thermal models:

- The fuel cladding temperatures are below the regulatory limit (ISG-11 [4.1.4]) under all storage scenarios (uniform and regionalized) in all MPCs.

- The maximum temperature of the basket structural materials are within their design limits.

- The maximum temperature of the neutron absorbers are below their design limits.

- The maximum temperatures of the MPC pressure boundary materials are below their design limits.

- The maximum temperatures of concrete is within the guidance of the governing ACI Code (see Table 4.3.1).

The above observations lead us to conclude that the temperature field in the HI-STORM System with a loaded MPC containing heat emitting SNF complies with all regulatory temperature limits. In other words, the thermal environment in the HI-STORM System is in compliance with Chapter 2 Design Criteria.

4.4.4.2 Minimum Temperatures

In Table 2.2.2 of this report, the minimum ambient temperature condition for the HI-STORM storage overpack and MPC is specified to be -40°F. If, conservatively, a zero decay heat load with no solar input is applied to the stored fuel assemblies, then every component of the system at steady state would be at a temperature of -40°F. Low service temperature (-40^{o}F) evaluation of the HI-STORM is provided in Chapter 3. All HI-STORM storage overpack and MPC materials of construction will satisfactorily perform their intended function in the storage mode at this minimum temperature condition.

4.4.4.3 Effects of Elevation

The reduced ambient pressure at site elevations significantly above the sea level will act to reduce the ventilation air mass flow, resulting in a net elevation of the peak cladding temperature. However,

Table 4.4.3

MAXIMUM PERMISSIBLE HEAT LOAD FOR LOCATIONS WITH DFCs UNDER UNIFORM LOADING

MPC Type	Decay Heat for Locations with Damaged Fuel Assemblies and Fuel Debris (kW)
MPC-24E/24EF	1.114
MPC-32/32F	0.718
MPC-68/68FF/68M	0.393

Table 4.4.4

MAXIMUM PERMISSIBLE HEAT LOAD FOR LOCATIONS WITH DFCs UNDER REGIONALIZED LOADING

MPC Type	Decay Heat for Locations with Damaged Fuel Assemblies and Fuel Debris (kW)
MPC-24E/24EF	$0.75*q_2$ (Note 1)
MPC-32/32F	$0.65*q_2$ (Note 1)
MPC-68/68FF/68M	$0.75*q_2$ (Note 1)
Note 1: q_2 is the maximum permissible heat load allowed for intact fuel in Region 2.	

connection and heated water will exit from the vent port. The minimum water flow rate required to maintain the MPC cavity water temperature below boiling with an adequate subcooling margin is determined as follows:

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

where:

M_W = minimum water flow rate (lb/hr)
C_{pw} = water heat capacity (Btu/lb-°F)
T_{max} = maximum MPC cavity water mass temperature (must be less than 212°F)
T_{in} = MPC water inlet temperature
Q = Coincident fuel decay heat in the canister (Btu/hr)

For example, the MPC cavity water temperature limited to 150°F, MPC water inlet temperature at 125°F and design basis maximum heat load (36.9 kW, approximately 125,908 Btu/hr), the water flow rate computes as 5038 lb/hr (10.1 gpm).

4.5.3 MPC Temperatures During Moisture Removal Operations

4.5.3.1 Vacuum Drying Operation

The initial loading of SNF in the MPC requires that the water within the MPC be drained, fuel dried and the water replaced with helium. Vacuum drying of fuel is conducted by evacuating the MPC after completion of MPC draining operation. For MPCs containing Moderate Burnup Fuel (MBF) assemblies only, this operation may be carried out using the vacuum drying method up to the threshold heat loads defined in Table 4.5.1. In this Table Q1 is the threshold heat load for vacuum drying operations without time limits. The requirements and limits for moisture removal are provided in LCO 3.1.1 of the HI-STORM 100 CoC and are specific to the amendment to which the HI-STORM 100 System is being loaded. To minimize fuel temperatures during vacuum drying operations the HI-TRAC annulus must be water filled.

At heat loads greater than the threshold heat load defined above, the peak cladding temperature cannot be maintained below the ISG-11, Revision 3 limit of 570°C for MBF under a vacuum condition of infinite duration. Under this scenario, cycles of vacuum drying resulting in heatup followed with cooling by helium are performed until drying criteria is achieved. Similarly, vacuum drying of MPCs containing one or more High Burnup Fuel (HBF) assemblies is also permitted under time limits. The peak cladding temperature for drying HBF must be maintained below ISG-11 Rev 3 limit of 400°C. It must be noted that the permissible time for heatup/cooldown cycles is a function of canister specific heat loads. At lower heat loads the duration of vacuum drying cycles is higher. The thermal model defined below must be used for heatup/cooldown cycles for site-specific canister heat load maps. It must be ensured per ISG-11 Rev 3 that the repeated thermal cycling is limited to less than 10 cycles, with cladding temperature variations less than 65°C (117°F) each cycle. Fuel drying may also be conducted by using forced helium drying (FHD) process as discussed in Section 4.5.3.2.

A 3-D FLUENT thermal model of the MPC is constructed in the same manner as described in Section 4.4. The principal input to this model is the effective conductivity of fuel under vacuum drying operations. To reasonably bound vacuum drying operations the effective conductivity of fuel is computed assuming the MPC is filled with water vapor at a very low pressure (1 torr) for the entire duration of vacuum drying[17]. The methodology for computing the effective conductivity is given in Section 4.4.1. To ensure a conservative evaluation the thermal model is incorporated with the following assumptions:

i. Threshold heat load Q1, defined in Table 4.5.1, is assumed and steady-state condition reached under Q1 results in vacuum drying of only MBF without time limits.
ii. The external surface of the MPC shell is postulated to vary linearly from 100°C (212°F) normal boiling temperature of water at the top to 111°C (231°F) elevated pressure boiling temperature at the bottom to account for the hydrostatic head.
iii. The bottom surface of the MPC is insulated.
iv. MPC internal convection heat transfer is suppressed.
v. Top surface of the MPC is in communicative contact with air (Table 2.2.2). Natural convection and radiation cooling from the MPC top is included in the thermal model.

The principle objective of the vacuum drying analysis is to ensure that fuel temperatures are below ISG-11, Rev. 3 temperature limits (See Table 4.3.1). Under threshold heat load Q1 the results and margins are tabulated in Table 4.5.5. The results show that ISG-11, Rev. 3 limits are met with ample margins.

4.5.3.2 Forced Helium Dehydration

To dry the MPC cavity using a Forced Helium Dehydration (FHD) system, a conventional, closed loop dehumidification system consisting of a condenser, a demoisturizer, a compressor, and a pre-heater is utilized to extract moisture from the MPC cavity through repeated displacement of its contained helium, accompanied by vigorous flow turbulation. A vapor pressure of 3 torr or less is assured by verifying that the helium temperature exiting the demoisturizer is maintained at or below the psychrometric threshold of 21°F for a minimum of 30 minutes. See Appendix 2.B for detailed discussion of the design criteria and operation of the FHD system.

The FHD system provides concurrent fuel cooling during the moisture removal process through forced convective heat transfer. The attendant forced convection-aided heat transfer occurring during operation of the FHD system ensures that the fuel cladding temperature will remain below the applicable peak cladding temperature limit for normal conditions of storage, which is well below the high burnup cladding temperature limit 752°F (400°C) for all combinations of SNF type, burnup, decay heat, and cooling time. Because the FHD operation induces a state of forced convection heat transfer in the MPC, (in contrast to the quiescent mode of natural convection in long term storage), it

[17] This is conservative as the MPC pressure is progressively lowered below ambient pressure to facilitate moisture removal. Near the end of the vacuum drying operation the pressure is substantially lowered to approximately 1 torr to facilitate the 30-minute 3-torr vacuum rebound test followed by backfilling of the MPC with helium.

Table 4.5.1

THRESHOLD HEAT LOADS FOR MOISTURE REMOVAL OPERATIONS

Drying Method	Fuel Burnup	Threshold Heat Load (Note 1)	Time Limits
Vacuum Drying	MBF	Q1	None
Vacuum Drying	MBF	MPC Heat Load > Q1	Yes (Note 2)
Vacuum Drying	HBF	36.9 kW	Yes (Note 2)
FHD	MBF and/or HBF	36.9 kW	None

Note 1: Threshold heat load is defined as Q1 = 26 kW (Uniform)
Note 2: Vacuum drying of the MPC must be performed using cycles of the drying system, according to the guidance contained in ISG-11 Revision 3 and as described in Paragraph 4.5.3.1. The time limit for these cycles shall be determined based on site specific conditions.

Table 4.5.2

HI-TRAC TRANSFER CASK LOWERBOUND
WEIGHTS AND THERMAL INERTIAS

Component	**Weight (lbs)**	**Heat Capacity (Btu/lb-°F)**	**Thermal Inertia (Btu/°F)**
Water Jacket	7,000	1.0	7,000
Lead	52,000	0.031	1,612
Carbon Steel	40,000	0.1	4,000
Alloy-X MPC (empty)	39,000	0.12	4,680
Fuel	40,000	0.056	2,240
MPC Cavity Water*	6,500	1.0	6,500
			26,032 (Total)

* Conservative lower bound water mass.

Table 4.5.4

THRESHOLD HEAT LOADS FOR SUPPLEMENT COOLING SYSTEM REQUIREMENT

Condition*	Fuel in MPC	Heat Load Reduction Factor *	SCS Required
1	All MBF	100%	NO
2	One or More HBF	≤ 90%	NO
3	One or More HBF	> 90%	YES

* The threshold heat load is obtained by multiplying the design basis heat load per storage cell defined in Subsection 2.1.9.1 by the reduction factor listed in this table.

Table 4.5.5

MAXIMUM FUEL TEMPERATURES UNDER VACUUM DRYING OPERATIONS

Threshold Heat Load[Note 1]	Time Limit	Temperature (^{o}F)	Temperature Limit[Note 2]	Margin (^{o}F)
Q1	None	1046	1058	12

Notes:

1) Threshold heat load is defined in Table 4.5.1.
2) Temperature limit of moderate burnup fuel shown. Vacuum drying of high burn-up fuel is discussed in Subsection 4.5.3.

Figure 4.5.2: INTENTIONALLY DELETED

assumption is conservative. Starting from a baseline condition evaluated in Section 4.4 (normal ambient temperature and limiting fuel storage configuration) the temperatures of the HI-STORM 100 System are conservatively assumed to rise by the difference between the extreme and normal ambient temperatures (45^{o}F). The HI-STORM extreme ambient temperatures computed in this manner are reported in Table 4.6.4. The co-incident MPC pressure is also computed (Table 4.6.2) and compared with the accident design pressure (Table 2.2.1). The result is confirmed to be below the accident limit.

4.6.2.4 100% Blockage of Air Inlets

This event is defined as a complete blockage of all four bottom inlets. The immediate consequence of a complete blockage of the air inlets is that the normal circulation of air for cooling the MPC is stopped. An amount of heat will continue to be removed by localized air circulation patterns in the overpack annulus and outlet ducts, and the MPC will continue to radiate heat to the relatively cooler storage overpack. As the temperatures of the MPC and its contents rise, the rate of heat rejection will increase correspondingly. Under this condition, the temperatures of the overpack, the MPC and the stored fuel assemblies will rise as a function of time.

As a result of the considerable inertia of the storage overpack, a significant temperature rise is possible if the inlets are substantially blocked for extended durations. This accident condition is, however, a short duration event that is identified and corrected through scheduled periodic surveillance. Nevertheless, this event is conservatively analyzed assuming a substantial duration of blockage. The event is analyzed using the FLUENT CFD code. For MPC heat load up to the full design basis, the HI-STORM thermal model is the same 3-Dimensional model constructed for normal storage conditions (see Section 4.4) except for the bottom inlet ducts, which are assumed to be impervious to air. Using this model, a transient thermal solution of the HI-STORM 100 System starting from normal storage conditions is obtained. The results of the blocked ducts transient analysis that support the required action completion times for clearing the inlets are presented in Table 4.6.5 and confirmed to be below the accident temperature limits (Table 2.2.3). The co-incident MPC pressure is also computed and compared with the accident design pressure (Table 2.2.1). The result (Table 4.6.2) is confirmed to be below the limit.

For MPC heat loads which meet the values in Table 2.1.31, the results of the transient analysis that support the required action completion times for clearing the inlets are presented in Table 4.6.7 and confirm all temperatures are below the accident temperature limits (Table 2.2.3).

30-Day 100% Vent Blockage Accident

As noted above, the fuel and component temperatures rise due to complete blockage of HI-STORM vents. This temperature rise is small for casks where heat loads are much lower than design basis heat loads. A threshold heat load is defined for all MPCs in Table 4.6.8 at or below which fuel and component temperatures remain below their respective 30-day accident temperature limits (Table 2.2.3) under steady state conditions. A steady state evaluation of a complete vent blockage at threshold heat loads is performed for both MPC-32 and MPC-68. Steady state temperature and MPC

Table 4.6.5

100% BLOCKED INLET DUCTS MAXIMUM HI-STORM TEMPERATURES FOR DESIGN BASIS HEAT LOAD

Component	Temperatures@32 hrs (°F)	Temperatures@24 hrs (°F)
Fuel Cladding	890	860
MPC Basket	884	855
MPC Shell	583	561
MPC Lid (Note 1)	599	574
Overpack Inner Shell	480	454
Lid Concrete Bottom Plate	433	411
Overpack Body Local Temperature	477	450
Lid Concrete Local Temperature	433	411
Note 1: Maximum thru thickness section average temperature reported.		

Table 4.6.6

SUMMARY OF INPUTS FOR BURIAL UNDER DEBRIS ANALYSIS

Thermal Inertia Inputs: M (Lowerbound HI-STORM 100 Weight) Cp (Carbon steel heat capacity)[25]	 150000 lb 0.1 Btu/lb-°F
Cask initial temperature[26]	728°F
Q (Decay heat)	1.3×10^5 Btu/hr
ΔT (clad temperature margin)[27]	300°F

[25] Carbon steel has the lowest heat capacity among the principal materials employed in MPC and overpack construction (carbon steel, stainless steel and concrete).

[26] Conservatively overstated.

[27] The clad temperature margin is conservatively understated in this table.

SUPPLEMENT 4.III[1]

THERMAL EVALUATION OF THE MPC-68M

4.III.0 OVERVIEW

The MPC-68M is a 68 cell BWR canister engineered with a high B^{10} containing Metamic-HT basket for enhanced criticality control. The MPC-68M is evaluated for storage in the aboveground family of HI-STORM overpacks. For a bounding evaluation an MPC-68M emplaced in the most flow resistive HI-STORM 100S Version B overpack[2] is analyzed under normal, off-normal and accident conditions. The evaluations described herein parallel those of the aboveground HI-STORM cask contained in the main body of Chapter 4 of this FSAR. In addition, a new heat load layout is added which is referred to as the "Quarter Symmetric Heat Load" (QSHL) pattern. In this pattern, the maximum permissible heat load in each storage cell, q, is specific to its location within the quadrant and is limited to a unique prescribed value given in Figure 2.III.1. This QSHL pattern seeks to minimize the large temperature differences between cladding temperatures in proximate fuel assemblies and is especially suited for canisterizing of fuel with widely varying specific heat loads such as at a plant undergoing decommissioning.

It should be noted that the QSHL pattern is a special case of regionalized loading, but is identified simply as “QSHL” to avoid confusion.

To ensure readability, the section in the main body of the chapter to which each section in this supplement corresponds is clearly identified. All tables in this supplement are labeled sequentially.

4.III.1 INTRODUCTION

The information presented in this supplement is intended to serve as a complement to the information provided in the main body of Chapter 4. Except for the fuel basket and basket support materials, the information in Chapter 4 that remains applicable to the MPC-68M analysis is not repeated herein. Specifically the following information in the main body of Chapter 4 is not repeated:

1. The thermal properties of materials in Section 4.2 applicable to the MPC-68M.

2. The specifications for components in Section 4.3 applicable to the MPC-68M.

3. The descriptions of the thermal modeling of the MPC and its internals, including fuel assemblies, in Section 4.4 which are applicable in their entirety to the MPC-68M.

4. The descriptions of the short-term loading operations, carried out using the HI-TRAC transfer cask, in Section 4.5 applicable to the MPC-68M.

1 For ease of supplement review the sections are numbered in parallel with the main Chapter 4.
2 This approach is identical to the HI-STORM thermal analysis in Section 4.4.

