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 S32205 [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.

The duplex stainless steel is deemed to be extremely resistant to stress corrosion cracking (SCC) in marine environments. However, its properties begin to deteriorate rapidly at temperatures above 600 ^{o}F reaching an uncertain state of fragility at 887 ^{o}F [1.A.4] and above. Therefore, 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.
For other stainless steels listed as members of Alloy X above, the design temperature limits in Table 2.2.3 remain unmodified.

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 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.1]. 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 to -20^{o}F. The design temperature of the MPC is -40^{o}F to 725^{o}F as stated in Table 1.2.2. Most of the above-mentioned properties become increasingly favorable as the temperature drops. Conservatively, 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 exception is the thermal conductivity. The thermal conductivity decreases with the decreasing temperature. The thermal conductivity value for -40^{o}F is linearly extrapolated from the 70^{o}F value using the difference from 70^{o}F to 100^{o}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. ~~Further discussion of the justification for u~~Using the minimum value~~s of coefficient~~ of thermal conductivity has the effect of reducing the heat rejection rate from the canister which is ~~given in Chapter 3~~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. ~~Figures 1.A.1-1.A.5 provide a graphical representation of the varying material properties with temperature for the Alloy X materials.~~

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-741 (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..

Table 1.A.1

ALLOY X AND CONSTITUENT DESIGN STRESS INTENSITY (S_m) vs. TEMPERATURE

Temp. (°F)	Type 304	Type 304LN	Type 316	Type 316LN	Duplex Stainless Steel S32205 [Notes 3 and 4]	Alloy X (minimum of constituent values)
-40	20.0	20.0	20.0	20.0	31.7	20.0
100	20.0	20.0	20.0	20.0	31.7	20.0
200	20.0	20.0	20.0	20.0	31.7	20.0
300	20.0	20.0	20.0	20.0	30.6	20.0
400	18.7	18.7	19.3	18.9	29.4	18.7
500	17.5	17.5	18.0	17.5	28.7	17.5
600	16.4	16.4	17.0	16.5	28.4	16.4
650	16.2	16.2	16.7	16.0	28.3	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 AND CONSTITUENT TENSILE STRENGTH (S_u) vs. TEMPERATURE

Temp. (°F)	Type 304	Type 304LN	Type 316	Type 316LN	Duplex Stainless Steel S32205 [Notes 4 and 5]	Alloy X (minimum of constituent values)
-40	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	95 (95)	75.0 (70.0)
100	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	95 (95)	75.0 (70.0)
200	71.0 (66.2)	71.0 (66.2)	75.0 (70.0)	75.0 (70.0)	95 (95)	71.0 (66.2)
300	66.0 (61.5)	66.0 (61.5)	73.4 (68.5)	70.9 (66.0)	91.7 (91.7)	66.0 (61.5)
400	64.4 (60.0)	64.4 (60.0)	71.8 (67.0)	67.1 (62.6)	88.2 (88.2)	64.4 (60.0)
500	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	64.6 (60.3)	86.1 (86.1)	63.5 (59.3)
600	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	63.1 (58.9)	85.2 (85.2)	63.1 (58.9)
650	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	62.8 (58.6)	85.0 (85.0)	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 (S32205), 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 529 of [1.A.2] for Duplex Stainless Steel S32205

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 AND CONSTITUENT YIELD STRESSES (S_y) vs. TEMPERATURE

Temp. (^oF)	Type 304	Type 304LN	Type 316	Type 316LN	Duplex Stainless Steel S32205 [Notes 3 and 4]	Alloy X (minimum of constituent values)
-40	30.0	30.0	30.0	30.0	65.0 (70.0)	30.0
100	30.0	30.0	30.0	30.0	65.0 (65.1)	30.0
200	25.0	25.0	25.8	25.5	57.8 (62.2)	25.0
300	22.5	22.5	23.3	22.9	53.7 (57.9)	22.5
400	20.7	20.7	21.4	21.0	51.2 (55.2)	20.7
500	19.4	19.4	19.9	19.4	49.6 (53.4)	19.4
600	18.2	18.2	18.8	18.3	47.9 (51.6)	18.2
650	17.9	17.9	18.5	17.8	46.9 (50.5)	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 676 and 677 of [1.A.2] for Duplex Stainless Steel S32205. Values in paratheses are based on SA-182 forged material (S32205) 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 AND CONSTITUENT COEFFICIENT OF THERMAL EXPANSION vs. TEMPERATURE

Temp. (°F)	Type 304 and Type 304LN	Type 316 and Type 316LN	Duplex Stainless Steel S32205 [Notes 3 and 4]	Alloy X Maximum	Alloy X Minimum
-40	8.55	8.54	7.1	8.55	~~8.54~~7.1
100	8.55	8.54	7.1	8.55	~~8.54~~7.1
150	8.67	8.64	7.3	8.67	~~8.64~~7.3
200	8.79	8.76	7.5	8.79	~~8.76~~7.5
250	8.90	8.88	7.6	8.90	~~8.88~~7.6
300	9.00	8.97	7.8	9.00	~~8.97~~7.8
350	9.10	9.11	7.9	9.11	~~9.10~~7.9
400	9.19	9.21	8.0	9.21	~~9.19~~8.0
450	9.28	9.32	8.1	9.32	~~9.28~~8.1
500	9.37	9.42	8.3	9.42	~~9.37~~8.3
550	9.45	9.50	8.4	9.50	~~9.45~~8.4
600	9.53	9.60	8.4	9.60	~~9.53~~8.4
650	9.61	9.69	8.5	9.69	~~9.61~~8.5
700	9.69	9.76	8.6	9.76	~~9.69~~8.6
750	9.76	9.81	8.7	9.81	~~9.76~~8.7
800	9.82	9.90	8.8	9.90	~~9.82~~8.8

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.2] for Duplex Stainless Steel S32205.

