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HOLTEC INTERNATIONAL

Holtec Center, 555 Lincoln Drive West, Marlton, NJ 08053
Telephone (609) 797-0900
Fax (609) 797-0909

July 2, 1999

Mr. Mark S. Delligatti
Senior Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Reference: Holtec Project 70651
Private Fuel Storage L.L.C. P.O. #3
PFS Docket No. 72-22

Dear Mr. Delligatti:

Attached to this letter, please find an insolation sensitivity study of the HI-STORM EHT thermal model for PFS. We trust that the above information fulfills the verbal commitment made by us in an earlier telecon.

Sincerely,

Indresh Rampall

Indresh Rampall, Ph.D.
Principal Engineer

Evan Rosenbaum
Technical Concurrence

K. P. Singh
Approval

cc: Dr. Max DeLong. Northern States Power
Mr. John Donnell (Stone & Webster)
Document I.D.: 7065112

ATTACHMENT A TO HOLTEC

LETTER NO 7065112

HI-STORM EHT THERMAL MODEL SENSITIVITY STUDY

[Number of pages = 8 & Appendix A (2 pages)]

1.0 SCOPE

The extended HI-STORM thermal model (EHT) presented in the reference [1] considered the effect of insolation on the ISFSI concrete pad using the provisions of 10CFR71. In this Attachment, results of additional sensitivity analyses to study the effect of insolation on the thermal performance of HI-STORM 100 are presented. In addition, the results of the sensitivity study are evaluated for physical plausibility. In other words, a trending assessment is performed using both sensitivity data and physical reasoning to verify that the results are consistent with the expected thermal behavior of the system.

2.0 PROBLEM DESCRIPTION

The analysis presented in reference [1] evaluates the thermal performance of a HI-STORM 100 System arrayed in a grid pattern. The thermal model considers one typical cask in the array for analysis. Based on physical reasoning and cask array symmetry considerations, a hypothetical shell is built around this typical cask. The inside surface of this hypothetical shell is a reflecting boundary which simulates the radiant energy input from surrounding casks to the typical cask under consideration. The hypothetical cylinder is also assumed to be impervious to air flow. Thus, the ambient air cannot access the overpack inlet ducts except by travelling down the annulus formed by the HI-STORM overpack and the hypothetical cylinder (HC). This is quite clearly a most conservative mathematical construct for the physical problem. Another conservatism is introduced in the model by the selection of the inside diameter of the HC. As explained in [1], the diameter of the HC is calculated by determining the equivalent cylindrical shell which has the same area as the tributary area of the cask pad attributable to each overpack. Strictly speaking, the diameter of the HC should be computed using the equivalence in hydraulic diameters. This calculation, performed below, shows that a much larger flow annulus (than that based on the tributary area basis) will be applicable. For conservatism, we use the smaller HC diameter in the thermal model.

HC based on tributary area (A_o) of cask array

$$HC = \sqrt{\frac{A_o}{(\pi/4)}} = \sqrt{\frac{346\ ft^2}{(\pi/4)}} = 21\ ft$$

HC based on hydraulic diameter of cask array

HI-STORM overpack diameter (d)	= 11.04 ft
Cask array square pitch (p)	= 18.6 ft
Flow area per cask	= $p^2 - (\pi/4)d^2$
	= 250.2 ft^2
Wetted perimeter (W_p)	= πd
	= 34.7 ft

$$Hydraulic = diameter\ (D_h) = 4 \times \frac{Flow\ Area}{Wetted\ Perimeter} \times \frac{250.2}{34.7} = 28.9\ ft$$

Therefore, HC diameter	= $d + D_h$
	= 11.04 + 28.9 = 39.94 ft
HC diameter (used in analysis)	= min. of (21 ft, 39.94 ft)
	= 21 ft

The sensitivity study summarized in this appendix considers the effect of two parameters, namely, the insolation heat flux Q and *cask pad* view factor, F. In the HI-STORM 100 analyses [1, 2], Q is equal to the 12-hour solar flux set forth in 10CFR71 averaged over a 24-hour period to account for heating during daytime and cooling during nighttime (labeled as "100% insolation"). In the present study, the HI-STORM 100 thermal calculations are performed under an overly conservative 24 hours sunshine assumption. Thus, effectively, the heat received by the HI-STORM modules over a 24-hour period is twice the Part 71 stipulated 12-hour solar heating and is labeled as "200% insolation".