As confirmed by appropriate supporting analyses, the heat rejection capacity of the MPC-68M[1] is equal to or better than its counterparts (strictly speaking, much better because of the highly conducting Metamic-HT fuel basket). This renders its resistance to accident events such as fire with greater margins of safety.

4.III.2 THERMAL PROPERTIES OF MATERIALS[2]

The material properties compiled in Section 4.2 of the FSAR provide the required information, except for the material properties of Metamic-HT fuel basket, aluminum basket shims[3] and solid shims. The Metamic-HT and shims thermo-physical properties data is provided in Table 4.III.1.

4.III.3 SPECIFICATIONS FOR COMPONENTS[4]

All applicable material temperature limits in Section 4.3 of the FSAR continue to apply to the MPC-68M. Temperature limits of MPC-68M fuel basket and basket shim materials is specified in Table 4.III.2.

4.III.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF STORAGE[5]

4.III.4.1 Thermal Model

The MPC-68M thermal design is same as that of the currently licensed MPC-68. It features a 68 cells capacity fuel basket for storing BWR fuel. The basket is engineered with a bottom plenum by providing flow holes, a top open plenum by providing an engineered clearance and a peripheral downcomer to facilitate heat dissipation by thermosiphon action. The MPC-68M is helium pressurized to backfill specifications as discussed below:

- Case 1: Initial helium backfill pressure is defined in Chapter 4, Table 4.4.12 under uniform and regionalized loading based on regionalization parameter X (Section 2.1.9), and
- Case 2: Initial helium backfill pressure is defined in Table 1.III.1 under QSHL pattern defined in Supplement 2.III.

The principal differences are in the basket material of construction (Metamic-HT), the installation of aluminum basket shims in the basket peripheral spaces and replacement of the cell walls sandwich

1 Heat rejection capacity is defined as the amount of heat the storage system containing an MPC loaded with CSF stored in uniform storage will reject with the ambient environment at the normal temperature and the peak fuel cladding temperature at 400ºC.

2 This section supplements Section 4.2.
3 The terms basket shims and extruded shims are interchangeably used in this chapter.
4 This section supplements Section 4.3.
5 This section supplements Section 4.4.

be supported on a subgrade at 77ºF. This is the same boundary condition applied to the bottom of the ISFSI pad for the HI-STORM 100 modeling in Section 4.4.

4.III.4.2 Thermal Analysis

The MPC-68M has been designed to permit storage under the array of uniform and regionalized heat loads defined in Chapter 2 as a function of the regionalization parameter X. As shown in Chapter 4 the highest cladding temperatures are reached under regionalized storage at X = 0.5. This scenario is co-incident with the maximum permissible MPC heat load and therefore temperatures of other sub-systems (such as fuel basket, MPC shell and overpack) also reach their highest values. The fuel cladding temperature under long term storage in HI-STORM is presented in Table 4.III.3.a

The QSHL pattern has also been analyzed using the same FLUENT model previously used in this FSAR: no changes were made to the existing thermal model. The selected heat loads in Figure 2.III.1 are suitably limited to ensure that the peak cladding temperature in the MPC remains below that in the governing MPC analyzed in this FSAR (MPC-32) under all thermal scenarios. Thus the peak cladding temperature for the QSHL pattern is limited by a previously analyzed and licensed MPC.

Other important safety aspects of the QSHL pattern are:

1. The hottest fuel assemblies are located in-board of the peripheral locations in the basket so that the colder fuel in the peripheral cells helps block the radiation emitted by the hottest fuel assemblies.

2. The cell specific heat load, q, provided in Figure 2.III.1 is the maximum value permitted for that location. In virtually every case, the actual heat load in every cell will be lower than the allowed limit, thus resulting in a lower cladding temperature field overall than that computed herein.

3. The fuel cladding temperature for QSHL pattern under long term storage in HI-STORM is presented in Table 4.III.3.a. The predicted PCT is higher than that for the scenario with decay heat based on regionalized parameter X defined in Chapter 2. For this reason, QSHL pattern is adopted as the licensing basis pattern for MPC-68M.

4. The PCT and basket temperatures under the QSHL pattern is lower than that in the thermally governing case (MPC-32).

This QSHL scenario is adopted for demonstration of compliance with the temperature and pressure limits set forth in this Supplement and Chapter 2. The limiting scenario is analyzed and maximum temperatures and pressures under normal storage tabulated in Tables 4.III.3b and 4.III.4. The results are below the Chapter 2 and Supplement 4.III normal temperature and pressure limits. In accordance with NUREG-1536 MPC-68M pressures are computed assuming 1% (normal), 10% (off-normal) and 100% (accident) rod ruptures with 100% rods fill gases and fission gases release in accordance

with NUREG-1536 release fractions. The pressures are computed and tabulated in Table 4III.4. The 100% rods rupture pressure is below the accident design pressure (Table 2.2.1).

4.III.4.3 Engineered Clearances to Eliminate Thermal Interferences

To minimize thermal stresses in load bearing members, the MPC-68M is engineered with adequate gaps to permit free thermal expansion of the fuel basket and MPC in axial and radial directions. In this subsection, differential thermal expansions are evaluated to ensure the adequacy of engineered gaps. The following gaps are evaluated:

a. Fuel Basket-to-MPC Radial Gap
b. Fuel Basket-to-MPC Axial Gap
c. MPC-to-Overpack Radial Gap
d. MPC-to-Overpack Axial Gap

The FLUENT thermal model articulated above provides the temperature field in the HI-STORM overpack and MPC-68M from which the changes in the above gaps are directly computed. The nominal cold gaps are presented on the drawings in Section 1.5 and the corresponding differential expansions under normal storage conditions are presented in Table 4.III.8. The calculations show significant margins against restraint to free-end expansion are available in the design.

4.III.4.4 Evaluation of Fuel Debris Storage

Fuel debris is permitted for storage in up to eight peripheral cells under the permitted heat load pattern shown in Figure 2.III.2. Although fuel debris is not required to meet cladding temperature limits, its effect on fuel stored in the interior cells must be assessed. Fuel debris in the canister is thermally conservatively evaluated assuming a bounding debris configuration and design heat load in all storage cells. The following assumptions are adopted to maximize the computed cladding temperatures:

1. The fuel debris is assumed to be completely pulverized and compacted into a square prismatic bar enclosed by the damaged fuel canister (DFC) with open helium space above it. In this manner the height of the prismatic bar emitting heat is minimized resulting in the maximization of lineal thermal loading (kw/ft) of the DFC and co-incident local heating of the fuel basket and neighboring storage cells.
2. Fuel debris assumed to be completely composed of UO_2. As UO_2 has a lower conductivity relative to cladding, heat dissipation is understated.
3. The fuel debris is assumed to block through flow of helium inside the DFC.
4. All 16 peripheral storage locations (not just the 8 permitted by CoC) are assumed to contain fuel debris emitting maximum heat permitted by Technical Specifications (CoC Appendix B, Figure 2.4-2) and all interior cells are emitting design basis heat under the applicable heat load scenario.
5. The MPC operating pressure is understated to minimize internal convection heat transfer

The results of the analysis are tabulated in Table 4.III.11. The results support the following conclusions:

- Cladding temperature is substantially below the ISG-11, Rev. 3 limit.
- MPC basket is below the design limit (Table 4.III.2) by large margin.
- MPC shell and Overpack metal temperatures are below design limits (Table 2.2.3).
- Overpack body and lid concrete are well below design limits (Table 4.3.1).

4.III.5 THERMAL EVALUATION OF SHORT TERM OPERATIONS

4.III.5.1 HI-TRAC Thermal Model

The HI-TRAC thermal model presented in Section 4.5 is adopted for the evaluation of MPC-68M under short term operations.

4.III.5.2 Maximum Time Limit During Wet Transfer Operations

Time-to-boil is calculated using the same methodology described in Section 4.5.2. Table 4.III.13 summarizes the thermal inertia of the constituent components in the loaded HI-TRAC transfer cask. Using the methodology described in Section 4.5.2, the time-to-boil is provided at representative initial temperatures for maximum QSHL in Table 4.III.14. This is an example calculation for the maximum design basis heat load. The same methodology can be adopted to determine the time-to-boil for canisters loaded at lower heat loads. An alternate method using the FLUENT thermal model described in Section 4.III.5.1 can be adopted to evaluate the time for water within the MPC to boil for site-specific conditions. Principal modeling steps and acceptance criteria are defined in Table 4.5.11.

4.III.5.3 MPC Temperature During Moisture Removal Operations

4.III.5.3.1 Vacuum Drying

Prior to helium backfill the MPC-68M must be drained of water and demoisturized. At the start of draining operation, both the HI-TRAC annulus and the MPC are full of water. The presence of water in the MPC ensures that the fuel cladding temperatures are lower than design basis limits by large margins. As the heat generating region is uncovered during the draining operation, the fuel and basket mass will undergo a monotonic heat up from the initially cold conditions when the heated surfaces were submerged under water. To limit fuel temperatures demoisturization of the MPC-68M by the vacuum drying method is permitted provided the HI-TRAC annulus remains water filled during vacuum drying operations. To support vacuum drying operations two limiting scenarios are defined below:

Scenario A: The MPC-68M is loaded with Moderate Burnup Fuel assemblies generating heat at the maximum permissible rate defined in Chapter 2 under the bounding regionalized storage scenario X = 0.5.

Scenario B: The MPC-68M is loaded with one or more High Burnup Fuel assemblies and the MPC-68M decay heat is less than a conservatively defined threshold heat load Q = 29 kW[1].

Scenario C: The MPC-68M is loaded with Moderate Burnup Fuel assemblies generating heat at the maximum permissible rate defined under QSHL pattern (Figure 2.III.1).

To evaluate the above scenarios the vacuum drying analysis methodology presented in Section 4.5 is adopted and an MPC-68M specific thermal model constructed. The principal features of the thermal model are as follows:

i. A bounding steady-state analysis is performed under the heat loads defined in the scenarios above.
ii. The water in the HI-TRAC annulus is conservatively assumed to be boiling under the hydrostatic head of water at the annulus bottom (232°F).
iii. The bottom surface of the MPC is insulated.

The thermal model articulated above is used to compute the maximum cladding temperature under the vacuum drying scenarios defined above. The results tabulated in Table 4.III.5 are in compliance with the ISG-11 temperature limits of Moderate Burnup Fuel (Scenario A) and High Burnup Fuel (Scenario B).

At heat loads greater than threshold heat load defined above, the peak cladding temperature cannot be maintained below the ISG-11, Revision 3 limit of 400°C for HBF under a vacuum condition of infinite duration. Under this scenario, cycles of vacuum drying resulting in heatup followed with cooling by helium are performed until drying criteria is achieved. The thermal model described above is used for heatup/cooldown cycles for site-specific canister heat load maps. It must be ensured per ISG-11 Rev 3 that the repeated thermal cycling is limited to less than 10 cycles, with cladding temperature variations less than 65°C (117°F) each.

4.III.5.3.2 Forced Helium Dehydration

Evaluation of Forced Helium Dehydration in Section 4.5 is applicable to MPC-68M.

4.III.5.4 Cask Cooldown and Reflood During Fuel Unloading Operations

Evaluation of cask cooldown and reflood operation in Section 4.5 is applicable to MPC-68M.

1 Threshold heat load is defined as the product of maximum loaded assembly heat load r_{max} and the number of fuel storage cells (n=68). Under this stipulation r_{max} must not exceed 0.426 kW.

4.III.5.5 HI-TRAC Onsite Transfer Operation

A 3D FLUENT thermal model of an MPC-68M emplaced in a HI-TRAC transfer cask is constructed to evaluate the thermal state of fuel under onsite transport in the vertical orientation[1]. A bounding analysis is performed under the following conditions:

(i) Steady state maximum temperatures have reached.
(ii) The MPC-68M is loaded with fuel generating heat at the maximum permissible level under the limiting Quarter Symmetric Heat Load (QSHL) pattern.
(iii) The HI-TRAC annulus is air filled.

The scenario defined above represents upper bound temperatures reached in the HI-TRAC without the aid of any auxiliary cooling such as the Supplemental Cooling System (SCS) defined in Section 4.5. The maximum cladding temperatures computed using the thermal model articulated above are tabulated in Table 4.III.6. As the cladding temperatures are below the limiting High Burnup Fuel temperature limits mandated by ISG-11 [4.1.4] SCS cooling is not necessary for ensuring cladding safety under onsite transfer operations for the MPC-68M canister. Accordingly SCS cooling is not mandated in the MPC-68M Technical Specifications. Additionally, the peak fuel cladding temperatures are bounded by MPC-32 (Section 4.5).

4.III.5.6 Sensitivity Study

In lieu of anodization of the extruded shims used in the MPC-68M, they are passivated in water to form a thin oxide layer. The emissivity of extruded shim surfaces is therefore reduced and requires a thermal evaluation.

In addition to the above, the radial gap between the basket, extruded shims and MPC shell is controlled using thin solid aluminum plates, which may be inserted between the basket and extruded shims to meet the gap criterion specified on the drawing (see Section 1.III.5). If the gap criterion on the drawing is met, solid shims are not required. These solid thin shim plates are made of aluminum and are supported by the extruded shims. A thermal analysis is performed in this subsection to determine the effect of these thin solid shim plates and low emissive extruded shims.

The following changes are made to the thermal model discussed in previous sub-sections to study the impact of the above mentioned design enhancements:

1. The panel notch gap on each side of the intersecting basket panels is increased to 0.8mm.
2. The gap between the basket and extruded shims is modeled with an effective thermal conductivity. The effective thermal conductivity of the gap between the basket and extruded shims is calculated based on a two-dimensional CFD model. This 2-D model includes the solid shim placed between the basket and extruded shims. A schematic of the model is shown in Figure 4.III.1.
3. A conservatively lowerbound emissivity of 0.03 is used for the passivated extruded shim surfaces.

1 In accordance with Section 4.5 onsite transfer in the horizontal orientation is not permitted.

4. Emissivity of solid shims is shown in Table 4.III.1.

The solid shims are conservatively modeled to be equidistant from the basket wall and extruded shim wall. The effective thermal conductivity of the gap between the basket and extruded shims with the presence of solid shim plate bounds the scenario without the presence of solid shims. The sensitivity study documented herein therefore considers only the scenario with solid shim plate placed in the gap between the basket and extruded shim.

A sensitivity study is performed to evaluate the most limiting thermal scenario with least margins to fuel cladding temperature limit i.e. vacuum drying Scenario B defined in Section 4.III.5.3. The results of the sensitivity study to evaluate the effect of design enhancements made to the MPC and its contents are reported in Table 4.III.12. The results demonstrate that fuel temperature is well below its temperature limit and is also bounded by the results based on the licensing basis thermal model in Table 4.III.5.

Therefore, the design enhancements discussed in this subsection are bounded by the licensing basis thermal analysis documented in this chapter. No additional thermal analysis for other conditions (also considering the large temperature margins to limits) is therefore warranted.

4.III.6 THERMAL EVALUATION OF OFF-NORMAL AND ACCIDENT CONDITIONS[1]

4.III.6.1 Off-Normal Conditions

(a) Elevated Ambient Air Temperature

This off-normal event is defined in Paragraph 4.6.1.2. The principal effect of elevated ambient temperature is a rise of the HI-STORM 100 temperatures from the baseline normal storage temperatures by the difference between elevated ambient and normal ambient temperatures. The results of this event (maximum temperatures and pressures) are provided in Table 4.III.15. The results are below the off-normal condition temperature and pressure limits (Tables 2.2.1, 4.III.2 and 2.2.3).

(b) Partial Blockage of Air Inlets

This off-normal event is defined in Paragraph 4.6.1.3. The principal effect of partial inlet vent blockage is a temperature rise in HI-STORM 100 System components from the baseline normal storage temperatures. Reasonably bounding evaluations in Paragraph 4.6.1.3 yield a certain rise in fuel cladding and component temperatures due to this off-normal event. This temperature adder is applied to HI-STORM MPC-68M storage temperature field in Table 4.III.3b and presented in Table 4.III.15. The results yield substantial margins for assuring safe storage of spent nuclear fuel, fuel basket and MPC confinement boundaries.

1 This section supplements Section 4.6.

temperature increase by assuming that the cask inner wall is adiabatic. The fuel temperature increase should then be determined by dividing the decay energy released during the fire by the thermal capacity of the basket-fuel assembly combination."