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 AND CONSTITUENT THERMAL CONDUCTIVITY vs. TEMPERATURE

Temp. (^{o}F)	Type 304 and Type 304LN	Type 316 and Type 316LN	Duplex Stainless Steel S32205 [Notes 3 and 4]	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	10.9	10.7
700	11.8	11.0	11.2	11.0
750	12.0	11.2	11.4	11.2
800	12.2	11.5	11.6	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-^{o}F.
3. Table TCD on page 773 of [1.A.2] for Duplex Stainless Steel
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)	525
Short-Term Events, Off-Normal, and Accident Condition Temperature Limits (^{o} F)	650

† These temperature limits take precedence over those in Table 2.2.3

FIGURES 1.A.1 through 1.A.5
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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 42.83 kW (MPC-68M)	-	Section 4.4
Minimum Cooling Time:	3 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

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

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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. <u>Thermal</u>

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. <u>Shielding</u>

Same as Subsection 2.0.1.

iv. <u>Criticality</u>

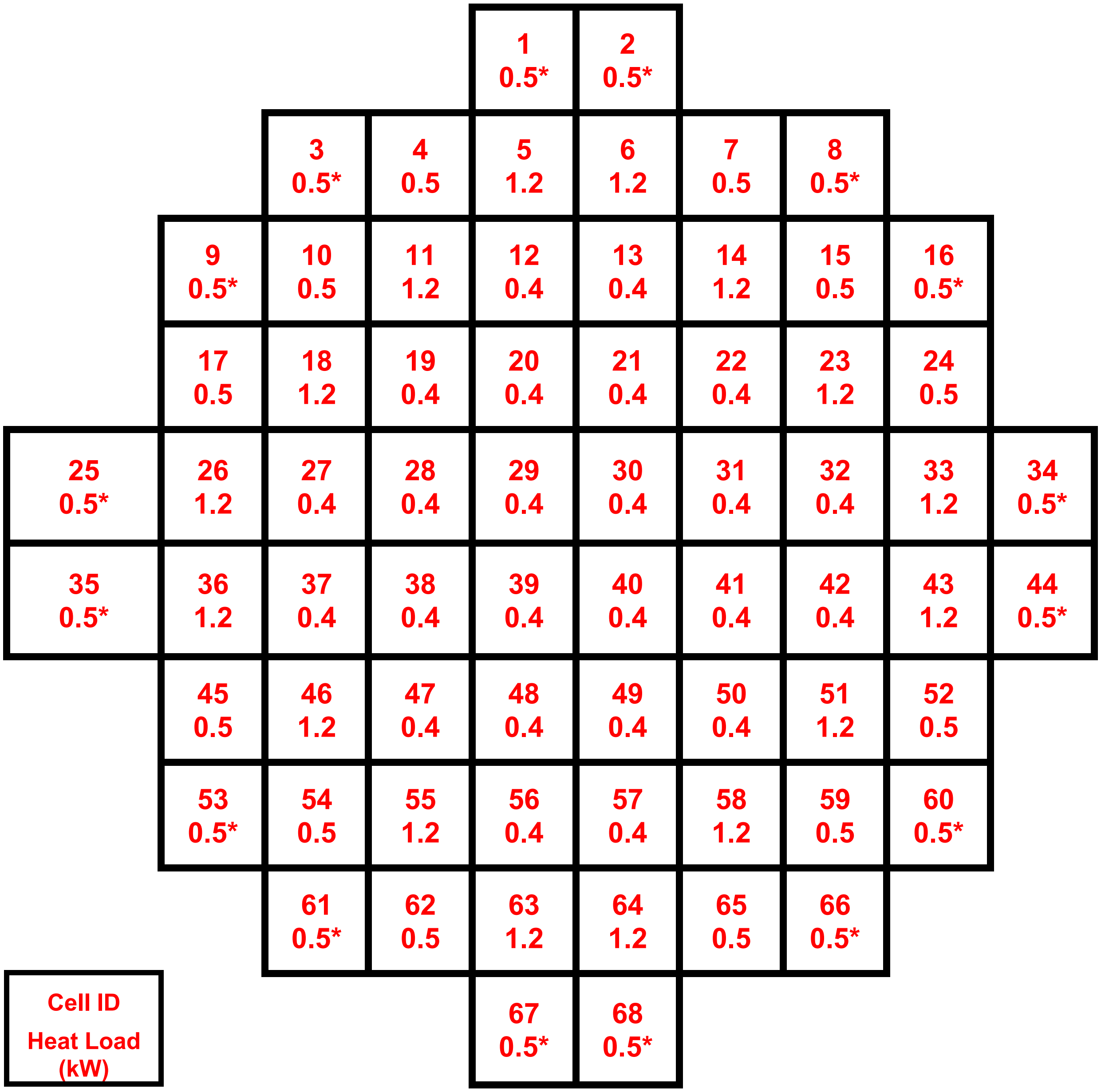
Same as Subsection 2.0.1 with the clarifications herein.

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. <u>Confinement</u>

Same as Subsection 2.0.1

vi. <u>Operations</u>



* 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

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~~3~~.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 ~~Devices~~Attachment Points

The structural analyses of the lifting ~~devices~~ 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

$$K_{IC} = 30ksi\sqrt{in}$$

based on Charpy V-notch absorbed energy (CVE) correlations for steels. The estimated value is consistent with the range for aluminum alloys, which is 20 to 50 $MPa\sqrt{m}$ or 18.2 to 45 $ksi\sqrt{in}$ per Table 3 of [3.III.4]. Next the minimum crack size, a_{min}, for crack propagation to occur is calculated below using the formula for a through-thickness edge crack given in [3.1.5]. Although the formula is derived for a straight-edge specimen, the use of the peak stress, σ_{max}, at a notch in the fuel basket panel (instead of the average stress in the panel as required by the formula) essentially compensates for the geometric difference between the basket panel and the specimen. Moreover, the maximum size of a pre-existing crack (1/16") in the fuel basket panel is less than 1/6th of the basket panel thickness (0.40"). Thus, the assumption of a through-thickness edge crack is very conservative. The result is

$$a_{min} = \frac{\left(\frac{K_{IC}}{1.12\sigma_{max}}\right)^2}{\pi} = \frac{\left[\frac{30ksi\sqrt{in}}{1.12(12.78~~17.426~~ksi)}\right]^2}{\pi} = 1.398~~0.752~~in$$

and the safety factor against crack propagation (based on a 1/16" minimum detectable flaw size) is

$$SF = \frac{a_{min}}{a_{det}} = \frac{1.398~~0.752~~in}{0.0625in} = 22.4~~12.0~~$$

The calculated minimum crack size is more than ~~12~~ 22 times greater than the maximum possible pre-existing crack size in the fuel basket (based on 100% surface inspection of each panel). The large safety factor ensures that crack propagation in the MPC-68M fuel basket will not occur due to the non-mechanistic tipover event.

