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July 7, 2009

Subject: AP1000 Response to Request for Additional Information (SRP 6)

Westinghouse is submitting a response to the NRC request for additional information (RAI) on SRP Section 6. This RAI response is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in this response is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Enclosure 1 provides the response for the following RAI(s):

RAI-SRP6.2.2-SRSB-11 R2

Questions or requests for additional information related to the content and preparation of this response should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

Robert Sisk, Manager
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/Enclosure

1. Response to Request for Additional Information on SRP Section 6

D063
NRO

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ENCLOSURE 1

Response to Request for Additional Information on SRP Section 6

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-11
Revision: 2

Question:

Provide responses to the following questions related to APP-PXS-GLR-001, Revision 0, "Impact on AP1000 Post-LCOA Long Term Cooling of Postulated Containment Sump Debris," issued April 28, 2008:

a. In the DEDVI break cases, it is noted that the containment water level exceeds the elevation of the break so that water can flow directly into the reactor pressure vessel bypassing the sump screens. For each of the cases analyzed, including the two sensitivity cases, provide the debris and chemical loading for the water bypassing the sump screens and that taken downstream of the sump screens.

b. Provide the hydraulic head of the IRWST, and the hydraulic head (i.e., water elevation in the containment) over the DVI break location and the recirculation screens with respect to time, the losses in the broken DVI line, and the core inlet resistance for each case analyzed, including the two sensitivity cases.

c. Provide plots of the integrated core boiloff rate and integrated core inlet flow rate for each of the cases analyzed, including the two sensitivity cases.

d. Figure 2-2 indicates the core collapsed level is decreasing. Explain why the level with the unblocked core inlet would decrease while those for the sensitivity cases, Figures 3.1-2 and 3.2-2, decrease for approximately 1500 seconds, then level off for the remainder of the transient. Also explain why the core collapsed liquid levels in the two sensitivity cases are generally higher than the base case.

e. Considering the differences in the core inlet flow rates between the base case and the sensitivity cases as shown by the intact and broken DVI line mixture flow rates (Figures 2-13, 2-14, 3.1-13, 3.1-14, 3.2-13, and 3.2-14), explain why the upper plenum collapsed liquid levels remain almost the same between the base and sensitivity cases (Figures 2-8, 3.1-8 and 3.2-8).

f. Discuss the local heatup effects due to capture of the debris and potential precipitates on fuel rods within the spacer grids and between the spacer grids. The discussion should also consider maximum pre-existing cladding oxide and crud. Justify the amount of oxide and crud assumed for the analysis.

g. On page 1 of APP-PXS-GLR-001, the staff notes that credit is taken for cooling the core from the bypass flow through the broken DVI line from the containment to the downcomer. In DCD Section 15.6.5.4B.3.1, on page 15.6-39, Westinghouse stated that a venturi was inline to limit the flow out the break is located in the DVI line. The bypass flow that flows to the core carries debris through this venturi.

Confirm that the plugging of this venturi has been factored into the cooling flow for the core. If not considered or factored in, please provide an evaluation.

h. In Section 1, "Introduction," Westinghouse provides five reasons or considerations for selecting the DCD long-term cooling case [DVI line break] as the base for the sensitivity study. The first bullet describes the amount of debris bypassing the containment recirculation screens and being transported to the core for cold leg and hot leg breaks. The second bullet describes a DEDVI break in a PXS room would make available only a small portion of the debris that would be available for a loop break. Explain how these two bullets justify the DEDVI break being the limiting break for long-term cooling sensitivity study. Explain why the DEDVI break chosen is the limiting case from a head-loss standpoint for the IRWST screens, recirculation screens and the core. Also explain when the analyses were begun and why debris would not be present prior to the analysis.

Additional Question:

a. The RAI requested the debris and chemical loading for water bypassing the sump screen and Westinghouse's response refers to TR 26, Revision 3, Table 5 for the latent debris. Table 5 does not provide the answer for a.

b. When does the reverse flow into the DVI break line occur? What is the time dependent water level in the containment? How is % bypass factor determined from these flows? What is the % bypass during the transient, not the average integrated bypass, but the time dependent % bypass.

c. Why are the integrated core boiloff for the sensitivity cases (Figures RAI-SRP 6.2.2 – SRSC-11c-5 and -7) lower than that of the DCD base case (Figure RAI-SRP 6.2.2 – SRSC-11c-2) having the same decay heat?

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

a. Technical Report 26 ,APP-GW-GLR-079, Revision 3, "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA", March 2008 provides this information in Table 4 for the latent debris.

The results have been calculated using the minimum post-accident recirculation volume of coolant for the AP1000. Table 4 also lists the chemical precipitants in terms of a mass concentration using the minimum recirculation water volume

Table 4: AP1000 Predicted Chemical Precipitate Formation

Precipitants	kg	lb	ppm
$NaAlSi_3O_8$	1.5	3.3	0.6
AlOOH	19.7	43.4	8.3
$Ca_3(PO_4)_2$	0.5	1.1	0.2

b. The hydraulic head of the IRWST, expressed as its liquid level elevation inside the containment during the IRWST injection phase, and the liquid level in containment during the recirculation phase are as follows in the DCD Revision 17 Chapter 15.6.5.4C DEDVI break analysis. The same values apply to containment debris sensitivity cases one and two analyzed using the WCOBRA/TRAC AP1000 long-term cooling methodology.

