Response to Second Request for Additional Information—ANP-10278P
"U.S. EPR Realistic Large Break Loss of Coolant Accident Topical Report"
(TAC NO. MD4978)

RAI-10. *In response to NRC concern that the plant licensing basis LOCA analysis should not be performed at less than the full licensed power level (Reference 1, slide # 40) AREVA indicated that, "The methodology will be changed to eliminate sampling of core power, and that the core power should be held constant throughout the case, set at a value equal to the plant rated power plus the established measurement uncertainty. For the plants that will not incorporate measurement uncertainty reduction, the applied uncertainty should be set at 2%".*

It is noted that the U. S. EPR RLBLOCA Topical Report (Reference 2) is based on EMF- 2103(P)(A) (Reference 1).

Table A-6 (Reference 2, page A-12) summarizes the major parameters for the limiting transient. The core power for the limiting case is 4,570 MWt which is less the plant rated power (4,590 MWt, see Reference 2, Table A-3, page A-7).

Please explain the differences between the AREVA's position and the Table A-6 results (Reference 2) in regards to representation of core power in the limiting case.

Reference 1: RLBLOCA (EMF-2103(P)(A) Revision 0, Issue Resolution meeting in Rockville, Maryland on 12/12/2007.

Reference 2: ANP-10278P, "U. S. EPR Realistic Large Break LOCA TR Revision 0.

Response to RAI-10:

AREVA NP submitted ANP-10278P on March 26, 2007. The NRC staff issued and draft safety evaluation for AREVA NP Topical Report EMF-2103P, Revision 1 May 25, 2008. The draft safety evaluation identified certain issues, included the restriction to change the methodology to set core power at the full licensed power level. In a December 12, 2007 meeting, AREVA NP informed the NRC staff that it would not sample based on core power uncertainty when applying EMF-2103 to any future first time submittals unless the work had already been performed. Plants that have an approved RLBLOCA analysis are not governed by this agreement. During a March 6, 2008, telecon with the NRC staff, AREVA NP agreed that it would treat core power deterministically using the maximum measurement uncertainty in any future U.S. EPR RLBLOCA analyses.

To ascertain the effect of treating core power deterministically with the maximum uncertainty (i.e., 100.48% of rated power or 4612 MWt) a sensitivity study was conducted using two cases from the sample problem presented in Appendix A of ANP-10278P.

The maximum peak cladding temperature (PCT) case, Case 44, is characterized as a bottom-peaked, lower power case. The second case in the study, Case 8, has a high PCT and a lower power, but it is top-peaked. A summary of the results is presented in

Table 10-1. In both cases, the change in PCT because of an increase in power level to 100.48% of rated power is negligible.

Licensing of a core power measurement uncertainty of less than 2% of rated power is permitted in 10 CFR 50, Appendix K. The U.S. EPR design bases consider a maximum heat balance measurement uncertainty of ± 22 MWt (0.48% or ~0.5% of rated power). A calculation of core thermal power with a secondary side heat balance shows the uncertainty in core power measurement to be less than 0.48% of rated power. To measure the feedwater flow rate, the calculation assumes the use of a Caldon CheckPlus UFM, previously approved as noted in NRC Regulatory Issue Summary 2007-24.

Table 10-1—Summary of Results

Case Number	Axial Skew	Core Power, MW	% Nominal Power	PCT, °F	PCT node	PCT Time, s	Rod Description	PCT Elevation, ft
44	Bottom	4570.34	99.57	1425	9	33.882	4% Gd	2.2
		4612.03	100.48	1433		35.103	4% Gd	
	Change	41.69	0.91	8		1.221		
8	Top	4578.35	99.75	1389	43	4.6856	4% Gd	11.385
		4612.03	100.48	1398		4.6936	4% Gd	
	Change	33.68	0.73	9		0.008		

RAI-11. *Page 5-3: A statement is made that U.S. EPR accumulators are configured similar to those in current plants. Their design is such that they are not subject to a single failure nor are they allowed out of service for preventive maintenance. Thus, all four accumulators are available for accident mitigation.*

Figure 2-3 shows that MHSI, LHSI and one accumulator all enter a cold leg through a common line. If the break to the RCS is to this line (after the check valves), then coolant from the affected MHSI/LHSI, and also the affected accumulator would be lost to the break. Please justify the assumption in Table 3-2 that all four accumulators are available for break areas that are equal to or greater than the accumulator line flow area.

Response to RAI-11:

In ANP-10278Q1, Response RAI-03B explained why an accumulator is not considered a single-failure in the RLBLOCA analysis. The worst single failure in the RLBLOCA analysis is the complete loss of one train of pumped emergency injection (one MHSI and one LHSI). This is stated on page D-3 of EMF-2103(P)(A) “Realistic Large Break LOCA Methodology for Pressurized Water Reactors” Rev. 0.

Of the four trains of pumped safety injection, one train is assumed conservatively to be unavailable due to maintenance work and another train is subject to single failure (ANP-10278P, Section 3.5). On this basis, two of the four trains start and deliver flow. One of the two operating trains is assumed conservatively to inject into the reactor coolant system (RCS) cold leg with the break. Figure A-1 of ANP-10278P shows the S-RELAP5 noding diagram for the RCS. Because the emergency core cooling system (ECCS) connection is near the break, all of the ECCS flow delivered to the broken RCS cold leg spills into the containment. A break in the ECCS line itself at the cold leg nozzle is less than 10% of the cold leg area and is analyzed as a small break LOCA.

RAI-12. *The limiting transient (Table A-8) shows that the PCT occurs coincident with Bottom of Core Recovery at 33.9 sec. Before this time, the core should be heating up nearly adiabatically because of stagnant flow conditions. Please justify this instant reversal in cladding temperature and identify the mechanisms by which S-RELAP cools the PCT location so quickly. Table A-9 for example shows vapor Reynolds number (Re) less than 3000, which would provide a low Nusselt Number (Nu) even if a transition to turbulent flow was assumed to be complete. The liquid Re is also low (Re<1000) according to Table A-9. Show how the assessment for S-RELAP bounds the very high heat transfer rate as this rapid turn-around implies in spite of these low Re and a low hot assembly mass flux.*

For the limiting transient, please provide as a function of time:

a. Upper head pressure
b. Hot Assembly (HA) Inlet Mass Flux and Void Fraction (or alternatively the liquid and vapor phase flow rates
c. HA Liquid and Vapor Temperatures
d. Power Shape assumed
e. Axial Fuel Centerline and Cladding Temperature Profile in HA at BOC.

Provide as a data file with values every 0.1 second.

Response to RAI-12:

The timing of the end of the refill phase presented in Table A-9 of ANP-10278P indicates an approximate time for the onset of the reflood or the beginning of the core recovery phase. The beginning of core recovery is calculated as the time when the void fraction in the bottom-most hot channel hydrodynamic volume drops below 0.5. Figure 12-1 shows that the time it takes for the void fraction to drop from approximately 1.0 to less than 0.5 is short. Therefore, this criterion is appropriate.

The cladding temperature reversal does not occur instantaneously. The core power axial peak for the maximum peak cladding temperature (PCT) case is at 2.2 ft (bottom-peaked); therefore, reversal of PCT would be sooner than for a top-peaked case.

As shown in Figure 12-1, the vapor mass flowrate increases at about 33.0 seconds in response to the lower plenum filling with liquid. This initial surge in steam flow, which peaks at about 33.1 seconds, occurs at the same time as an increase in the heat flux from the hottest rod, which is the 4% Gd rod (see Figure 12-2). This heat flux increase is enough to produce a slight drop in cladding temperature at the PCT node. The cladding temperature begins to rise again, but a second increase in steam flow tempers the cladding temperature rise.

As liquid enters the bottom of the core at 33.8 seconds, some liquid is entrained and swept upward into the core. This produces a second decrease in cladding temperature. With the added heat flux, the liquid content near the PCT elevation is once more reduced and the cladding temperature increases. At ≈35 seconds, a third pulse of steam entrains liquid, lowering the void fraction, and producing a more substantial drop in cladding temperature. Just after 40 seconds, a reasonably stable

low void fraction is established at the PCT location and the hot spot initiates a stable cooldown (See Figure A-11 of ANP-10278P). It is the entrainment of liquid coincident with the introduction of liquid at the bottom of the core and the resultant steam generation as the lower portions of the hot assembly quench that is responsible for the initial variability in cooling and eventual stable cooldown of the lower core regions.

RAI-12 Case 44 Data.xls contains the following data for the maximum PCT case (Case 44) as a function of time:

a) Upper head pressure.
b) Hot assembly inlet mass flux, void fraction, vapor flowrate, and liquid flowrate.
c) Hot assembly liquid and vapor temperatures at the PCT node.
d) Power shape assumed for the hot rod, hot assembly.
e) Axial fuel centerline and cladding temperature profile in hot assembly.
f) 4% Gd rod heat flux at the PCT location.

Figure 12-1—Hot Channel Inlet Void Fraction and Vapor Flowrate

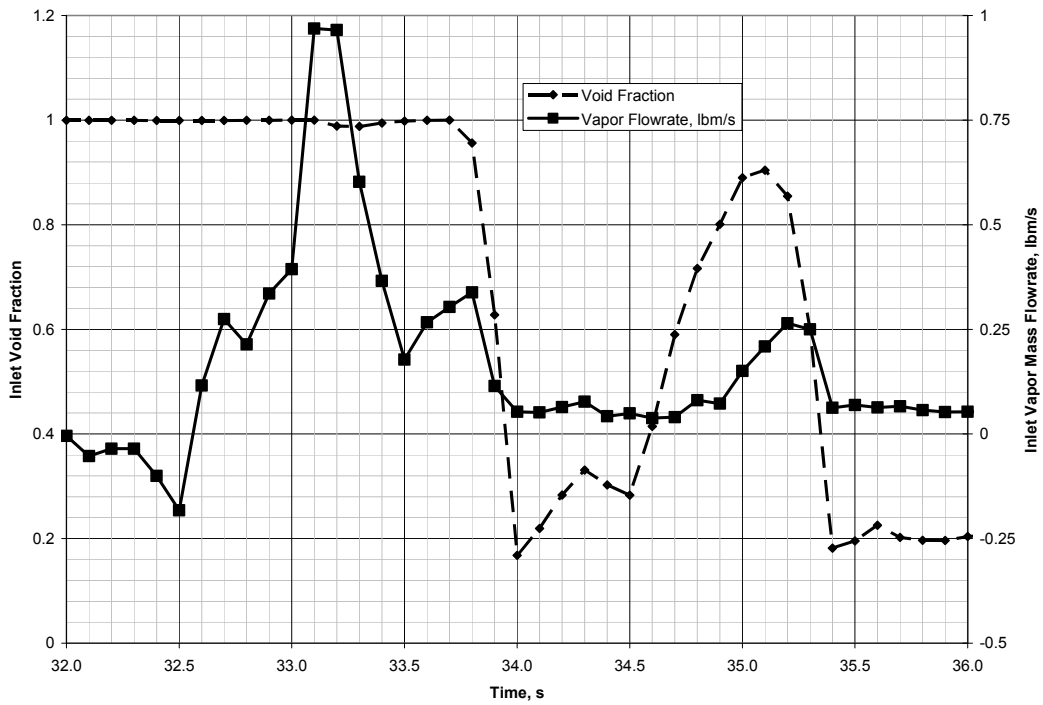
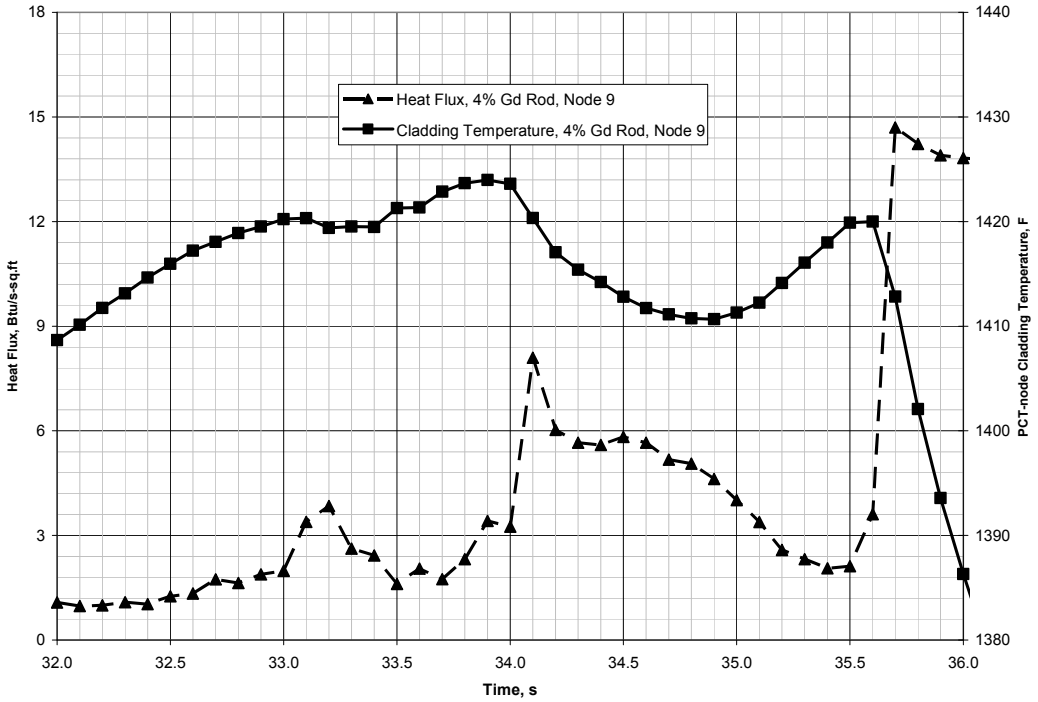


Figure 12-2—PCT Node Heat Flux and Cladding Temperature



RAI-13. *The AREVA S-RELAP5 model appears to have two different accumulators discharge pipe sizing. Please confirm that the accumulator's piping modeled in the EPR S-RELAP5 model is consistent with the EPR plant design.*

Response to RAI-13:

The accumulator piping modeled in the S-RELAP5 LOCA simulation for the U.S. EPR is consistent with plant design.

The U.S. EPR accumulator lines in Loops 1 and 4 are about 10 ft longer in total length than the corresponding lines in Loops 2 and 3. This is reflected in the S-RELAP5 modeling of the respective accumulator lines.

The section of piping between the accumulator discharge nozzle and the safety injection connection point consists of two sizes of pipe: one with a flow area of 0.7530 ft^2 and the other, 0.5592 ft^2. In order to preserve the total volume and length of piping in the S-RELAP5 control volumes, an effective area is calculated: 0.7238 ft^2 for Loops 1 and 4 and 0.714 ft^2 for Loops 2 and 3. Flow resistance also is preserved. The resulting model is a correct representation of the U.S. EPR accumulator system.

RAI-14. *Please provide the power shape which is used in the EPR's RLBLOCA model and discuss the methodology that is used in obtaining this power shape. Explain the differences between the power shapes that are used for the RLBLOCA for the operating plants (12 ft fuel) and the EPR design?*

Response to RAI-14:

RAI-15. *Please evaluate the reactor coolant pump status in the broken loop and its impact on PCT. If the RCS pump in the broken loop locks and fails resulting in higher PCT, please justify why the proposed methodology is still applicable.*

Response to RAI-15:

The approved RLBLOCA methodology, EMF-2103(P)(A), models all un-powered reactor coolant pump (RCP) as non-failed, free spinning rotors throughout the transient. This position is documented in AREVA NP's response to NRC questions 71i and 71j on page 156 of the section labeled NRC:02:062 of EMF-2103(P)(A), "pump seizure is not considered part of a best-estimate LBLOCA scenario; and, for this reason, is not considered in this methodology."

The consequence of this modeling approach has been evaluated in two studies. In response to NRC question 24 of the section labeled NRC:02:062 of EMF-2103(P)(A) on page 43, AREVA NP performed a suite of calculations to assess cladding temperature sensitivity to realistic variations in loop resistances. Two specific parameters, a broken-loop RCP form loss and a broken vessel side form loss were added to the model and their values varied over a fairly wide range in the study. The base model incorporates no form losses at the junctions to the break nodes where the sensitivity study form losses were applied. The results of the study showed a maximum increase in PCT **[ ]** when the sensitivity study RCP form loss was ≈6 times larger than the vessel side form loss.

A confirmatory study was performed for the U.S. EPR, setting the broken-loop RCP speed to zero at varying times after pump trip. The sensitivity study uses three cases, chosen based on calculated PCT, time of PCT, and axial peaking. Table 15-1 provides the results of the study, which show an insignificant increase in PCT. Thus, the additional resistance associated with seizure of the pump rotor is not significant to the determination that the criteria of 10 CFR 50.46 are met with high probability.

Table 15-1—Sensitivity of PCT to Broken-Loop Pump Resistance

Case	Case Characteristics	Pump Trip Time, s	Time that Broken-Loop Pump Speed is Set to Zero, s	PCT, °F	ΔPCT, °F	PCT Time, s
44	max PCT, bottom-peaked	10.3244	base case	1425	-	33.88
			34.1	1424	-1	41.51
			19.6	1443	18	42.29
			14.1	1448	23	40.85
8	high PCT, top-peaked	LOOP, pumps trip at transient initiation	base case	1389	-	4.69
			10.1	1389	0	4.68
			5.1	1389	0	4.68
19	high PCT occurring during reflood (reflood trip at ~26s)		base case	1323	-	107.44
			4.1	1355	32	93.57
			22.1	1343	20	91.98
			29.1	1358	35	100.37

RAI-16. *Please provide information regarding the methodology and the containment model that are used to calculate the containment back pressure during a LBLOCA. Is the methodology approved for the EPR design by the NRC?*

Response to RAI-16:

The methodology used to calculate U.S. EPR containment back-pressure during a LBLOCA is approved by the NRC.