The time constant of the cask body (i.e., the overpack) can be determined using the formula:

$$\tau = \frac{c_p \times \rho \times L_c^2}{k}$$

where:

c_p = Overpack Specific Heat Capacity (Btu/lb-°F)
ρ = Overpack Density (lb/ft^3)
L_c = Overpack Characteristic Length (ft)
k = Overpack Thermal Conductivity (Btu/ft-hr-°F)

The concrete contributes the majority of the overpack mass and volume, so we will use the specific heat capacity (0.156 Btu/lb-°F), density (140 lb/ft^3) and thermal conductivity (1.05 Btu/ft-hr-°F) of concrete for the time constant calculation. The characteristic length of a hollow cylinder is its wall thickness. The characteristic length for the HI-STORM Overpack is therefore 29.5 in, or approximately 2.46 ft. Substituting into the equation, the overpack time constant is determined as:

$$\tau = \frac{0.156 \times 140 \times 2.46^2}{1.05} = 126\, hrs$$

One-tenth of this time constant is approximately 12.6 hours (756 minutes), substantially longer than the fire duration of 3.62 minutes, so the MPC is evaluated by considering the MPC canister as an adiabatic boundary. The fuel temperature rise is computed next.

Table 4.III.13 lists lower-bound thermal inertia values for the MPC-68M and the contained fuel assemblies. Applying design heat load (42.8 kW (1.46x10^5 Btu/hr)) and adiabatic heating for the 3.62 minutes fire, the fuel temperature rise computes as:

$$\Delta T_{fuel} = \frac{Decay\ heat \times Time\ duration}{(MPC + Basket\ \&\ Shims + Fuel)\ Thermal\ Inertia} = \frac{1.46 \times 10^5 \frac{Btu}{hr} \times \left(\frac{3.62}{60}\right) hr}{(2184 + 1307 + 931 + 2665) Btu/^{\circ}F} = 1.25^{\circ}F$$

This is a very small increase in fuel temperature. Consequently, the impact on the MPC internal helium pressure will be quite small. Based on a conservative analysis of the HI-STORM 100 System response to a hypothetical fire event, it is concluded that the fire event does not adversely affect the temperature of the MPC or contained fuel. We conclude that the ability of the HI-STORM 100 System to cool the spent nuclear fuel within design temperature limits during and after fire is not compromised.

An alternate method using the FLUENT thermal model described in Section 4.III.4 can be adopted to evaluate HI-STORM site-specific fire accident event similar to that described in Section 4.6 of HI-STORM FW FSAR. Principal modeling steps and acceptance criteria are defined in Table 4.6.11.

(ii) HI-TRAC Fire[1]

To demonstrate the fuel cladding and MPC pressure boundary integrity under an exposure to a hypothetical short duration fire event during on-site handling operations, a fire accident analysis of the loaded 100-ton HI-TRAC is performed. This analysis, because of the lower mass of the 100-ton HI-TRAC, bounds the effects for the 125-ton HI-TRAC. In this analysis, the contents of the HI-TRAC are conservatively postulated to undergo a transient heat-up as a lumped mass from the decay heat input and heat input from the short duration fire. The rate of temperature rise of the HI-TRAC depends on the thermal inertia of the cask, the cask initial conditions, the spent nuclear fuel decay heat generation, and the fire heat flux. Using conservatively bounding inputs – lowerbound thermal inertia, steady state maximum cask temperatures (Table 4.III.6) and design heat load (42.8 kW) - a bounding cask temperature rise of 5.21°F per minute is computed from the combined radiant and forced convection fire and decay heat inputs to the cask. During the handling of the HI-TRAC transfer cask, the transporter is limited to a maximum of 50 gallons. The duration of the 50-gallon fire using the methodology articulated above for HI-STORM fire is 4.775 minutes. Therefore, the temperature rise computed as the product of the rate of temperature rise and the fire duration is 24.9°F, and the co-incident fuel cladding temperature (734°F)[2] is below the 1058°F accident limit.

The elevated temperatures as a result of the fire accident will cause the pressure in the water jacket to increase and cause the overpressure relief valves to vent steam to the atmosphere. Based on the fire heat input to the water jacket, less than 11% of the water in the water jacket can be boiled off. However, it is conservatively assumed, for dose calculations, that all the water in the water jacket is lost. In the 125-ton HI-TRAC, which uses Holtite in the lids for neutron shielding, the elevated fire temperatures would cause the Holtite to exceed its design accident temperature limits. It is conservatively assumed, for dose calculations, that all the Holtite in the 125-ton HI-TRAC is lost.

Due to the increased temperatures the MPC experiences as a result of the fire accident in the HI-TRAC transfer cask, the MPC internal pressure increases. The pressure rise is computed using the Ideal Gas Law and upperbound helium backfill pressure defined in Table 1.III.1 and results tabulated in Table 4.III.9. The computed MPC accident pressure is substantially below the accident design pressure (Table 2.2.1).

An alternate method using the FLUENT thermal mode described in Section 4.III.5 can be adopted to evaluate HI-TRAC site-specific fire accident event. Principal modeling steps and acceptance criteria are defined in Table 4.6.12.

(b) Flood

1 The HI-TRAC fire accident methodology is same as the generic methodology in Section 4.6 of the HI-STORM 100 FSAR.

2 Computed by adding the fire temperature rise to initial fuel temperature (Table 4.III.6).

The flood accident is defined in Chapter 2 as a deep submergence event. The worst flood from a thermal perspective is a "smart flood" that just rises to the top of the inlets to prevent airflow without the benefit of MPC cooling by water. This effect is bounded by the 100% inlets ducts blockage accident evaluated herein in Section 4.III.6.2(d).

(c) Burial Under Debris

This accident event is defined in Paragpragh 4.6.2.5. The methodology for the burial under debris evaluation in Section 4.6 is employed to determine the minimum available time for the fuel cladding to reach the accident limit. Using the equation presented in Paragraph 4.6.2.5 and same clad temperature margin presented in Table 4.6.6, burial time is obtained and presented in Table 4.III.16. The coincident MPC pressure is also computed and compared with the accident design pressure (Table 2.2.1). The result (Table 4.III.16) is confirmed to be below the permissible limit.

(d) 100% Blockage of Air Ducts

This accident is defined in Section 4.6 as 100% blockage of the air inlet ducts. This event is evaluated by blocking the air inlets in the FLUENT thermal model and computing the temperature rise of the MPC and stored fuel with time. The results of the blocked ducts transient analysis that support the required action completion times for clearing the inlets are tabulated in Table 4.III.7. The results show that fuel cladding and component temperatures remain below their respective accident limits specified in Chapter 2 and Supplement 4.III. The increase in temperature results in a concomitant rise of the MPC pressure. The maximum accident pressure tabulated in Table 4.III.7 is below the design limit specified in Chapter 2.

Since the temperatures of MPC-68M are bounded by the MPCs evaluated in Chapter 4, threshold heat load defined in Table 4.6.8 can also be adopted for MPC-68M. A threshold heat load is defined in Table 4.6.8 at or below which periodic surveillance or vent blockage corrective actions are not necessary. See section 4.6.2.4 for further details.

(e) Extreme Environmental Temperature

The accident event is defined in Paragraph 4.6.2.3. The principal effect of elevated ambient temperature is a rise of the HI-STORM 100 temperatures from the baseline normal storage temperatures by the difference between elevated ambient and normal ambient temperatures. The results of this event (maximum temperatures and pressures) are provided in Table 4.III.17. The results are below the accident condition temperature and pressure limits (Tables 2.2.1, 4.III.2 and 2.2.3).

(f) 100% Rods Rupture Accident

In accordance with NUREG-1536 a 100% rods rupture accident is evaluated assuming 100% of the rods fill gases and fission gases release in accordance with NUREG-1536 release fractions. The

MPC-68M pressure under this postulated accident is computed and tabulated in Table 4.III.4. The pressure is below the accident design pressure (Table 2.2.1).

(g) Jacket Water Loss

The principal effect of jacket water loss accident is a temperature increment in the stored fuel and MPC from the baseline conditions under in a HI-TRAC. As the MPC-68M temperatures in the HI-TRAC are bounded by MPC-32 temperatures (see Table 4.5.6) the jacket water loss temperatures are likewise bounded by the HI-TRAC jacket water loss evaluation in Section 4.6.

4.III.7 REGULATORY COMPLIANCE

As required by ISG-11, the fuel cladding temperature at the beginning of dry cask storage is maintained below the anticipated damage-threshold temperatures for normal conditions for the licensed life of the HI-STORM System.

As required by NUREG-1536 (4.0,IV,3), the maximum internal pressure of the cask remains within its design pressure for normal, off-normal, and accident conditions. Design pressures are specified in Table 2.2.1.

As required by NUREG-1536 (4.0,IV,4), all cask materials and fuel cladding are maintained within their temperature limits under normal, off-normal and accident conditions to enable them to perform their intended safety functions. Material temperature limits are specified in Tables 2.2.3 and 4.III.2.

As required by NUREG-1536 (4.0,IV,5), the cask system ensures a very low probability of cladding breach during long-term storage. For long-term normal conditions, the maximum CSF cladding temperature is below the ISG-11 limit of 400°C (752°F).

As required by NUREG-1536 (4.0,IV,7), the cask system is passively cooled. All heat rejection mechanisms described in this supplement, including conduction, natural convection, and thermal radiation, are passive.

As required by NUREG-1536 (4.0,IV,8), the thermal performance of the cask is within the normal storage design criteria specified in Chapters 2 and 4. All thermal results are within the limits under normal conditions of storage.

4.III.8 REFERENCES

[4.III.1] Aluminum Alloy 2219 Material Data Sheet, ASM Aerospace Specification Metals, Inc., Pompano Beach, FL.

[4.III.2] United States Code of Federal Regulations, Title 10, Part 71.

[4.III.3] Gregory, J.J. et. al., “Thermal Measurements in a Series of Large Pool Fires”, SAND85-1096, Sandia National Laboratories, (August 1987).

[4.III.4] Jakob, M. and Hawkins, G.A., “Elements of Heat Transfer,” John Wiley & Sons, New York, (1957).

Table 4.III.1: Thermal Properties of Fuel Basket, Basket Extruded Shim and Solid Shim Materials

Property	**Minimum Value**	**Reference**
Metamic-HT (fuel basket)		
Conductivity	See Table 1.III.3	[1.III.3]
Emissivity	Note 1	[1.III.3]
Density	See Table 1.III.3	[1.III.3]
Heat Capacity	See Table 1.III.3	[1.III.3]
Aluminum Alloy 2219 (extruded shims)		
Conductivity	69.3 Btu/ft-hr-^{o}F	[4.III.1]
Emissivity	0.1 Note 2	[4.2.5]
Density	177.3 lb/ft^{3}	[4.III.1]
Heat Capacity	0.207 Btu/lb-^{o}F	[4.III.1]
Aluminum Alloy (solid shims)		
Conductivity	86.6 Btu/ft-hr-^{o}F	Section 1.III.5
Emissivity	Note 1	[1.III.3]
Density	177.3 lb/ft^{3}	[4.III.1]
Heat Capacity	0.207 Btu/lb-^{o}F	[4.III.1]

Note 1: Fuel basket and solid shims are hard anodized to yield high emissivities. Lowerbound emissivity defined in Table 1.III.3 is adopted.
Note 2: Extruded shims are passivated to allow formation of a thin protective oxide layer that result in emissivity lower than that defined in Table 1.III.3. However, all the thermal analyses documented in this chapter are based on emissivity values of extruded shims as defined in Table 1.III.3. A sensitivity study is performed in Paragraph 4.III.5.6 to demonstrate the acceptability of low emissivity extruded shims.

Table 4.III.3a: Fuel Loading Patten Screening Evaluations

Loading Pattern[Note 4]	**Total Decay Heat, kW**	**Peak Cladding Temperature, °F**
Case 1: X=0.5 (Note 1)	36.9	598
Case 2: QSHL (Note 2)	42.8	**708**

Note 1: The decay heat distribution is described in Section 2.1.9.
Note 2: Quarter symmetric heat load pattern is defined in Figure 2.III.1
Note 3: Since the highest PCT is reached for the QSHL pattern, it is adopted for all the licensing basis evaluations of fuel storage in MPC-68M.
Note 4: Cases 1 and 2 are defined in Section 4.III.4.1.

Table 4.III.3b: Maximum Temperatures Under Normal Long-Term Storage

Component	**Temperature (°F)**
Fuel Cladding	708
Basket	674
Basket Shims	563
MPC Shell	499
Overpack Inner Shell	358[1]
Overpack Body Concrete[2]	252
Overpack Lid Concrete[2]	257
Overpack Outer Shell	190
Area Averaged Air Outlet[3]	244

[1] Nominal exceedance of temperature limits has no risk on its structural integrity.
[2] Maximum thru thickness section average temperature reported.
[3] Reported herein for the option of outlet ducts air temperature surveillance set forth in the Technical Specifications.

Table 4.III.4: Maximum Pressures Under Normal Long Term Storage

Condition	Pressure (psig)
Initial maximum backfill* (at 70°F)	46.5
Normal: intact rods 1% rods rupture**	 98.7 99.2
Off-Normal (10% rods rupture)	104.0
Accident (100% rods rupture)	152.0

* Conservatively assumed at the Tech. Spec. maximum value (see Table 4.4.12).

** Per NUREG-1536, pressure analysis with ruptured fuel rods is performed with release of 100% of the ruptured fuel rod fill gas and 30% of the significant radioactive gaseous fission products.

Table 4.III.5: Maximum MPC-68M Temperatures Under Vacuum Drying Scenarios

Component	Scenario A (^oF)	Scenario B (^oF)	Scenario C (^oF)
Fuel Cladding	754	732	896
Fuel Basket	729	698	854
Basket Shims	522	482	592
MPC Shell	325	307	343

Notes:

(1) The peak cladding temperatures are below the ISG 11 temperature limits of Moderate Burnup Fuel (Scenarios A and C) and High Burnup Fuel (Scenario B).

(2) The component temperatures are below the Chapter 2 and Supplement III temperature limits.

Table 4.III.6: Maximum Steady State HI-TRAC Temperatures and Pressures During On-site Transfer Operations

Component	Temperature [°F]
Fuel Cladding	709[1]
MPC Basket	676
Basket Periphery	606
MPC Shell	488
Aluminum Shims	555
HI-TRAC Inner Shell	286
HI-TRAC Outer Shell	274
Water Jacket Shell	263
Water Jacket Bulk Water	257
Top Lid Neutron Shield (Holtite)[2]	289
Pressure (psig)	
Initial Maximum Backfill	46.5
Operating Pressure	100.5

1 The calculated value is below the permissible limit for high-burnup fuel. Therefore auxiliary cooling of the HI-TRAC is not necessary to ensure cladding safety under onsite transfer operations involving the MPC-68M. Accordingly SCS cooling is not mandated in the MPC-68M Technical Specifications

2 Local neutron shield section temperature.

Table 4.III.7: Maximum Temperatures and Pressures Under 100% Air Inlets Blockage Accident

Component	**Case 2[Note 2] Temperature@32hrs (°F)**	**Case 2[Note 2] Temperature@16hrs (°F)**	**Case 1[Note 2] Temperature@32hrs (°F)**
Fuel Cladding	849	789	722
Fuel Basket	818	754	709
Basket Shims	702	645	626
MPC Shell	639	584	571
MPC Lid[Note 1]	599	549	521
Overpack Inner Shell	531	467	462
Body Concrete (Local Temperature)	525	461	456
Lid Concrete (Local Temperature)	447	397	375
Pressure (psig)			
MPC	116.3	109.5	111.6
Note 1: Maximum thru thickness section average temperature reported. Note 2: Cases 1 and 2 are defined in Section 4.III.4.1.			

Table 4.III.8: Differential Thermal Expansion

Gap Description	**Differential Expansion * mm (in)**
Fuel Basket-to-MPC Radial Gap	2.72 (0.107)
Fuel Basket-to-MPC Axial Gap	12.72 (0.501)
MPC-to-Overpack Radial Gap	3.55 (0.140)
MPC-to-Overpack Minimum Axial Gap	14.75 (0.581)
*The differential expansion values reported in this table are bounded by the nominal cold gaps presented on the drawings in Section 1.5.	

Table 4.III.9: MPC-68M Pressure Under HI-TRAC Fire Accident

Initial Operating Pressure	See Table 4.III.6
Fire Pressure Rise	2.9 psig
Fire Accident Pressure	103.4 psig

Table 4.III.10: Deleted

Table 4.III.11: HI-STORM Temperatures Under Fuel Debris Storage

Component	Temperature, °F
Fuel Cladding	687 Note 1
Basket	656
Aluminum Shims	538
MPC Shell	482
Overpack Inner Shell	342
Overpack Outer Shell	189
Overpack Body Concrete Note 2	239
Overpack Lid Concrete Note 2	253
Average Air Outlet	244

Note 1: It is recognized that the assumption of all 16 DFC locations having fuel debris instead of permitted 8 cells has the effect of slightly understating the MPC heat load because of the lower per assembly heat permitted in DFC cells. However, because the effect is small (40.4 kW with all 16 cells versus 41.6 kW with permitted 8 cells) and the margins from limits are substantial, this has no adverse effect on the reported temperatures or conclusions. Moreover, the DFC is stored in the basket periphery cells. The effect of a slight change in the heat load in the periphery cells will have a second order effect on the peak cladding temperature which occurs in the inner cell locations.
Note 2: Maximum thru thickness section average temperature reported.