IRWST hydraulic head, then containment hydraulic head		DEDVI LOCA, long-term cooling		
Transient Time (time after break occurs) (sec)	Analysis Time (WC/T time) (sec)	IRWST level: then Sump Level during Recirculation (ft)	Level relative to IRWST injection line location, @ 97.0 ft (ft)	
3000.00	500.00	125.96	28.96	
5232.53	2732.53	117.81	20.81	
6486.28	3986.28	113.79	16.79	
7390.81	4890.81	111.16	14.16	
7820.00	5320.00	110.00	13.00	
9098.65	6598.65	110.00	13.00	
9300.00	6800.00	110.00	13.00	← Sump injection switchover time
9400.24	6900.24	106.86	9.86	For restart run
9450.47	6950.47	106.93	9.93	
9701.15	7201.15	107.80	10.80	
10654.80	8154.80	107.80	10.80	
11257.40	8757.40	107.80	10.80	
12666.80	10166.80	107.80	10.80	
14377.50	11877.50	107.80	10.80	

At the initiation of switchover, a reduced value of the level is assumed for recirculation to accommodate any dynamic effects from the draining the IRWST into the sump that might slightly affect the static head available for flow into the reactor vessel. The equilibrium containment floodup level of 107.80 ft. is established over the recirculation screens that feed the intact DVI line once 400 seconds have elapsed in the WCOBRA/TRAC restart problem, and this value is maintained thereafter. The 400 second time frame is the period between 'Sump injection switchover time (6800.00 sec)' and '7201.15 sec' in the analysis time (WC/T time column).

The hydraulic head of the IRWST, expressed as its liquid level elevation inside the containment during the IRWST injection phase, and the liquid level in containment during the recirculation phase are as follows in the containment debris sensitivity case three analyzed using the WCOBRA/TRAC AP1000 long-term cooling methodology. The slower drain rate of the IRWST due to the postulated screen and core entrance blockage resistance is reflected in these values.

IRWST hydraulic head, then				DEDVI LOCA		
containment hydraulic head				long-term cooling		
Analysis Time (WC/Time) (sec)				IRWST level, then Sump Level during Recirculation(ft)	Level relative to IRWST injection line location @ 97.0 ft. (ft)	
0.00				125.96	28.96	
500.00				125.96	28.96	
2732.53				118.34	21.34	
3986.28				114.61	17.61	
4890.81				112.19	15.19	
5320.00				111.13	14.13	
6800.00				110.00	13.00	
7200.00				110.00	13.00	
7300.00				106.86	9.86	
7400.00				107.80	10.80	
8154.80				107.80	10.80	
8757.40				107.80	10.80	
10166.80				107.80	10.80	

At the initiation of switchover, a reduced value of the level is assumed for recirculation to accommodate any dynamic effects from the draining the IRWST into the sump that might slightly affect the static head available for flow into the reactor vessel. The equilibrium containment floodup level of 107.80 ft. is established over the recirculation screens that feed the intact DVI line once 200 seconds have elapsed in the WCOBRA/TRAC restart problem, and this value is maintained thereafter. The 200 second time frame is the period between 'Sump injection switchover time (7200.00 sec)' and '7400 sec' in the analysis time (WC/T analysis time column).

The hydraulic head of water in the PXS room with the broken DVI pipe, expressed as the liquid level elevation inside the containment, is identical to the above table values from 6900.2 seconds onward in WCOBRA/TRAC in Sensitivity Cases 1 and 2 and 7300 seconds onward in Sensitivity Case 3. During the IRWST injection phase of the DEDVI transient, the value is 107.1 ft. from WCOBRA/TRAC analysis time zero until 6598.65 seconds in every case. A value of 106.61 ft. @ 6800 seconds is the sole intermediate input value between the 6598.65 and 6900.24 second points in the DCD Revision 16 Chapter 15.6.5.4C analysis and also in the sensitivity cases 1 and 2.

Consistent with the 107.8 ft. containment floodup level value in the above tables being specified for flow from the IRWST, the design value of hydraulic resistance for the broken DVI line input into WCOBRA/TRAC is increased to include an additional loss coefficient (K-factor) of 1.5 to conservatively represent the exit loss for flow from the severed pipe into the PXS room and the subsequent entrance loss from the room into the pipe segment connected to the DVI nozzle.

In Sensitivity Case 1, the resistance at the core entrance due to postulated blockage equals 2.6*10-6 ft/gpm2; this value is approximately five orders of magnitude greater than the (unblocked) AP1000 core entrance resistance value used in the DCD long-term cooling case. In Sensitivity Case 2, the resistance at the core entrance due to postulated blockage is double that of Sensitivity Case 1, and in Sensitivity Case 3 this resistance is five times that of Sensitivity Case 1.

c. The plots of integrated core boiloff rate and integrated core inlet flow rate are provided for the DCD long-term cooling analysis presented in Chapter 15.6.5.4C for both the IRWST injection and the containment recirculation segments of the DEDVI break transient, and for the three core entrance resistance sensitivity cases for an equivalent length of time during the containment recirculation phase.

   Containment recirculation phase sensitivity cases 1 and 2 are window mode computations that begin at 6500 seconds WCOBRA/TRAC problem time; Sensitivity Case 3 begins at 7200 seconds WCOBRA/TRAC problem time. Each case ultimately reflects the quasi-steady-state containment floodup level. The core inlet flow rate integrals show less liquid enters the core in Sensitivity Case 1 than in the DCD analysis, that less liquid enters the core in Sensitivity Case 2 (a higher resistance sensitivity case) than Sensitivity Case 1, and that less liquid enters the core in Sensitivity Case 3 (the highest resistance sensitivity case) than Sensitivity Case 2. Thus, lower core inlet flow results from the reduced DVI flow rates that are predicted for containment recirculation as a consequence of the postulated sump screen and core inlet blockages.