Consistent with the EHT model assumptions for solar heating, the annular cask pad is considered to receive full insolation which would be obtained when a cask is alone (isolated) on a pad. This assumption is used in the sensitivity study involving the Q parameter. In a cask array, it is recognized that the pad does not have 100% radiation view factor owing to partial blockage by the upright overpacks. The view factor, F, as determined by rigorous calculations presented in the next section, is quite small (less than 10%). Therefore, sensitivity calculations involving the F parameter are performed by setting F equal to a reasonably conservative value of 0.1.

The details of the thermal modeling are described in the HI-STORM 100 TSAR [2] and, therefore, are not discussed here. A listing of thermal analysis cases under the above mentioned scenarios are provided below:

Scenario (I) 100% insolation, 100% pad view factor

Case A Off-normal ambient (100°F)

Case B Extreme hot ambient (125°F)

Scenario (II) 200% insolation, 100% pad view factor

Case A_q Off-normal ambient (100°F)

Case B_q Extreme hot ambient (125°F)

Scenario (III) 200% insolation, realistic pad view factor

Case A_f Off-normal ambient (100°F)

Case B_f Extreme hot ambient (125°F)

Cases A and B are reported in reference [1] for off-normal and extreme hot temperatures. Corresponding Q sensitivity run cases A_q & B_q and F sensitivity run cases A_f & B_f are reported herein. The PFS thermal analysis calculation package [1] is being updated to include the analysis of the four additional cases for archival reference purposes.

3.0 CALCULATION OF PAD VIEW FACTOR

As discussed in reference [1], a conservatively postulated HI-STORM cask configuration (EHT model) is developed for thermal analysis. The geometry of this configuration consists of two co-axially aligned cylinders having air filling the annular space. The annulus is open at the top to admit ambient air and closed at the bottom. The inner cylinder represents the HI-STORM overpack, the outer cylinder represents the hypothetical cylinder and the closed bottom represents the concrete pad. These surfaces are labeled as 1, 2 and 3, respectively.

The EHT model geometry is completely specified by three parameters a, b, and c, representing the HI-STORM overpack diameter, hypothetical cylinder diameter, and height of the overpack, respectively. Rohsenow and Hartnett [3] report mathematical formulas for computing view factors from surface 1 to surface 2 (F_{12}), surface 1 to itself (F_{11}) and surface 1 to surface 3 (F_{13}). Using these formulas and additional rules governing the transformation of view factors, namely, the reciprocity rule ($A_iF_{ij} = A_j F_{ji}$) and unity rule ($\sum_j F_{ij} = 1$), the view factor between surface 3 and the open top is readily obtained. These calculations are provided in Appendix A to this attachment. The pad-to-ambient view factor (F) is computed as 0.083. This view factor is conservatively rounded to 0.1 and used in computing the insolation heating of the pad for cases A_f and B_f defined earlier. Consistent with the HI-STORM thermal model discussed in [1], the insolation energy (Q_2) absorbed by the concrete pad is modeled as a volumetric heat source term in a two-inch layer of concrete pad. The numerical value is computed as follows:

$$Q_2 = a_R\ F\ [(24\,\text{hr}/24\,\text{hr}) * 774\ \text{W/m}^2]/(0.051\,\text{m})$$

where: a_R = solar absorbtivity (conservatively assumed to be unity)

F = annulus bottom-to-ambient view factor

thus: Q_2 = 1518 W/m^3 (for F = 0.1).

= 15,176 W/m^3 (for F = 1).