Table 4.III.13

HI-TRAC Transfer Cask with MPC-68M: Lowerbound Weights and Thermal Inertias

Component	**Weight (lbs)**	**Heat Capacity (Btu/lb-°F)**	**Thermal Inertia (Btu/°F)**
Lead	52,000	0.031	1,612
Carbon Steel	40,000	0.1	4,000
Alloy-X MPC (empty)	18,200	0.12	2,184
Fuel	47,600	0.056	2,665
Metamic-HT	6,670	0.196	1,307
Basket Shims (Aluminum)	4,500	0.207	931
MPC Cavity Water*	6,170	1.0	6,170
			18,869 (Total)
* Conservative lower bound water mass.			

Table 4.III.14

Time-to-Boil for Water in the MPC-68M Cavity at QSHL

Initial Temperature (°F)	Time (hrs)
80	17.0
90	15.7
100	14.4
110	13.1
120	11.8
125	11.2

Table 4.III.15: Off-Normal Condition Maximum HI-STORM Temperatures and MPC Cavity Pressures

Component	Off-Normal Ambient Temperature[1] (°F)	Partial Inlet Ducts Blockage (°F)
Fuel Cladding	728	722
Basket	694	687
MPC Shell	519	508
Overpack Inner Shell	378	375
Overpack Body Concrete (Local Temperature)	375 Note 1	372
Overpack Lid Concrete (Local Temperature)	328 Note 1	327
MPC Cavity Pressure (psig)		
MPC Pressure	101.0	100.1
Note 1: Obtained by adding the off-normal to ambient temperature difference of 20°F to the local maximum concrete temperatures durng normal conditions.		

Table 4.III.16: Summary of Burial under Debris Accident Results

Item	Results
Burial Time	30.7 hours
MPC Cavity Pressure	133.3 psig

[1] Obtained by adding the off-normal-to-normal ambient temperature difference of 20°F to normal condition HI-STORM temperatures reported in Table 4.III.3b.

Table 4.III.17: Extreme Environmental Accident Condition Maximum HI-STORM Temperatures[1] and MPC Cavity Pressure

Component	**Temperature (°F)**
Fuel Cladding	753
Basket	719
Basket Shims	608
MPC Shell	544
Overpack Inner Shell	403
Overpack Body Concrete (Local Temperature)	400 Note 1
Overpack Lid Concrete (Local Temperature)	353 Note 1
Overpack Outer Shell	235
MPC Cavity Pressure (psig)	
MPC Pressure	103.9
Note 1: Obtained by adding the extreme ambient to normal ambient temperature difference of 45°F to the local maximum concrete temperatures durng normal conditions.	

[1] Obtained by adding the extreme ambient to normal ambient temperature difference of 45°F to normal condition HI-STORM temperatures reported in Table 4.III.3b.

$$B_u = A*q + B*q^2 + C*q^3 + D*E_{235}{}^2 + E*E_{235}*q + F*E_{235}*q^2 + G \qquad \text{Equation 5.2}$$

where:
B_u = Burnup in MWD/MTU
q = assembly decay heat (kW)
E_{235} = wt.% ^{235}U

The coefficients for this equation were developed by fitting ORIGEN-S calculated data for a specific cooling time using GNUPLOT [5.2.16]. ORIGEN-S calculations were performed for enrichments ranging from 0.7 to 5.0 wt.% ^{235}U and burnups from 10,000 to 65,000 MWD/MTU for BWRs and 10,000 to 70,000 MWD/MTU for PWRs. The burnups were increased in 2,500 MWD/MTU increments. Using the ORIGEN-S data, the coefficients A through G were determined and then the constant, G, was adjusted so that all data points were bounded (i.e. calculated burnup less than or equal to ORIGEN-S value) by the fit. The coefficients were calculated using ORIGEN-S data for cooling times from 2 to 40 years. As a result, Section 2.1.9 provides different equation coefficients for each cooling time from 2 to 40 years Additional discussion on the determination of the equation coefficients is provided in Appendix 5.F. Since the decay heat increases as the enrichment decreases, the allowable burnup will decrease as the enrichment decreases. Therefore, the enrichment used to calculate the allowable burnups becomes a minimum enrichment value and assemblies with an enrichment higher than the value used in the equation are acceptable for storage assuming they also meet the corresponding burnup and decay heat requirements. Even though the lower limit of 0.7 wt.% ^{235}U was used in developing the coefficients, these equations are valid for the few assemblies that might exist with enrichments below 0.7 wt.% ^{235}U. This is because the curve fit is very well behaved in the enrichment range from 0.7 to 5.0 wt.% ^{235}U and, therefore, it is expected that the curve fit will remain accurate for enrichments below 0.7 wt.% ^{235}U.

Different array classes or combinations of classes were analyzed separately to determine the allowable burnup as a function of cooling time for the specified allowable decay heat limits. Calculating allowable burnups for individual array classes is appropriate because even two assemblies with the same MTU may have a different allowable burnup for the same allowable cooling time and permissible decay heat. The heavy metal mass specified in Table 5.2.25 and 5.2.26 and Section 2.1.9 for the various array classes is the value that was used in the determination of the coefficients as a function of cooling time and is the maximum for the respective assembly class. Equation coefficients for each array class listed in Tables 5.2.25 and 5.2.26 were developed. In the end, the equation for the 17x17B and 17x17C array classes resulted in almost identical burnups. Therefore, in Section 2.1.9 these array classes were combined and the coefficients for the 17x17C array class were used since these coefficients produce slightly lower allowable burnups.

There is some uncertainty associated with the ORIGEN-S calculations due to uncertainty in the physics data (e.g. cross sections, decay constants, etc.) and the modeling techniques. To estimate this uncertainty, an approach similar to the one in Reference [5.2.14] was used. The potential error in the ORIGEN-S decay heat calculations was estimated to be in the range of 3.5 to 5.5%

for cooling times 2 to 40 years. The difference is due to the change in isotopes important to decay heat as a function of cooling time. In order to be conservative in the derivation of the coefficients for the burnup equation, a uniform 5% decay heat penalty was applied for both the PWR and BWR array classes.

As a demonstration that the decay heat values used to determine the allowable burnups are conservative, a comparison between these calculated decay heats and the decay heats reported in Reference [5.2.7] are presented in Table 5.2.29. This comparison is made for a burnup of 30,000 MWD/MTU and a cooling time of 5 years. The burnup was chosen based on the limited burnup data available in Reference [5.2.7].

As mentioned above, the fuel assembly burnup and cooling times in Section 2.1.9 were calculated using the decay heat limits which are also stipulated in Section 2.1.9. The burnup and cooling times for the non-fuel hardware, in Section 2.1.9, were chosen based on the radiation source term calculations discussed previously. The fuel assembly burnup, decay heat, and enrichment equations were derived without consideration for the decay heat from BPRAs, TPDs, CRAs, or APSRs. This is acceptable since the user of the HI-STORM 100 system is required to demonstrate compliance with the assembly decay heat limits in Section 2.1.9 regardless of the heat source (assembly or non-fuel hardware) and the actual decay heat from the non-fuel hardware is expected to be minimal. In addition, the shielding analysis presented in this chapter conservatively calculates the dose rates using both the burnup and cooling times for the fuel assemblies and non-fuel hardware. Therefore, the safety of the HI-STORM 100 system is guaranteed through the bounding analysis in this chapter, represented by the burnup and cooling time limits in the CoC, and the bounding thermal analysis in Chapter 4, represented by the decay heat limits in the CoC.

5.2.5.4 Burnup, Enrichment and Cooling time values for Site Specific Dose Analyses

As discussed earlier in this Chapter, site-specific dose evaluations are required to show compliance with the regulatory requirements, and those need to consider the types, burnups, enrichments and cooling times of the fuel to be stored. Since it is impractical to evaluate every fuel assembly individually, a bounding approach is typically used where assemblies are grouped and bounding characteristics are selected and evaluated for each group. Recommendations and guidance for those selections are as follows:

For the fuel assembly type, the one approach would be to use the design basis assembly type, since this has been shown to bound all other assembly types (see Subsections 5.2.5.1 and 5.2.5.2). However, if this approach is considered too conservative, it is also acceptable to utilize a site-specific fuel assembly type. In this case, that fuel assembly type needs to be considered in both the radiation transport analyses and the source term evaluations.

For burnups, enrichments and cooling times, selecting an appropriate burnup and enrichment combination or combinations (for given lower bound cooling times) could be difficult, since the more conservative values are a higher burnup but a lower enrichment (see Subsection 5.2.2). One approach would be to have a single group, i.e. select bounding values for all those

[5.2.8] O. W. Hermann, et al., "Validation of the Scale System for PWR Spent Fuel Isotopic Composition Analyses," ORNL/TM-12667, Oak Ridge National Laboratory, March 1995.

[5.2.9] M. D. DeHart and O. W. Hermann, "An Extension of the Validation of SCALE (SAS2H) Isotopic Predictions for PWR Spent Fuel," ORNL/TM-13317, Oak Ridge National Laboratory, September 1996.

[5.2.10] O. W. Hermann and M. D. DeHart, "Validation of SCALE (SAS2H) Isotopic Predictions for BWR Spent Fuel," ORNL/TM-13315, Oak Ridge National Laboratory, September 1998.

[5.2.11] "Summary Report of SNF Isotopic Comparisons for the Disposal Criticality Analysis Methodology," B00000000-01717-5705-00077 REV 00, CRWMS M&O, September 1997.

[5.2.12] "Isotopic and Criticality Validation of PWR Actinide-Only Burnup Credit," DOE/RW-0497, U.S. Department of Energy, May 1997.

[5.2.13] B. D. Murphy, "Prediction of the Isotopic Composition of UO_2 Fuel from a BWR: Analysis of the DU1 Sample from the Dodewaard Reactor," ORNL/TM-13687, Oak Ridge National Laboratory, October 1998.

[5.2.14] O. W. Hermann, et al., "Technical Support for a Proposed Decay Heat Guide Using SAS2H/ORIGEN-S Data," NUREG/CR-5625, ORNL-6698, Oak Ridge National Laboratory, September 1994.

[5.2.15] C. E. Sanders, I. C. Gauld, "Isotopic Analysis of High-Burnup PWR Spent Fuel Samples from the Takahama-3 Reactor," NUREG/CR-6798, ORNL/TM-2001/259, Oak Ridge National Laboratory, January 2003.

[5.2.16] T. Williams and C. Kelley, "gnuplot An Interactive Plotting Program", Version 3.7, December 1998.

[5.2.17] Regulatory Guide 3.54, "Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation", Revision 1, USNRC, Washington, DC, January 1999.

[5.2.18] I. C. Gauld, B.D. Murphy, "Technical Basis for a Proposed Expansion to Regulatory Guide 3.54 – Decay Heat Generation in an Independent Spent Fuel Storage Installation," NUREG/CR-6999, ORNL/TM-2007/231, Oak Ridge National Laboratory, February 2010.

The equation in Section 5.2.5.2 was determined to be the best equation capable of reproducing the burnup versus enrichment and decay heat data calculated with ORIGEN-S. As an example, Figure 5.F.1 graphically presents ORIGEN-S burnup versus decay heat data for various enrichments for the 9x9C/D fuel assembly array/classes with 20 years cooling time. In these calculations, the decay heat data from ORIGEN-S are conservatively adjusted for uncertainty of 5%, as discussed in Section 5.2. This data could also be represented graphically as a surface on a three dimensional plot. However, the 2D plot is easier to visualize. Additional enrichments were used in the ORIGEN-S calculations and have been omitted for clarity.

Figures 5.F.2 through 5.F.4 show ORIGEN-S burnup versus decay heat data for specific enrichments. In addition to the ORIGEN-S data, these figures present the results of the best fit curve using the least squares method and Equation 5.2. This curve is referred here to as the “original fit.” Since in the original fit, some burnups are higher than the burnups in the ORIGEN-S file, the original fit is adjusted by modifying the constant coefficient “G” such that all burnups are conservatively bounded by ORIGEN-S burnups. This curve is referred to as the adjusted curve fit. Table 5.F.1 below shows the equation coefficients used for both curve fits. As these figures indicate, the original curve fit faithfully reproduces the ORIGEN-S data.

Figure 5.F.5 provides a different representation of the curve fit versus ORIGEN-S comparison. This figure was generated by taking the ORIGEN-S enrichment and decay heat data from Figure 5.F.1 for a constant burnup of 30,000 MWD/MTU and calculating the burnup using the fitted equation with coefficients from Table 5.F.1. The resulting burnup versus enrichment is plotted. Table 5.F.2 presents the ORIGEN-S and curve fit data in tabular form used to generate Figure 5.F.5. Since the ORIGEN-S calculations were performed for a specific burnup of 30,000 MWD/MTU, the ORIGEN-S data is represented as a straight line. Figures 5.F.6 and 5.F.7 provide the same representation for burnups of 45,000 and 65,000 MWD/MTU. These results also indicate that the non-adjusted curve fit provides a very good representation of the ORIGEN-S data. It is also clear that the adjusted curve fit always bounds the ORIGEN-S data by predicting a lower burnup which results in a more restrictive and conservative limit for the user.

Table 5.F.1

COEFFICIENTS FOR EQUATION IN SECTION 5.2.5.3 FOR THE 9X9C/D FUEL ASSEMBLY ARRAY/CLASSES WITH A COOLING TIME OF 20 YEARS

Coefficient	Original Curve Fit	Adjusted Curve Fit
A	238022	238022
B	-324930	-324930
C	227066	227066
D	-158.319	-158.32
E	7284.25	7284.25
F	5103.45	5103.45
G	-985.96	-1464.16

Table 5.F.2

ORIGEN-S AND CURVE FIT DATA FOR THE 9X9C/D FUEL ASSEMBLY ARRAY/CLASSES
WITH A COOLING TIME OF 20 YEARS

Specified Enrichment	ORIGEN-S calculated decay heat per assembly (W)[1]	ORIGEN-S calculated burnup (MWD/MTU)	Burnup calculated with original curve fit (MWD/MTU)[2]	Burnup calculated with adjusted curve fit (MWD/MTU)
0.7	1.55E+02	30000	29792	29314
1	1.53E+02	30000	29763	29284
1.35	1.52E+02	30000	29767	29289
1.7	1.50E+02	30000	29829	29351
2	1.50E+02	30000	29962	29484
2.3	1.49E+02	30000	30009	29531
2.6	1.49E+02	30000	30080	29602
2.9	1.49E+02	30000	30198	29720
3.2	1.50E+02	30000	30327	29848
3.4	1.50E+02	30000	30358	29880
3.6	1.49E+02	30000	30200	29721
3.9	1.48E+02	30000	30162	29684
4.2	1.48E+02	30000	30115	29636
4.5	1.48E+02	30000	30059	29581
4.8	1.48E+02	30000	29996	29518
5	1.49E+02	30000	30008	29530

[1] Decay heat from ORIGEN-S is increased by uncertainty as discussed in Section 5.2

[2] Burnups are rounded down to whole integers.