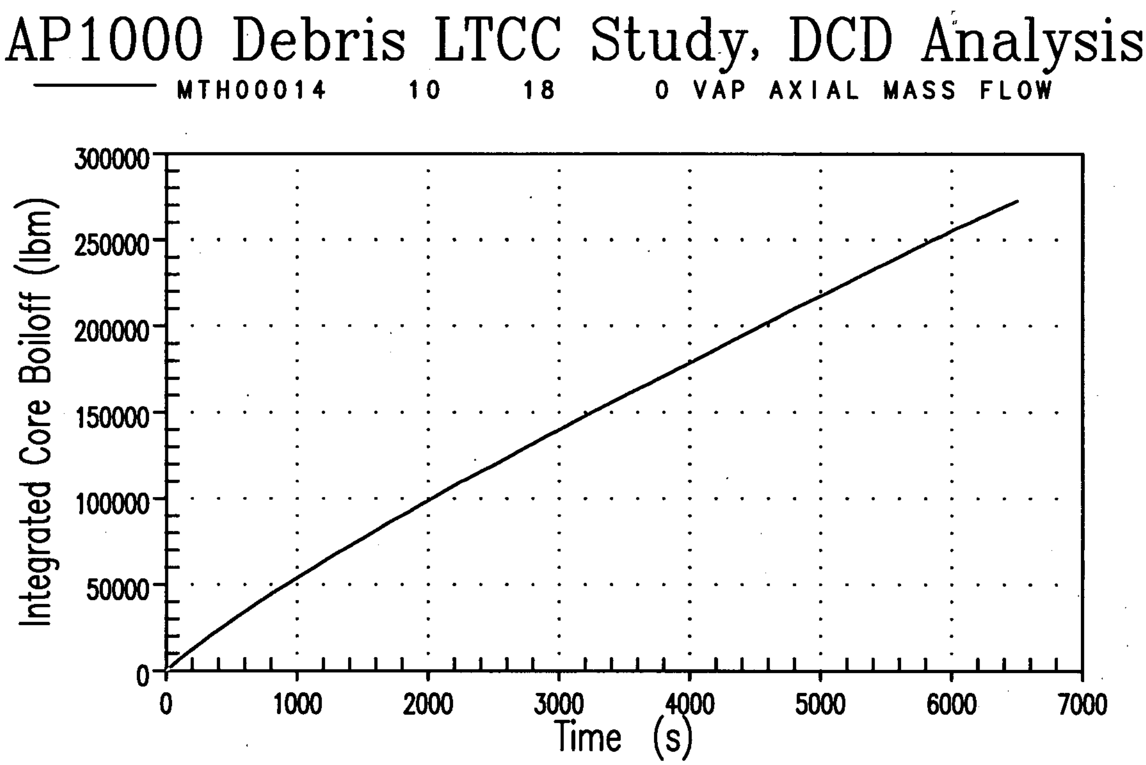

Figure RAI-SRP 6.2.2-SRSB-11c-1: DCD Chapter 15.6.5.4C Analysis Integrated Core Boiloff Rate, IRWST Injection Phase

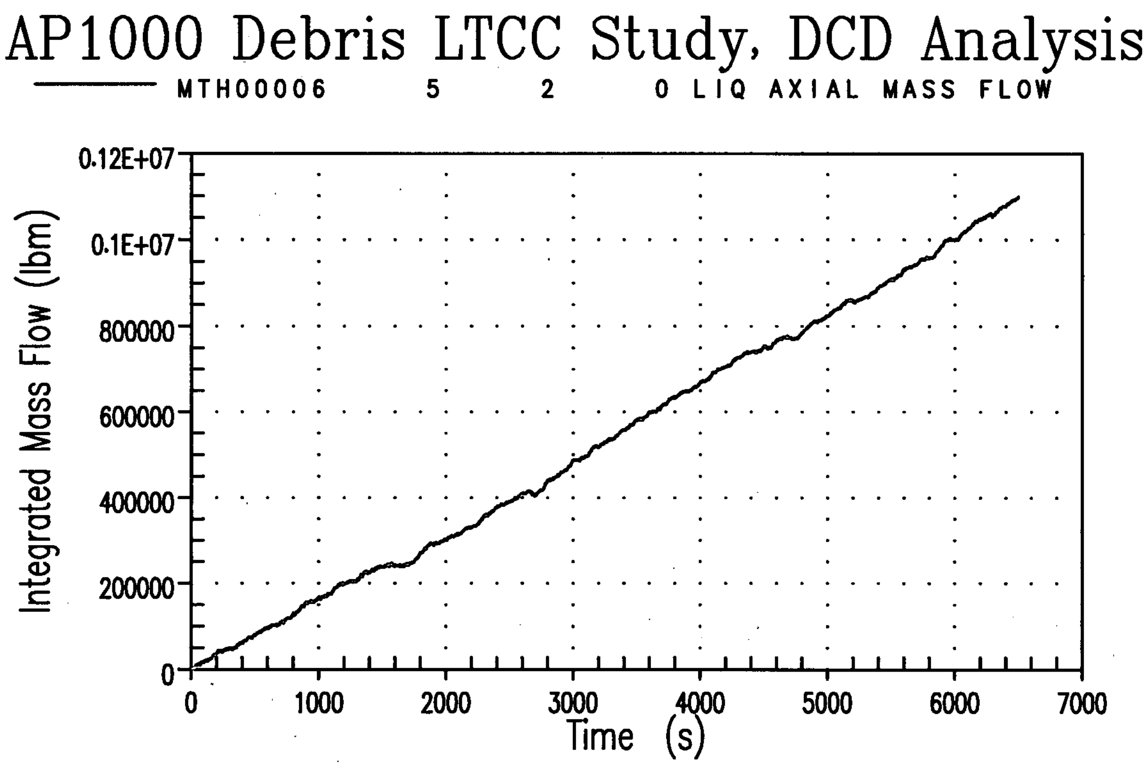

Figure RAI-SRP 6.2.2-SRSB-11c-2: DCD Chapter 15.6.5.4C Analysis Integrated Core Inlet Mass Flow Rate, IRWST Injection Phase