The dominant phenomenon of interest related to the containment model is the effect of containment pressure on PCT. Containment pressure is treated statistically in EMF-2103 for the RLBLOCA methodology **[**

] Section 4.3.3.2.12 of EMF-2103, Rev. 0 refers to sensitivity studies that show that lower containment pressure reduces PCT margins. Because the ICECON models provide only pressure and temperature for S-RELAP5, a simple model is adequate.

[

] Therefore, the U.S. EPR containment is within the modeling capabilities of ICECON and within the capabilities of the RLBLOCA methodology described in EMF-2103, Rev. 0.

The results of an assessment of the sensitivity of the U.S. EPR RLBLOCA analysis to containment back-pressure are shown in Table 16-1. The approved RLBLOCA methodology employs a 59-run case set to calculate the 95/95 PCT result. The sampled containment volume is increased by 60% for each case in the base case set. After incorporating the changes to the ICECON input file, the 59-run case set is rerun with the same sampling seeds.

The resulting decrease in pressure is around 10 psi on average. For example, in Case 44 (i.e., the maximum PCT case) PCT increases to 1451°F, a change of only 26°F. Case 19 experienced the largest increase in PCT, a change of 65°F, to 1388°F. The study indicates:

- The effect of containment pressure on PCT is small.
- The conservative bias towards low containment pressure is reasonable.
- The RLBLOCA methodology produces a slight bias toward low containment pressure through its approach to sampling on containment volume.

This study confirms that with respect to containment pressure, the RLBLOCA methodology demonstrates the criteria of 10 CFR 50.46 are met with high probability for the U.S. EPR.

Table 16-1—Sensitivity of PCT to Containment Pressure

Case	Base Case PCT, °F	Increased Containment Volume PCT, °F	ΔPCT, °F	Decrease in Peak Containment Pressure (P_{base} – $P_{increased_volume}$) psid
1	1083	1083	0	10.49
2	1382	1404	22	13.37
3	1358	1358	0	11.51
4	1170	1196	26	12.16
5	1311	1311	0	12.19
6	1337	1374	37	12.39
7	1286	1286	0	11.84
8	1389	1389	0	12.64
9	1028	1024	-4	8.34
10	1035	1047	12	9.72
11	1016	1011	-5	9.01
12	988	988	0	10.21
13	1276	1276	0	11.02
14	880	895	15	10.74
15	1200	1200	0	12.56
16	980	1002	22	9.72
17	1049	1057	8	9.40
18	1373	1402	29	12.95
19	1323	1388	65	11.14
20	1010	1010	0	6.79
21	1061	1072	11	11.62
22	1163	1198	35	11.75
23	1179	1179	0	9.55
24	1130	1157	27	12.56
25	1269	1269	0	12.80
26	978	986	8	11.51
27	921	921	0	10.67
28	1110	1121	11	9.46
29	1309	1309	0	10.88
30	1221	1238	17	11.06
31	925	959	34	11.20
32	864	848	-16	8.80
33	1127	1136	9	13.31
34	1124	1124	0	9.00
35	1154	1161	7	12.70
36	1020	1020	0	11.01
37	861	861	0	8.19
38	1263	1263	0	11.50
39	1256	1256	0	11.29
40	1250	1250	0	11.97
41	1044	1044	0	9.38
42	975	997	22	9.64
43	1233	1233	0	10.82
44	1425	1451	26	11.04

Case	Base Case PCT, °F	Increased Containment Volume PCT, °F	ΔPCT, °F	Decrease in Peak Containment Pressure (P_{base} – $P_{increased_volume}$) psid
45	987	990	3	9.72
46	1083	1083	0	11.06
47	1253	1246	-7	12.95
48	1123	1123	0	10.68
49	1052	1059	7	7.70
50	968	971	3	8.49
51	1275	1300	25	11.08
52	946	946	0	11.30
53	995	1018	23	9.48
54	1262	1262	0	9.16
55	1172	1172	0	10.62
56	1173	1191	18	8.95
57	983	979	-4	9.64
58	1134	1147	13	8.00
59	928	976	48	8.21

RAI-17. *Please provide the reference for the Decay Heat Curve that is used in the EPR's RLBLOCA. Please explain the 0.96132 multiplier listed in Table A-6, "Summary of Major Parameters for Limiting Transient."*

Response to RAI-17:

The decay heat multiplier represents the uncertainty in decay heat at rated power and is ranged over a normal distribution with a mean value of 1.0 and a standard deviation of 0.03 (Reference EMF-2103, Rev. 0, p. 4-95). Table A-6 of ANP-10278P shows that, for the maximum PCT case, the scaled decay heat multiplier is 0.96132. For the full 59-case RLBLOCA case set, the sampled decay heat values ranged from ≈0.925 to ≈1.075. Decay heat is obtained from the ANS/ANSI 5.1-1979 standard decay heat curve, which provides the basis for the uncertainty distribution.

RAI-18. *Please provide the nominal case for the EPR's RLBLOCA at 100% + MUR and 100% DEG break size. Please provide and discuss the choice of the range and the calculated values of all the sampled variables for the proposed 59 cases including the modeling input variables.*

Response to RAI-18:

Case 44, the maximum PCT case described in Appendix A of ANP-10278P, is the comparative case for the requested 100% double-ended guillotine break (DEGB) analysis at 100%+MUR power. With the exception of power and break size, which are set to their maximum values, the parameters described in Table A-5 and Table A-6 of ANP-10278P that range over a probability distribution are set to their nominal values. Table 18-1 provides the parameter values used in the analysis. Table 18-2 provides the key results for the 100% DEGB case. Table 18-3 provides PCT for the hot rods. Table 18-4 provides the ranges of the sampled parameters for the sample problem presented in Appendix A of ANP-10278P and a discussion of the statistical sampling methodology for each parameter.

Figure 18-1 through Figure 18-24 present the parameters of principal interest:

- PCT independent of elevation (Figure 18-1).
- Hot rod cladding temperature (Figure 18-2).
- Primary system pressure (Figure 18-3).
- Flows supplied to ECCS (Figure 18-4).
- Flows delivered by ECCS (Figure 18-5).
- Core inlet flow (Figure 18-6).
- Core outlet flow (Figure 18-7).
- Break flow (Figure 18-8).
- Collapsed liquid level in the downcomer (Figure 18-9).
- Core liquid level (Figure 18-10).
- Reactor power (Figure 18-11).
- Secondary system pressure (Figure 18-12).
- Downcomer mass flowrate (Figure 18-13).
- Core inlet temperature (Figure 18-14).
- Core inlet quality (Figure 18-15).
- Core outlet temperature (Figure 18-16).
- Core outlet quality (Figure 18-17).
- In-core temperature (Figure 18-18).
- In-core quality (Figure 18-19).
- Cladding temperature (Figure 18-20).
- Heat transfer coefficient (Figure 18-21).
- Primary to secondary heat transfer rate (Figure 18-22).
- Pump speed (Figure 18-23).
- Containment pressure (Figure 18-24).

The resulting PCT for Case 44 is 1240°F, which confirms the validity of a case set performed and demonstrating that the criteria of 10 CFR 50.46 are met with high probability.

Table 18-1—100% Power DEGB Case Parameters
(Parameters are described in Table 18-4.)

Parameter Name	Value Chosen	
Core power	1.0048	
Break area, each side	5.1434	ft^2
Initial flow rate	184,227,120.0	Total lbm/hr (all loops)
Initial average operating temperature	594.0	°F
Pressurizer pressure	2250.0	psia
Pressurizer level	54.3	% range
Containment volume	2888000.0	ft^3
Containment temperature	90.5	°F
Accumulator pressure	681.7	psia
Accumulator volume	1324.3	ft^3
Initial upper head temperature	1.0	
Discharge coefficient, vessel-side	1.003	
Discharge coefficient, pump-side	1.003	
Decay heat multiplier	1	
Pressurizer surgeline critical flow	1.003	
Film-boiling heat transfer coefficient	1.00	
Dispersed film-boiling coefficient	1.75	
Biasi critical heat flux	0.7241	
Minimum temperature	626	K
Initial stored energy	0	°F
Downcomer hot wall effects	0	
Steam generator inlet plenum FIJ	1.75	
Condensation interphase heat transfer coefficient	0.9	
Metal-water reaction constant	1	
Metal-water reaction exponent	1	
Offsite power	1	(available)
Axial skew	1	(bottom)
Break type	1	(guillotine)
Break size for Double-Ended Split Break (DESB)	n/a	
Intact loop number	4	
Time in cycle	31	
F_Q	2.578	
Fr5	0.526	
Fr3	1.173	

Table 18-2—Key Results for 100% DEGB Case

PCT (°F)	Hot Rod	Total Oxidation (%)	Maximum Oxidation (%)	PCT Time (sec)	PCT Elevation (ft)	End Time (sec)
1240	4% Gd Rod	< 0.01%	0.0793	28.376	2.200	200.0

Table 18-3—PCT Values for All Hot Rods for 100% DEGB Case

UO2 (°F)	PCT Elevation (ft)	2.0% Gd Rod (°F)	PCT Elevation (ft)	4.0% Gd Rod (°F)	PCT Elevation (ft)	8.0% Gd Rod (°F)	PCT Elevation (ft)
1225	2.2	1230	2.2	1240	2.2	1229	2.2

Table 18-4—Discussion of Choice and Range of Sampled Input Parameters

Parameter Name	Lower Value or Mean	Upper Value or Std. Dev	Units	Probability Density Function	Comment on Ranging
Plant Parameters					
Core power	0.9952	1.0048	fraction	uniform	Operational and measurement uncertainties are combined in the ± 22 MWt measurement uncertainty.
Initial flow rate	1.76E+08	1.98E+08	lbm/hr	uniform	Ranged from the minimum, thermal-hydraulic, RCS mass flow rate to the maximum, mechanical, RCS mass flow rate.
Initial average operating temperature	589	599	°F	uniform	RCS average temperature, best-estimate, is given as 594°F. The uncertainty on average temperature is ± 5°F.
Pressurizer pressure	2214	2286	psia	uniform	RCS operating pressure is 2250 psia. The uncertainty on RCS pressure is ± 36 psi.
Pressurizer level	49.3	59.3	% range	uniform	Nominal pressurizer level at 100% power is 54.3% range. The uncertainty on pressurizer level is ± 5% range.
Containment volume	2.888E+06	3.645E+06	ft^3	uniform	The nominal containment free volume is 2.888e+6 ft^3. The maximum volume is evaluated simply as the empty volume of the containment dome plus the empty volume of the containment cylinder yielding 3.645e+6 ft^3.
Containment temperature	59	122	°F	uniform	Maximum and minimum operating temperatures of the accumulators and IRWST are 122°F and 59°F, respectively.
Accumulator pressure	652.7	710.7	psia	uniform	Maximum and minimum accumulator operating pressure are 710.7 psia and 652.7 psia, respectively.

Parameter Name	Lower Value or Mean	Upper Value or Std. Dev	Units	Probability Density Function	Comment on Ranging
Accumulator volume	1236	1412.6	ft^3	uniform	Nominal and minimum accumulator volumes are 1324.3 ft^3 and 1236.0 ft^3, respectively. It is assumed that the difference between nominal and maximum is the same as the difference between nominal and minimum. The latter assumption yields a maximum accumulator volume of 1412.6 ft^3.
Model Parameters					
Initial upper head temperature	[ ]	[ ]	-	[ ]	[ ]
Discharge coefficient, vessel-side	[ ]	[ ]	-	normal	The homogeneous-equilibrium critical flow model in S-RELAP5 was assessed by comparison to full-scale critical flow tests at the Marviken facility. These assessments produced a subcooled choking bias with an uncertainty and a two-phase choking bias with an uncertainty. [ ]
Discharge coefficient, pump-side	[ ]	[ ]	-	normal	
Pressurizer surgeline critical flow	[ ]	[ ]	-	normal	
Decay heat multiplier	1	0.03	-	normal	The RLBLOCA methodology described in EMF-2103, Rev. 0, uses a realistic but slightly conservative decay heat curve as a function of time using the 1979 ANS standard. The decay heat calculated with these assumptions bounds the more detailed decay heat curves that would result if the conditions at the initiation of LOCA were known. These assumptions are: 1) infinite operating time at full power; 2) all fissions assumed from U-235; 3) 200 MeV/fission (conservatively low); 4) one standard deviation total decay heat of 3%.
Film-boiling heat transfer coefficient	0	1	-	special	Probability distribution functions are used for the modified Bromley and Forslund-Rohsenow film boiling correlations.
Dispersed film-boiling coefficient	0	1	-	special	

Parameter Name	Lower Value or Mean	Upper Value or Std. Dev	Units	Probability Density Function	Comment on Ranging
Biasi critical heat flux	[ ]	0	-	normal	Test results from the THTF Heat Transfer separate-effects test contributed to identifying a bias in the Biasi CHF correlation. [ ]
Minimum temperature	[ ]	[ ]	K	[ ]	From the FLECHT SEASET data and from an evaluation of code uncertainty with regard to how the LBLOCA multiplier relates to T_{min}, [ ]
Initial stored energy	0	130.063	°F	normal	The analysis of stored energy uncertainty was performed by assessing RODEX3A predictions for centerline fuel temperature relative to data taken at the Halden Reactor Project. Using a normal probability distribution function, the mean error in centerline fuel temperature is 0.0 with a standard deviation of 130°F. A bias in centerline temperature has been identified for each case that the sampled time in cycle is greater than 10 MWd/kgU. This bias is given by the expression: Y{°F}= -4.2232 * X{MWd/kgU}+39.183°F
Downcomer hot wall effects	[ ]	[ ]	-	[ ]	The results from UPTF Tests 6 and 7 demonstrated that S-RELAP5 will overpredict ECC bypass; however, many parameters may contribute to this phenomena. The hot wall effect can be separated since it is expected that that there is a direct relationship with the degree of nucleate boiling in the downcomer and ECC bypass. To maximize the hot wall effect, heat transfer in the downcomer can be locked into nucleate boiling by raising the CHF point to a high value. In the RLBLOCA Methodology, the hot wall effect [ ]

Parameter Name	Lower Value or Mean	Upper Value or Std. Dev	Units	Probability Density Function	Comment on Ranging
Steam generator inlet plenum FIJ	[ ]	0	-	normal	Steam generator liquid entrainment was examined in the code assessments for CCTF and UPTF. [ ]
Condensation interphase heat transfer coefficient	[ ]	[ ]	-	[ ]	S-RELAP5 was assessed against selected tests from W/EPRI 1/3 scale condensation experiment. [ ] which indicates that S-RELAP5 tends to overpredict slightly the interfacial condensation rate. For RLBLOCA analyses, [ ] bounds the uncertainty range of the interfacial condensation heat transfer coefficient in the ECC/steam mixing process.
Metal-water reaction constant	1	0.18237	-	normal	In ORNL/NUREG-17, uncertainties are provided for both the constant term and the exponential term. It is reported that the 90% confidence limits on the constant term is -23% to +30% and on the exponential term, it is ± 2.2%. A standard deviation is calculated from the upper 1-sided 95% probability point (+30%, 2.2%). Assuming a normal distribution, this corresponds to 1.645 standard deviations. Hence, the standard deviation is 18.237% on the constant term and 1.337% on the exponential term.
Metal-water reaction exponent	1	0.01337	-	normal	
Offsite power	0	1	-	binary	Binary distribution indicating the availability (1) or unavailability (0) of offsite power.

Parameter Name	Lower Value or Mean	Upper Value or Std. Dev	Units	Probability Density Function	Comment on Ranging
Axial skew	0	1	-	binary	The axial skew uses a binary distribution assuming an equal likelihood of the power profile being skewed either to the top (1) or to the bottom (0) of the core.
Break type	[ ]	[ ]	-	[ ]	[ ]
Break size for DESB	[ ]	[ ]	-	[ ]	Break size is given in terms of full cold leg pipe area. [ ]
Break size for DEGB, one-side break area	[ ]	[ ]	-	[ ]	Break size is given in terms of full cold leg pipe area. [ ]
Intact loop number	1	4	-	uniform	Of the four trains of pumped Safety Injection, one train is conservatively assumed to be unavailable due to maintenance and another train is subject to single failure. One of the two operating trains is assumed to be delivered to the RCS cold leg containing the break. The location of the other operating train is ranged over a uniform distribution. If the random value is greater than or equal to 3, then the intact loop is set to loop 4. If the random value is less than 3, the random value is truncated to the nearest integer (1 or 2).
Calculation Parameters					
Time in cycle	0	40	-	uniform	Upper bound set to 40, which is equal to the number of unique time steps found in the first set of data in the first power history file.