3.III.4.4.3.2 Elastic Stability and Yielding of the MPC-68M Fuel Basket under Compression Loads (Load Case F3 in Table 3.1.3)

Under certain conditions, the fuel basket plates may be under direct compressive load. Although the finite element simulations can predict the onset of an instability and post-instability behavior, the computation in this subsection uses (the more conservative) classical instability formulations to demonstrate that an elastic instability of the basket plates is not credible.

A solution for the stability of the fuel basket plate is obtained using the classical formula for buckling of a wide bar [3.III.1]. Material properties are selected corresponding to a metal temperature of ~~325ºC~~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 ~~325ºC~~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 = ~~7,850~~6,125 ksi (Table 1.III.2). Then, the classical critical buckling stress is computed as ~~31.014~~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).

In addition, since the MPC-68M does not require any physical changes to the HI-STORM overpacks or the HI-TRAC transfer casks for MPC loading, the missile penetration analyses presented in Subsection 3.4.8 remain valid.

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 ~~(see Supplement 1.III)~~[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 ~~350~~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 ~~Supplement 1.III~~[1.III.3]) and performing the above integration numerically yields δ = 0.138~~095~~ inch. In other words, the computed shrinkage of the basket is less than 0.069~~48~~% 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 Design and Service Life

Same as in Subsection 3.4.13.

3.III.5 FUEL RODS

Same as in Section 3.5.

3.III.6 SUPPLEMENTAL DATA

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
~~8.9~~1.008 × 10^{-34}	0.005	~~5.62~~4.96

Notes:

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

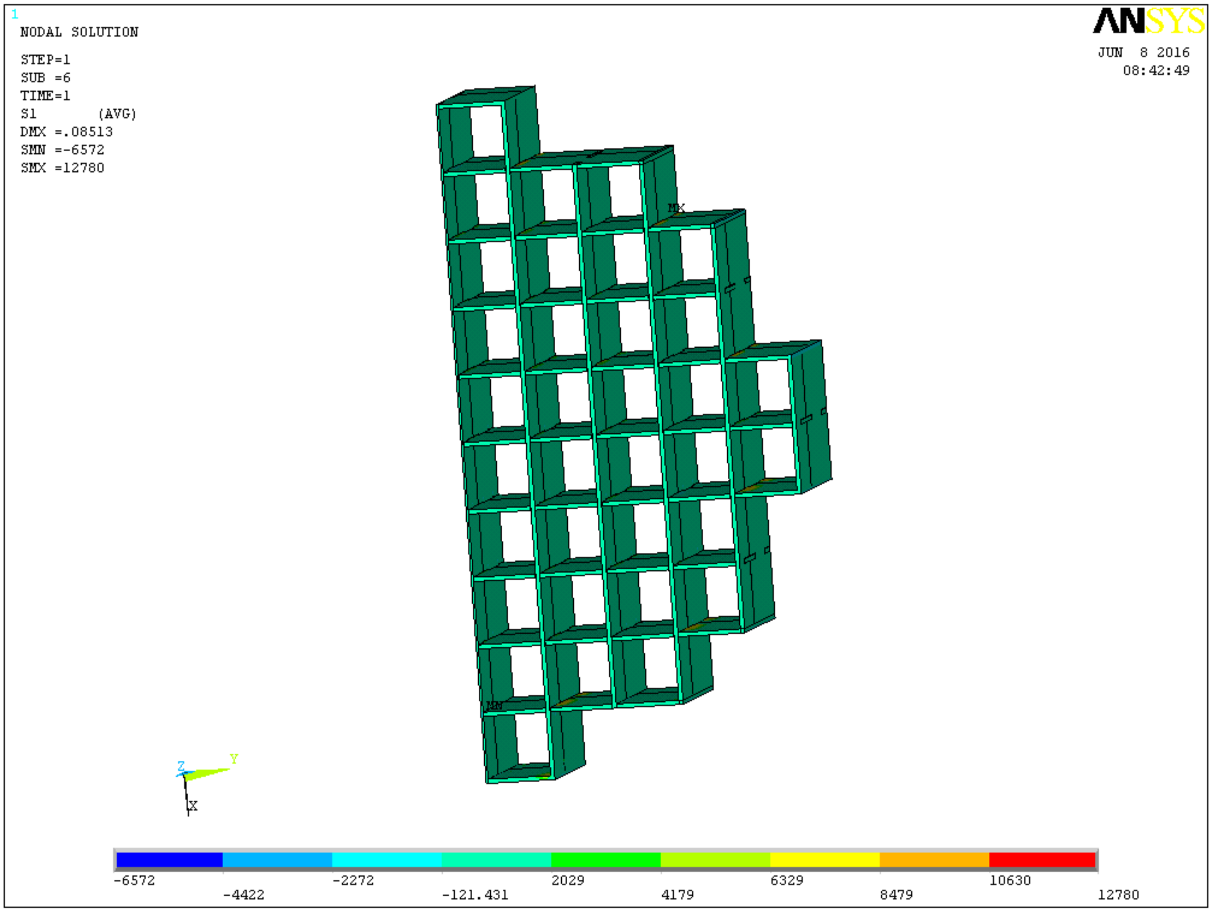


FIGURE 3.III.2: ~~FIRST PRINCIPAL~~TRUE STRESS DISTRIBUTION IN MPC-68M FUEL BASKET UNDER 60G LOAD

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°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[deleted] 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.	