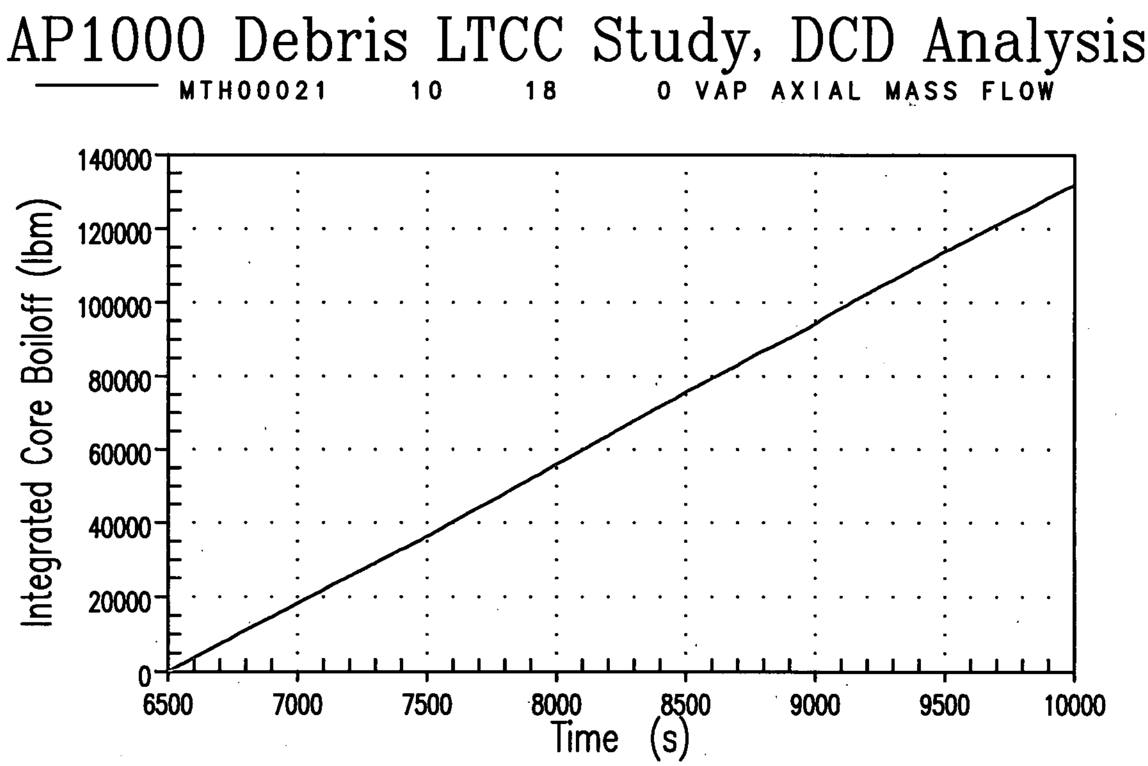

Figure RAI-SRP 6.2.2-SRSB-11c-3: DCD Chapter 15.6.5.4C Analysis Integrated Core Boiloff Rate, Containment Recirculation Phase

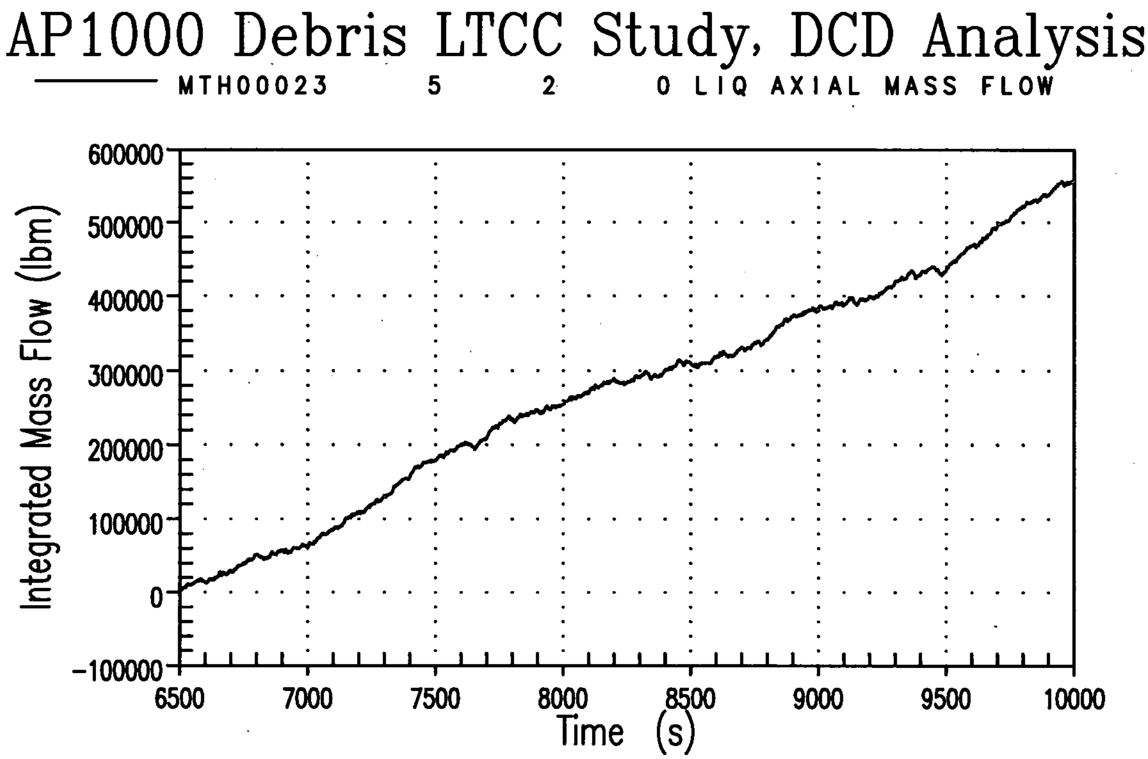

Figure RAI-SRP 6.2.2-SRSB-11c-4: DCD Chapter 15.6.5.4C Analysis Integrated Core Inlet Mass Flow Rate, Containment Recirculation Phase