Parameter Name	Lower Value or Mean	Upper Value or Std. Dev	Units	Probability Density Function	Comment on Ranging
F_Q	[ ]	2.6	-	uniform	The F_Q upper bound is set to the Technical Specification value. [ ]
[ ]	[ ]	[ ]	-	[ ]	[ ]
[ ]	[ ]	[ ]	-	[ ]	[ ]

Figure 18-1—PCT Independent of Elevation

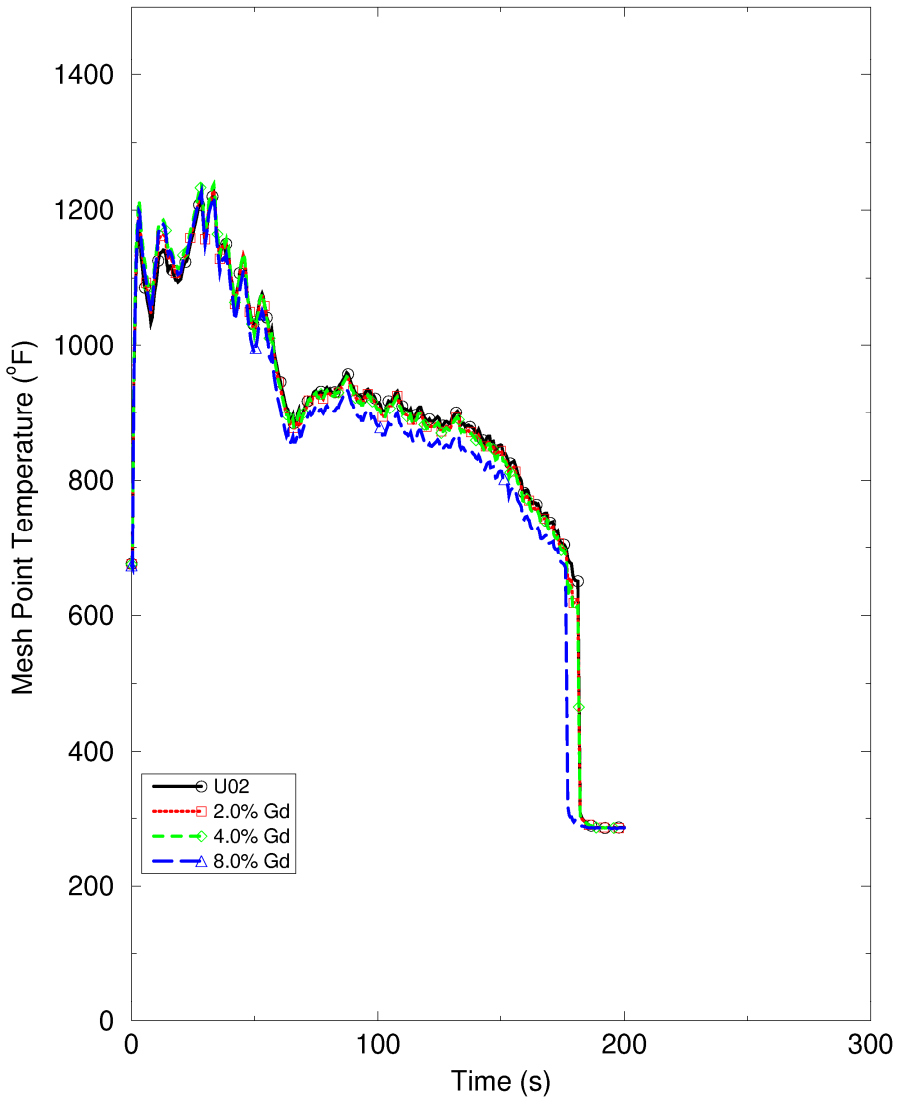


Figure 18-2—Hot Rod Cladding Temperature

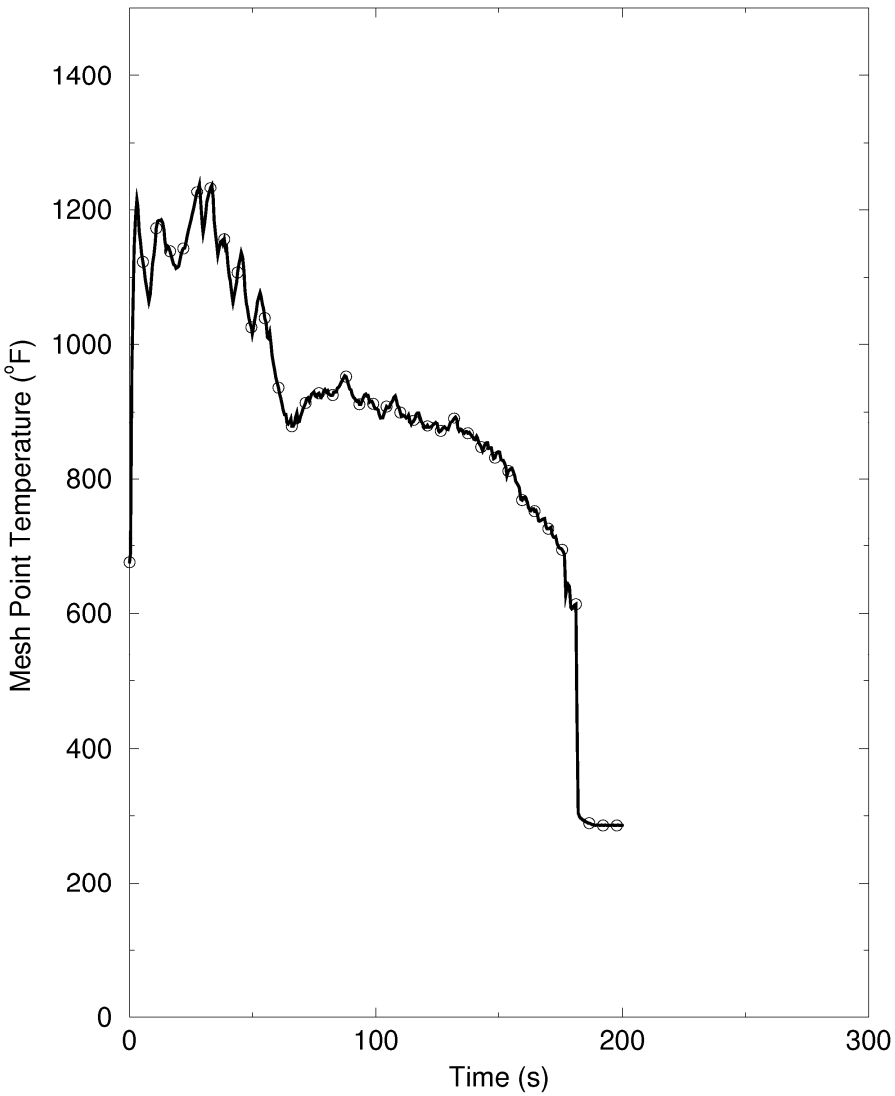


Figure 18-3—Primary System Pressure

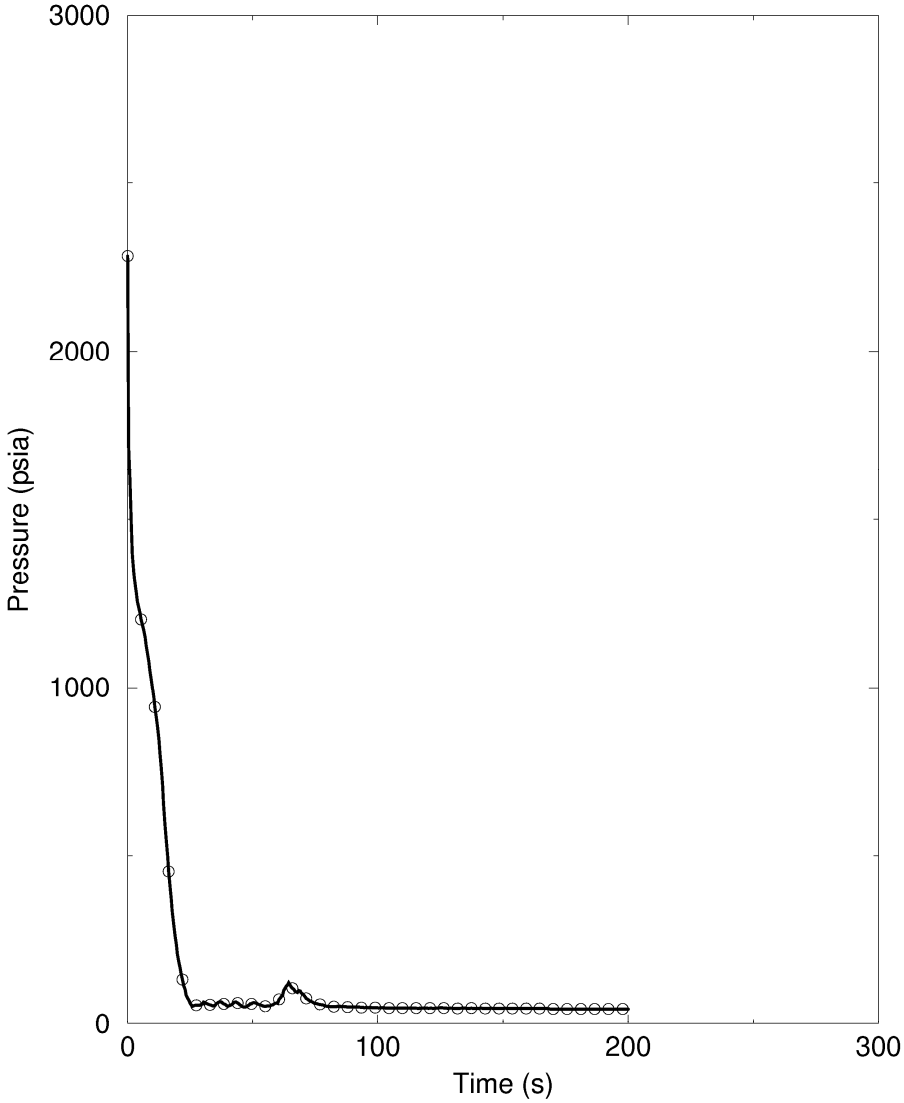


Figure 18-4—Flows Supplied to ECCS

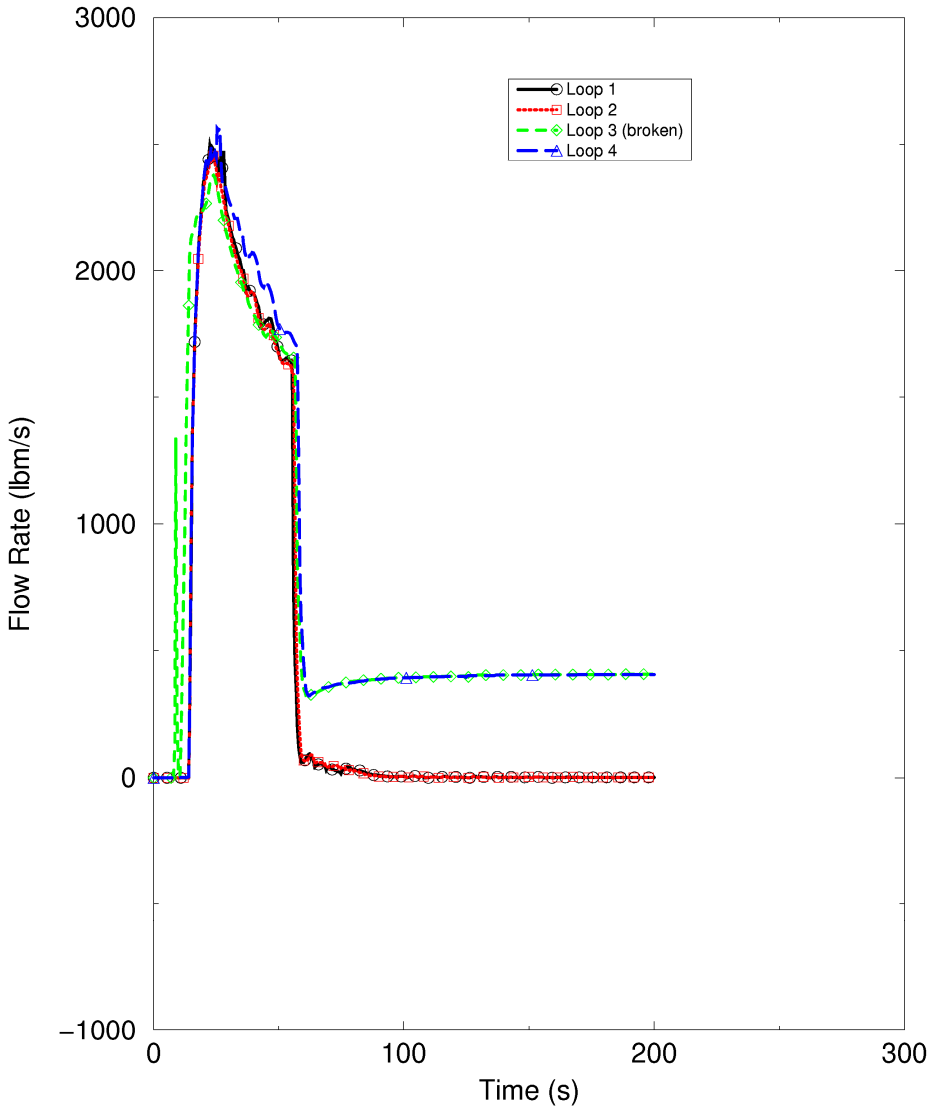


Figure 18-5—Flows Delivered by ECCS

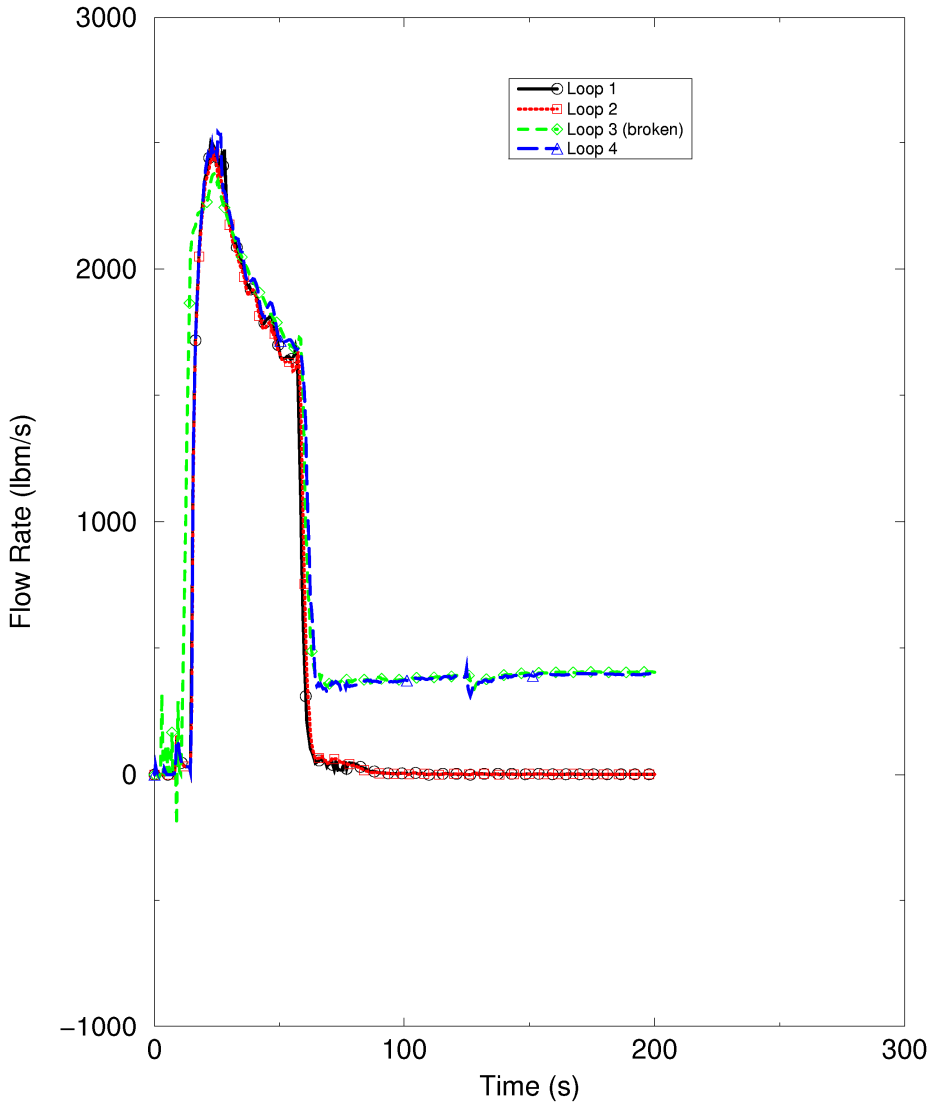


Figure 18-6—Core Inlet Flow

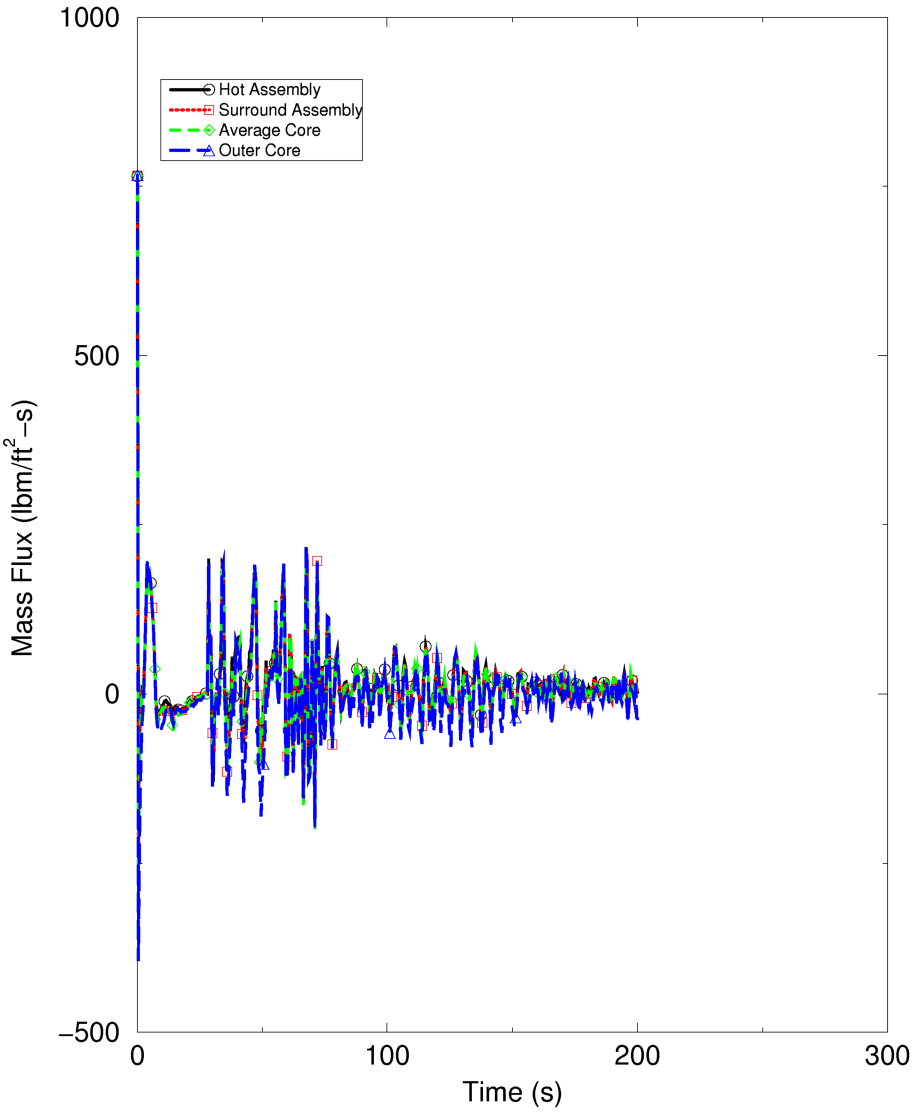


Figure 18-7—Core Outlet Flow

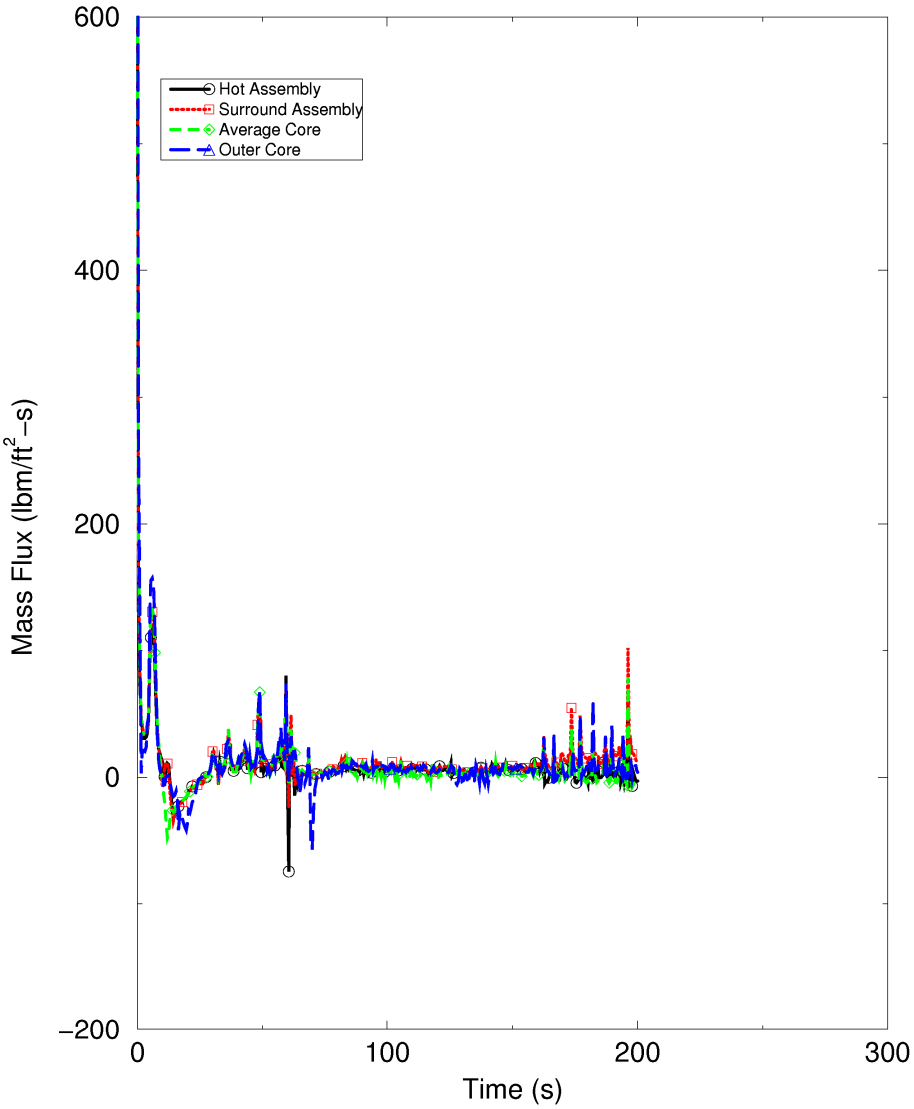


Figure 18-8—Break Flow

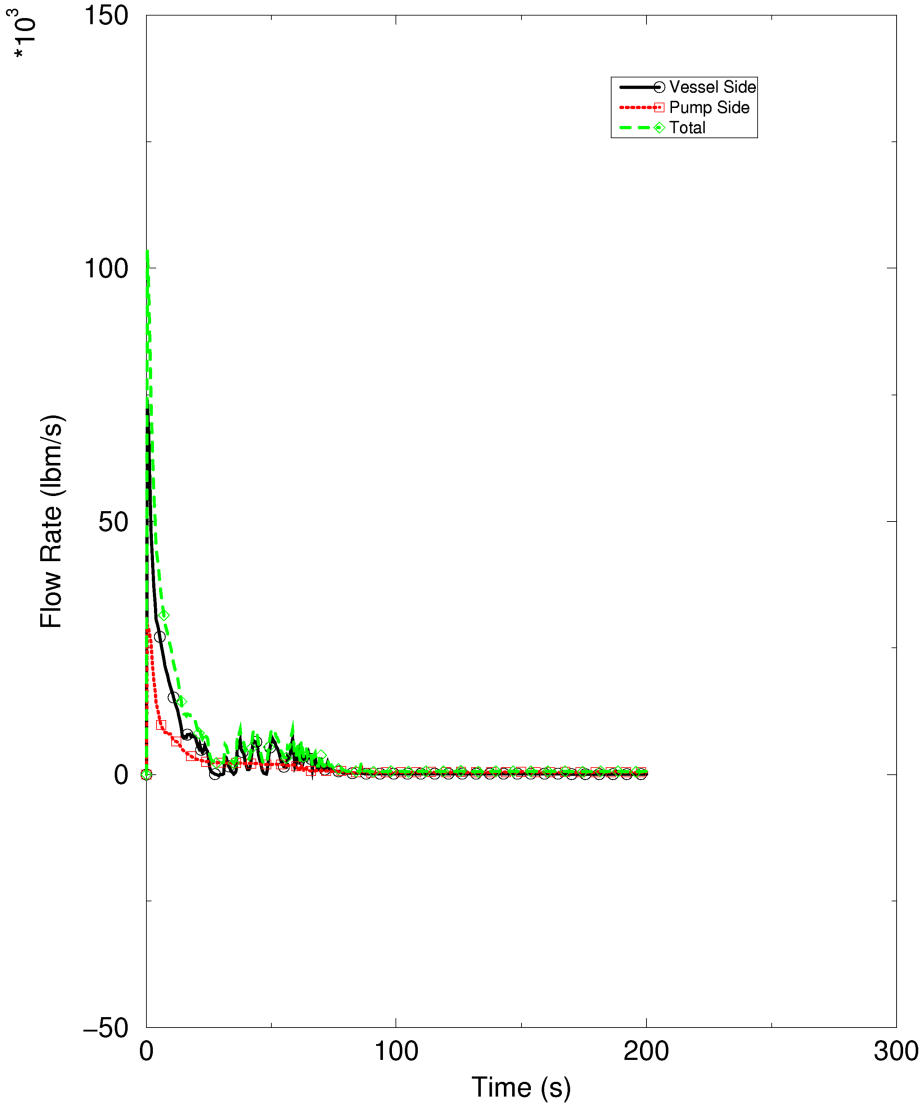


Figure 18-9—Collapsed Liquid Level in the Downcomer

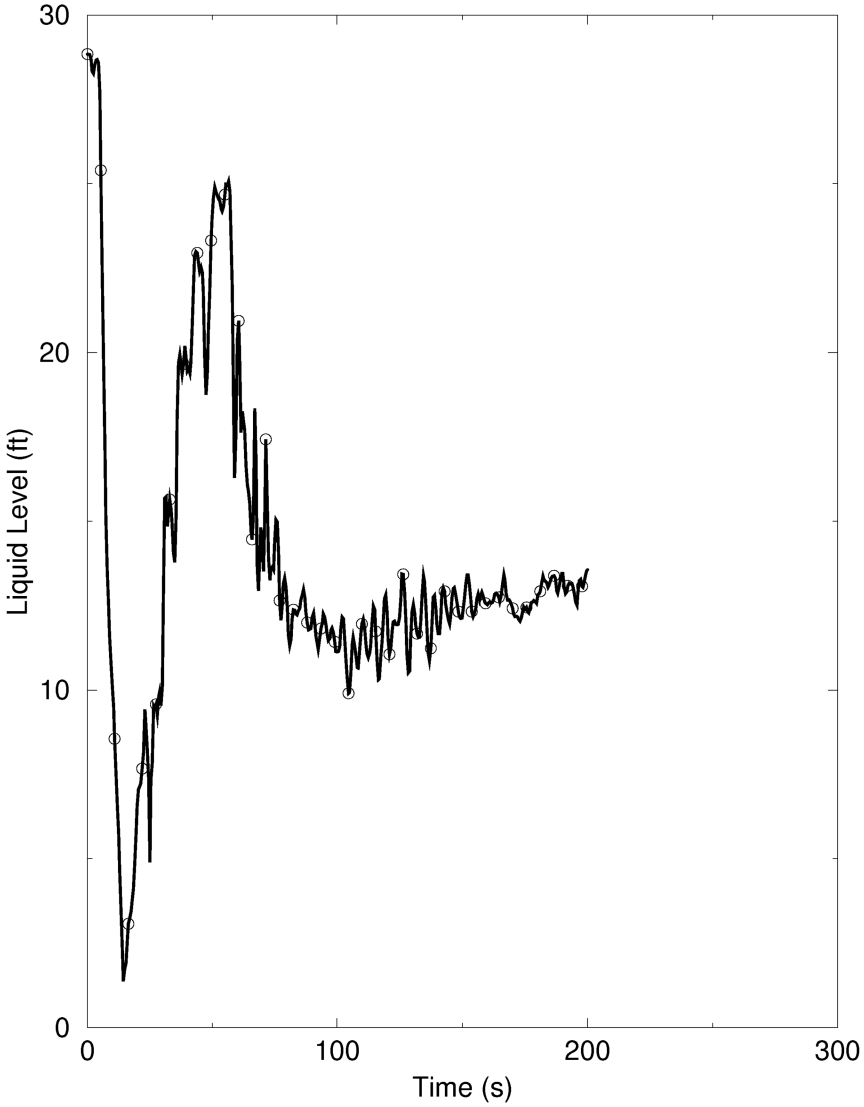


Figure 18-10—Core Liquid Level

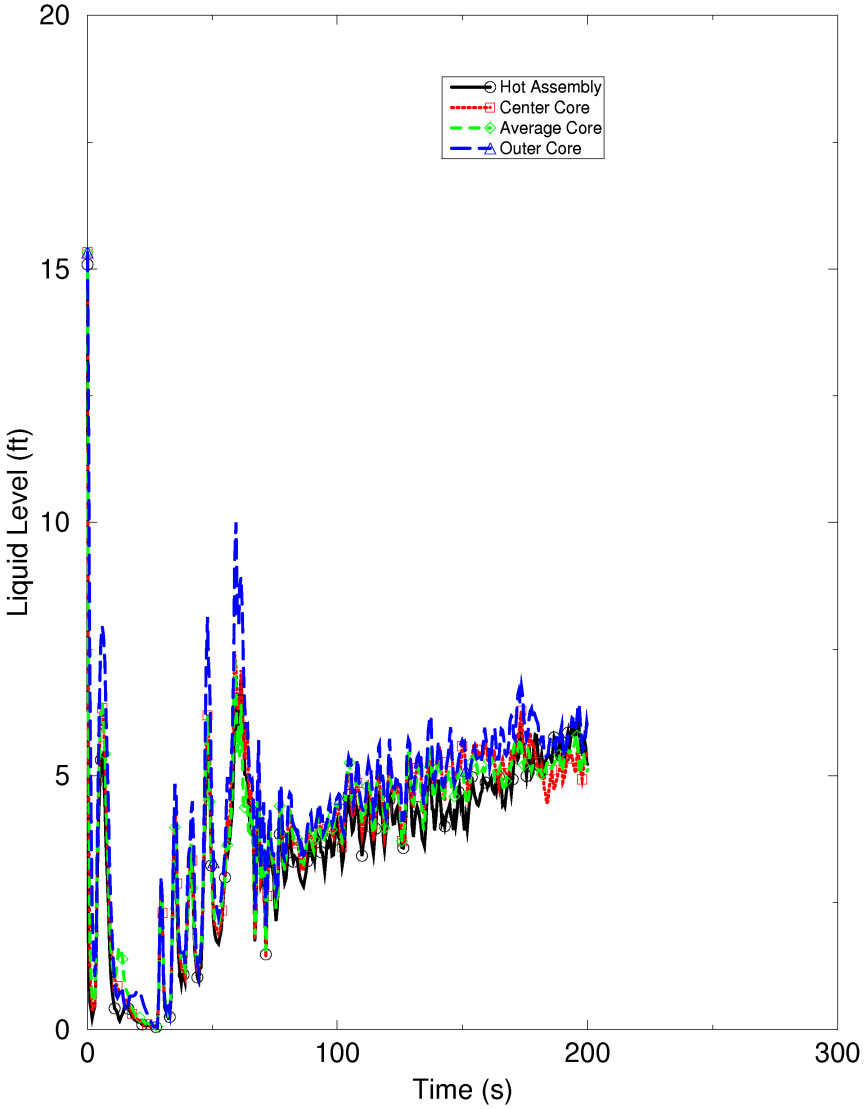


Figure 18-11—Reactor Power

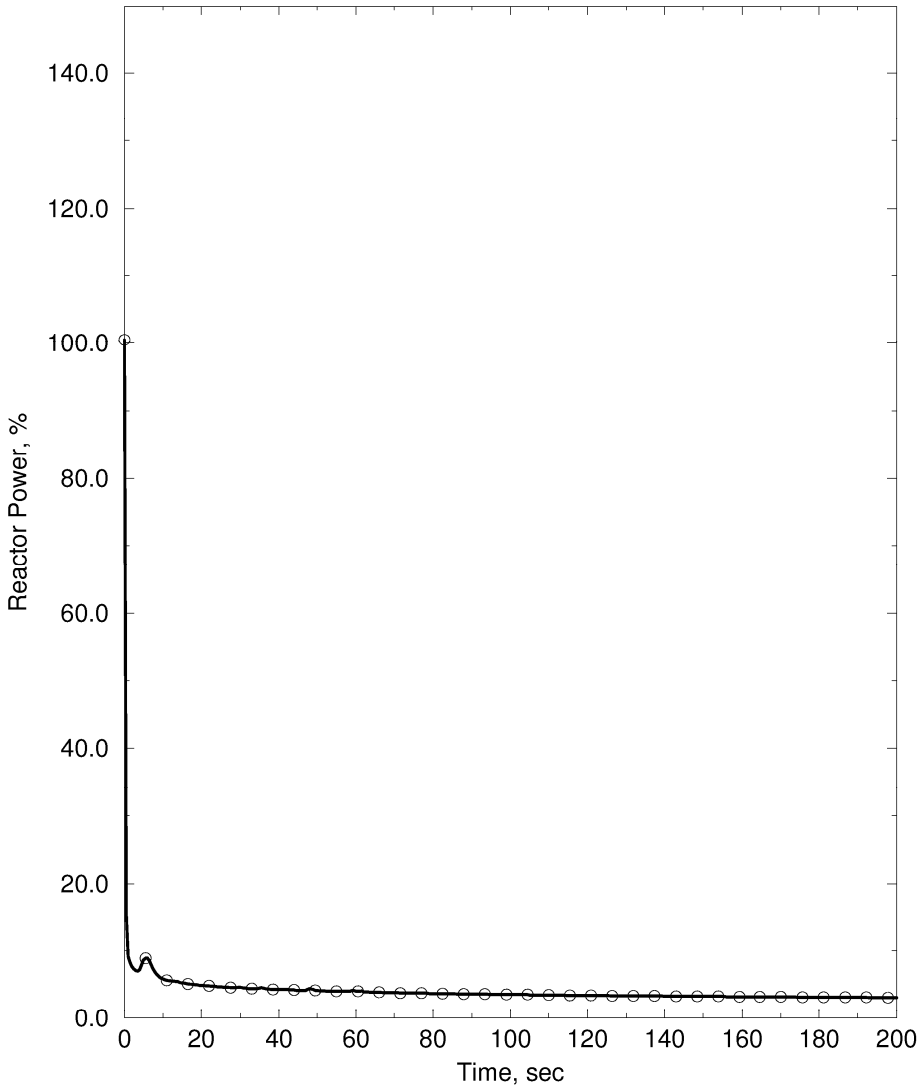


Figure 18-12—Secondary System Pressure

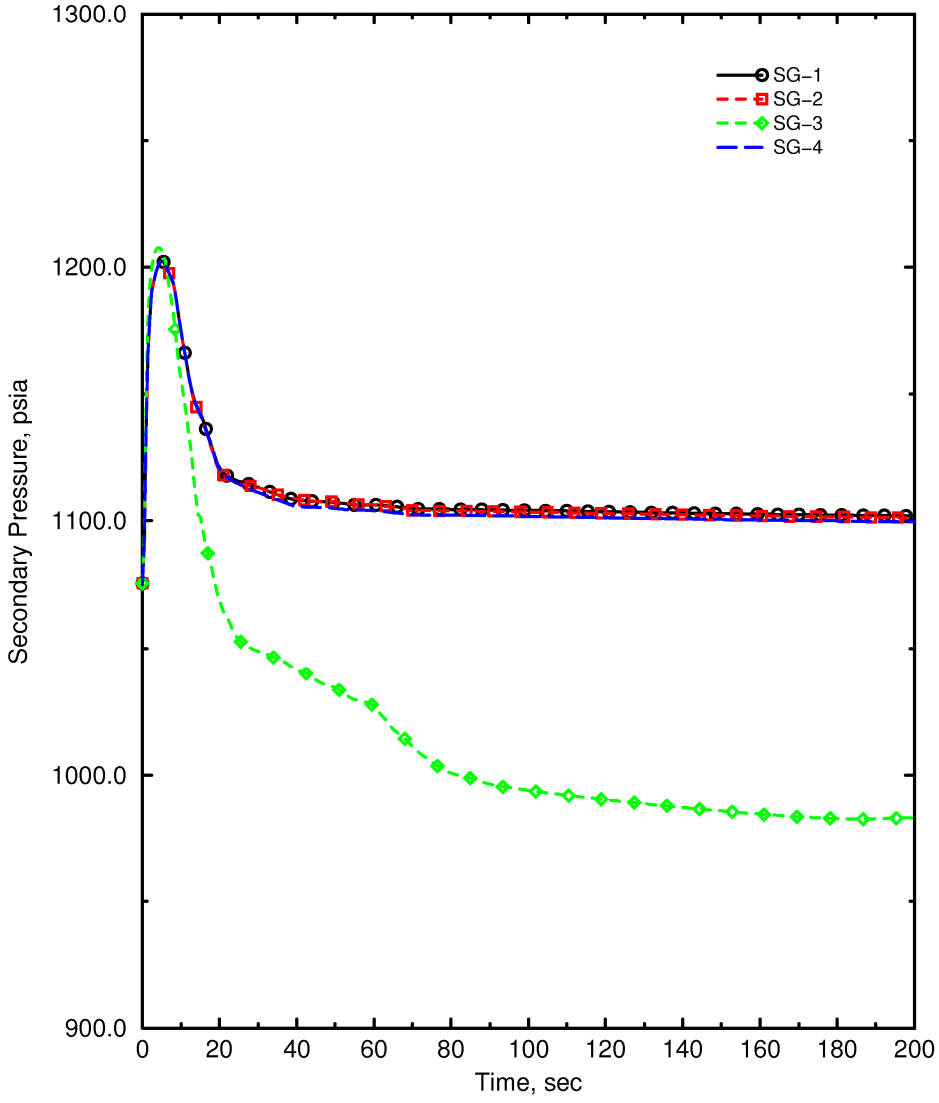