[deleted]

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 ~~threshold heat loads Q1 and Q2 are defined wherein~~ Q1 is the threshold heat load for vacuum drying operations without time limits ~~and Q2 is the threshold heat load for time-limited vacuum drying~~. 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, v~~V~~acuum drying of MPCs containing one or more High Burnup Fuel (HBF) assemblies is also ~~not~~ 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. ~~High burnup f~~Fuel drying ~~must be~~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. ~~Threshold heat load Q2, defined in Table 4.5.1, is assumed and a transient calculation is performed to determine the permissible vacuum drying time under Q2. The transient calculation is started assuming the MPC has reached 212°F boiling temperature in the operational step preceding vacuum drying (i.e. water blow down operations). The vacuum drying clock starts when the MPC is drained.~~

~~iii.~~ 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.

~~iv.~~iii. The bottom surface of the MPC is insulated.

~~v.~~iv. MPC internal convection heat transfer is suppressed.

~~vi.~~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. ~~Under the time limited threshold heat load Q2 the peak cladding temperature plot is shown in Figure 4.5.2.~~ The results ~~under the scenarios Q1 and Q2 (with appropriate time limit)~~ show that ISG-11, Rev. 3 limits are met with ample margins.

4.5.3.2 <u>Forced Helium Dehydration</u>

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,

[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 and ≤ Q2	Yes (Note 2) (40 hrs)
Vacuum Drying	HBF	36.9 kW	Yes (Note 2)
FHD	MBF and/or HBF	36.9 kW	None
Note 1: Threshold heat load iss are defined below: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 conditionsQ2 = 30 kW (Uniform).			

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 (°F)	Temperature Limit Note 2	Margin (°F)
Q1	None	1046	1058	12
~~Q2~~	~~40 hrs~~	~~1035~~	~~1058~~	~~23~~

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 ~~not permitted~~discussed in ~~(See~~ Subsection 4.5.3.~~).~~

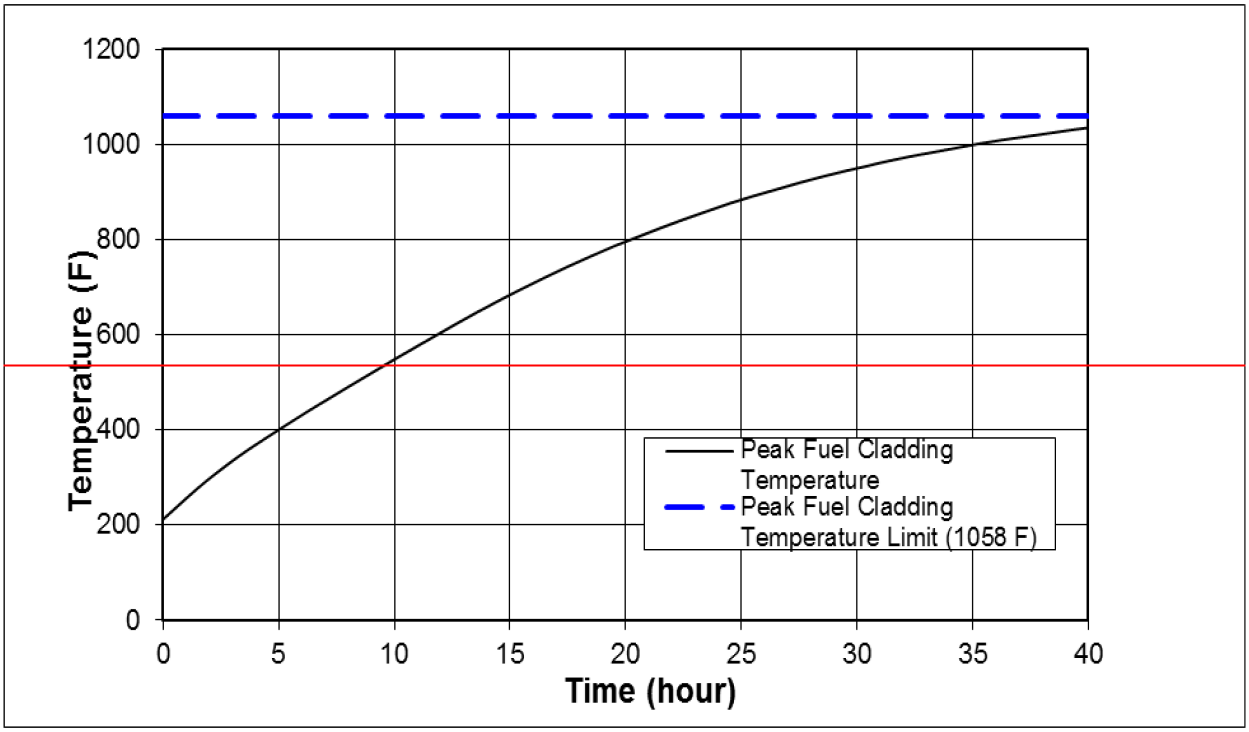


Figure 4.5.2: ~~PEAK CLADDING TEMPERATURE CURVE UNDER VACUUM DRYING OPERATIONS AT THRESHOLD HEAT LOAD Q2~~INTENTIONALLY DELETED

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 ~~same~~ backfill specifications as discussed below:

- 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~~.~~
- 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:

~~e.~~a. Fuel Basket-to-MPC Radial Gap
~~f.~~b. Fuel Basket-to-MPC Axial Gap
~~g.~~c. MPC-to-Overpack Radial Gap
~~h.~~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 ~~uniform loading heat load limits specified in Section 2.4 of the Technical Specifications~~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, ~~Section 2.4, Table 2.4-1~~Figure 2.4-2) and all interior cells are emitting design basis heat under the ~~uniform~~ applicable heat load~~ing storage~~ 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

~~As the MPC thermal inertia credited in the time-to-boil calculations is bounded by the MPC-68M thermal inertia the evaluation of wet transfer operations in Section 4.5 remains applicable to the MPC-68M.~~ 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 ~~using~~ for site-specific conditions.

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].

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^{o}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^{o}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^{o}C (117^{o}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.5.3.3 Open Loop Low Pressure Drying (LPD) Method

Dehydration of the MPC cavity after draining off its bulk water can be carried out using the vacuum drying method. Calculations show that below a threshold heat load Q_L (Scenario B in Paragraph 4.III.5.3.1), the peak cladding temperature of the used fuel is assured to remain below the ISG-11 Rev 3 limit of 400^{o}C for HBF regardless of the duration of near vacuum conditions.