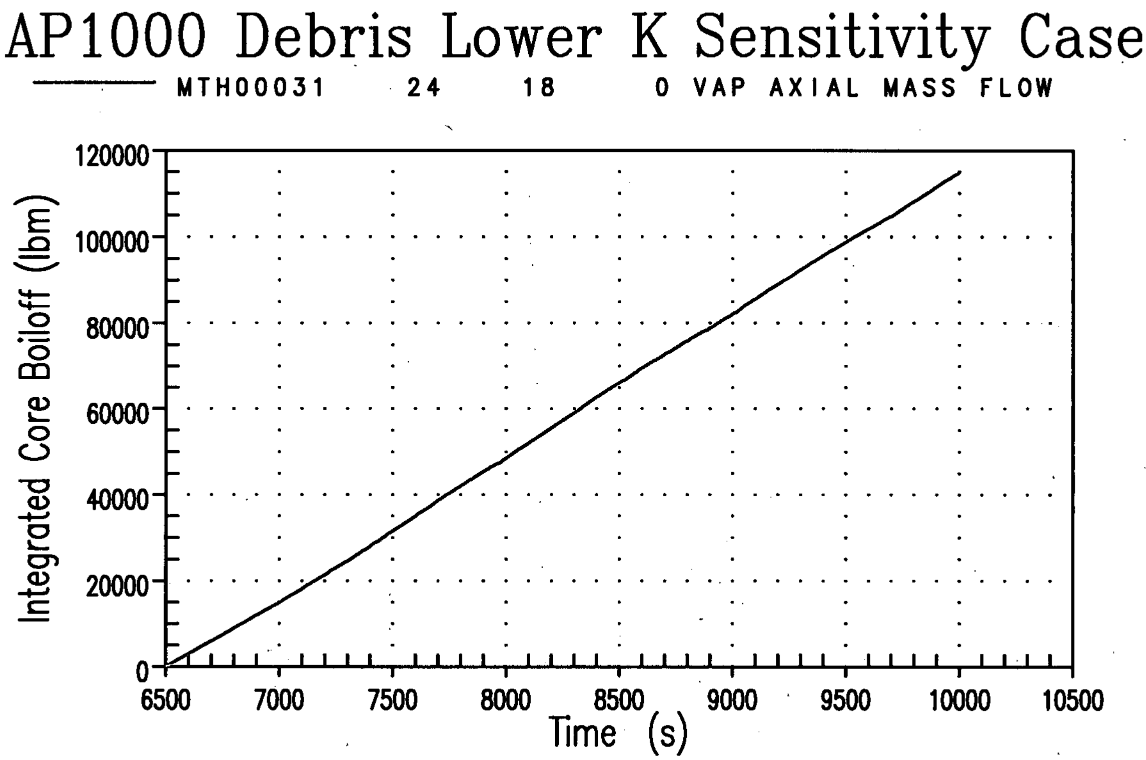

Figure RAI-SRP 6.2.2-SRSB-11c-5: Containment Recirculation Sensitivity Case 1 Integrated Core Boiloff Rate, Containment Recirculation Phase

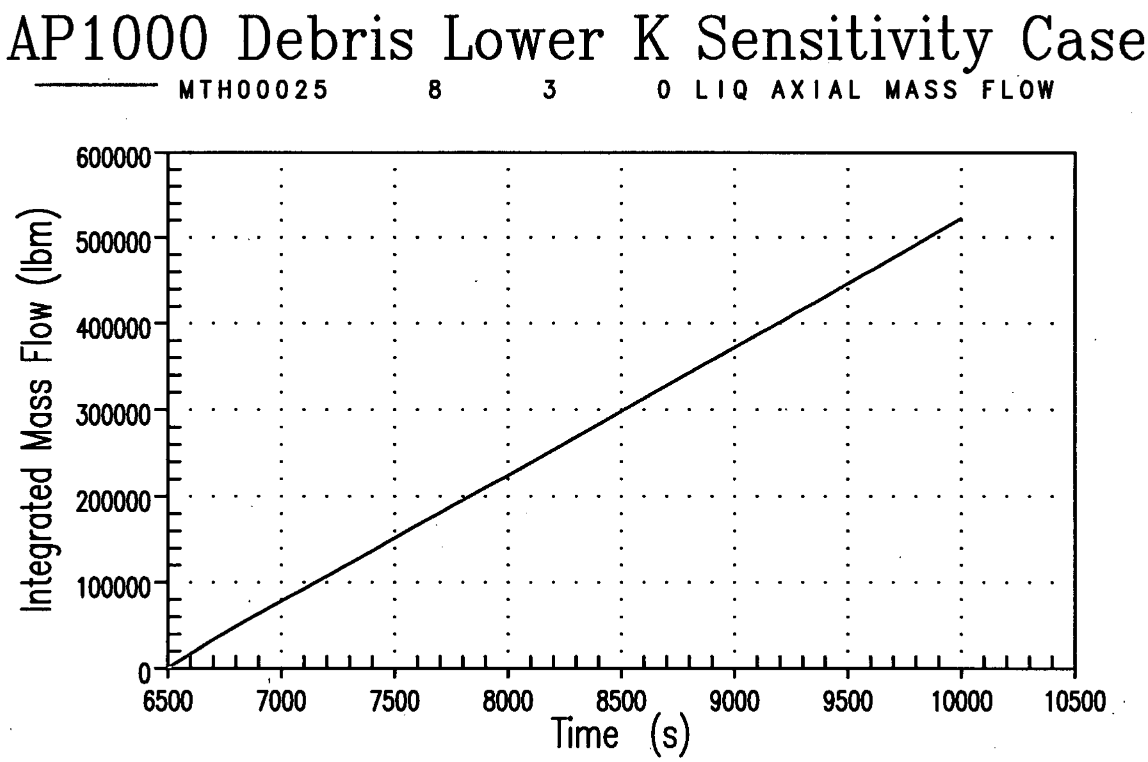

Figure RAI-SRP 6.2.2-SRSB-11c-6: Containment Recirculation Sensitivity Case 1 Integrated Core Inlet Flow Rate, Containment Recirculation Phase

