RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

07/08/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 223-1996 REVISION 0**
SRP SECTION:	**03.08.01 – Concrete Containment**
APPLICATION SECTION:	**3.8.1**
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QUESTION NO. 03.08.01-07:

In DCD Subsection 3.8.1.4.1.2, the first paragraph (Page 3.8-10) states "The average and equivalent linear gradients considering thermal stress of the liner plate are applied to the FE model of the PCCV."

The applicant is requested to provide the following information:

a) Explain the meaning of "the average and equivalent linear gradients considering thermal stress".
b) Provide the thermal gradients across the thickness of the PCCV cylindrical walls, the basemat, and the dome that were used for the design, and describe how these thermal gradients were obtained.

ANSWER:

This answer replaces the previous MHI answers that were transmitted by letter UAP-HF-09161 (ML091060749) dated April 14, 2009 and letter UAP-HF-10033 (ML100430768) dated February 4, 2010.

The previous answers were based on the methodology and analyses completed by Mitsubishi Heavy Industries (MHI) at that time. This response supersedes all prior responses and is based on the current methodology and completed analyses.

The sentence in question should read, "The average *temperature distribution* and equivalent linear gradients considering thermal stress of the liner plate are applied to the FE model of the PCCV." This is explained below.

The current methodology is based on American Concrete Institute (ACI) 349-06 Appendix E. The detailed methodology and corresponding results are presented below:

a) Methodology regarding the average temperature distribution and equivalent linear thermal gradients.

   The equivalent linear temperature distribution is idealized for analysis purposes from the true non-linear variation of temperature across the section thickness.

The thermal profile through the prestressed concrete containment vessel (PCCV) concrete dome, wall, and basemat is a function of environmental (air) temperature on both the inside and outside concrete surfaces and the thermal resistance of the concrete. This is expressed through the following equation:

$$qk = -kA\ dT/dx$$

where: qk = rate of heat flow by conduction

k = material thermal conductivity

A = section area perpendicular to the direction of heat flow

dT/dx = temperature gradient through the section

During normal operation, over an extended period of time, a steady-state condition is established, where qk, k, and A become constant and the thermal gradient simply becomes the difference between the inside and outside temperature divided by the thickness of the concrete section. This gradient is the cause of the thermal moment used to establish thermal effects (T_o) required by American Society of Mechanical Engineers (ASME) Section CC-3221.1.

The thermal accident (T_a) condition of ASME Section CC-3222.3 is created by a transient Design Basis Accident (DBA) -Loss of Coolant Accident (LOCA). The design condition assumes that after the previously described steady-state condition has been established through the PCCV structure, the inside environmental temperature is instantaneously increased to the accident temperature. The analysis to determine the resulting through-wall temperature profiles for the dome, cylindrical shell, and basemat, as a function of time and distance (dx/dT), is provided below.

$$T_m = \frac{\int_{-d/2}^{d/2} [T_{NL}]dy}{d}$$

The thermal (i.e., temperature) distribution is calculated using a numerical evaluation technique that incorporates the initial temperatures at each face of the concrete section, thermal properties of concrete, and section geometry. Values of temperature are evaluated at multiple points, equally spaced through the wall thickness, at each time step (Δt). The equation used in this numerical evaluation technique is:

$$T_{t,i}=T_{t-1,i}+C'\Delta t\ (T_{t-1,i-1}+T_{t-1,i+1}-2T_{t-1,i})$$

Where: T = Temperature (°F)

$\Delta t = t_i - t_{i-1}$

The subscript *i* indicates the step number with regard to distance and the subscript *t* indicates the step with regard to time. The variable C' is 'defined as:

$$C'=\alpha/(\ \Delta d^2)$$

Where: $\alpha = k/(Cp \cdot \rho) = 0.025\ ft^2/hour$

Cp = 0.21 Btu/lb·°F (Specific heat for concrete)

$\rho = 150\ lb/ft^3$ (Unit weight of concrete)

$k = 0.8$ Btu/ft·h·°F (Thermal conductivity of concrete)

$\Delta d = d_i - d_{i-1}$ (Section thickness increment)