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.

Therefore, at or below Q_L, the vacuum drying operation can be continued for as long as necessary to achieve the target vacuum pressure of 3 torr (or dew point of the contained helium gas <21 deg. F). At heat loads above Q_L, the vacuum drying operation cannot be continued indefinitely lest the PCT rise above the ISG-11 Rev 3 limit. The duration t for which the state of near vacuum can be held to keep the PCT below the ISG-11 Rev 3 limit is computed by a transient analysis for the site-specific heat load using the FLUENT model described in Paragraph 4.III.5.3.1. Accordingly, the vacuum drying process is stopped at time t and the next phase, termed "feed and bleed" is initiated.

The feed and bleed process entails introducing helium in sufficient quantity through the canisters's top vent opening to the cask cavity to raise the pressure to approximately 500 mm Hg thus lowering the canister spatial temperature by a modest amount, After that, a slow introduction of helium through the top vent is begun along with a concomitant slow withdrawal through the drain port. A nominal rate of helium "feed and bleed" is provided in Table 4.III.10 . The slow bleed and feed process is intended to create quiescent conditions in the cask cavity which would facilitate the settling of the water vapor near the bottom of the cask and stratification of the helium mass above it. The bleeding of the gas from the bottom thus steadily dew scavenges the water vapor from the cask reducing the helium mass' relative humidity. The "dew point" of the exiting vapor (target ≤ 21 deg. F) provides the definitive proof as to whether the canister has been dried to the requisite level.

The steady state peak cladding temperature assuming helium at atmospheric pressure under the most limiting pattern i.e. QSHL pattern, is presented in Table 4.III.10. The PCT during feed and bleed process is below the ISG-11 Rev 3 temperature limit of 400^{o}C.

The above process has the principal benefit of avoiding cyclic heating and quenching of the fuel associated with vacuum drying & flooding which is limited in the number of permitted cycles and the related cyclic temperature range by regulatory guidance to avoid high thermal stresses.

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.

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 ~~regionalized storage scenario X = 0.5~~Quarter Symmetric Heat Load (QSHL) pattern.

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

(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 ~~involving~~ 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.
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).

~~As the normal storage temperatures under MPC-68M storage in the HI-STORM 100 overpack are bounded by the HI-STORM 100 System temperatures reported in Section 4.4, the temperatures under this event are likewise bounded by the off-normal ambient evaluation in Section 4.6.~~

(b) Partial Blockage of Air Inlets

This off-normal event is defined in Paragraph 4.6.1.3. The principal effect of partial inlet svent blockage is a ~~rise in the HI-STORM 100 annulus~~ temperature rise in HI-STORM 100 System components from the baseline normal storage temperatures~~and to leading order a similar rise in the MPC temperatures~~. ~~As the normal storage temperatures under MPC-68M storage in the HI-STORM 100 overpack are bounded by the HI-STORM 100 System temperatures reported in Section 4.4, the temperatures under this event are likewise bounded by the partial ducts blockage evaluation in Section 4.6.~~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.

(c) Off-Normal Pressure

1 This section supplements Section 4.6.

This event is defined as a combination of (a) maximum helium backfill pressure (Table ~~4.4.12~~1.III.1), (b) 10% fuel rods rupture, and (c) limiting fuel storage configuration. The principal objective of the analysis is to demonstrate that the MPC off-normal design pressure (Table 2.2.1) is not exceeded. The MPC-68M off-normal pressure is reported in Table 4.III.4. The result[1] is below the off-normal design pressure (Table 2.2.1).

4.III.6.2 Accident Conditions

(a) Fire

Although the probability of a fire accident affecting a HI-STORM 100 System during storage operations is low due to the lack of combustible materials at an ISFSI, a conservative fire event has been assumed and analyzed. The only credible concern is a fire from an on-site transport vehicle fuel tank. Under a postulated fuel tank fire, the outer layers of HI-TRAC or HI-STORM overpacks are heated for the duration of fire by the incident thermal radiation and forced convection heat fluxes. The amount of fuel in the on-site transporter is limited to a volume of 50 gallons.

<u>(i) HI-STORM Fire[2]</u>

The fuel tank fire is conservatively assumed to surround the HI-STORM Overpack. Accordingly, all exposed overpack surfaces are heated by radiation and convection heat transfer from the fire. Based on NUREG-1536 and 10 CFR 71 guidelines [4.III.2], the following fire parameters are assumed:

1. The average emissivity coefficient must be at least 0.9. During the entire duration of the fire, the painted outer surfaces of the overpack are assumed to remain intact, with an emissivity of 0.85. It is conservative to assume that the flame emissivity is 1.0, the limiting maximum value corresponding to a perfect blackbody emitter. With a flame emissivity conservatively assumed to be 1.0 and a painted surface emissivity of 0.85, the effective emissivity coefficient is 0.85. Because the minimum required value of 0.9 is greater than the actual value of 0.85, use of an average emissivity coefficient of 0.9 is conservative.

2. The average flame temperature must be at least 1475°F (800°C). Open pool fires typically involve the entrainment of large amounts of air, resulting in lower average flame temperatures. Additionally, the same temperature is applied to all exposed cask surfaces, which is very conservative considering the size of the HI-STORM cask. It is therefore conservative to use the 1475°F (800°C) temperature.

3. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond the external surface of the cask. Use of the minimum ring width of 1 meter yields a deeper pool for a fixed quantity of combustible fuel, thereby conservatively maximizing the fire duration.

1 Pressures relative to 1 atm absolute pressure (i.e. gauge pressures) are reported throughout this section.
2 The HI-STORM fire accident methodology is same as the generic methodology in Section 4.6 of the HI-STORM 100 FSAR.

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

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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:

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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~~0~~ lists lower-bound thermal inertia values for the MPC-68M and the contained fuel assemblies. Applying design heat load (~~36.9~~42.8 kW (1.4~~2~~6x10^5 Btu/hr)) and adiabatic heating for the 3.62 minutes fire, the fuel temperature rise computes as:

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

~~$$\Delta T_{fuel} = \frac{\text{Decay heat} \times \text{Time duration}}{\text{(MPC + Basket \& Shims + Fuel) heat capacities}} = \frac{1.26 \times 10^5\ \text{Btu/hr} \times (3.62/60) hr}{(2400 + 2339 + 2780)\ \text{Btu/}°F} = 1.0°F$$~~

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 HO-STORM FW FSAR.