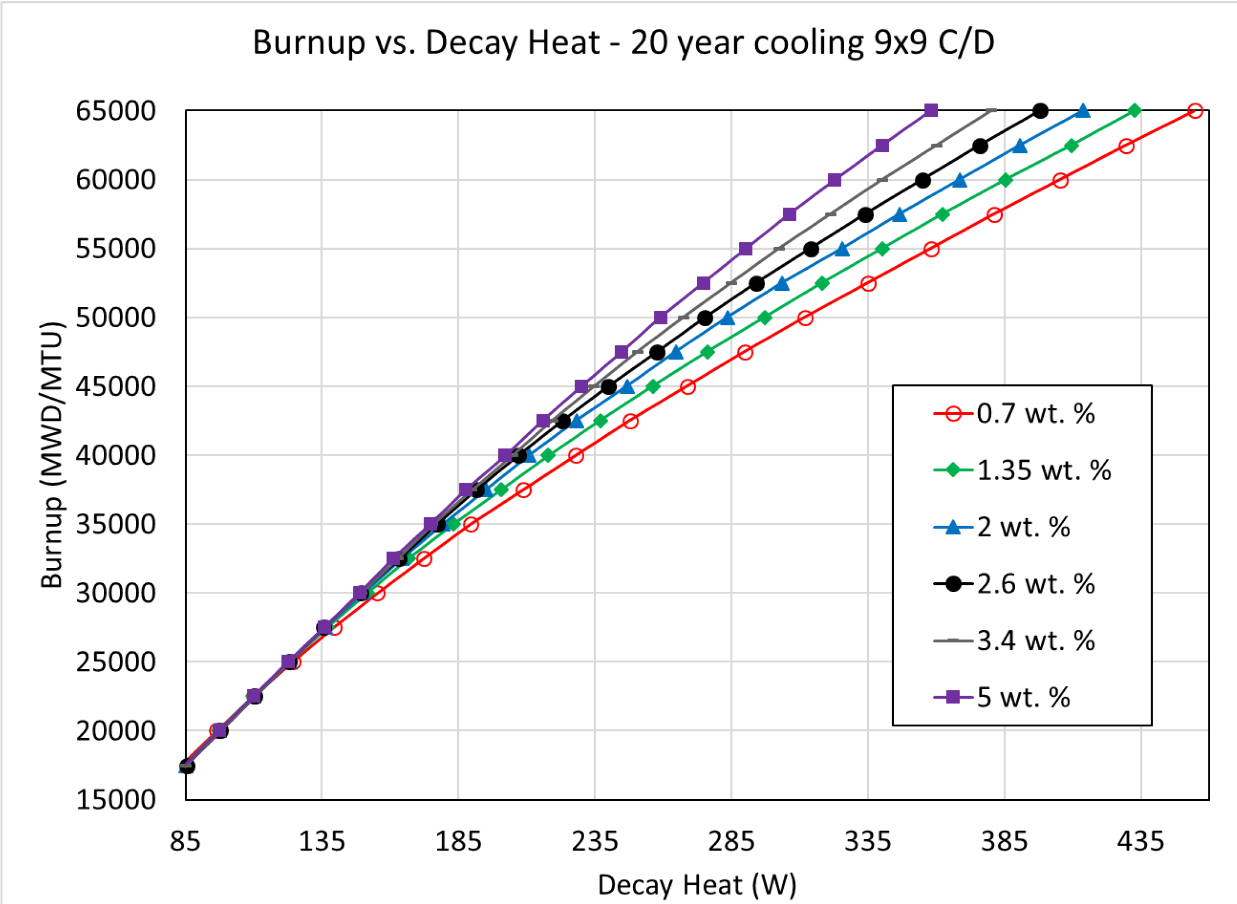


FIGURE 5.F.1; ORIGEN-S CALCULATED BURNUP VERSUS DECAY HEAT FOR VARIOUS ENRICHMENTS

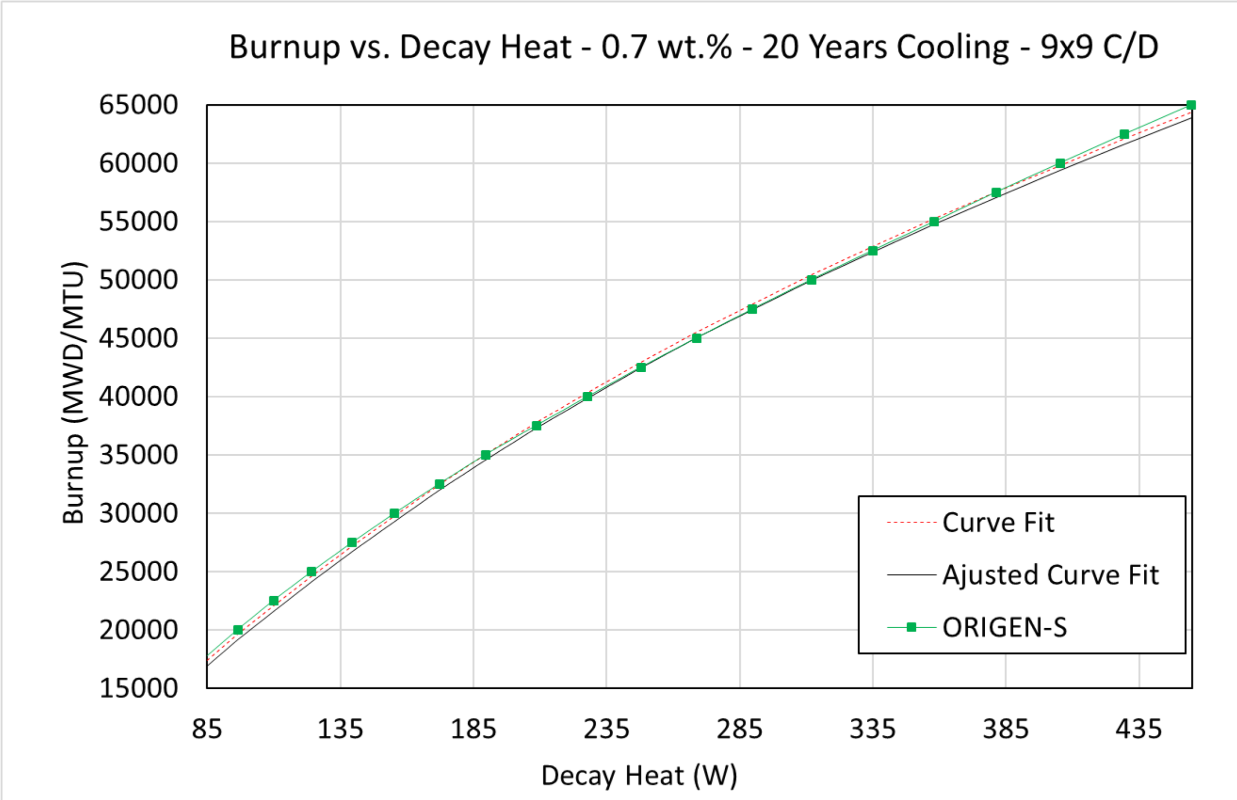


FIGURE 5.F.2; A COMPARISON OF THE BURNUP VERSUS DECAY HEAT CALCULATIONS FROM ORIGEN-S, THE ORIGINAL CURVE FIT, AND THE ADJUSTED CURVE FIT FOR AN ENRICHMENT OF 0.7 WT.% ^{235}U.

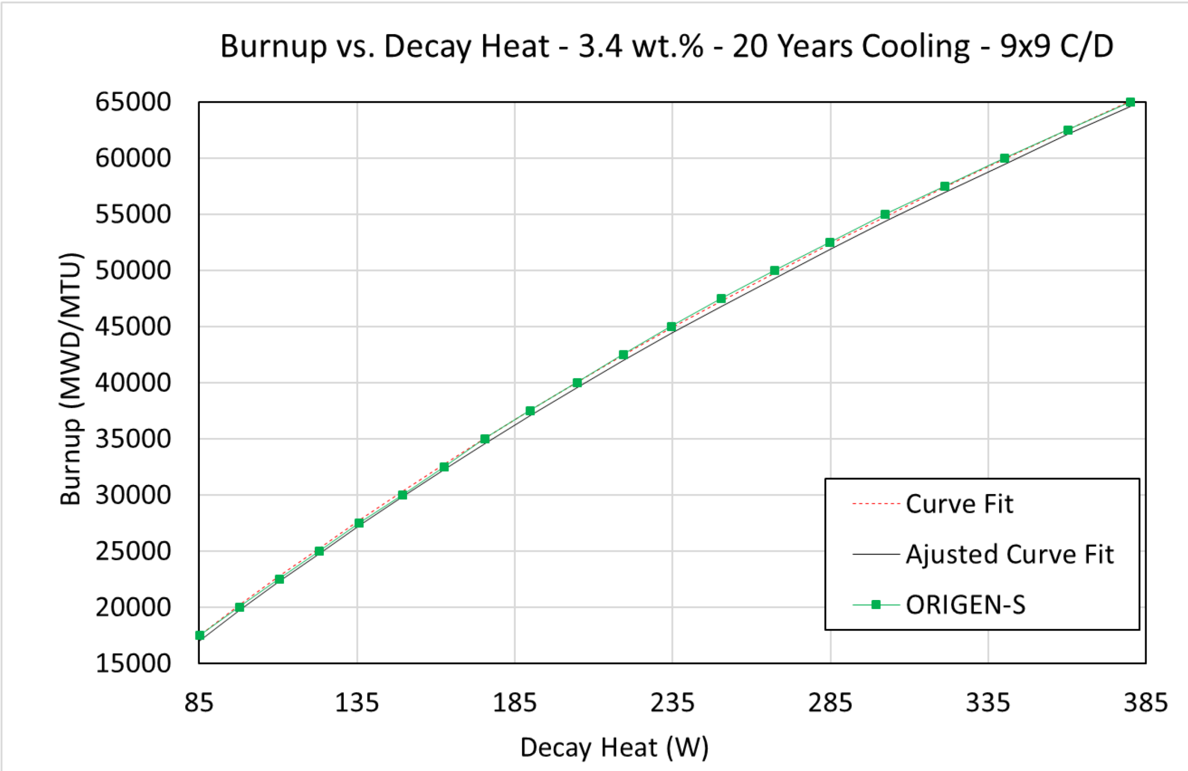


FIGURE 5.F.3; A COMPARISON OF THE BURNUP VERSUS DECAY HEAT CALCULATIONS FROM ORIGEN-S, THE ORIGINAL CURVE FIT, AND THE ADJUSTED CURVE FIT FOR AN ENRICHMENT OF 3.4 WT.% ^{235}U.

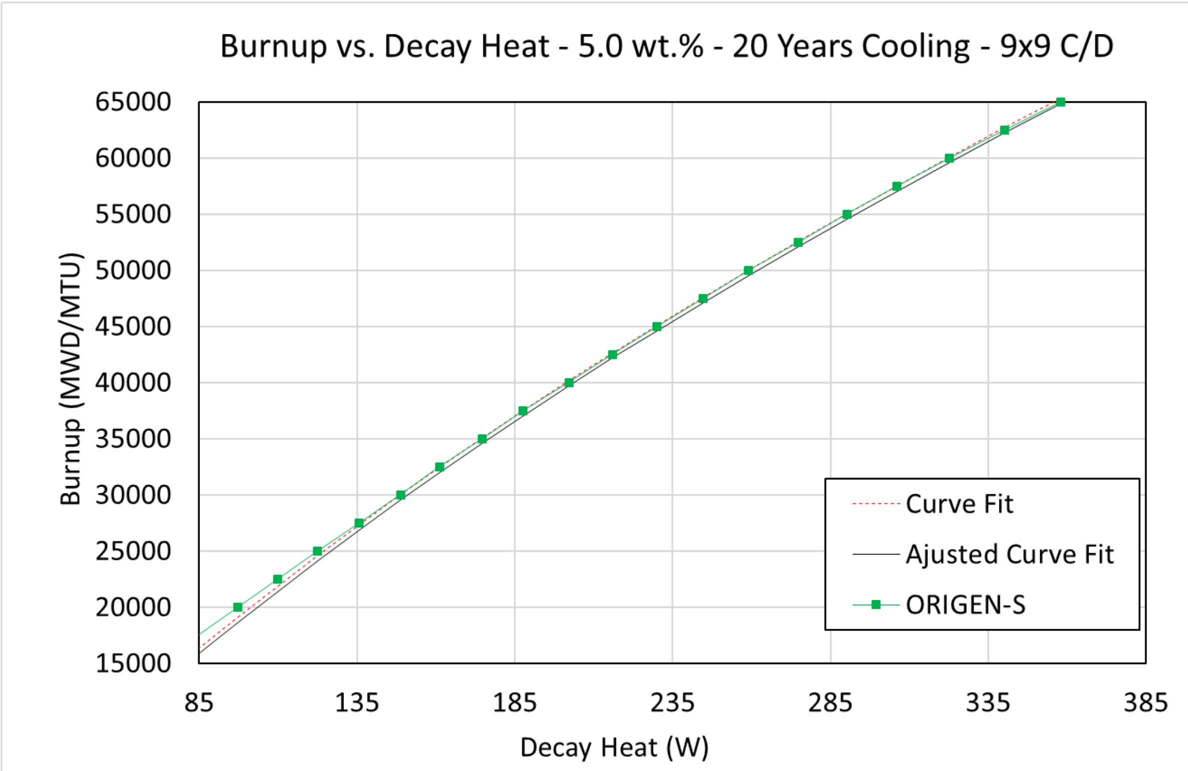


FIGURE 5.F.4; A COMPARISON OF THE BURNUP VERSUS DECAY HEAT CALCULATIONS FROM ORIGEN-S, THE ORIGINAL CURVE FIT, AND THE ADJUSTED CURVE FIT FOR AN ENRICHMENT OF 5.0 WT.% ^{235}U.

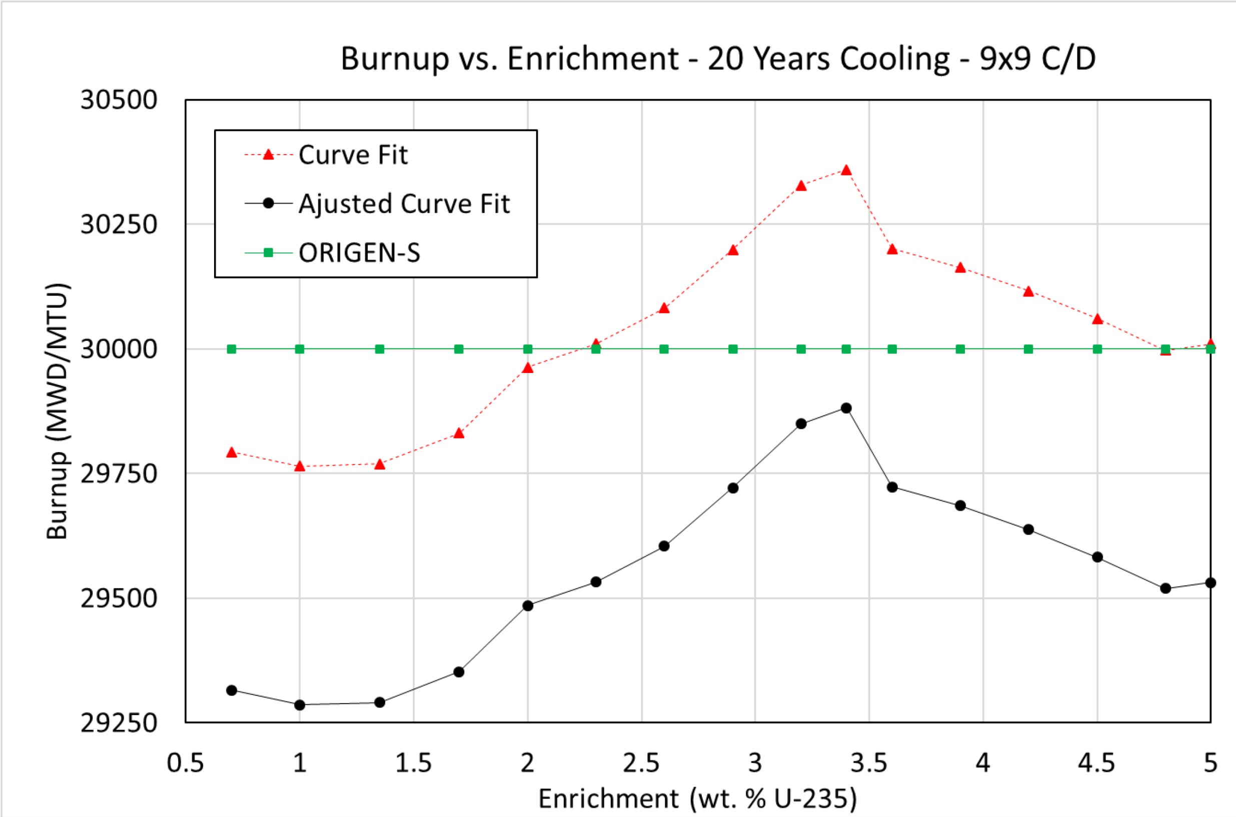


FIGURE 5.F.5; A COMPARISON OF THE CALCULATED BURNUPS USING THE CURVE FIT AND THE ADJUSTED CURVE FIT FOR VARIOUS ENRICHMENTS. ALL ORIGEN-S CALCULATIONS YIELDED A BURNUP OF 30,000 MWD/MTU.