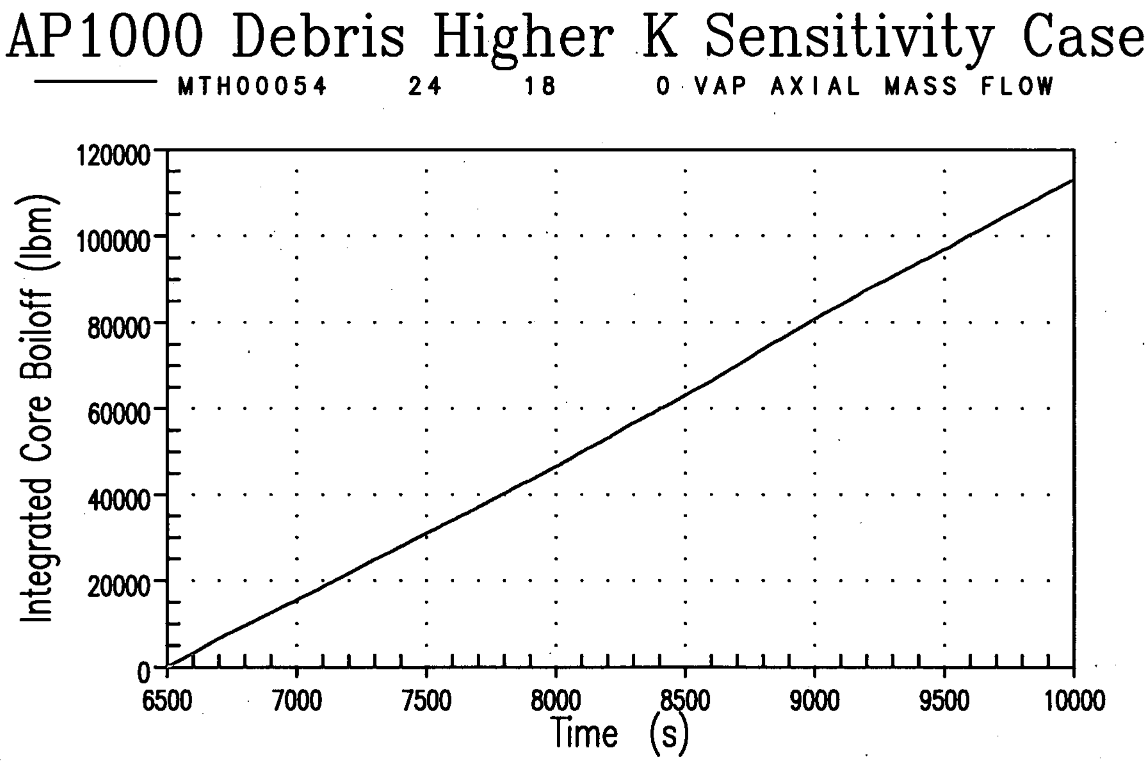

Figure RAI-SRP 6.2.2-SRSB-11c-7: Containment Recirculation Sensitivity Case 2 Integrated Core Boiloff Rate, Containment Recirculation Phase

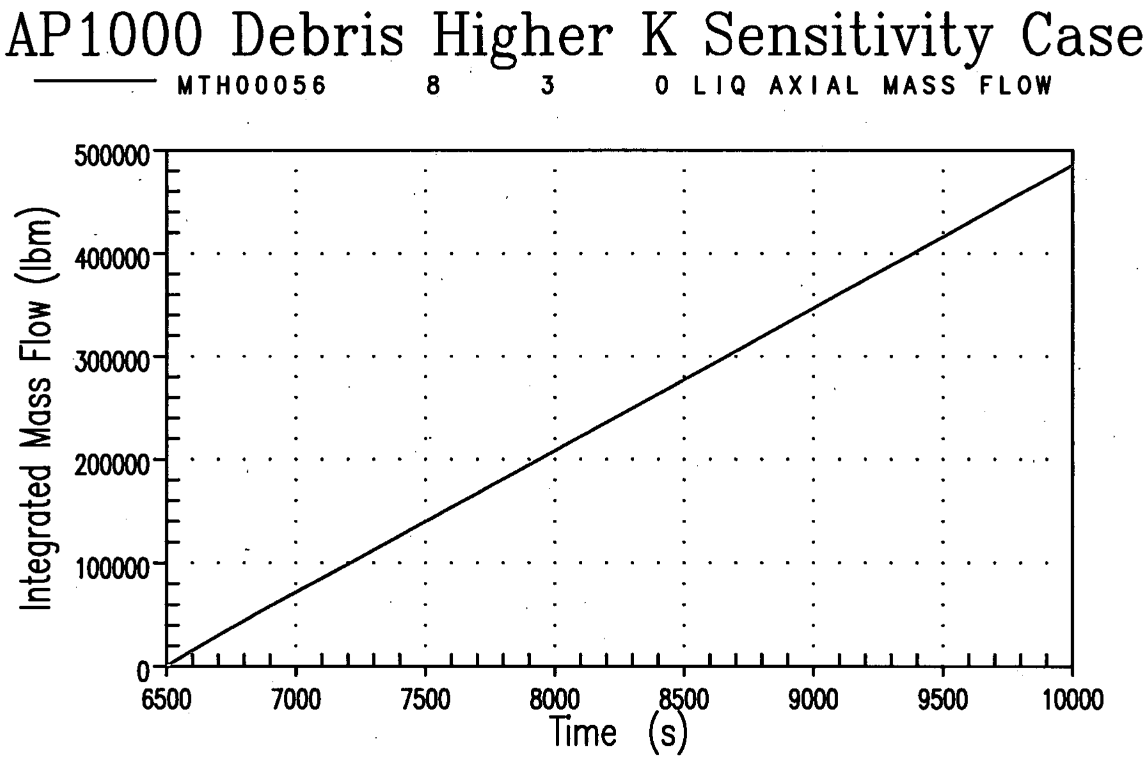

Figure RAI-SRP 6.2.2-SRSB-11c-8: Containment Recirculation Sensitivity Case 2 Integrated Core Inlet Flow Rate, Containment Recirculation Phase