(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~~36.9~~ kW) - a bounding cask temperature rise of 5.21~~178~~°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~~7~~°F, and the co-incident fuel cladding temperature (734~~664.7~~°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 ~~Chapter 4,~~ Table 1.III.14~~.4.12~~ 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.

(b) Flood

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

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 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 tThe 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 ~~bounding because of the following:~~

~~(i) The MPC thermal inertia is neglected.~~
~~(ii) The initial storage temperatures under MPC-68M storage are less than the HI-STORM 100 System temperatures.~~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 for 32 hours. This event is evaluated by blocking the air inlets in the FLUENT thermal model and computing the 32-hour temperature rise of the MPC and stored fuel. The results of this analysis 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).~~ As the normal storage temperatures under MPC-68M storage in the HI-STORM 100 overpack are bounded by the HI-STORM 100 System temperatures reported in Section 4.4, the temperatures under this event are likewise bounded by the extreme ambient evaluation in Section 4.6.~~

(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-~~68~~ 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).

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-°F	[4.III.1]
Emissivity	0.1~~03~~ Note 2	[4.2.5]
Density	177.3 lb/ft^3	[4.III.1]
Heat Capacity	0.207 Btu/lb-°F	[4.III.1]
Aluminum Alloy (solid shims)		
Conductivity	86.6 Btu/ft-hr-°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-°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	Total Decay Heat, kW	Peak Cladding Temperature, °F
X=0.5 (Note 1)	36.9	598
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.

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

Component	Temperature (°F)
Fuel Cladding	708~~598~~
Basket	674~~585~~
Basket Shims	563~~500~~
MPC Shell	499~~443~~
Overpack Inner Shell	358[1]~~309~~
Overpack Body Concrete[2]	252~~234~~
Overpack Lid Concrete[2]	257~~228~~
Overpack Outer Shell	190~~169~~
Area Averaged Air Outlet[3]	~~220~~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~~8~~.5
Normal: intact rods 1% rods rupture**	 98.7~~5.5~~ 99.2~~6~~
Off-Normal (10% rods rupture)	104.0~~0.5~~
Accident (100% rods rupture)	152.0~~45.8~~

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

** Per NUREG-1536, pressure analysis with ruptured fuel rods ~~(including BPRA rods for PWR fuel)~~ 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 (°F)	Scenario B (°F)
Fuel Cladding	754	732
Fuel Basket	729	698
Basket Shims	522	482
MPC Shell	325	307

Notes:

(1) The peak cladding temperatures are below the ISG 11 temperature limits of Moderate Burnup Fuel (Scenario A) 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 ~~Under~~ During On-site Transfer Operations

Component	Temperature [°F]
Fuel Cladding	709~~640~~[1]
MPC Basket	676~~626~~
Basket Periphery	606~~567~~
MPC ~~Outer~~ Shell ~~Surface~~	488~~442~~
Aluminum Shims	555~~528~~
HI-TRAC Inner Shell ~~Inner Surface~~	286~~331~~
~~Water Jacket Inner Surface~~HI-TRAC Outer Shell	274~~264~~
~~Enclosure Shell Outer Surface~~Water Jacket Shell	263~~261~~
Water Jacket Bulk Water	257~~250~~
Top Lid Neutron Shield (Holtite)[2]	289~~296~~
Pressure (psig)	
Initial Maximum Backfill	46~~8~~.5
Operating Pressure	100.5~~1.6~~
~~With 1% rods rupture~~	~~102.1~~
~~With 10% rods rupture~~	~~106.9~~

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 32-Hour 100% Air Inlets Blockage Accident

Component	Temperature (^{o}F)
Fuel Cladding	849~~722~~
Fuel Basket	818~~709~~
Basket Shims	702~~626~~
MPC Shell	639~~571~~
MPC Lid[Note 1]	599~~543~~
Overpack Inner Shell	531~~462~~
Body Concrete (Local Temperature)	525~~456~~
Lid Concrete (Local Temperature)	447~~375~~
Pressure (psig)	
MPC	~~111.6~~116.3
Note 1: Maximum thru thickness section average temperature reported.	

Table 4.III.8: Differential Thermal Expansion

Gap Description	Differential Expansion * mm (in)
Fuel Basket-to-MPC Radial Gap	3.24 (0.128)~~2.55 (0.101)~~
Fuel Basket-to-MPC Axial Gap	11.50 (0.453)~~9.69 (0.382)~~
MPC-to-Overpack Radial Gap	3.55 (0.140)~~3.07 (0.121)~~
MPC-to-Overpack Minimum Axial Gap	14.91 (0.587)~~13.16 (0.52)~~
*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 ~~101.6 psig~~Table 4.III.6
Fire Pressure Rise	2.9 psig
Fire Accident Pressure	103.4~~4.5~~ psig

Table 4.III.10: Open Loop Low Pressure Drying (LPD) Method Parameters for MPC-68M ~~MPC-68M Thermal Inertia~~

~~Fuel~~	~~2780 Btu/°F~~
~~Basket and Aluminum Shims~~	~~2339 Btu/°F~~
~~Pressure Boundary (lid, baseplate and shell)~~	~~2400 Btu/°F~~

Item	**Value**	**Comment**
Threshold heat load, Q_L	29 kW	Defined as the steady state fuel cladding temperature at near vacuum conditions (3 torr internal vapor pressure)
Time duration t, hours corresponding to site specific heat load	Note 1	The duration of vaccum conditions when the peak cladding temperature will approach 400°C under site-specific heat load
Nominal rate of helium feed and bleed	2.8 lb/hr	To insure a steady rate of vapor stripping from the canister
Peak Cladding Temperature during feed and bleed	700°F	Steady state fuel cladding temperature with 1 atm helium and bounding QSHL decay heat
Note 1: The duration of vacuum conditions when the PCT will approach the ISG-11 Rev 3 limit of 400°C under site-specific heat load must be determined from the transient analysis methodology defined in Paragraph 4.III.5.3.1.		