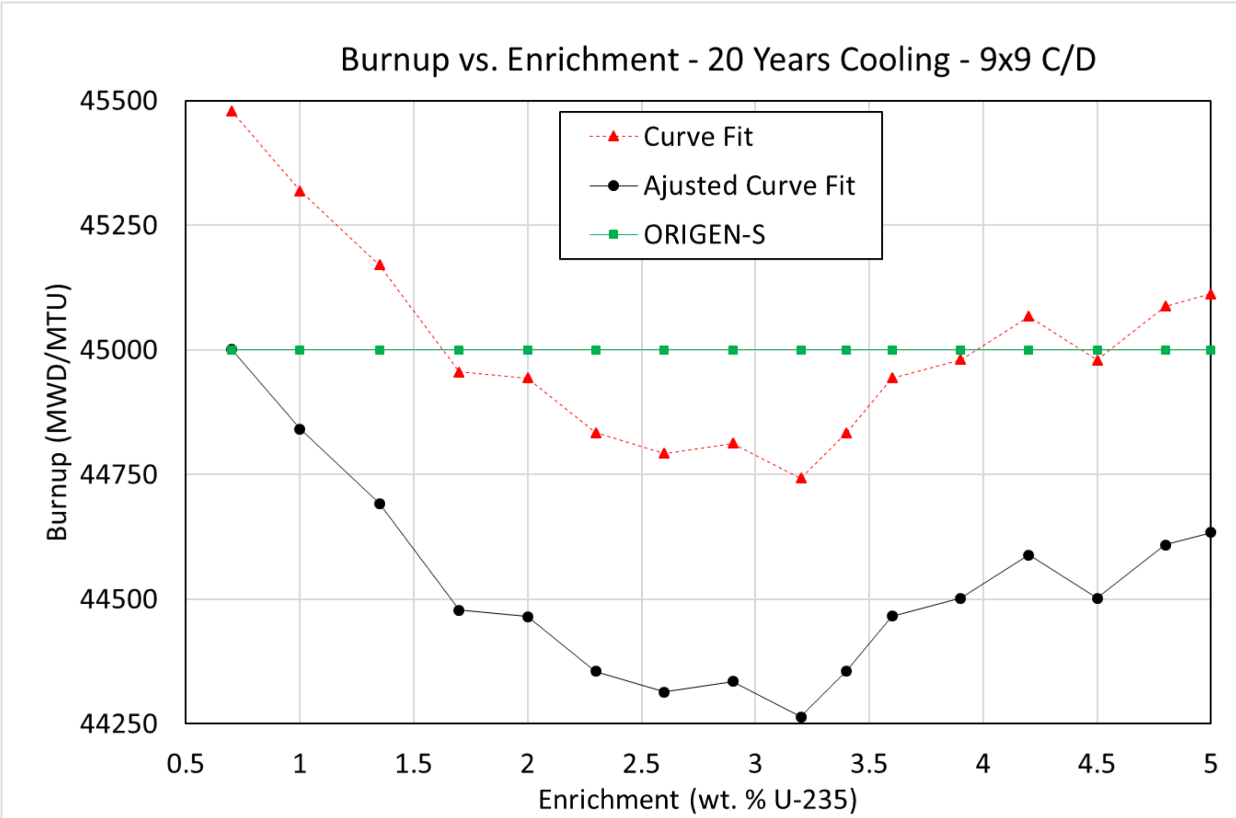


FIGURE 5.F.6; A COMPARISON OF THE CALCULATED BURNUPS USING THE CURVE FIT AND THE ADJUSTED CURVE FIT FOR VARIOUS ENRICHMENTS. ALL ORIGEN-S CALCULATIONS YIELDED A BURNUP OF 45,000 MWD/MTU.

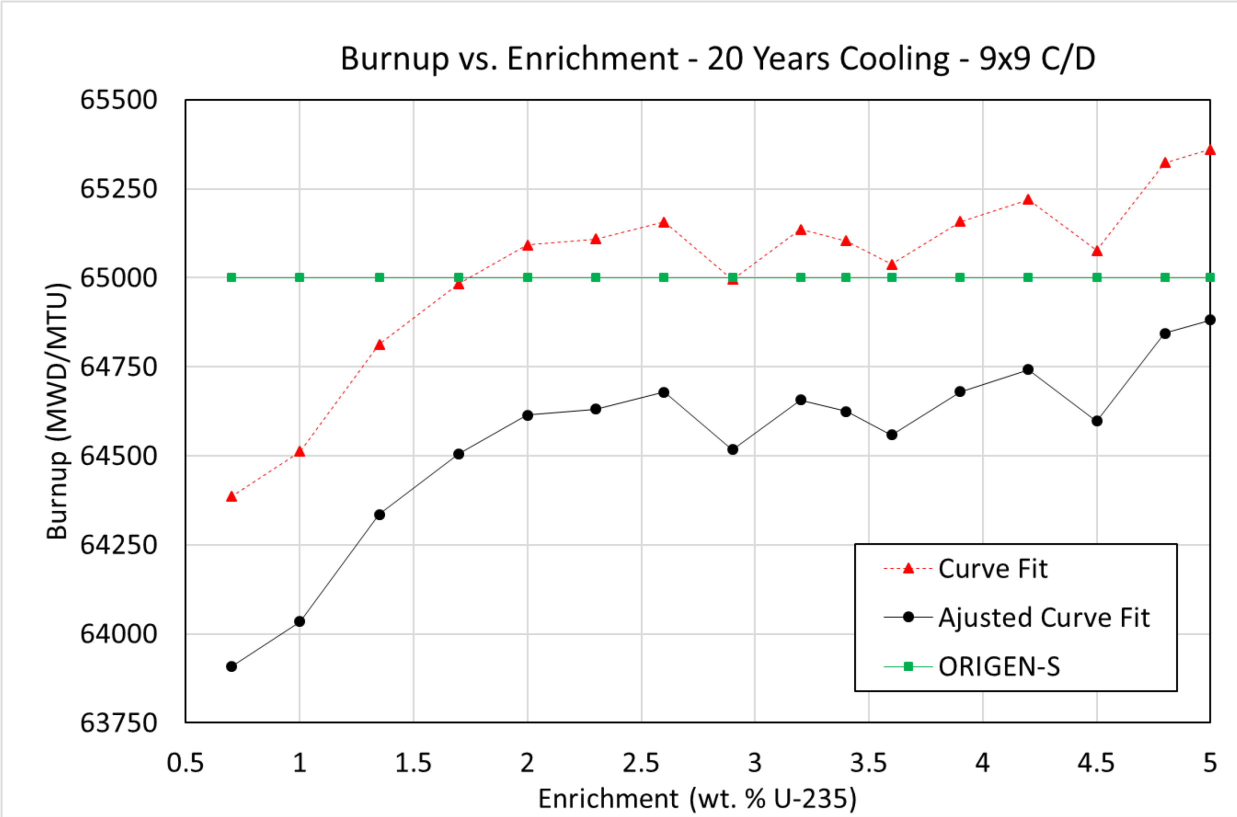


FIGURE 5.F.7; A COMPARISON OF THE CALCULATED BURNUPS USING THE CURVE FIT AND THE ADJUSTED CURVE FIT FOR VARIOUS ENRICHMENTS. ALL ORIGEN-S CALCULATIONS YIELDED A BURNUP OF 65,000 MWD/MTU.

SUPPLEMENT 5.III

EVALUATION OF THE MPC-68M BASKET, AND THE 10x10F AND 10x10G ASSEMBLY CLASSES

5.III.0 DISCUSSION

The MPC-68M is a variation of the 68 cell BWR canister MPC-68 evaluated in the main part of this chapter, but with a basket design consisting of aluminum oxide and finely ground boron carbide dispersed in a metal matrix of pure aluminum. The boron carbide content is 10% (minimum) by weight. This results in a B-10 areal density that is slightly above that in the MPC-68. The relevant differences between the baskets are listed below, and then discussed in respect to its effect on the photon and neutron dose rates.

Differences between the MPC-68M compared to the MPC-68, in respect to the characteristics important for the dose calculations, are as follows:

- The MPC-68M has a slightly higher B-10 content
- The MPC-68M is lighter, since it consists of aluminum and boron carbide, but no steel
- In the enclosure shell, the MPC-68M is surrounded by aluminum basket shims

To evaluate the effect of these differences, studies in the main part of Chapter 5 regarding dose contributions from a regionalized loading scheme are utilized. These studies, described in Section 5.4, show that the inner region on an MPC-68 (32 assemblies = 47 % of the content) contributes about 27% of the neutron dose rate, but only about 2 % of the photon dose rate. This means that the self-shielding of the fuel and basket for neutron radiation is low, while for photon radiation it is very high. The low neutron self-shielding means that the neutron doses are not significantly affected by the reduced basket weight, since the majority of the neutron shielding function is provided by the overpack around the MPC. Also, for MPCs filled with water, there is a further reduction in neutron dose due to the increased absorption of thermal neutrons from the increased B-10 loading. The high self-shielding for photons means that only the outer basket panels are effective for gamma shielding. For the MPC-68M, the shielding in this area is enhanced due to the presence of the basket shims, and therefore comparable to the absorption in the steel basket walls. In summary, the effect of the design differences between MPC-68 and MPC-68M on dose rates is small.

Additionally, two BWR array classes designated 10x10F and 10x10G have been added as approved contents in the MPC-68M only. From a radiological perspective, the additional array classes are bounded by the design basis GE 7x7 source term calculations, since those design basis assemblies have higher initial uranium masses. In terms of grouping assemblies for the polynomial factors presented in Section 2.1.9, the new array classes are added to groups which represent assemblies of a higher mass. This is conservative since a heavier assembly results in a

higher decay heat, which reduces the allowable assembly burnup. In summary, no new analyses are necessary to qualify those additional array classes.

Therefore, the main body of this chapter remains fully applicable for the HI-STORM 100 System using an MPC-68M and the new assembly classes.

As discussed in Subsection 2.0.1, each MPC basket, except MPC-68F, allows for two loading strategies, namely the uniform fuel loading and the regionalized loading with two regions. An additional 3-region loading pattern, shown in Figure 2.III.1, is evaluated to determine acceptability as approved contents in the MPC-68M only. This evaluation performs a dose rate comparison between a uniform loading pattern (results shown in Table 5.4.9) and a 3-region pattern (Table 5.III.1) in which one region contains 2-year cooled spent nuclear fuel.

It should be noted that the design basis GE 7x7 source term calculations, discussed in Section 5.2 of the main part of this chapter, are performed using the SCALE 4.3 system [5.1.2, 5.1.3]. The evaluation in this Supplement 5.III is performed with an updated version of SCALE (SCALE 5.1) which is consistent with other approved Holtec applications [5.III.3]. (SCALE 4.3 is no longer maintained by Oak Ridge National Laboratory, and does not work on contemporary computer operating systems.) To ensure that the dose rate comparison is not affected by the SCALE code version, a comparison between results generated using SCALE 4.3 and SCALE 5.1 was performed. There were no significant differences in the neutron and fuel gamma source terms between the two SCALE versions. The Cobalt-60 photon source calculated with SCALE 5.1 were substantially higher than the Cobalt-60 source calculated using SCALE 4.3 which is encompassed in the first two dose rate results columns of Table 5.III.2. The remaining comparisons shown in Table 5.III.2 are performed using the updated version of SCALE (SCALE 5.1), which compared the uniform loading pattern (50,000 MWD/MTU, 3-year cooling time) against the 3-region loading pattern presented in Table 5.III.1 for both the MPC-68[1] and MPC-68M.

Table 5.III.2 shows the dose rates for the 3-region loading pattern (Figure 2.III.1 and Table 5.III.1) are bounded by the uniform loading pattern (50,000 MWD/MTU and 3-year cooling). For this reason, the 3-region loading pattern shown in Figure 2.III.1 is added as approved contents of the MPC-68M. The minimum cooling time criteria for the MPC-68M is updated to 2.0 years (see Table 2.0.1). The minimum cooling time criteria for the MPC-68 remains at 3.0 years (see Table 2.0.1).

[1] The 3-region loading pattern shown in Figure 2.III.1 and Table 5.III.1 is approved for the MPC-68M only. All results related to the 3-region loading pattern (in Figure 2.III.1 and Table 5.III.1) in the MPC-68 are for the purposes of comparison only.

5.III.1 REFERENCES

[5.III.1] I.C. Gauld and O.W. Hermann, "SAS2: A Coupled One-Dimensional Depletion and Shielding Analysis Module," ORNL/TM-2005/39, Revision 5.1, , Oak Ridge National Laboratory, November 2006.

[5.III.2] I.C. Gauld, O.W. Hermann, and R.M. Westfall, "ORIGEN-S: SCALE System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms," ORNL/TM-2005/39, Version 5.1, Oak Ridge National Laboratory, November 2006.

[5.III.3] Holtec International Report HI-2114830, Final Safety Analysis Report on the HI-STORM FW System, USNRC Docket 72-1032, latest revision.

[5.III.4] Holtec International Report HI-2146423 Revision 1, HI-STAR 190 Source Terms and Loading Patterns.

Table 5.III.1

3-REGION LOADING PATTERN FOR MPC-68M

Region	**Assemblies Per Region**	**Heat Load Limit[1] (kW)**	**Burnup (MWD/MTU)**	**Enrichment (wt%)**	**Cooling Time (years)**	**Calculated Heat Load[2] (kW)**
1	24	0.4	50000	3.6	7	0.436
2	16	1.2			2	1.336
3	28	0.5			5	0.550

[1] As shown in Figure 2.III.1.

[2] Decay heat is calculated in Reference [5.III.4]; this shielding analysis reference case conservatively exceeds the heat load limits set in Figure 2.III.1.

Table 5.III.2

DOSE RATES COMPARISON BETWEEN UNIFORM[6] AND 3-REGION[7] LOADING PATTERN FOR 100-TON HI-TRAC

Dose Point Location	Totals Uniform MPC-68 From Table 5.4.9 (SCALE 4.3) (mrem/hr)	Totals Uniform MPC-68 (SCALE 5.1) (mrem/hr)	Totals 3-Region MPC-68 (SCALE 5.1) (mrem/hr)	Totals Uniform MPC-68M (SCALE 5.1) (mrem/hr)	Totals 3-Region MPC-68M (SCALE 5.1) (mrem/hr)
ADJACENT TO THE 100-TON HI-TRAC					
1	1745.39	1978.3	1631.8	2068.0	1706.5
2	2992.98	3025.3	1803.6	2742.7	1672.9
3	991.17	1145.0	950.0	1526.4	1240.3
4	715.82	767.4	570.2	866.7	625.6
5 (pool lid)	8069.5	9414.2	6815.3	9848.6	6979.4
ONE METER FROM THE 100-TON HI-TRAC					
1	552.67	575.2	381.7	541.2	369.0
2	1257.27	1278.1	750.5	1169.9	702.7
3	289.97	323.3	242.9	375.1	284.7

[6] Design Basis GE 7x7 spent fuel with a burnup of 50,000 MWD/MTU, cooling time of 3 years, and initial enrichment of 3.6 wt% U-235.

[7] As shown in Figure 2.III.1 and Table 5.III.1.

Table 7.1.1

SUMMARY OF CONFINEMENT BOUNDARY DESIGN SPECIFICATIONS

Design Condition	**Design Pressure (psig)**	**Design Temperature* (^oF)**
Normal	100	See Table 2.2.3
Off-Normal/Short-Term	110	
Accident	200	
*Temperature limits in Table 1.A.6 shall take precedence in case Duplex Stainless Steels are used for the fabrication of confinement boundary components.		