Figure 18-13—Downcomer Mass Flowrate

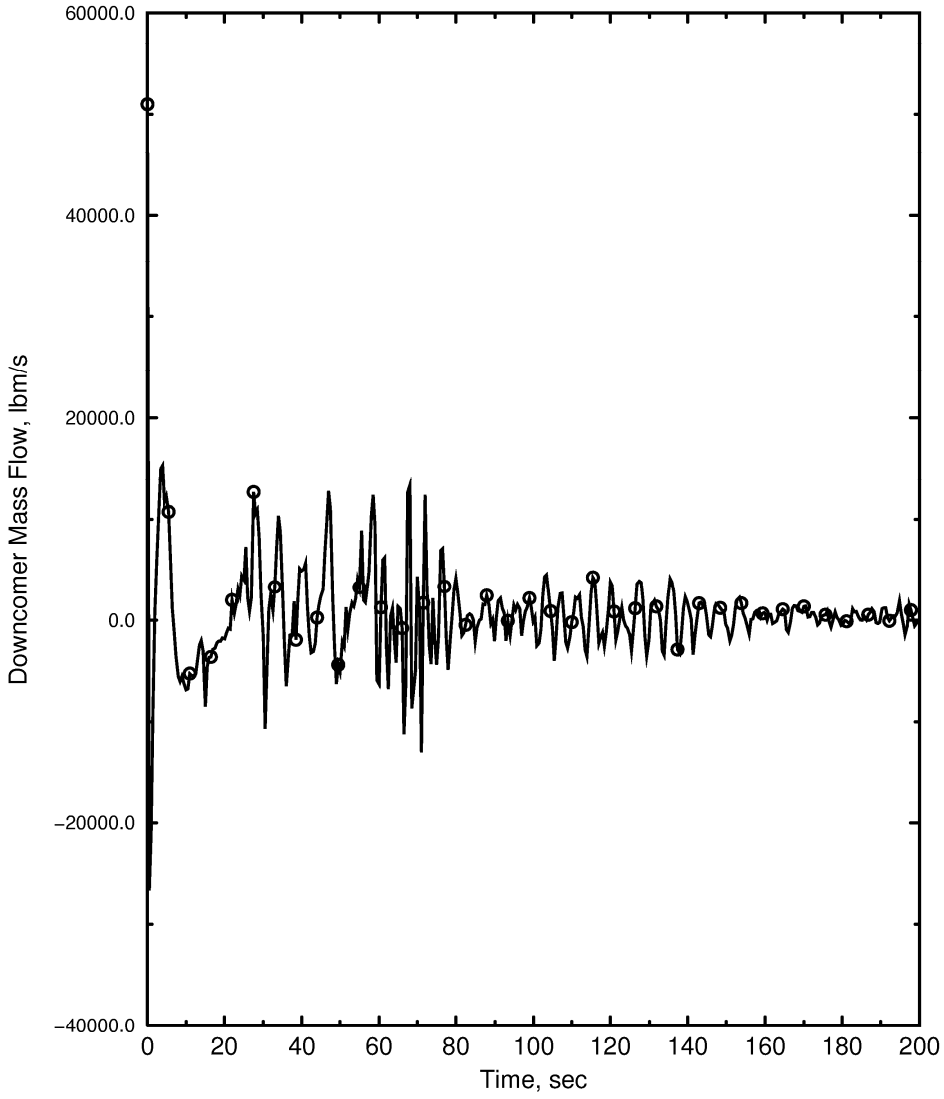


Figure 18-14—Core Inlet Temperature

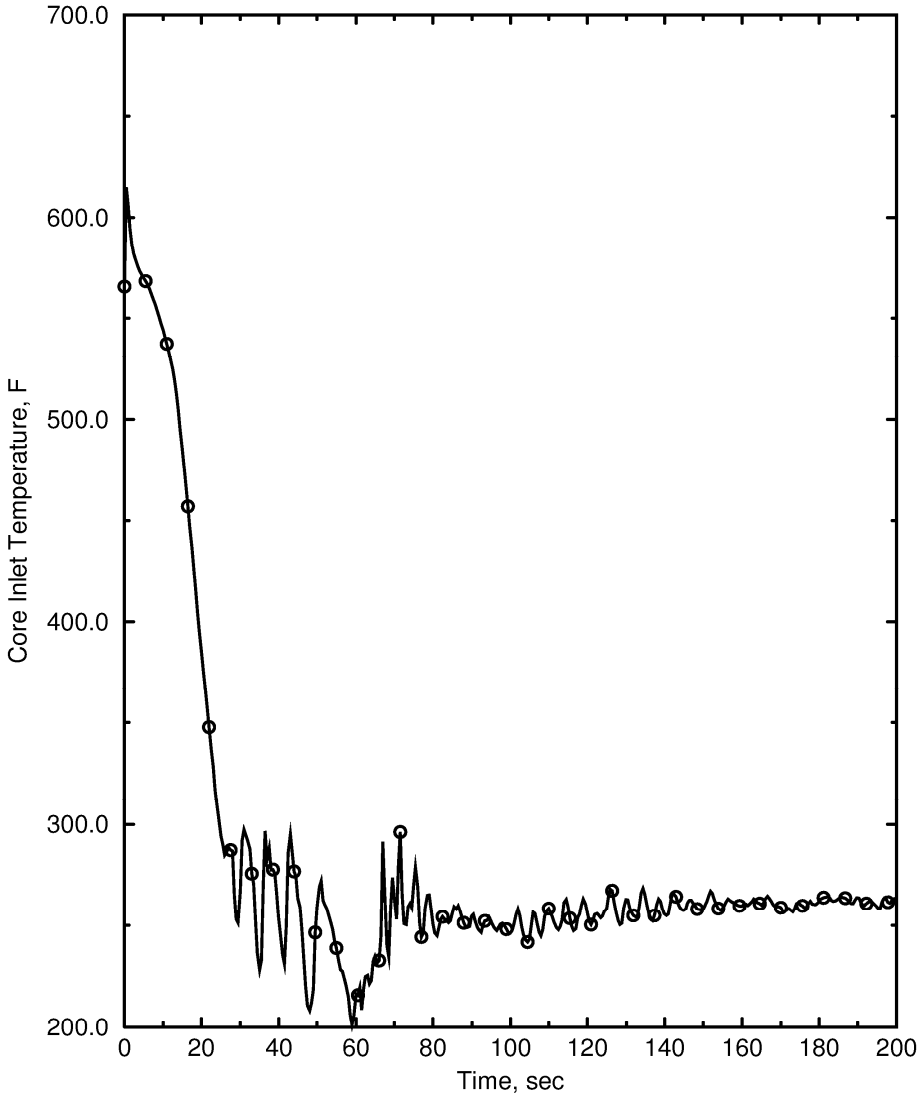


Figure 18-15—Core Inlet Quality

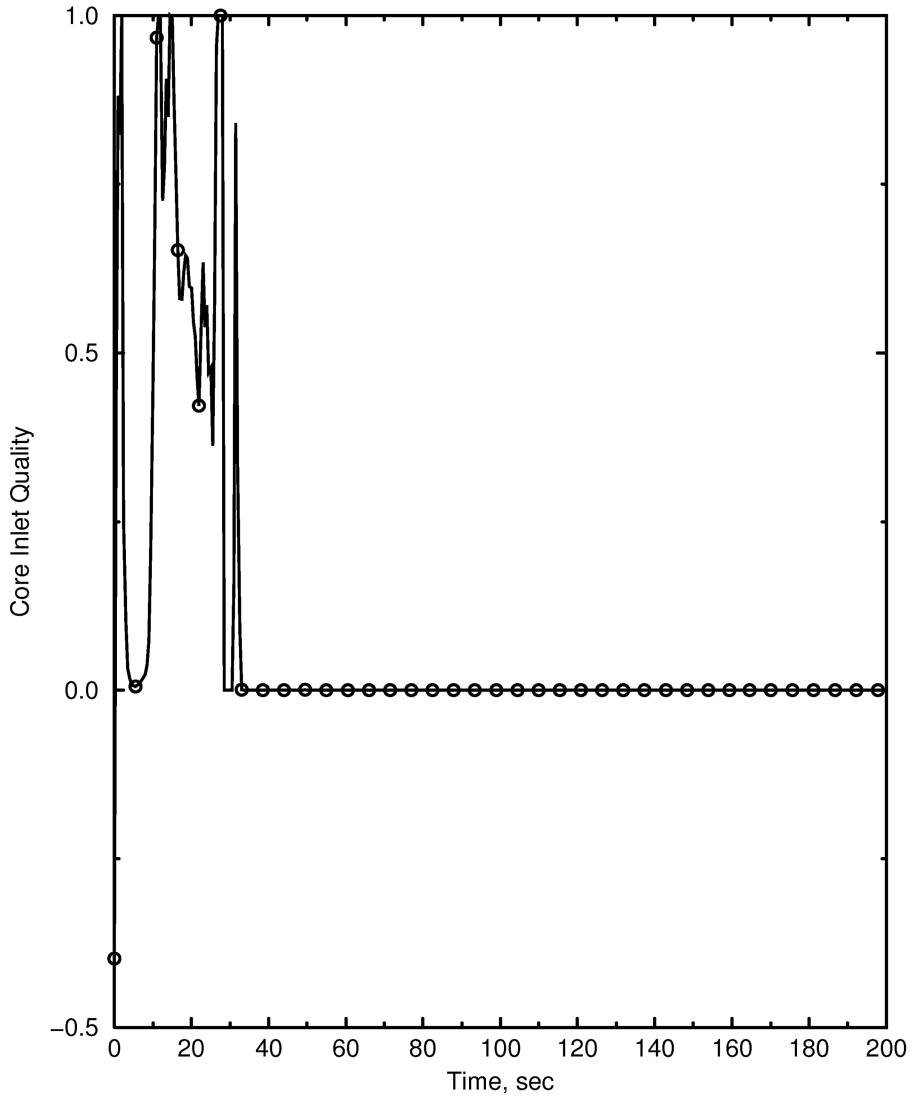


Figure 18-16—Core Outlet Temperature

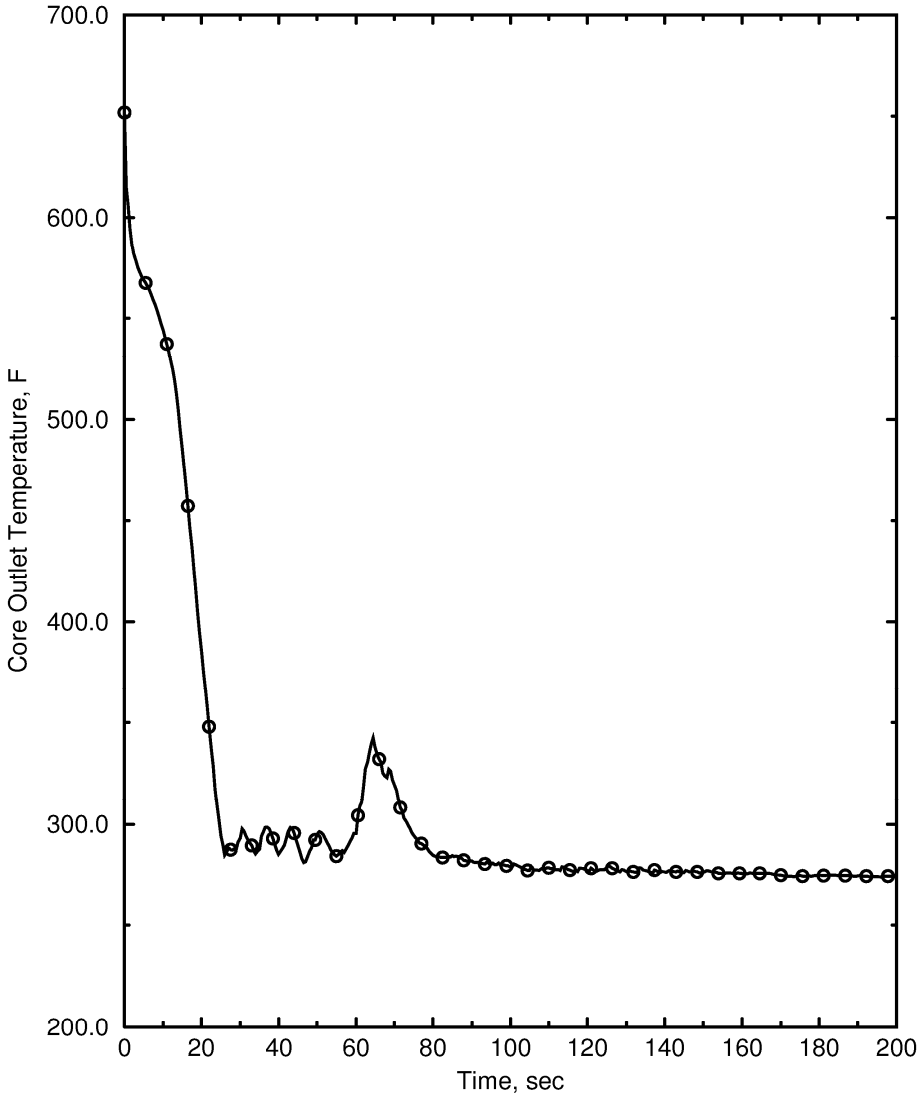


Figure 18-17—Core Outlet Quality

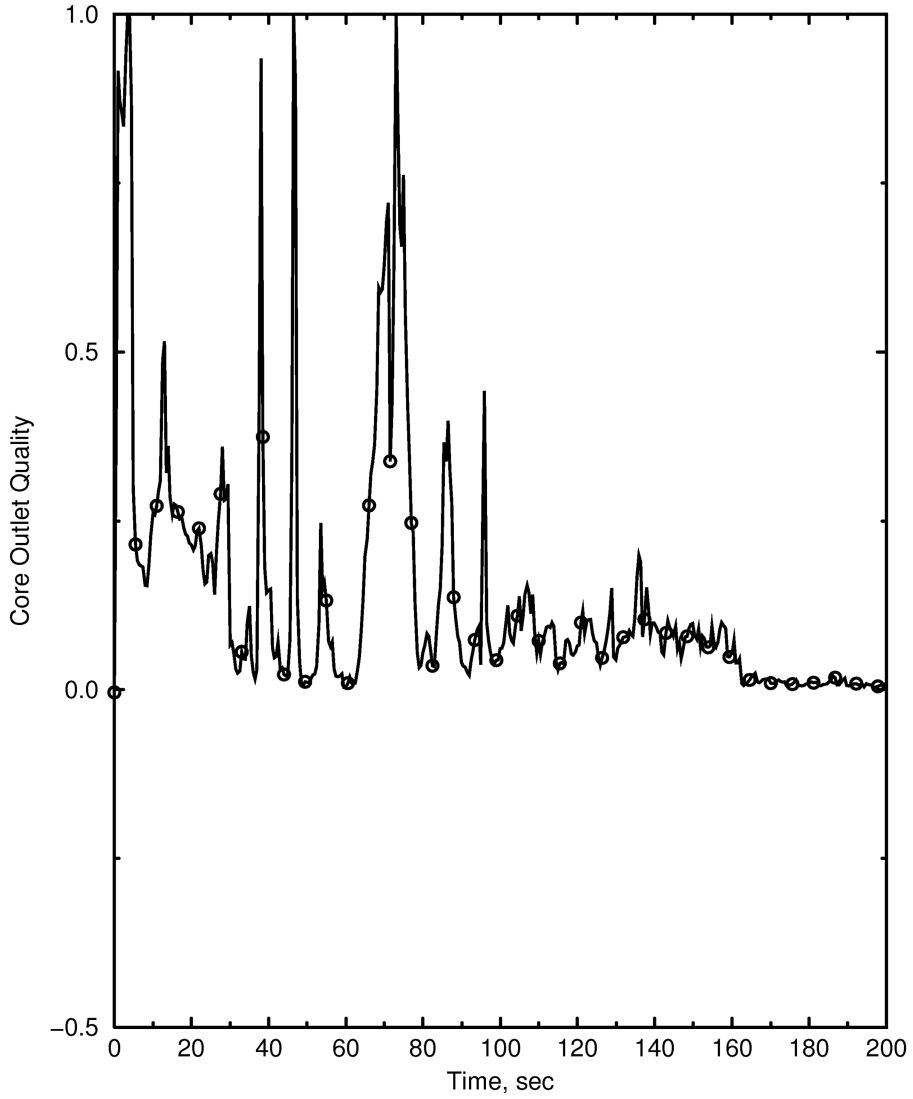


Figure 18-18—In-core Temperature

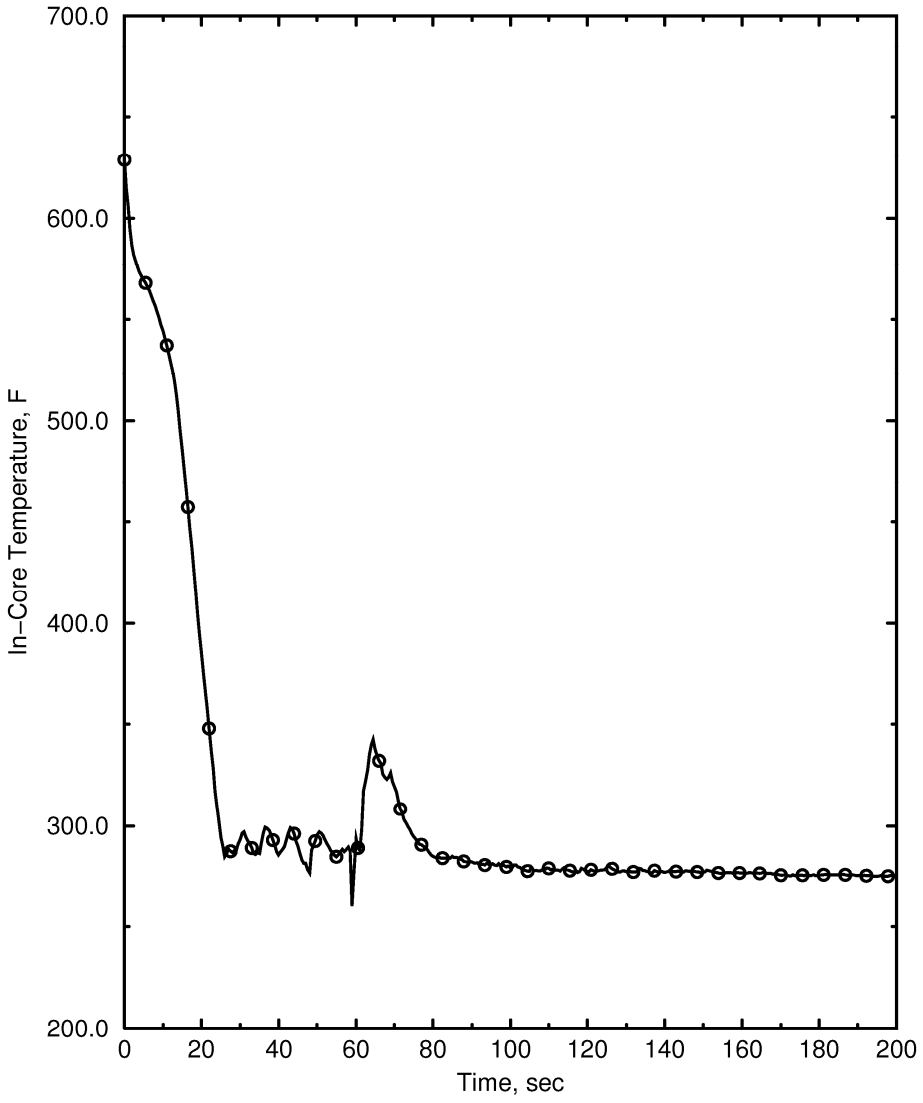


Figure 18-19—In-core Quality

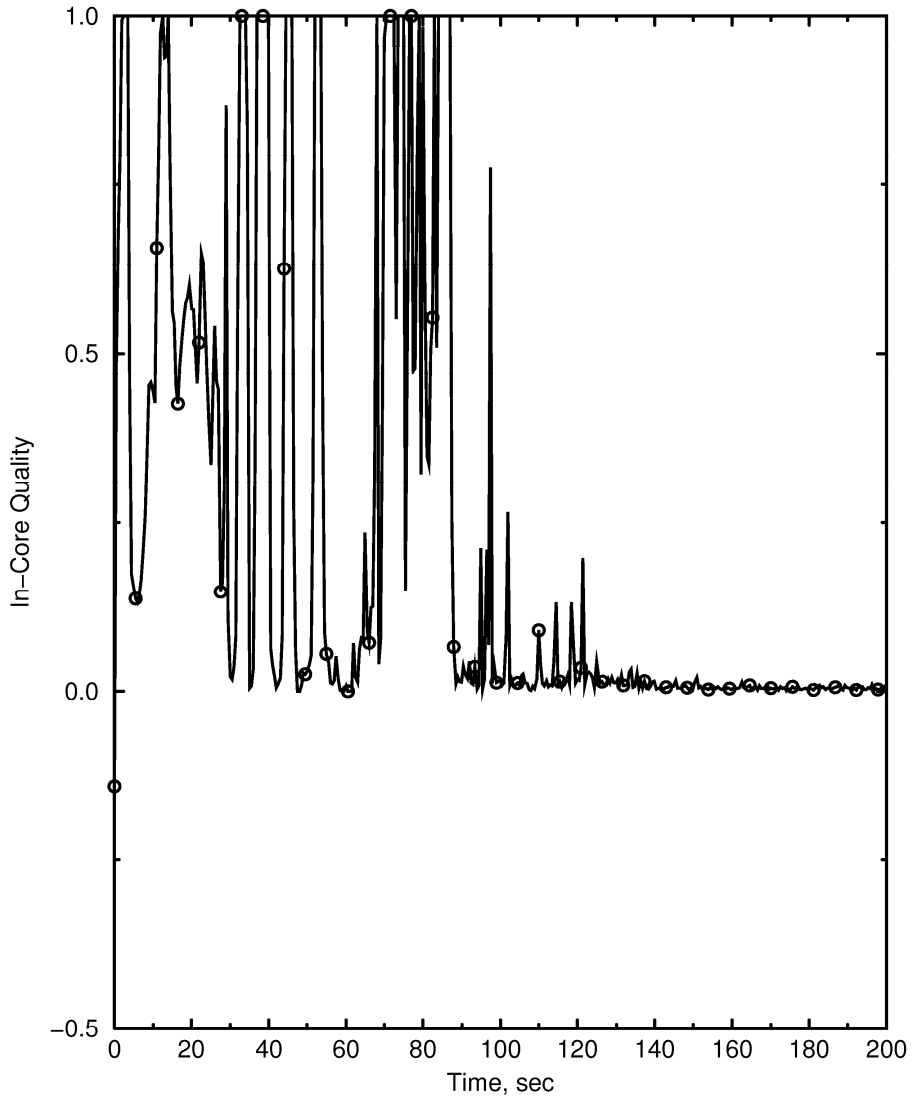


Figure 18-20—Cladding Temperature

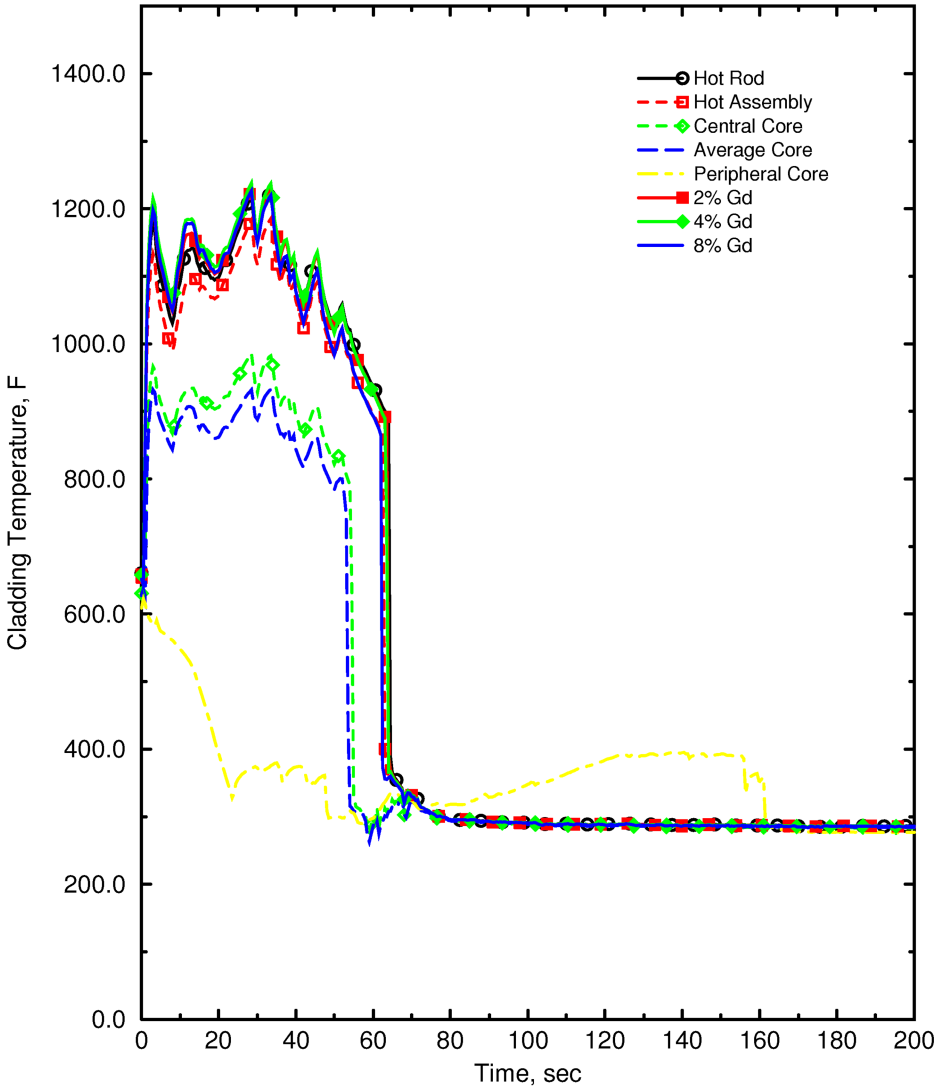


Figure 18-21—Heat Transfer Coefficient

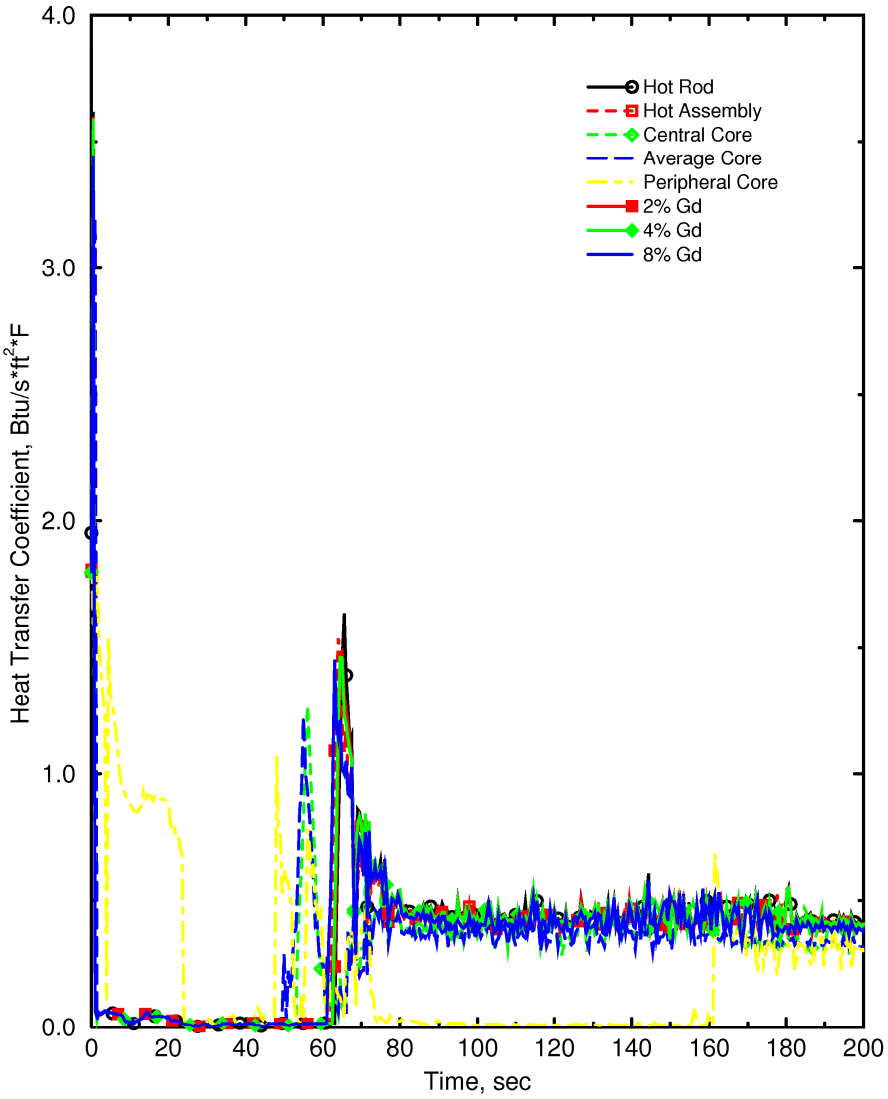


Figure 18-22—Primary to Secondary Heat Transfer Rate

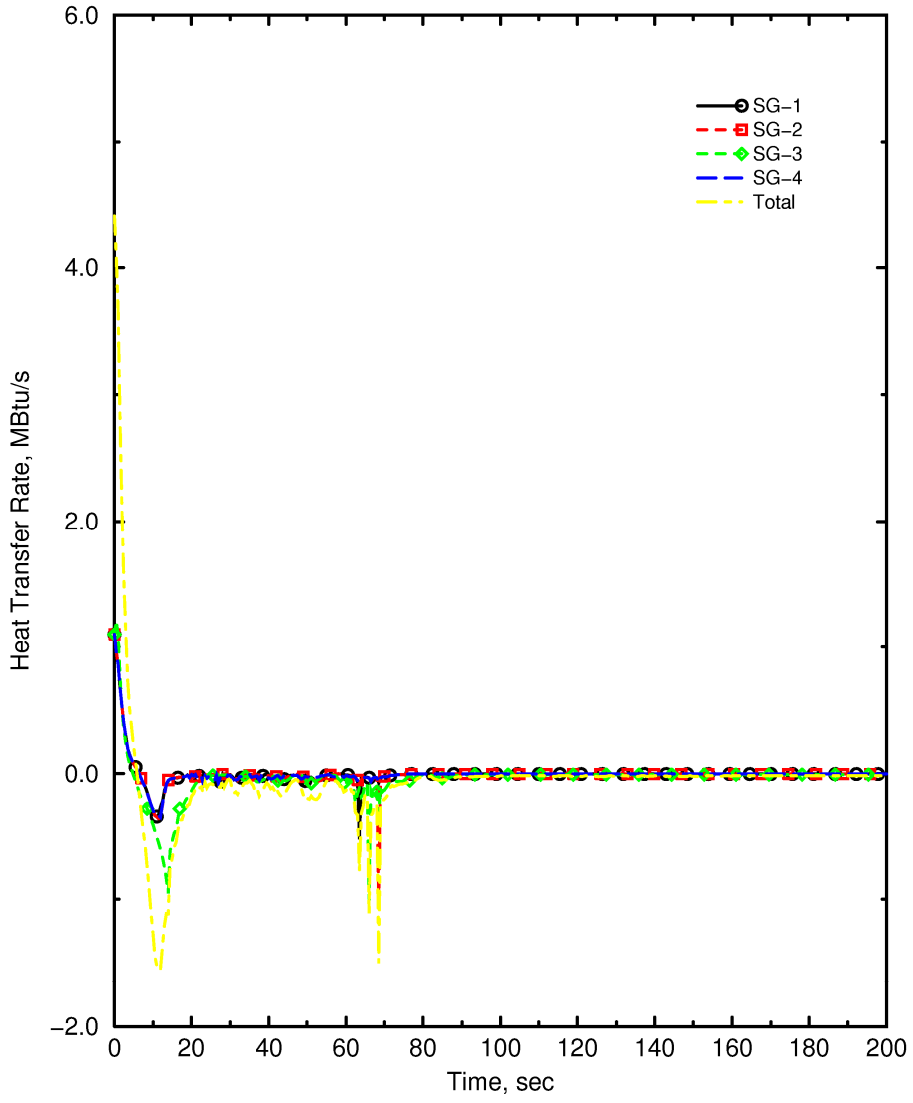


Figure 18-23—Pump Speed

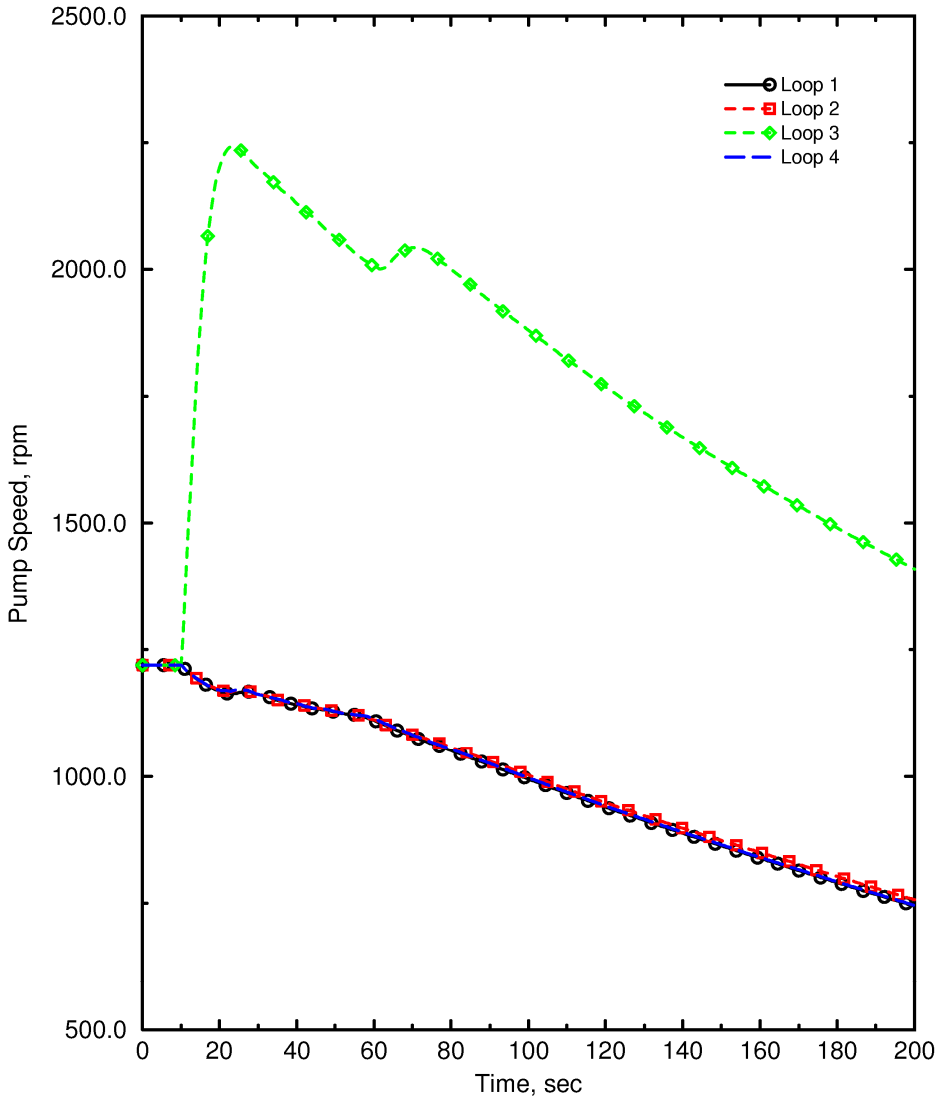
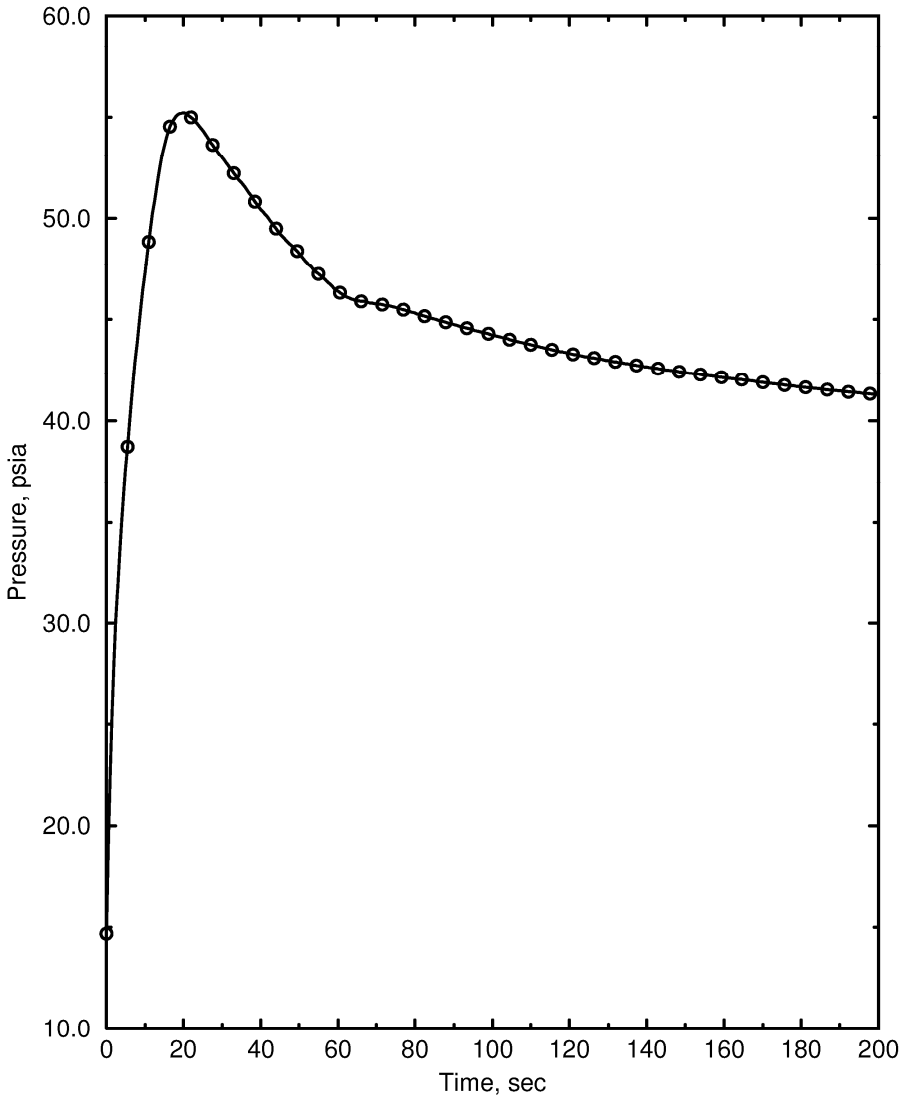


Figure 18-24—Containment Pressure



RAI-19. *Please provide validation of the calculated core inlet, outlet flow and core outlet quality information [such as Figure 15.6-32, Figure 15.6-33, and Figure 15.6-43 (pages15.6-92, 15.6-92, and 15.6-103) of the U.S. EPR Final Safety Analysis Report]. Please demonstrate that the oscillatory core flow predicated by S-RELAP during reflood is supported by experimental data such as the FLECHT experiments predictions.*