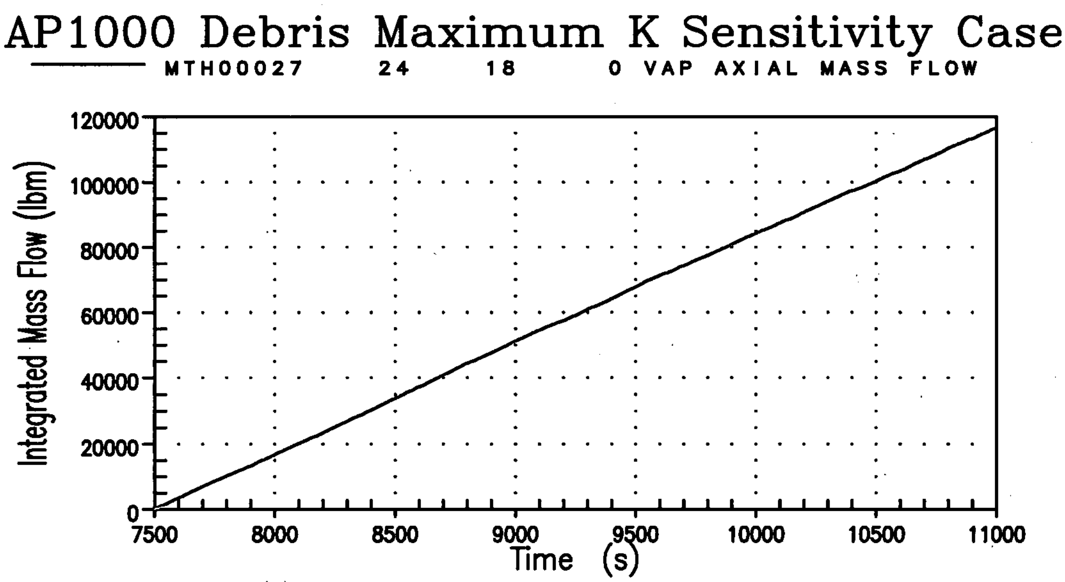

Figure RAI-SRP 6.2.2-SRSB-11c-9: Containment Recirculation Sensitivity Case 3 Integrated Core Boiloff Rate, Containment Recirculation Phase

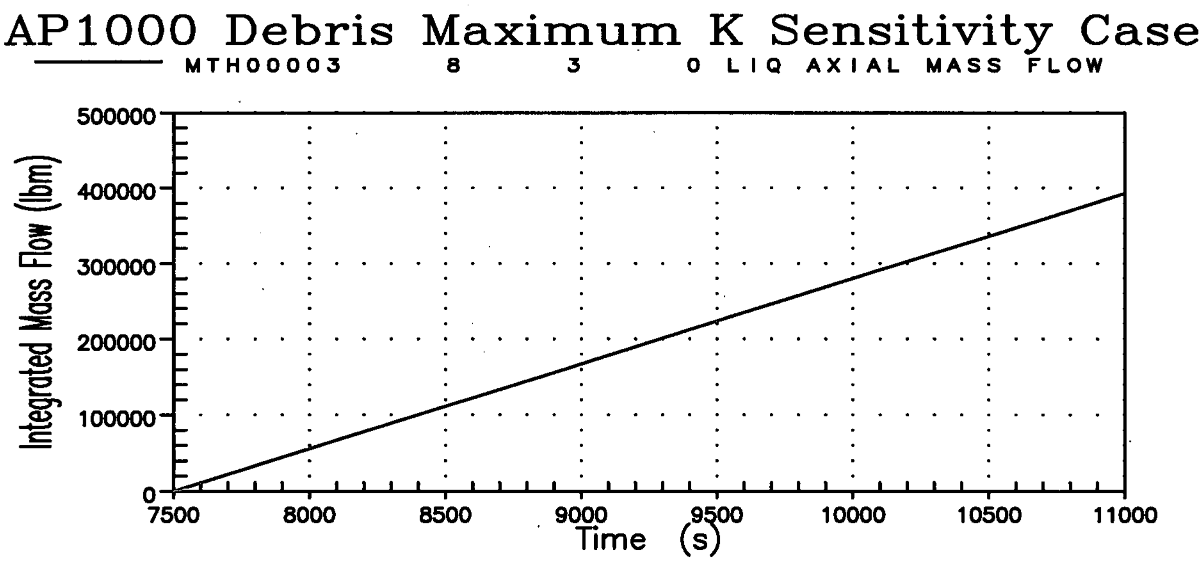

Figure RAI-SRP 6.2.2-SRSB-11c-10: Containment Recirculation Sensitivity Case 3 Integrated Core Inlet Flow Rate, Containment Recirculation Phase

d. The DCD analysis collapsed liquid level in Figure 2-2 is actually essentially constant over the final 1800 seconds of the calculation, as are the corresponding levels in the two sensitivity cases. In both the DCD analysis and the sensitivity cases, the core level decreases at the start of containment recirculation in response to the containment water level boundary condition presented in the part (b) response. Once the containment water level boundary condition becomes constant, the core collapsed liquid level reaches an equilibrium with it.

The long-term cooling behavior within the reactor vessel is a manometric phenomenon in which liquid in the vessel downcomer proceeds into the core on a net flow basis, as shown in the part (c) response. However, on a microscopic time scale, the flow at the core inlet can fluctuate back and forth, reversing direction when the downcomer and core collapsed liquid levels ebb and flow back and forth due to boiling heat transfer effects in the core. In the design basis (DCD) case, with a small resistance at the core inlet, the manometric flow direction can readily change as core boiling continues. However, in the sensitivity cases the core entrance resistance is orders of magnitude higher, making it much more difficult for reversals in flow to occur due to the manometric effects. The core entrance flow is much more stable in the sensitivity cases because the manometer fluctuations between core and downcomer are damped. In sensitivity cases 1 and 2, the core inlet flooding rate decreases only a small amount because the downcomer level in these cases increases to provide the liquid driving head necessary to overcome the increased resistance postulated at the core inlet with little reduction in flow rate. In Sensitivity Case 3 the downcomer is totally filled with liquid, and the core inlet flooding rate decreases more significantly.

The continuous manometric perturbations predicted at the core inlet in the DCD case cause fluctuations in flow within the core which impact its predicted collapsed liquid level. The void fraction in the core is higher in the DCD case due to the impact of the inlet flow fluctuations, so the predicted collapsed liquid level is lower in the DCD case with equivalent decay heat removal.

e. During AP1000 long-term cooling, abundant liquid is continuously available in the reactor vessel during the containment recirculation quasi-steady-state process. With abundant liquid present, the predicted upper plenum collapsed liquid level is not directly related to the core inlet flow rates.