Table 7.1.4

COMPARISON OF HOLTEC MPC DESIGN WITH ISG-18 GUIDANCE FOR STORAGE

DESIGN/QUALIFICATION GUIDANCE	HOLTEC MPC DESIGN	FSAR REFERENCE
The canister is constructed from Alloy X type material	The MPC enclosure vessel is constructed entirely from Alloy X material. Alloy X is defined as Type 304, 304LN, 316, or 316LN or duplex stainless steel material. It should be noted that duplex steel material shall not be used for the fabrication of MPC baskets and internal components.	Section 1.2.1.1 and Appendix 1.A
The canister closure welds meet the guidance of ISG-15 (or approved alternative), Section X.5.2.3	The MPC lid-to-shell (LTS) closure weld meets ISG-15, Section X.5.2.3 for austenitic stainless steels. UT examination is permitted and NB-5332 acceptance criteria are required. An optional multi-layer PT examination is also permitted. The multi-layer PT is performed at each approximately 3/8" of weld depth, which corresponds to the critical flaw size. A weld quality factor of 0.45 (45% of actual weld capacity) has been used in the stress analysis.	Section 9.1.1.1 and Tables 2.2.15 and 9.1.4. HI-STAR FSAR Section 3.4.4.3.1.5 and Appendix 3.E (Docket 72-1008)
The canister maintains its confinement integrity during normal conditions, anticipated occurrences, and credible accidents, and natural phenomena	The MPC is shown by analysis to maintain confinement integrity for all normal, off-normal, and accident conditions, including natural phenomena. The MPC is design to withstand 45 g deceleration loadings and the cask system is analyzed to verify that decelerations due to credible drops and non-mechanistic tipovers will be less than 45 g's.	Section 3.4.4.3 and Appendix 3.A. HI-STAR FSAR Section 3.4.4.3
Records documenting the fabrication and closure welding of canisters shall comply with the provisions 10 CFR 72.174 and ISG-15. Record storage shall comply with ANSI N45.2.9.	Records documenting the fabrication and closure welding of MPCs meet the requirements of ISG-15 via controls required by the FSAR and HI-STORM CoC. Compliance with 10 CFR 72.174 and ANSI N.45.2.9 is achieved via Holtec QA program and implementing procedures.	Section 9.1.1.1 and Table 2.2.15 Section 13.0
Activities related to inspection, evaluation, documentation of fabrication, and closure welding of canisters shall be performed in accordance with an NRC-approved quality assurance program.	The NRC has approved the Holtec quality assurance program under 10 CFR 71. That QA program approval has been adopted for activities governed by 10 CFR 72 as permitted by 10 CFR 72.140(d).	Section 13.0

Note:
Vacuum drying or moisture removal using FHD (for high burn-up fuel or high decay heat) is performed to remove moisture and oxidizing gasses from the MPC. This ensures a suitable environment for long-term storage of spent fuel assemblies and ensures that the MPC pressure remains within design limits. The vacuum drying process described herein reduces the MPC internal pressure in stages. Dropping the internal pressure too quickly may cause the formation of ice in the fittings. Ice formation could result in incomplete removal of moisture from the MPC. The moisture removal process limits bulk MPC temperatures by continuously circulating gas through the MPC. Section 8.1.5 Steps 6a through q are used for the vacuum drying method of drying and backfill. Section 8.1.5 Steps 7a through i are used for the FHD method of drying and backfill.

6. Dry and Backfill the MPC as follows (Vacuum Drying Method):

Note:
During vacuum drying, the annulus between the MPC and the HI-TRAC must be maintained full of water. Water lost due to evaporation or boiling must be replaced to maintain the water level. The vacuum drying process described herein reduces the MPC internal pressure in stages. Dropping the internal pressure too quickly may cause the formation of ice in the fittings. Ice formation could result in incomplete removal of moisture from the MPC.

a. Fill the annulus between the MPC and HI-TRAC with clean water. The water level must be within 6” of the top of the MPC.

b. Attach the drying system (VDS) to the vent and drain port RVOAs. See Figure 8.1.22a. Other equipment configurations that achieve the same results may also be used.

Note:
The vacuum drying system may be configured with an optional fore-line condenser. Other equipment configurations that achieve the same results may be used.
Note:
To prevent freezing of water, the MPC internal pressure should be lowered in incremental steps. The vacuum drying system pressure will remain at about 30 torr until most of the liquid water has been removed from the MPC.
Caution:
For MPC heat loads greater than defined threshold limits, cyclic vacuum drying can be used. The method and acceptance criteria to determine the cycle time limits are specified in Section 4.5. Once vacuum drying time limit is reached for a cycle, MPC shall be backfilled with helium as described in Section 4.5 and vacuum drying cycle shall be repeated.

c. Open the VDS suction valve and reduce the MPC pressure to below 3 torr. Refer to Section 4.5 for method to determine vacuum drying time and cycle limits. If MPC vacuum drying acceptance criteria are not met during allowable time, backfill the MPC cavity with helium to a pressure of ≥ 0.5 atm and reset the vacuum drying time (see Technical Specifications).

Note:
Helium used for drying shall be in accordance with the Technical Specification using 99.995% (minimum) purity. Other equipment configurations that achieve the same results may be used.

d. Shut the VDS valves and verify a stable MPC pressure on the vacuum gage.

Note:
The MPC pressure may rise due to the presence of water in the MPC. The dryness test may need to be repeated several times until all the water has been removed. Leaks in the vacuum drying system, damage to the vacuum pump, and improper vacuum gauge calibration may cause repeated failure of the dryness verification test. These conditions should be checked as part of the corrective actions if repeated failure of the dryness verification test is occurring.

e. Perform the MPC drying pressure test in accordance with the technical specifications. If MPC vacuum drying acceptance criteria are not met during allowable time, backfill the MPC cavity with helium to a pressure of ≥ 0.5 atm and reset the vacuum drying time (see Technical Specifications) and restart vacuum drying.

f. Close the vent and drain port valves.

g. Disconnect the VDS from the MPC.

h. Stop the warming pad, if used.

i. Close the drain port RVOA cap and remove the drain port RVOA.

Note:
Helium backfill shall be in accordance with the Technical Specification using 99.995% (minimum) purity. Other equipment configurations that achieve the same results may be used.

j. Set the helium bottle regulator pressure to the appropriate pressure.

k. Purge the Helium Backfill System to remove oxygen from the lines.

l. Attach the Helium Backfill System to the vent port as shown on Figure 8.1.23 and open the vent port.

m. Slowly open the helium supply valve while monitoring the pressure rise in the MPC.

Note:
If helium bottles need to be replaced, the bottle valve needs to be closed and the entire regulator assembly transferred to the new bottle.

n. Carefully backfill the MPC in accordance with the technical specifications

o. If used, stop the water flow through the annulus between the MPC and HI-TRAC. Drain the water from the annulus

p. Disconnect the helium backfill system from the MPC.

q. Close the vent port RVOA and disconnect the vent port RVOA.

7. Dry and Backfill the MPC as follows (FHD Method):

with ASME Code, Section III, Subsection NB, with alternatives as noted below. The MPC basket and basket supports (or basket shims) shall be fabricated and inspected in accordance with ASME Code, Section III, Subsection NG, with alternatives as noted below. Metal components of the HI-TRAC transfer cask and the HI-STORM overpack, as applicable, shall be fabricated and inspected in accordance with ASME Code, Section III, Subsection NF, Class 3 or AWS D1.1, as shown on the design drawings, with alternatives as noted below.

NOTE: NRC-approved alternatives to these Code requirements are discussed in FSAR Section 2.2.4.

3. ASME Code welding shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX and the applicable ASME Section III Subsections (e.g., NB, NG, or NF, as applicable to the SSC). AWS code welding may be performed using welders and weld procedures that have been qualified in accordance with applicable AWS requirements or in accordance with ASME Code Section IX

4. Code welds shall be visually examined in accordance with ASME Code, Section V, Article 9 with acceptance criteria per ASME Code, Section III, Subsection NF, Article NF-5360, except the MPC fuel basket cell plate-to-cell plate welds, fuel basket support-to-canister welds, and basket shims-to-MPC fuel basket welds which shall have acceptance criteria to ASME Code Section III, Subsection NG, Article NG-5360, (as modified by the design drawings). Table 9.1.4 identifies additional nondestructive examination (NDE) requirements to be performed on specific welds, and the applicable codes and acceptance criteria to be used in order to meet the inspection requirements of the applicable ASME Code, Section III. Acceptance criteria for NDE shall be in accordance with the applicable Code for which the item was fabricated. These additional NDE criteria are also specified on the design drawings for the specific welds. Weld inspections shall be detailed in a weld inspection plan which shall identify the weld and the examination requirements, the sequence of examination, and the acceptance criteria. The inspection plan shall be reviewed and approved by Holtec in accordance with its QA program. NDE inspections of code welds shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [9.1.2] or other site-specific, NRC-approved program for personnel qualification. Non-code welds shall be examined and repaired in accordance with written and approved procedures.

9.4 REFERENCES

[9.0.1] U.S. Code of Federal Regulations, Title 10, "Energy", Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste".

[9.0.2] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems", January 1997.

[9.1.1] American Society of Mechanical Engineers, " Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 1995 Edition, including Addenda through 1997.

[9.1.2] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, December 1992.

[9.1.3] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kilograms) or More", ANSI N14.6, September 1993.

[9.1.4] NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants", U.S. Nuclear Regulatory Commission, Washington, D.C., July 1980.

[9.1.5] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials Leakage Tests on Packages for Shipment", ANSI N14.5, January 1997.

[9.1.6] Holtec International Position Paper DS-213, "Acceptable Flaw Size in MPC Lid-to-Shell Welds", Revision 4.

Table 9.III.1
Metamic-HT Testing Requirements

Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
B_4C powder (raw material) (see note 1)	Particle size distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchase Specification [1.III.7]
	Purity	One sample per lot	To verify material supplier's data sheet	ASTM C-750
Al powder (raw material)	Particle Size Distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchase Specification [1.III.7]
	Purity	One sample per lot	To verify material supplier's data sheet	Must be 99% (min.) pure aluminum
B_4C/Al Mix	B_4C Content (by the wet chemistry method)	One sample per mixed/blended powders lot	To ensure B_4C content requirements compliance	The B_4C content in accordance with the drawing package in Section 1.5
Finished Metamic-HT panel	Thickness	Each Panel	To ensure fabricability of the basket	Per Holtec's Purchasing Specification [1.III.7]
	Width, straightness, camber, and bow	Per Sampling Plan (see note 3)	To ensure fabricability of the basket	Per Holtec's Purchasing Specification [1.III.7]
	Properties listed in Table 9.III.3	Per Sampling Plan (see note 2)	To ensure structural performance.	MGV per Table 9.III. 3
	B_4C content (by neutron attenuation testing)	One coupon from each Metamic-HT manufactured lot	To ensure criticality safety	The B_4C content in accordance with licensing drawing in Section 1.5

Notes:

1. The B_4C testing requirements apply if the raw material supplier is not in Holtec's Approved Vendor List.
2. Sampling Plan is included in the Metamic-HT Manufacturing Manual [1.III.4].
3. The sampling plan for the dimensional analysis of the finished Metamic-HT panels shall start at Tier No. 4 of Table 9.III.2 with samples coming from the first and last panel of every lot or operating shift, whichever comes first. If it is required to move up a Tier No. per the notes in Table 9.III.2, then the

required number of panels shall be tested in the beginning and end of each lot or operating shift, whichever comes first, and one sample shall be taken from each panel.

MPCs are safe at off-normal and accident conditions coincident with the 100% vent blockage event at threshold heat load.

Shielding

There is no effect on the shielding performance of the system as a result of this event, since the concrete temperatures do not exceed the short-term condition design temperature provided in Table 2.2.3.

Criticality

There is no effect on the criticality control features of the system as a result of this event.

Confinement

There is no effect on the confinement function of the MPC as a result of this event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this event.

Based on this evaluation, it is concluded that the 100% blockage of air inlets accident does not affect the safe operation of the HI-STORM 100 System, if the blockage is removed in the specified time period.

11.2.13.3 100% Blockage of Air Inlets Dose Calculations

As shown in the analysis of the 100% blockage of air inlets accident, the shielding capabilities of the HI-STORM 100 System are unchanged because the peak concrete temperature does not exceed its short-term condition design temperature. The elevated temperatures will not cause the breach of the confinement system and the short term fuel cladding temperature limit is not exceeded. Therefore, there is no radiological impact.

11.2.13.4 100% Blockage of Air Inlets Accident Corrective Action

Analysis of the 100% blockage of air inlet accident shows that the temperatures for cask system components and fuel cladding are within the accident temperature limits if the blockage is cleared within the required action completion times. Upon detection of the complete blockage of the air inlet ducts, the ISFSI operator shall assign personnel to clear the blockage with mechanical and manual means as necessary. After clearing the overpack ducts, the overpack shall be visually and radiologically inspected for any damage. If exit air temperature monitoring is performed in lieu of direct visual inspections, the difference between the ambient air temperature and the exit air temperature will be the basis for assurance that the temperature limits are not exceeded.

SUPPLEMENT 11.III

ACCIDENT ANALYSIS OF THE MPC-68M

11.III.0 INTRODUCTION

The MPC-68M is canister which contains a Metamic-HT basket. The Metamic-HT basket has improved heat transfer as well as criticality control. This supplement presents the evaluation of the MPC-68M of the HI-STORM 100 System for the effects of off-normal and postulated accident conditions.

The supplemental information has been presented in the same format as the main body of Chapter 11. The basic changes that have been made on the MPC-68 are discussed in Supplement 1.III. The significant changes include the fuel basket and the precision extruded aluminum shims between the fuel basket and the Enclosure Vessel. The changes result in significant reduction in bending stresses under a canister slap-down event, improved heat transfer and criticality performance of the system.

All the off-normal conditions and the postulated accident conditions have been critically evaluated for the introduction of the MPC-68M. The structural integrity and the thermal performance of the HI-STORM 100 System with the MPC-68M are discussed in Supplement Sections 3.III and 4.III.

This Supplement is in full compliance with NUREG-1536; no exceptions are taken.

11.III.1 OFF-NORMAL CONDITIONS

All the off-normal conditions considered in FSAR Chapter 11 have been evaluated for MPC-68M. The Supplemental Cooling System (SCS) is not required as explained in Supplement Section 4.III. Therefore, the SCS power failure is not applicable. The thermal consequences of the off-normal conditions for the HI-STORM 100 system with the MPC-68M are presented below.

Supplement Section 4.III.6 provides details of the thermal evaluations for the off-normal conditions.

11.III.1.1 Off-Normal Pressure

The off-normal pressure of the MPC internal cavity is a function of the initial helium fill pressure and the temperature reached within the cavity under normal storage as described in Sub-section 11.1.1. The normal storage temperature and pressure in the MPC-68M are reported in Section 4.III.4. FSAR Section 11.2 is applicable.

11.III.1.2 Off-Normal Environmental Temperatures

This off-normal condition is the same as that described in Sub-section 11.1.2. The off-normal environment temperatures are evaluated in Section 4.III.6. All the temperatures are below their respective temperature limit presented in Table 2.2.3. FSAR Section 11.1 is applicable.

11.III.1.3 Leakage of One Seal

FSAR Section 11.1.3 is applicable.

11.III.1.4 Partial Blockage of Air Inlets

This off-normal condition is the same as that described in Sub-section 11.1.4. Supplement Section 4.III.6 confirms that under bounding (steady state) conditions, all system components are below the off-normal temperature limits presented in Table 2.2.3 FSAR Section 11.1 is applicable.

11.III.1.5 Off-Normal Handling of HI-TRAC

FSAR Section 11.1.5 is applicable.

11.III.1.6 Malfunction of FHD System

FSAR Section 11.1.6 is applicable.

11.III.1.7 SCS Power Failure

As mentioned earlier the Supplementary Cooling System (SCS) is not necessary and therefore, the SCS power failure is a not applicable for MPC-68M.

11.III.2 ACCIDENTS

All the accident conditions considered in the FSAR Chapter 11 have been evaluated for the HI-STORM 100 system with MPC-68M. It has been demonstrated that the consequences of the accident conditions are either the same or bounded by those presented in Chapter 11. Some additional discussions are provided below.

11.III.2.1 HI-TRAC Transfer Cask Handling Accident

Supplement Section 3.III.4 evaluated the potential consequences of the HI-TRAC drop events for a loaded MPC-68M inside the HI-TRAC and concluded that the drop analyses presented in the FSAR Subsection 3.4.9 are valid.

11.III.2.2 HI-STORM Overpack Handling Accident

Supplement Section 3.III.4 evaluated the potential consequences of the drop events for HI-STORM overpack carrying the loaded MPC-68M and concluded that although the resulting deceleration is higher than the maximum deceleration calculated in the FSAR Appendix 3.A, it is still less than the design basis vertical deceleration limit.

11.III.2.3 Tip-Over

Supplement Section 3.III.4 evaluated the potential consequences of the non-mechanistic tip-over of the HI-STORM overpack the loaded MPC-68M on to the ISFSI pad carrying. It is concluded that the resulting deceleration is less than the design basis deceleration limit. Also the total deformations of the basket walls during accident conditions are far below the limit imposed in the structural analysis in Supplement 3.III and analyzed in the criticality analysis in Supplement 6.III.

11.III.2.4 Fire Accident

It is concluded in the Supplement Section 4.III.6 that the thermal consequences of fire accident are similar to those presented in the FSAR Section 4.6. Therefore, FSAR Section 11.2 is applicable.