Response to RAI-19:

The purpose of the U.S. EPR RLBLOCA calculation is to demonstrate through a best estimate approach that the criteria of 10 CFR 50.46 are met with a high level of probability. As part of the RLBLOCA statistical methodology, a substantial number of parameters that affect the fluid and heat transfer solution are varied over their uncertainty ranges to resolve the statistical statement on compliance.

During the reflood phase of LOCA events, complex system oscillations occur due to quenching of the hot fuel rods and due to ECCS injection in the cold legs. The flow oscillations are caused by condensation driven oscillation, which is due primarily to the mixing of cold ECCS water with superheated steam in the cold leg, and the manometer oscillation, which is due primarily to the flow coupling between the core and downcomer regions. Boiler channel oscillations include the pressure and density wave oscillation that is attributed to the thermal-hydraulic phenomena occurring in the bundle region.

Various degrees of oscillations have been observed experimentally in test facilities (e.g., LOFT, Semiscale, UPTF, SCTF, CCTF, FLECHT-SEASET). Core flow oscillations for the LBLOCA event in the LOFT facility are shown in Figure 19-1 and Figure 19-2. The LOFT test L2-5 is a representative test to present this oscillatory behavior, but these types of flow oscillations can be seen for any of the tests reported in EMF-2103, Rev. 0.

The prediction of plant performance relies on the use of computer simulations to make the adjustment in scale from the experimental case to that of the plant. The described oscillatory behavior is observed within the computer simulations, as seen in the benchmarks provided in Figure 19-3 and Figure 19-4. The complexity of oscillations and the limitations of measurement techniques make the accurate benchmark of the magnitudes and frequencies difficult. Therefore, the capability of the simulation techniques has been established through integral effects within the experiments and benchmarks. The most obvious of these is the use of cladding or fuel temperature predictions, which, due to their heat capacity, act as integrators of the transient evolution.