After the temperature distribution is established using the methodology described above, per ACI 349-06 Appendix E, the mean temperature distribution (T_m) is calculated by summing the area between the curve and the horizontal axis over the thickness of the wall, and dividing by the thickness.

$$T_m = \frac{\int_{-d/2}^{d/2} [T_{NL}] dy}{d}$$

where: T_{NL} is Non-Linear Temperature Distribution

d is section thickness

And the thermal gradient (ΔT) of the equivalent linear temperature distribution is calculated by :

$$\Delta T = \left(\frac{12}{d^2}\right) \int_{-d/2}^{d/2} T_{NL}\, y\, dy$$

The calculated mean temperature distribution (T_m) and equivalent linear thermal gradient (ΔT) are then used as thermal inputs for the FE model of the PCCV.

b) A summary of mean temperature and equivalent linear gradients are presented in Tables 1 through 6.

Table 1 PCCV Dome Thermal Input at Normal Operating Condition

Season	Area	Surface Temperature, °F			Wall Thickness, in.	Temperature Gradient, °F/in.
		Inside	Outside	Mean Temp.		
Winter	Outside Air	105	-40	32.5	44	3.3
Summer	Outside Air	120	115	117.5	44	0.1

Table 2 PCCV Cylindrical Wall Thermal Input at Normal Operating Condition

Season	Area	Surface Temperature, °F			Wall Thickness, in.	Temperature Gradient, °F/in.
		Inside	Outside	Mean Temp.		
Winter	Outside Air	105	-40	32.5	52	2.8
	Reactor Building Atmosphere	105	50	77.5	52	1.1
	Soil	105	35	67.5	52	1.3
Summer	Outside Air	120	115	117.5	52	0.1
	Reactor Building Atmosphere	120	105	112.5	52	0.3
	Soil	120	80	100	52	0.8

Table 3 PCCV Basemat Thermal Input at Normal Operating Condition

Season	Area		Thickness (in.)	Surface Temperature (°F) Inside (upper)	Surface Temperature (°F) Outside (lower)	Mean	Temperature Gradient (°F/in.)
Winter	Basemat	Reactor Cavity	373	105	0	52.5	0.282
		Below CIS - Surrounding Reactor Cavity	507	105	0	52.5	0.207
		Outside PCCV Wall	507	50	0	25.0	0.099
		Under R/B (basemat)	160	50	0	25.0	0.312
	PCCV Wall		52	105	50	77.5	1.058
	RB Atmosphere		-	50			-
	CIS Atmosphere		-	105			-
	Soil		-	0			-
Summer	Basemat	Reactor Cavity	373	120	55	87.5	0.174
		Below CIS - Surrounding Reactor Cavity	507	120	55	87.5	0.128
		Outside PCCV Wall	507	105	55	80.0	0.099
		Under R/B (basemat)	160	105	55	80.0	0.312
	PCCV Wall		52	120	50	85.0	1.346
	RB Atmosphere		-	105			-
	CIS Atmosphere		-	120			-
	Soil		-	55			-

Table 4 PCCV Dome Thermal Input at DBA-LOCA Condition

Season	Area	Section Thickness	Original Input: Inside Surface Temperature	Original Input: Outside Surface Temperature	Mean Temperature @ 4 days	Temperature Gradient @ 1 day	Linearized Result: Inside Surface Temperature	Linearized Result: Outside Surface Temperature
		(in.)	(°F)	(°F)	(°F)	(°F/in.)	(°F)	(°F)
Winter	Outside Air	44	300	-40	89.2	7.3	249.8	-71.4
Summer	Outside Air		300	115	167.8	3.8	251.4	84.2

Table 5 PCCV Cylindrical Wall Thermal Input at DBA-LOCA Condition

Season	Area	Section Thickness	Original Input: Inside Surface Temperature	Original Input: Outside Surface Temperature	Mean Temperature @ 4 days	Temperature Gradient @ 1 day	Linearized Result: Inside Surface Temperature	Linearized Result: Outside Surface Temperature
		(in.)	(°F)	(°F)	(°F)	(°F/in.)	(°F)	(°F)
Winter	Outside Air	52	300	-40	84	5.9	237.4	-69.4
	R/B Atmosphere		300	50	129	4.2	238.2	19.8
	Soil		300	35	121.5	4.5	238.5	4.5
Summer	Outside Air		300	115	163.2	3	241.2	85.2
	R/B Atmosphere		300	105	158.2	3.2	241.4	75
	Soil		300	80	145.7	3.7	241.9	49.5