The insolation energy absorbed by the HI-STORM overpack enclosure shell (Q_1) and overpack top lid (Q_3) is obtained as described in reference [1] for a 24-hour sunshine assumption below:

$$Q_1 = 1*[1 - 0.818]*[(24\ \text{hr}/24\ \text{hr})*387\ \text{W/m}^2]/0.0191\ \text{m}$$
$$= 3688\ \text{W/m}^3$$

$$Q_3 = 1*1*[(24\ \text{hr}/24\ \text{hr})*774\ \text{W/m}^2]/0.101\ \text{m}$$
$$= 7663\ \text{W/m}^3$$

4.0 RESULTS

All three scenarios listed in Section 2.0 have been analyzed using the insolation parameters computed herein and the HI-STORM EHT model [1]. The results of the thermal model sensitivity analysis are tabulated in Table A. Within each scenario, the EHT model sensitivity to the ambient temperature parameter is also analyzed. A discussion of these results are discussed next.

In each scenario, steady state HI-STORM thermal response to off-normal (100°F) and extreme ambient (125°F) temperatures is analyzed. In Table A, maximum temperatures of key HI-STORM components, cooling ducts flow rates and velocities are reported. The ambient temperature change (Δ_a) from off-normal to extreme ambient temperature is 25°F. Examining the fuel cladding, MPC shell and overpack inner shell results, the temperature changes (Δ_c) for these components in Scenario I are 19°F, 27°F and 30°F respectively. The magnitude of HI-STORM system temperatures changes and ambient temperature parameter changes are on the same order. Nevertheless, residual second order differences in the numerical magnitude of the changes remain. These second order differences are readily quantified by defining a sensitivity parameter δ as the difference between Δ_c and Δ_a. A response which lags ambient temperature change is indicated by a δ with a negative sign. A positive δ indicates a response which leads ambient temperature change.

The δ for the fuel cladding, MPC shell and overpack inner shell is -6°F, 2°F and 5°F respectively for Scenario I (The δ for other two scenarios are similar). The fuel cladding temperature lag is a consequence of enhanced radiation heat transfer in the basket at higher temperatures. The positive overpack inner shell temperature sensitivity is as a consequence of two factors: (i) enhanced radiation heating of the inner shell by the MPC shell and (ii) lower annulus convective cooling as a result of reduced air flow rate at higher ambient temperature. The positive MPC shell temperature sensitivity is a result of lower annulus convective cooling at higher ambient temperature.

The maximum cladding, MPC shell and overpack inner shell temperatures for Case B_q under a 24 hour sunshine assumption with no credit for insolation blocking by surrounding casks are reported as 790°F, 360°F and 258°F respectively. The corresponding short term limits [1] are 1058°F, 775°F and 350°F respectively. The overly conservative features of the model are readily discernible from the results which show a 23°F heating of the ambient air before it enters the inlet ducts. Substantial margins of safety for cladding and confinement integrity and radiation shielding effectiveness are demonstrated under these physically implausible conditions. In Scenario III, additional cases are analyzed using a modestly conservative pad view factor to account for the presence of surrounding casks. The ambient air temperature rise reported in Table A is 7°F. The temperature rise under a Part 71 solar heating assumption (i.e. 100% Insolation Case) will therefore be even smaller.

A comparison of air flow rates between the Scenario I and Scenario II results show a slight increase in air flow induced by increased pad insolation. Raising the temperature of air entering the inlet ducts is akin to adding heat at the bottom of the annulus. As explained in the HI-STORM TSAR [2], the chimney effect will be enhanced by this heating. Rigorous calculations by FLUENT confirm this result which is deduced from physical reasoning.

5.0 REFERENCES

[1] "HI-STORM Thermal Analysis for PFS RAI", Holtec Report HI-992134, Rev. 0.

[2] "TSAR for the HI-STORM 100 Cask System", Holtec Report HI-951312, Rev. 6.

[3] Rohsenow, W.M. and Hartnett, J.P., "Handbook of Heat Transfer", McGraw Hill, NY(1973).