The ability of the code and methodology to predict the integrated plant cooling performance is illustrated in the PCT prediction for the LOFT test L2-5, Figure 19-5 and Figure 19-6. Both the base and the biased PCT (adjusted to provide a best estimate in developmental benchmarks) conservatively envelope the data and the quench time. These figures along with benchmarks to other experiments were presented in EMF-2103. These benchmarks against data, in combination with the range of sampled parameters, demonstrate that the S-RELAP5 based RLBLOCA

methodology is capable of establishing that the criteria of 10 CFR 50.46 are met for the U.S. EPR with high probability.

The code benchmarking and statistical methodology (EMF-2103) have been reviewed and approved by the NRC.

Figure 19-1 Experimental Oscillations: Fluid Velocity at lower end box of Fuel Assembly 5

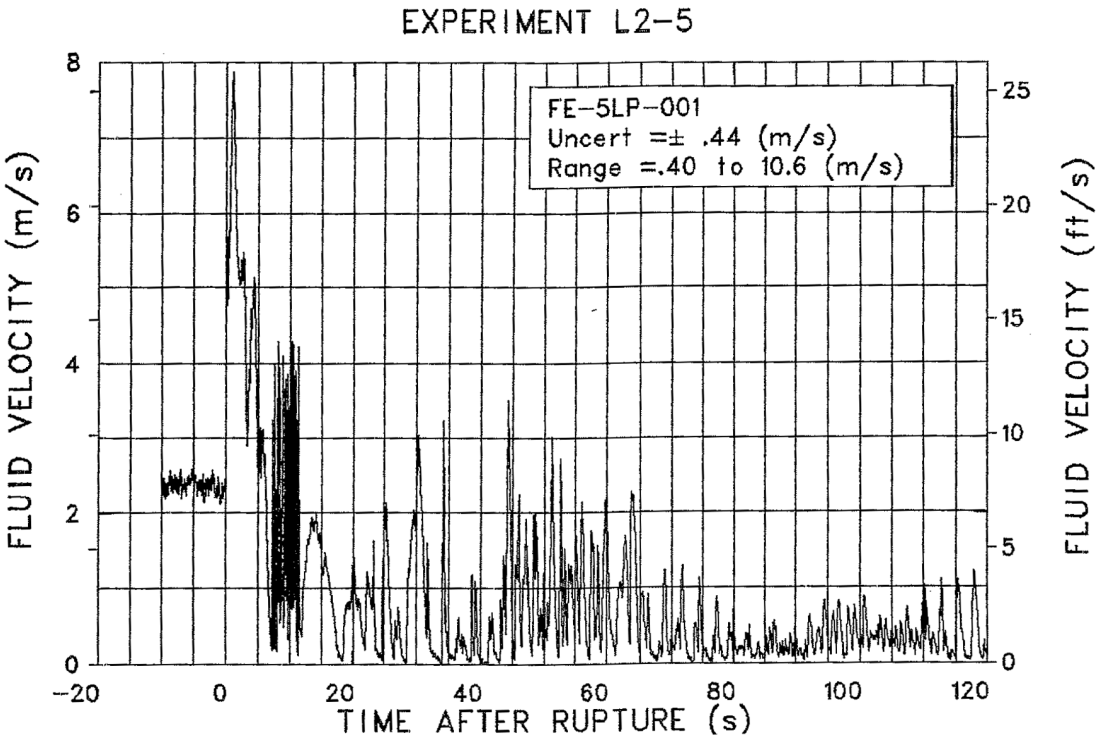


Figure 19-2 Experimental Oscillations: Fluid Velocity above end box of Fuel Assembly 5

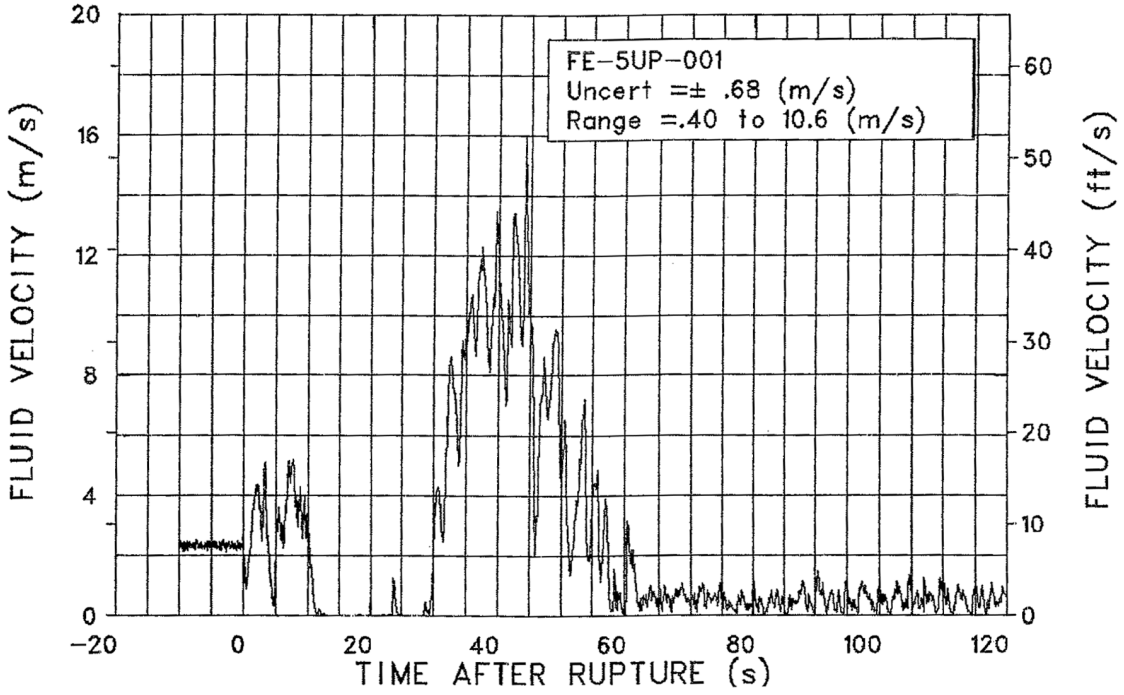


Figure 19-3—Analytical Oscillations: S-RELAP5 Calculated LOFT L2-5 Core Inlet Mass Flux

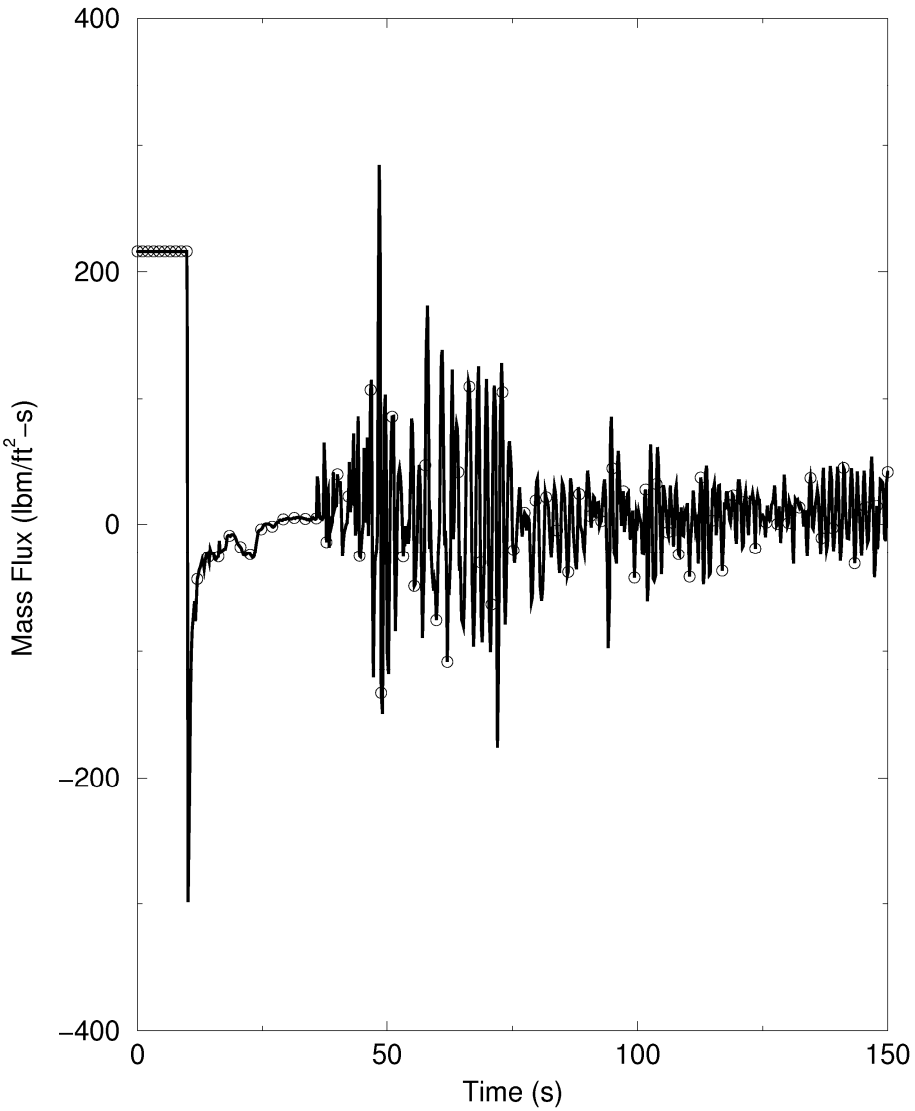


Figure 19-4—Analytical Oscillations: S-RELAP5 Calculated LOFT L2-5 Core Outlet Mass Flux