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

Component	**Temperature, °F**
Fuel Cladding	687~~583°F~~ Note 1
Basket	656~~561°F~~
Aluminum Shims	538~~451°F~~
MPC Shell	482~~406°F~~
Overpack Inner Shell	342~~268°F~~
Overpack Outer Shell	189~~162°F~~
Overpack Body Concrete Note 2	239~~194°F~~
Overpack Lid Concrete Note 2	253~~210°F~~
Average Air Outlet	244~~208°F~~

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 (~~32.288~~40.4 kW with all 16 cells versus ~~33.144~~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 (^{o}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 (^{o}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^{o}F to the local maximum concrete temperatures durng normal conditions.	

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

calculated by dividing 120% of the thermal power for commercial BWR reactors by the number of assemblies in the core. The higher thermal power, 120%, was used to account for potential power uprates. The power level used for the 7x7 is an additional 4% higher for consistency with previous revisions of the FSAR which also used this assembly as the design basis assembly.

Since the LaCrosse fuel assembly type is a stainless steel clad 10x10 assembly it was analyzed separately. The maximum burnup and minimum cooling time for this assembly are limited to 22,500 MWD/MTU and 10-year cooling as specified in Section 2.1.9. This assembly type is discussed further in Section 5.2.3.

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

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

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

5.2.5.3 Methodology to Calculate Heat Loads for Zircaloy Clad Fuel

A standardized method to compute the decay heat load emitted by a used fuel assembly has not been previously specified in this FSAR, which has led to different methods used by different users. This paragraph identifies a conservative procedure using SAS2H/ORIGEN S, long in use for heat load calculations in the industry, and in the Holtec safety analysis reports for decay heat load verification, as the preferred method for heat load calculations, which would promote consistency among all users of Holtec MPCs. A discussion of the benchmarking of SAS2H/ORIGEN S and its QA veracity is presented below, followed by a description of the computation procedure.

Uncertainties and Conservatisms

There is some uncertainty associated with the ORIGEN-S calculations to determine heat loads, due to uncertainty in the physics data (e.g. cross sections, decay constants, etc.) and the modeling techniques. In the initial use of the method, in order 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% at 3 year cooling time and 1.5 to 3.5% at 20 year cooling. The difference is due to the change in isotopes important to decay heat as a function of cooling time. The heat load verification approach, when deriving the coefficients

for the burnup equation, then applied a 5% decay heat penalty for both the PWR and BWR array classes.

To evaluate if such uncertainty consideration is needed, additional evaluations were performed, using information from Regulatory Guide (RG) 3.54 [5.2.17], and from NUREG/CR-6999 [5.2.18]:

Table 5.2.29 shows a comparison of heat load value calculated with the methodology proposed here with those from RG 3.54 [5.2.17]. Note that all values in the table are reported without any added uncertainty. The comparison shows that the results are comparable between the methods, but that the values calculated with the method proposed here are about 1 to 3% lower than those from the RG 3.54. Appendix B of NUREG/CR-6999 [5.2.18] provides a comparison between RG 3.54 and more than 100 directly measured heat load values. This comparison shows that the RG 3.54 values, overestimate the measured values on average by about 13% for PWR fuel and 23% for BWR fuel. For the fuel compared in NUREG/CR-6999 the average uncertainty (safety factor) applied by RG 3.54 method is 8%. Therefore, the average overestimation or conservativism of the method is in order of 5% for PWR fuel and 15% for BWR fuel. This conservatism is sufficient to offset the 1 to 3% difference between RG 3.54 and the methodology proposed here. This indirect comparison of the method proposed here with the measurements reported in NUREG/CR-6999 therefore supports the conclusion that the proposed method results in conservative values.

Assembly Specific Inputs

The assembly specific inputs are enrichment, cooling time, burnup, fuel weight and assembly power a full power conditions. These are discussed below:

Enrichment

The enrichment has a second order effect on the assembly heat load, and is also typically well known. Hence either the design value or the as built value of an assembly is acceptable to be used as input to the calculations. If a bounding value is to be used, this needs to be a lower bound, since heat load values increase slightly with a reduction in enrichment.

Cooling Time

While the cooling time can have a significant impact on heat loads, it is typically known very accurately, hence the actual cooling time is acceptable to be used. If a bounding value is to be used, this needs to be lower bound, since heat load values increase with a reduction in cooling time.

Burnup

The assembly burnup has a significant impact of heat loads, with a practically linear (proportional) relationship. However, the assembly burnup is not and cannot be directly measured, instead, it is derived by calculation from the flux measurements and other measurements of the core operation. It has therefore been a common practice to assume a 5% uncertainty in the burnup value for an individual assembly, a value that is considered bounding and typically acceptable without any further justification. With additional justifications, values

as low as 2% have been applied. However, the justification of the methodology based on comparison with measured heat loads (see above) already inherently includes any uncertainty in the assembly burnup. Therefore, the nominal (plant record) burnup value of the assembly is acceptable to be used to calculate the assembly heat load.

Assembly power at full power condition
Using a single cycle at full power condition is one of the important conservatisms in the evaluation. A lower assembly power should therefore not be used in the heat load determination. However, if the assembly has operated, on average through its irradiation time, at a higher power, then the heat load should be calculated using that higher power.

Code Version
The source term calculations for the HI-STORM 100 system, including the calculations of the heat load, go back to the late 1990ties, and initially used Scale Version 4.3. Since then, several newer versions of the Scale Code have been issued, but the code version used for the source term calculations for the HI-STORM 100 system has remained the same. However, the newer versions do not result in any significant changes in the results of heat load calculations for spent fuel assemblies. Therefore it is acceptable to perform calculations to determine heat loads with Scale Version 4.3 or any newer version. If a newer version is used, a comparison needs to be performed and documented that confirms that using the newer version does not result in significantly different results.

Fuel Weight (Uranium Mass)
The calculational method presented here uses a conservative upper bound fuel (uranium) weight, resulting in a correspondingly conservative heat load value. Using those conservative weights is acceptable, and simplifies the analyses since no further assembly-specific data is needed. However, it is also acceptable to use a lower fuel weight, as low as the as-built fuel weight of an assembly, in order to reduce any overly conservative assumptions.