TABLE A: RESULTS OF SENSITIVITY ANALYSIS

Scenario	(I) 100% Insolation, 100% Pad View Factor		(II) 200% Insolation, 100% Pad View Factor		(III) 200% Insolation, Realistic Pad View Factor	
	Case A	Case B	Case A_q	Case B_q	Case A_f	Case B_f
1. Fuel Cladding (°F)	765	784	772	790	763	781
2. MPC Shell (°F)	324	351	334	360	320	346
3. Overpack Inner Shell (°F)	213	243	230	258	214	241
4. Ducts Inlet (°F)	114	139	123	148	107	132
5. Inlet Flow (10^3 lb/hr)	2.32	2.17	2.36	2.23	2.27	2.14
6. Inlet Velocity (ft/s)	0.32	0.31	0.33	0.32	0.31	0.31
7. Ducts Outlet (°F)	221	248	238	264	222	248
8. Outlet Flow (10^3 lb/hr)	2.32	2.17	2.36	2.22	2.27	2.14
9. Outlet Velocity (ft/s)	0.64	0.62	0.66	0.65	0.63	0.62

APPENDIX A: HI-STORM PAD TO AMBIENT VIEW FACTOR CALCULATIONS

$a := 5.52$ **HI-STORM Overpack Outside Radius (ft)**

$b := 10.50$ **Hypothetical Cylinder Radius (ft)**

$c := 19.27$ **HI-STORM Overpack Height (ft)**

Define Parameters & Compute View Factors

$$X := \frac{b}{a} \qquad Y := \frac{c}{a} \qquad A := Y^2 + X^2 - 1 \qquad B := Y^2 - X^2 + 1$$

$$F12 := \frac{1}{X} - \frac{1}{\pi \cdot X} \cdot \left[\operatorname{acos}\left(\frac{B}{A}\right) - \frac{1}{2 \cdot Y} \cdot \left[\left[(A+2)^2 - 4 \cdot X^2 \right]^{0.5} \cdot \operatorname{acos}\left(\frac{B}{X \cdot A}\right) + B \cdot \operatorname{asin}\left(\frac{1}{X}\right) - \pi \cdot \frac{A}{2} \right] \right]$$

$F12 = 0.43$ **Outer Cylinder to Inner Cylinder View Factor**

$F21 := F12 \cdot \frac{b}{a}$ **Inner Cylinder to Outer Cylinder View Factor (Reciprocity Relationship)**

$F21 = 0.818$

$$F11 := 1 - \frac{1}{X} + \frac{2}{\pi \cdot X} \cdot \operatorname{atan}\left[2 \cdot \frac{\left(X^2 - 1\right)^{0.5}}{Y} \right] - \frac{Y}{2 \cdot \pi \cdot X} \cdot \left[\frac{\left(4 \cdot X^2 + Y^2\right)^{0.5}}{Y} \cdot \operatorname{asin}\left[\frac{\left[4 \cdot \left(X^2 - 1\right) + \frac{Y^2}{X^2} \cdot \left(X^2 - 2\right) \right]}{Y^2 + 4 \cdot \left(X^2 - 1\right)} \right] \right]$$

$$F11 := F11 + \frac{Y}{2 \cdot \pi \cdot X} \cdot \left[\operatorname{asin}\left[\frac{\left(X^2 - 2\right)}{X^2} \right] - \frac{\pi}{2} \cdot \left[\frac{\left(4 \cdot X^2 + Y^2\right)^{0.5}}{Y} - 1 \right] \right]$$

$F11 = 0.303$ **Outer Cylinder Self-View Factor**

$F13 := \frac{1}{2} \cdot (1 - F12 - F11)$ **Outer Cylinder to Annulus Bottom View Factor**

$F13 = 0.133$

$F23 := \frac{1}{2} \cdot (1 - F21)$ **Inner Cylinder to Annulus Bottom View Factor**

$F23 = 0.091$

Compute Outer, Inner & Annulus Bottom Areas

$A1 := 2 \cdot \pi \cdot b \cdot c$ $A1 = 1.271 \cdot 10^3$

$A2 := 2 \cdot \pi \cdot a \cdot c$ $A2 = 668.345$

$A3 := \pi \cdot \left(b^2 - a^2\right)$ $A3 = 250.635$

$F31 := \frac{A1}{A3} \cdot F13$ $F31 = 0.675$ **Annulus Bottom to Outer Cylinder View Factor**

$F32 := \frac{A2}{A3} \cdot F23$ $F32 = 0.242$ **Annulus Bottom to Inner Cylinder View Factor**

$F3e := 1 - F31 - F32$ $F3e = 0.083$ **Annulus Bottom to Ambient View Factor**