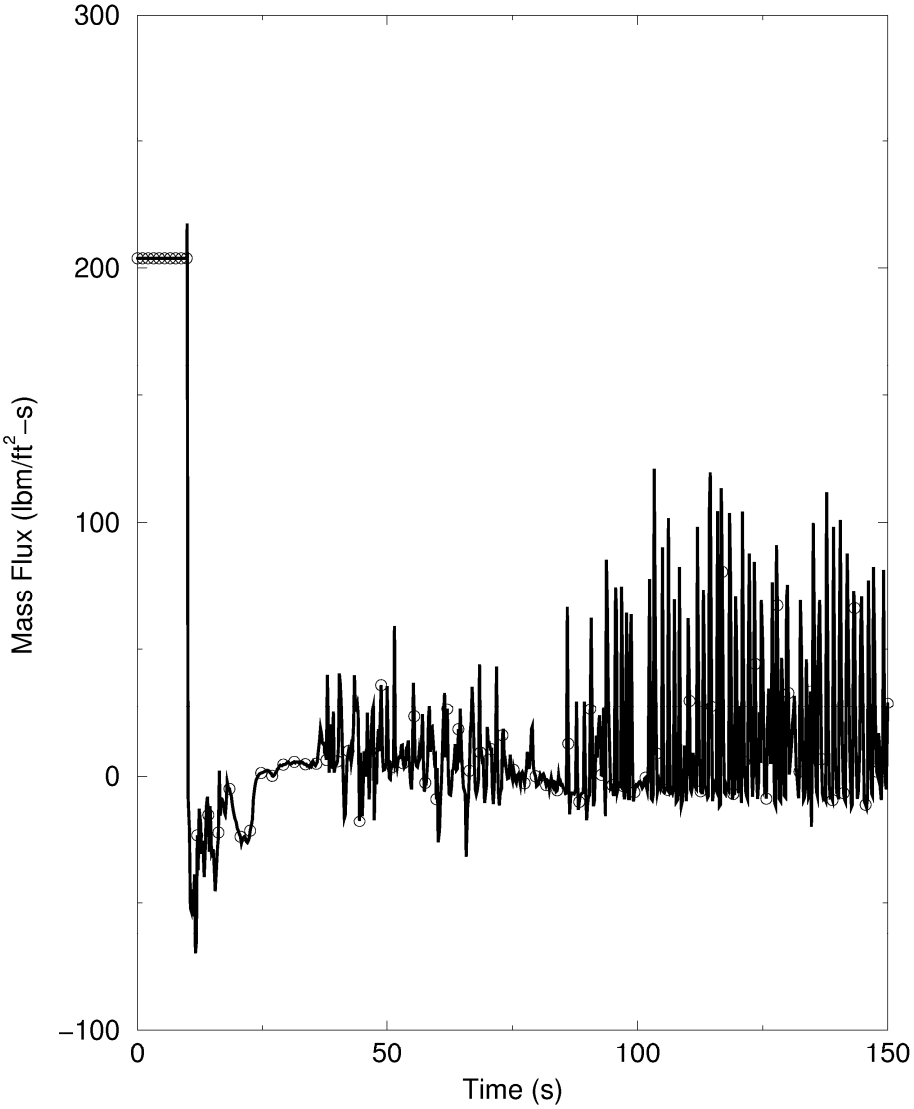


Figure 19-5—Results Comparison: LOFT L2-5 Temperatures at Measured PCT Node

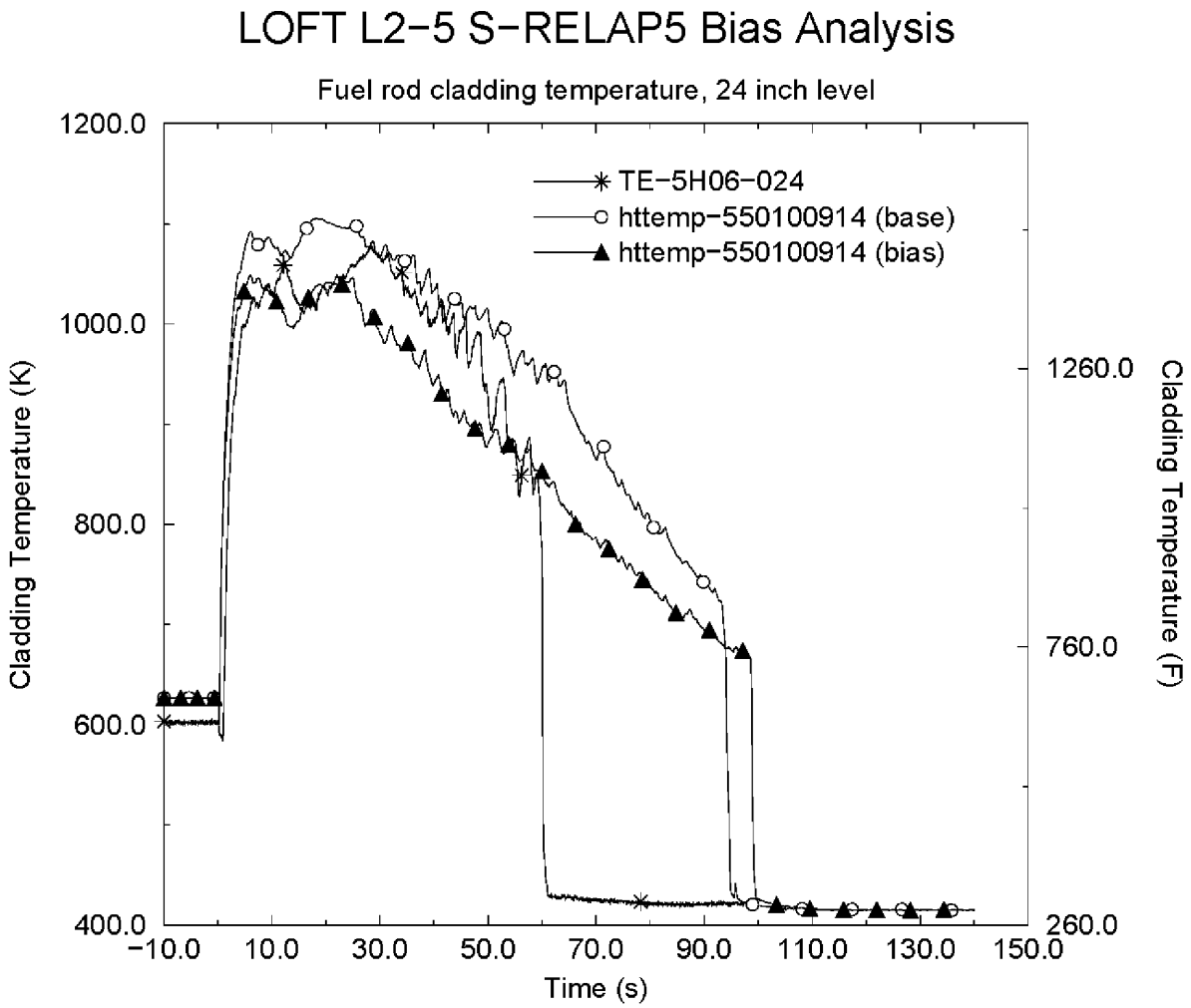
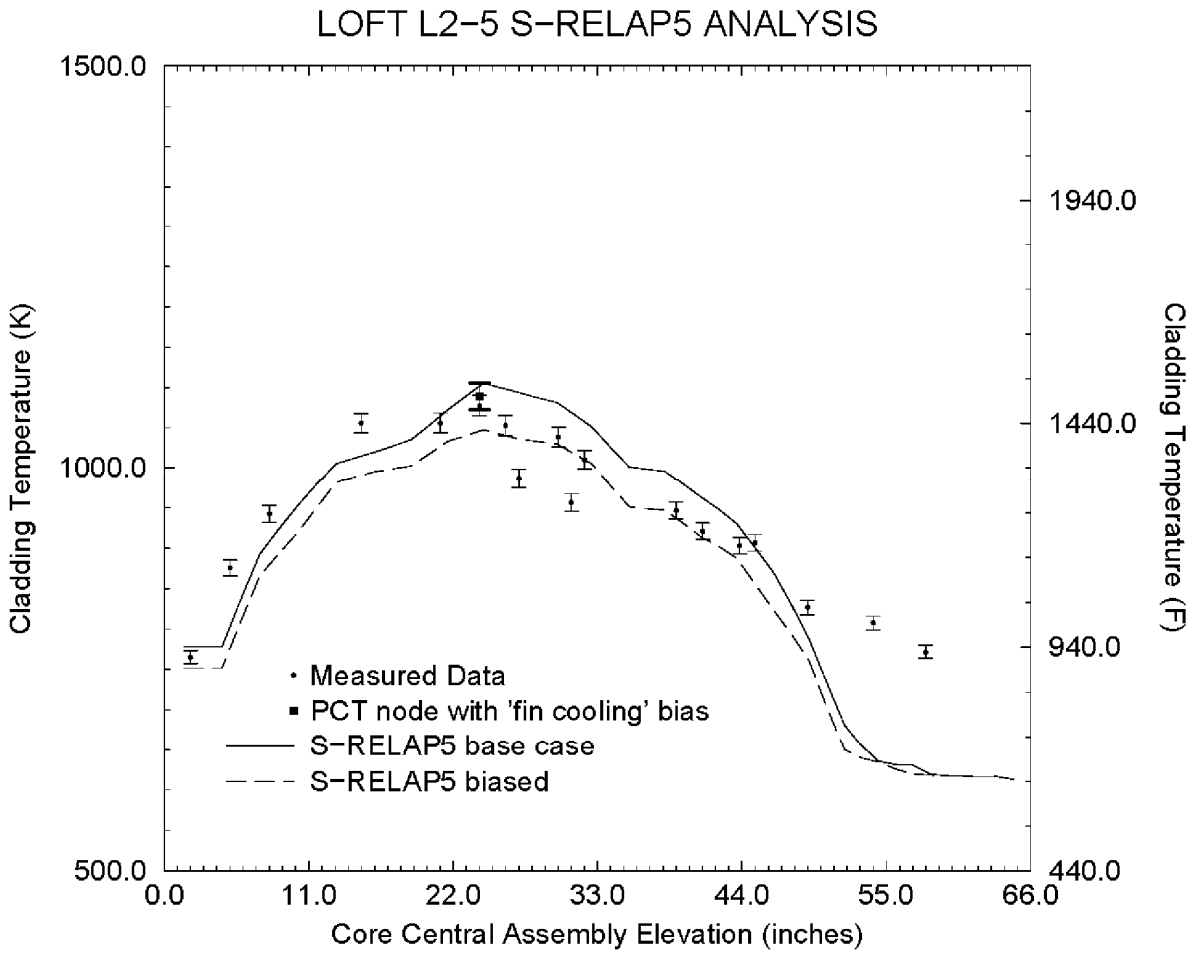


Figure 19-6—Results Comparison: LOFT L2-5 PCT Profile



RAI-20. *The S-RELAP calculation for the RLBLOCA indicates a system pressure of about 150 psi during accumulator injection phase. Please explain this phenomenon.*

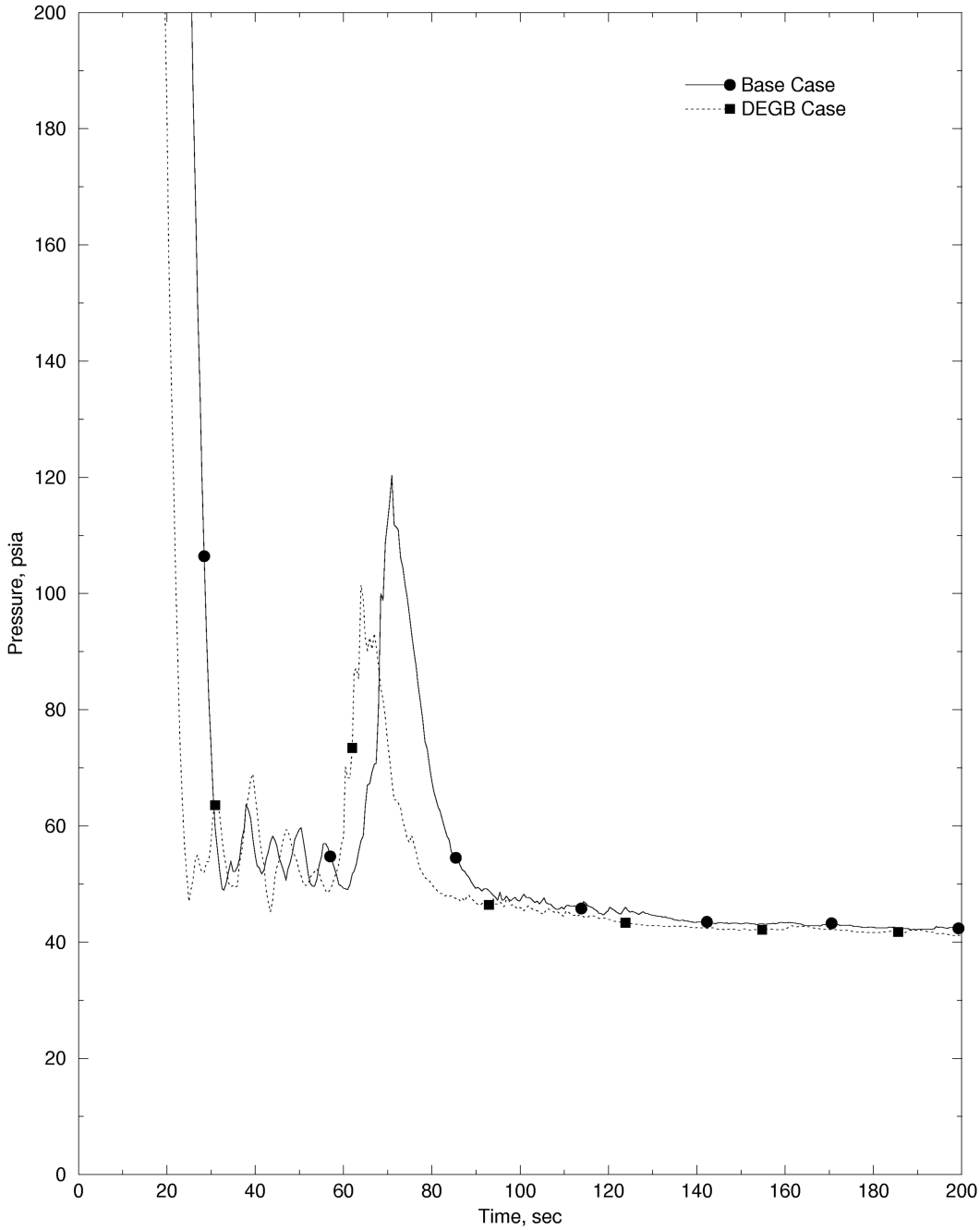
Response to RAI-20

RCS pressure for the maximum PCT case, Case 44, increases about 70 psi to 120 psia when the accumulators empty of liquid. This increase is associated with the rapid discharge of cold nitrogen from the accumulators into the RCS, which then heats and expands. The same behavior was observed in the Semiscale tests investigating this phenomenon.

NUREG/CR-4945, Section 4.1.8 describes Semiscale blowdown experiments that examined the thermal-hydraulic response to nitrogen injection following depletion of the accumulator tank liquid. As shown in Figure 23 of NUREG/CR-4945, the injection of accumulator nitrogen causes a pressure increase of approximately 0.4 MPa (60 psi) for a double-ended guillotine (DEG) cold leg break.

To assess the magnitude of the pressure increase seen in the U.S. EPR analysis against the Semiscale test result, an analysis was performed in which the break size for the maximum PCT case, Case 44, was increased from a 65% DEGB to a 100% DEGB to correspond to the Semiscale test. The result was an increase in pressure of about 50 psi to 100 psia when the accumulators emptied (see Figure 20-1). This is comparable to the 60 psi increase observed in the test and demonstrates that the increase calculated by S-RELAP5 for U.S. EPR in Case 44 is reasonable.

Figure 20-1—Sensitivity Study Upper Plenum Pressure Comparison



Revision to Previous Response to RAI-03B

RA- 03 *Regarding the information provided in Table A-3, "RLBLOCA Analysis Plant Parameter Values,"*

A. Justify the core power range in 2.1-a.
B. Explain why a single failure is not assumed for the accumulators in 2.2-g.
C. Provide an explanation for IRWST temperature in 3.0-h.

Revision to Previous Response to RAI-03B

In ANP-10278Q1, Response RAI-03B stated that the worst single failure is "the loss of one low-pressure safety injection pump. This is retained for the U.S. EPR."

The specific language used in the response is inconsistent with the RLBLOCA analyses and with the approved RLBLOCA methodology documented in EMF-2103, Rev. 0 (see page D-3). The correct wording should be the following: "Sensitivity studies reported in EMF-2103, Rev. 0 identified the worst single failure as the loss of one train of pumped ECCS injection, which, for the U.S. EPR, equates to the loss of one MHSI and one LHSI pump."

The conclusions presented in ANP-10278Q1, Response RAI-03B are unaffected by this correction.