Table 6 PCCV Basemat Thermal Input at DBA-LOCA Condition

Season	Section Description	Section Thickness	Original Input: Inside Surface Temperature	Original Input: Outside Surface Temperature	Mean 30 days	Gradient 30 days	Linearized Result: Inside Surface Temperature	Linearized Result: Outside Surface Temperature
		(in.)	(°F)	(°F)	(°F)	(°F/in.)	(°F)	(°F)
Winter	Reactor Cavity	373	300	55	93.7	0.30	149.7	37.8
	Outside Circumference of CIS Floor	507	300	55	90.2	0.19	138.4	42.0
Summer	Reactor Cavity	373	300	55	98.8	0.31	156.6	41.0
	Outside Circumference of CIS Floor	507	300	55	95.9	0.21	149.1	42.7

Impact on DCD

As shown in Attachment 1, the last sentence in DCD Section 3.8.1.4.1.2 is revised as follows: “This uni-dimensional heat flow is normalized and the average temperature distribution and equivalent linear gradients are created and applied to the FE model of the PCCV.”

Impact on R-COLA

There is no impact on the R-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on the Technical/Topical Report.

This completes MHI’s response to the NRC’s question.

shell and the resulting profiles are calculated in a uni-dimensional heat flow analysis. ~~Temperatures within the concrete wall are calculated in a unidimensional heat flow analysis and the average and equivalent linear gradients considering thermal stress of the liner plate, are applied to the FE model of the PCCV, as during normal operation~~This uni-dimensional heat flow is normalized and the average and equivalent linear gradients are created and applied to the FE model of the PCCV. MIC-03-03-00046 MIC-03-03-00060

temperature distribution

3.8.1.4.1.3 Variation of Physical Material Properties

In the design analysis of the PCCV, the physical properties of materials are based on the values specified in applicable codes and standards. The design analysis takes into account the minimum/maximum values permitted by the codes and standards as appropriate to capture worst case analysis scenarios.

3.8.1.4.2 Design Methods

The design of the PCCV structure is based on the membrane forces, shear forces and bending moments resulting from the loads and load combinations defined in Subsection 3.8.1.3. The membrane forces, shear forces and bending moments in selected sections are obtained from the linear FE analysis~~ performed using the computer program ANSYS. The global analysis considers the major structural configurations, including the PCCV, R/B, and containment internal structure on a common basemat, using solid element modeling and linear material assumptions~~. MIC-03-03-00046

3.8.1.4.2.1 Concrete Cracking Considerations

As discussed in SRP 3.8.1 (Reference 3.8-7) Section II.4.D, concrete cracking can affect the stiffness of the PCCV and cause shifting of the natural frequency, thereby affecting the response/loads used to design the PCCV. Accordingly, the analysis used to calculate the dynamic response of the PCCV resulting from dynamic loads such as earthquake and hydrodynamic loads considers the potential effects of concrete cracking where significant. The addition of stiffness to the concrete sections due to the presence of the liner is not considered in the analysis and design of the PCCV concrete shell. MIC-03-03-00046

The concrete and reinforcement stresses are calculated considering the extent of concrete cracking at these sections. The following are assumptions for calculations:

- The concrete is isotropic and linear elastic but with zero tensile strength
- The thermal forces and moments are reduced according to the concrete cracking depth
- The redistribution of section forces and moments that occurs due to concrete cracking is taken into account

The depths of cracks were determined using an iterative process that initially determines the total load applied to an uncracked section. A crack ~~length~~depth is then postulated on the tensile face, the neutral axis is shifted, and the redistributed forces and moments are recalculated. This process is repeated with the ~~length~~depth of the crack being increased MIC-03-03-00046 MIC-03-03-00057