The upper plenum two-phase mixture level is a level swell phenomenon that is a function of the core boiloff flow rate and the interfacial drag prediction. Since the containment recirculation phase decay heat values are the same in all cases, the core boiloff rates are almost the same; therefore, the predicted interfacial drag in the upper plenum is about the same in every case, and the predicted upper plenum void fractions are about the same. The presence of the hot legs establishes the same maximum height of two-phase mixture in the upper plenum for every case. Because the same two-phase mixture level and approximately the same void fraction are present in the upper plenum in each case, it follows directly that the collapsed liquid level values are also approximately the same.

f. Technical Report 26 ,APP-GW-GLR-079, Revision 3, "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA", March 2008 provides this information on pages 22-26. Additional information on head loss across the core due to debris (latent and chemical) is provided in the report (APP-FA01-T2R-001, Revision 0, "Evaluation of Debris Loading Head Loss Tests for AP1000 Simulated Fuel Assembly During Post-Accident Recirculation", August 2008.) that provided the results of testing performed for an AP1000 simulated fuel assembly.

g. The venturi line has a 4 inch inside diameter. It has been included in the plugging effects analysis, and was shown to have no impact on flow.

h. A DEDVI LOCA located in a PXS room results in the limiting long-term cooling thermal hydraulic conditions as noted in the five bulleted discussion points. It is also why this case was selected for the limiting case analyzed in the DCD for long-term core cooling. The comment in the second bullet about there being less debris available for injection in this case just points out the conservatism of the sensitivity study performed. The head losses assumed in the sensitivity studies are not based on specific debris loadings for the AP1000. Rather they demonstrate the capability of the AP1000 to operate with significant head losses even with the most limiting LOCA break location. If the LOCA was not located in a PXS room then the thermal hydraulic conditions would be more favorable and the plant could tolerate higher head losses.

   Per the methodology documented in WCAP-14857, Figure 4-2, the initial segment of the AP1000 DCD DEDVI break transient analysis is performed with the NOTRUMP code. This LOCA break is analyzed with NOTRUMP from inception until continuous injection from the IRWST into the reactor vessel has been established. The transient is then continued into long-term cooling with the WCOBRA-TRAC code, which is initialized consistent with the final NOTRUMP-predicted system condition; the WCOBRA/TRAC long-term cooling results are presented in DCD Section 15.6.5.4C. As indicated in the response to part (b), the initial 500 seconds of the WCOBRA/TRAC problem are used to allow the code to equilibrate to the end-of-NOTRUMP condition.

Additional Responses:

| b. Response to this additional question can be found in RAI-SRP6.2.2-SRP-10, Rev. 2.

c. All of the referenced cases are performed using the 1971 ANS Infinite +20% decay heat function, according to 10CFR50 Appendix K. The difference in core boiloff observed is a consequence of the lower plenum liquid enthalpy being calculated.

   Oscillations in flow direction at the bottom of the core in the DCD base case calculation cause hot liquid present in the core bottom cell(s) to be sent into the lower plenum, increasing the enthalpy. When large resistances are modeled at the core inlet to simulate postulated sump debris in the sensitivity cases, these oscillations diminish, and the lower plenum node is the donor node for flow through the core bottom flow path(s) throughout the calculation. Therefore, the subcooling of liquid present in the lower plenum relative to saturation temperature in the sensitivity cases is not affected by the introduction of any core fluid. The lower plenum subcooling prediction in the sensitivity case modeling the lower core entrance flow resistance increase is compared with the DCD base case prediction in the attached Figure 1. Because more of the core decay power in the sensitivity case(s) is needed to heat to the saturation temperature the more highly subcooled fluid being introduced from the lower plenum, the calculated core boiloff is a bit lower in the sensitivity cases.

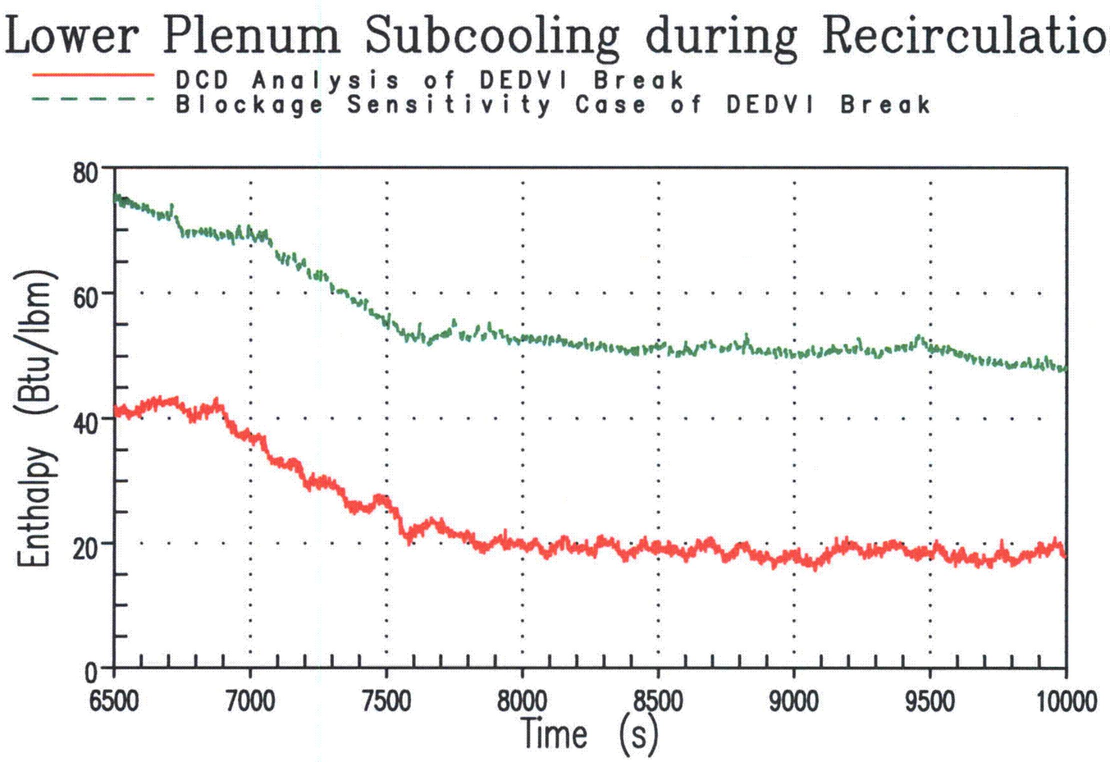

Figure 1: Lower Plenum Subcooling Comparison

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None