<u>Summary</u>
The methodology discussed here, including the above discussed inputs, is an acceptable method to determine fuel assembly heat loads for the purpose of showing that assemblies meet the heat load requirements delineated in this FSAR. Specifics of the calculation are listed in the unnumbered table below

Parameter	Acceptable / Reference value / approach	Acceptable alternative value / approach
Scale Code Version	4.3	4.4 or newer, with supporting evaluation
Assembly Enrichment	As built or design nominal	Lower bound
Cooling time	Actual	Lower Bound
Burnup	Nominal (Plant Record)	Upper bound
Fuel (UO2) Weight	Value in Table 5.2.25 or 5.2.26 as applicable	Actual value
Assembly power	Value in Table 5.2.25 or 5.2.26	Upper bound

	as applicable, if it's an upper bound for the actual assembly power averaged over the irradiation time. Otherwise the actual should be used.	

Table 5.2.29

COMPARISON OF CALCULATED DECAY HEATS FOR DESIGN BASIS FUEL AND VALUES REPORTED IN REG GUIDE 3.54

Fuel Assembly Burnup (GWd/mtU)	Fuel Assembly Cooling Time (years)	Fuel Assembly Initial Enrichment (%)	Decay Heat from RG 3.54 (watts/assembly)	Decay Heat from Source Term Calculations (watts/assembly)
PWR Fuel, (B&W 15x15)				
30	4	2.9	1092.1	1070
35	5	3.2	1001.4	976.6
40	5	3.4	1169.5	1137
45	7	3.6	1036.0	1004
50	10	3.9	974.9	957.2
BWR Fuel, (7x7)				
30	4	2.6	403.9	400.9
35	5	2.9	380.0	372.3
40	5	3	443.4	434.3
45	7	3.2	402.8	389.9

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

~~Fuel Assembly Class~~	~~Decay Heat from the DOE Database (watts/assembly)~~	~~Decay Heat from Source Term Calculations (watts/assembly)~~
~~**PWR Fuel**~~		
~~B&W 15x15~~	~~752.0~~	~~827.5~~
~~B&W 17x17~~	~~732.9~~	~~802.7~~
~~CE 16x16~~	~~653.7~~	~~734.3~~
~~CE 14x14~~	~~601.3~~	~~694.9~~
~~WE 17x17~~	~~742.5~~	~~795.4~~
~~WE 15x15~~	~~762.2~~	~~796.2~~

~~[‡] Reference [5.2.7].~~

~~WE 14x14~~	~~649.6~~	~~682.9~~
~~BWR Fuel~~		
~~7x7~~	~~310.9~~	~~315.7~~
~~8x8~~	~~296.6~~	~~302.8~~
~~9x9~~	~~275.0~~	~~286.8~~

~~Notes:~~

1. ~~The decay heat from the source term calculations is the maximum value calculated for that fuel assembly class.~~
2. ~~The decay heat values from the database include contributions from in-core material (e.g. spacer grids).~~
3. ~~Information on the 10x10 was not available in the DOE database. However, based on the results in Table 5.2.28, the actual decay heat values from the 10x10 would be very similar to the values shown above for the 8x8.~~
4. ~~The enrichments used for the column labeled "Decay Heat from Source Term Calculations" were consistent with Table 5.2.24.~~

[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.

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. The additional regionalized loading pattern shown in Figure 2.III.1, wherein the basket is segregated into three regions, has been added as approved contents in the MPC-68M only. The minimum cooling time criteria for the MPC-68M of 2.0 years (see Table 2.0.1) is lower than for the MPC-68 (3.0 years)~~, and, consequently, the source term for fuel of higher decay heat in the middle hot region (Region 2) may not be covered by the reference MPC-68 calculations~~. The shorter cooling time allowed within the MPC-68M ~~However, this~~ is offset~~well compensated~~ by the substantially reduced source term~~decay heat~~ per fuel storage location in the other two regions (Region 1 and Region 3).~~,~~ Using a reference 3-region loading pattern (shown in Figure 2.III.1) the surface dose rate results are bounded by the uniform loading pattern dose rate results shown in Table 5.4.9. ~~hence the overall results are still bounded by the results for the uniform loading patterns in Section 5.1 and the dose rates for specific burnup and cooling time combinations in a regionalized loading pattern shown in Figure 2.III.1 are not necessary.~~

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 ~~either the same or bounded by those~~ presented ~~in FSAR Section 11.1. Some additional discussions are provided~~ 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 ~~shown to be bounded by the temperature~~ reported in Section 4.III.4~~6~~. 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. ~~FSAR Section 11.1.2 is applicable~~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 ~~the thermal consequences of the~~under bounding (steady state) conditions, ~~partial blockage of air inlets~~all system components are ~~bounded~~ below~~by~~ the off-normal ~~same analysis presented in Section 4.6~~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 ~~bounded~~ similar to~~by~~ 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. ~~It is concluded in the Supplement Section 4.III.6 that the thermal consequences of fire accident are bounded by those presented in the FSAR Section 4.6. Therefore, FSAR Section 11.2 is applicable~~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. ~~It is concluded in the Supplement Section 4.III.6 that t~~The thermal consequences of 100% blockage of air inlets are ~~bounded by those~~ presented in the ~~FSAR~~ Supplement Section 4.III.6. ~~Therefore,~~ All the component temperatures and MPC cavity pressure are below their respective accident temperature and pressure

limits. 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. It is concluded in the Supplement Section 4.III.6 that tThe thermal consequences of burial under debris are bounded by those presented in the FSAR Supplement Section 4.III.6. Therefore, 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

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

This accident condition is the same as that defined in Sub-section 11.2.15. It is concluded in the Supplement Section 4.III.6 that tThe thermal consequences of extreme environmental temperature are bounded by those presented in the FSAR Supplement Section 4.III.6. Therefore, 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.

Based on above discussions it can be concluded the consequences of the off-normal and postulated accident conditions are basically the same or bounded by those presented the FSAR Chapter 11.

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.