11.III.2.5 Partial Blockage of MPC Basket Vent Holes

The MPC-68M basket vent holes are located above the level of the maximum accumulation of debris. The blockage of the vent holes is not credible. The evaluation in the FSAR Section 11.2.5 can be considered as bounding.

11.III.2.6 Tornado

It is concluded in Supplement Section 3.III.4 that the tornado loads due to missile impact/wind and depressurization presented in FSAR Subsection 3.4.8 are bounding for the MPC-68M inside a HI-

STORM overpack. It is also concluded that the missile penetration analyses presented in Subsection 3.4.8 remain valid. Therefore, FSAR Section 11.2 is applicable.

11.III.2.7 Flood

The flood accident is defined and evaluated in Sub-section 11.2.7. A smart flood condition that blocks the air flow but is not sufficient to allow water to come in contact with the MPC is bounded by the 100% inlet ducts blocked condition evaluation in Supplement Section 4.III.6. FSAR Section 11.2 is applicable.

11.III.2.8 Earthquake

It is concluded in Supplement Section 3.III.4 that the seismic analyses presented in FSAR Chapter 3 bound the scenario of a loaded MPC-68M inside a HI-STORM overpack. Therefore, FSAR Section 11.2 is applicable.

11.III.2.9 100% Fuel Rod Rupture

It is concluded in the Supplement Section 4.III.6 that the thermal consequences of the 100% fuel rod rupture are bounded by those presented in the FSAR Section 4.6. Therefore, FSAR Section 11.2 is applicable.

11.III.2.10 Confinement Boundary Leakage

FSAR Section 11.2 is applicable.

11.III.2.11 Explosion

It is concluded in Supplement Section 3.III.4 that the seismic analyses presented in FSAR Chapter 3 bound the scenario of a loaded MPC-68M inside a HI-STORM overpack. Therefore, FSAR Section 11.2 is applicable.

11.III.2.12 Lightning

FSAR Section 11.2 is applicable.

11.III.2.13 100% Blockage of Air Inlets

This accident condition is the same as that defined in Sub-section 11.2.13. The thermal consequences of 100% blockage of air inlets are presented in the Supplement Section 4.III.6. All the component temperatures and MPC cavity pressure are below their respective accident temperature and pressure limit. FSAR Section 11.2 is applicable.

11.III.2.14 Burial Under Debris

This accident condition is the same as that defined in Sub-section 11.2.14. The thermal consequences of burial under debris are presented in the Supplement Section 4.III.6. The evaluation demonstrates that the fuel cladding and confinement function of the MPC are not compromised. FSAR Section 11.2 is applicable.

11.III.2.15 Extreme Environmental Temperature

This accident condition is the same as that defined in Sub-section 11.2.15. The thermal consequences of extreme environmental temperature are presented in the Supplement Section 4.III.6. As concluded from this evaluation, all temperatures are within the accident condition allowable values specified in Table 2.2.3. FSAR Section 11.2 is applicable.

11.III.2.16 Supplemental Cooling System (SCS) Failure

As discussed earlier the Supplemental Cooling System (SCS) is not required for the HI-STORM 100 system with the MPC-68M canister.

MWD/MTU). Fuel Assembly Number 2 may be acceptable for loading if a new table is created specifically for an initial enrichment of 3.5 wt% and the allowable burnup is greater than 35250.

Fuel Assembly Number 3 is acceptable for loading based on the allowable burnups in Table 12.2.5.

12.2.11 Verifying Compliance with Total MPC Heat Load

Some operational steps and/or use of particular equipment are required if Q_{CoC} is above a certain value, e.g. 28.74 kW in the MPC-32. These include supplemental cooling, forced helium dehydration, helium backfill pressure, and surveillance requirements for LCO 3.1.2. These examples demonstrate the logic behind the decisions for these operational steps. Time to boil limits and vacuum drying are also considered in these examples.

Example 1:

Table 12.2.7 contains a proposed heat load pattern for loading a MPC-68 (non-duplex) into an aboveground HI-STORM 100 System. The table provides the decay heat of each storage location. It is assumed that each of these assemblies meets the burnup, cooling time and enrichment criteria for loading as described in the previous examples in Section 12.2.10.
General observations on this loading plan:

1. The heat loads in all cells meet the CoC limits for Uniform Loading, i.e. all cells are ≤ 0.50 kW (See Table 2.1.26).
2. The MPC is loaded preferentially for ALARA considerations, i.e. the assemblies with the lower heat loads are in the peripheral cells.
3. The aggregate MPC heat load, as defined in Section 2.1.9.1.2 as the simple summation of the assemblies in the MPC, is 18.917 kW.
4. The maximum heat load in any cell is 0.460 kW.
5. $Q_{CoC,}$ as defined in Section 2.1.9.1.2 equation c is 31.280 kW.

Recommendations based on the general observations <u>without further site-specific analysis</u>:

1. Vacuum drying: The MPC *cannot* be dried using vacuum drying because the Q_{CoC} heat load is greater than 30 kW (See FSAR Table 4.5.1).
2. Forced Helium Dehydration: The MPC should be dried using forced helium dehydration since the Q_{CoC} heat load exceeds the vacuum drying threshold heat loads (See FSAR Table 4.5.1).
3. Helium Backfill Pressure Range: The MPC should be backfilled to the higher pressure range given in the TS because the Q_{CoC} heat load exceeds the heat load in Table 3-2 of the CoC Appendix A and FSAR Table 1.2.2.
4. Supplemental Cooling System: A supplemental cooling system would be required for on-site transport of High Burnup Fuel in the HI-TRAC after the MPC is dried, backfilled and sealed because the Q_{CoC} heat load exceeds the 90% design basis threshold heat load in FSAR Table 2.1.26 and per cell limits in CoC Appendix B

Table 2.4-1.

5. Heat Removal Surveillance (LCO 3.1.2): The user has 24 hours to clear blockage on the system containing this MPC since the Q_{CoC} heat load (assuming the pattern is at the time of inspection) exceeds the 28.152 kW (=0.414 kW*68) threshold heat load in LCO 3.1.2.
6. Time to boil determination: The user can calculate the time to boil limit based on the aggregate MPC heat load of 18.917 kW since this is a bulk adiabatic heat up calculation strictly based on the aggregate heat in the MPC.
7. Air mass flow rate test requirements per Condition 9 of the CoC: The user can determine if this test needs to be performed based on the aggregate MPC heat load of 18.917 kW since the air flow on the outside of the MPC is strictly based on the aggregate heat in the MPC.

Example 2

Table 12.2.8 contains a proposed heat load pattern for loading a MPC-32 (non-duplex). The table provides the decay heat of each storage location. It is assumed that each of these assemblies meets the burnup, cooling time and enrichment criteria for loading as described in the previous examples in Section 12.2.10.

General observations on this loading plan:

1. The heat loads in all cells meet the CoC limits for Uniform Loading, i.e. all cells are ≤ 1.062 kW (See Table 2.1.26).
2. The MPC is loaded preferentially for ALARA considerations, i.e. the assemblies with the lower heat loads are in the peripheral cells.
3. The aggregate MPC heat load, as defined in Section 2.1.9.1.2 as the simple summation of the assemblies in the MPC, is 17.471 kW.
4. The maximum heat load in any cell is 0.826 kW.
5. $Q_{CoC,}$ as defined in Section 2.1.9.1.2 equation c is 26.432 kW.

Recommendations based on the general observations <u>without further site-specific analysis</u>:

1. Vacuum drying: The MPC can be dried using vacuum drying since the Q_{CoC} heat load is bounded by the threshold heat load Q2 in FSAR Table 4.5.1. The vacuum drying is time limited as Q_{CoC} exceeds threshold heat load Q1 in FSAR Table 4.5.1.
2. Forced Helium Dehydration: The MPC can be dried using forced helium dehydration but it is not required.
3. Helium Backfill Pressure Range: The MPC may be backfilled to either pressure range given in the TS because the Q_{CoC} heat load is bounded by the heat load limits in Table 3-2 of CoC Appendix A and FSAR Table 1.2.2.
4. Supplemental Cooling System: Since the maximum cell heat load is less than 90% of the design basis heat load per cell limit in FSAR Table 2.1.30, supplemental cooling is not required for on-site transport in the HI-TRAC if the higher helium backfill

range in FSAR Table 1.2.2 is used. However, the maximum cell heat load is higher than 90% of the design basis heat load per cell limit in FSAR Table 2.1.31, so supplemental cooling would be required if the MPC contains High Burnup Fuel and is backfilled to the lower helium backfill range in FSAR Table 1.2.2.

5. Heat Removal Surveillance (LCO 3.1.2): The user has 64 hours to clear blockage on the system containing this MPC since the Q_{CoC} heat load (assuming the pattern is at the time of inspection) is bounded by the 28.74 kW threshold heat load in LCO 3.1.2.
6. Time to boil determination: The user can calculate the time to boil limit based on the aggregate MPC heat load of 17.471 kW since this is a bulk adiabatic heat up calculation strictly based on the aggregate heat in the MPC.
7. Air mass flow rate test requirements per Condition 9 of the CoC: The user can determine if this test needs to be performed based on the aggregate MPC heat load of 17.471 kW since the air flow on the outside of the MPC is strictly based on the aggregate heat in the MPC.

Example 3

Table 12.2.9 contains a proposed heat load pattern for loading a MPC-32 (non-duplex). The table provides the decay heat of each storage location. It is assumed that each of these assemblies meets the burnup, cooling time and enrichment criteria for loading as described in the previous examples in Section 12.2.10.

General observations on this loading plan:

1. The heat loads do not meet the CoC limits for Uniform Loading, i.e. some cells are ≥ 1.0625 kW (See Table 2.1.26).
2. The X value that most closely meets this pattern (See Table 2.1.30) is 1.5 which means the inner locations cannot have a decay heat greater than 1.282 kW for each cell and the outer locations cannot have a decay heat greater than 0.854 kW for each cell. Note that the pattern also meets the criteria for any X value ≥ 1.5.
3. The aggregate MPC heat load, as defined in Section 2.1.9.1.2 as the simple summation of the assemblies in the MPC, is 20.697 kW.
4. The maximum heat load in any cell is 1.273 kW.
5. Since this MPC is loaded in a regionalized pattern, $Q_{CoC,}$ as defined in Section 2.1.9.1.2 equation e is 32.484 kW. (12*1.282+20*0.855)

Recommendations based on the general observations <u>without further site-specific analysis</u>:

1. Vacuum drying: The MPC *cannot* be dried using vacuum drying since the Q_{CoC} heat load under uniform loading (1.273 kWx32 equals 40.736 kW) exceeds the threshold heat loads in FSAR Table 4.5.1.
2. Forced Helium Dehydration: The MPC must be dried using forced helium dehydration only because vacuum drying is not permitted (see above) and regionalized loading Q_{CoC} is bounded by the design basis heat load in FSAR Table 4.5.1.

BASES

APPLICABLE SAFETY ANALYSIS (continued)	The complete blockage of all air inlets stops normal air cooling of the MPC. The MPC will continue to radiate heat to the relatively cooler OVERPACK. With the loss of normal air cooling, the SFSC component temperatures will increase toward their respective short-term temperature limits. None of the components reach their temperature limits over the duration of the analyzed event.
LCO	The SFSC Heat Removal System must be verified to be operable to preserve the assumptions of the thermal analyses. Operability is defined as at least 50% of the inlet and outlet air ducts are available for air flow (i.e., unblocked). Operability of the heat removal system ensures that the decay heat generated by the stored fuel assemblies is transferred to the environs at a sufficient rate to maintain fuel cladding and other SFSC component temperatures within design limits. The intent of this LCO is to address those occurrences of air duct blockage that can be reasonably anticipated to occur from time to time at the ISFSI (i.e., Design Event I and II class events per ANSI/ANS-57.9). These events are of the type where corrective actions can usually be accomplished quickly to restore the heat removal system to operable status (e.g., removal of loose debris).

(continued)

BASES

ACTIONS (continued)

B.1

If the heat removal system has been determined to be inoperable, it must be restored to operable status within the Completion Time per Table in CoC. This is a reasonable period of time to take action to remove the obstructions in the air flow path.

(continued)

BASES

ACTIONS (continued)

C.1

If the heat removal system cannot be restored to operable status within Completion Time per the table in the CoC, the innermost portion of the OVERPACK concrete may experience elevated temperatures. Therefore, dose rates are required to be measured to verify the effectiveness of the radiation shielding provided by the concrete. This Action must be performed immediately and repeated every twelve hours thereafter to provide timely and continued evaluation of the effectiveness of the concrete shielding. As necessary, the cask user shall provide additional radiation protection measures such as temporary shielding. The Completion Time is reasonable considering the expected slow rate of deterioration, if any, of the concrete under elevated temperatures.

C.2.1

In addition to Required Action C.1, efforts must continue to restore cooling to the SFSC. Efforts must continue to restore the heat removal system to operable status by removing the air flow obstruction(s) unless optional Required Action C.2.2 is being implemented.

This Required Action must be complete within Completion Time per the table in the CoC for all aboveground systems and in 16 hours for an underground system. These Completion Times are consistent with the thermal analyses of this event, which show that all component temperatures remain below their short-term temperature limits after event initiation.

(continued)

BASES

ACTIONS

C.2.1 (continued)

The Completion Time reflects the time to complete Required Action B.1 and the appropriate balance of time consistent with the applicable analysis results. The event is assumed to begin at the time the SFSC heat removal system is declared inoperable. This is reasonable considering the low probability of all air ducts becoming simultaneously blocked by trash or debris.

C.2.2

In lieu of implementing Required Action C.2.1, transfer of the MPC into a TRANSFER CASK will place the MPC in an analyzed condition and ensure adequate fuel cooling until actions to correct the heat removal system inoperability can be completed. Transfer of the MPC into a TRANSFER CASK removes the SFSC from the LCO Applicability since STORAGE OPERATIONS does not include times when the MPC resides in the TRANSFER CASK. In this case, the requirements of CoC Appendix A, LCO 3.1.4 apply.

An engineering evaluation must be performed to determine if any concrete deterioration has occurred which prevents it from performing its design function. If the evaluation is successful and the air flow obstructions have been cleared, the OVERPACK heat removal system may be considered operable and the MPC transferred back into the OVERPACK. Compliance with LCO 3.1.2 is then restored. If the evaluation is unsuccessful, the user must transfer the MPC into a different, fully qualified OVERPACK to resume STORAGE OPERATIONS and restore compliance with LCO 3.1.2

(continued)

BASES

ACTIONS

C.2.2 (continued)

In lieu of performing the engineering evaluation, the user may opt to proceed directly to transferring the MPC into a different, fully qualified OVERPACK or place the TRANSFER CASK in the spent fuel pool and unload the MPC.

The Completion Times per the table in the CoC reflect the Completion Time from Required Action C.2.1 to ensure component temperatures remain below their short-term temperature limits for the respective decay heat loads and OVERPACK styles.

SURVEILLANCE REQUIREMENTS

SR 3.1.2

The long-term integrity of the stored fuel is dependent on the ability of the SFSC to reject heat from the MPC to the environment. There are two options for implementing SR 3.1.2, either of which is acceptable for demonstrating that the heat removal system is OPERABLE.

Visual observation that all air inlets and outlets are unobstructed ensures that air flow past the MPC is occurring and heat transfer is taking place. Greater than 50% blockage of the total air inlet area or air outlet area renders the heat removal system inoperable and this LCO is not met. 50% or less blockage of the total air inlet area or air outlet area does not constitute inoperability of the heat removal system. However, corrective actions should be taken promptly to remove the obstruction and restore full flow through the affected air duct(s).

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 3.1.2 (continued)

As an alternative, for OVERPACKs with air temperature monitoring instrumentation installed in the air outlets, the temperature rise between ambient and the OVERPACK air outlet may be monitored to verify operability of the heat removal system. Blocked air ducts will reduce air flow and increase the temperature rise experienced by the air as it removes heat from the MPC. Based on the analyses, provided the air temperature rise is less than the limit stated in the SR, adequate air flow and, therefore, adequate heat transfer is occurring to provide assurance of long term fuel cladding integrity. The reference ambient temperature used to perform this Surveillance shall be measured at the ISFSI facility.

The Frequency for aboveground systems per the Completion Time Table in the CoC and 16 hours for underground systems is reasonable based on the time necessary for SFSC components to heat up to unacceptable temperatures assuming design basis heat loads, and allowing for corrective actions to take place upon discovery of blockage of air ducts.

REFERENCES

1. FSAR Chapter 4
2. FSAR Sections 11.2.13 and 11.2.14
3. ANSI/ANS 57.9-1992