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August 15, 2003

SUBJECT: Transmittal of Westinghouse Response to Boron Precipitation during LTC Phase

This letter transmits a Westinghouse response to U.S. NRC in regard to "Boron Precipitation during LTC Phase" that is submitted to NRC but is not assigned a DSER Open Item Number. This response is identified in the AP1000 Draft Safety Evaluation Report (DSER) in Section 15.2.7 that was issued on June 16, 2003. The response is provided as Attachment 1.

Please contact me if you have questions regarding this transmittal.

Very truly yours,

J. W. Winters, Manager
Passive Plant Projects & Development
AP600 & AP1000 Projects

/Attachment

1. Westinghouse Non-Proprietary Response to US Nuclear Regulatory Commission DSER Open Items, "Boron Precipitation during LTC Phase," dated August 15, 2003

D063

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DCP/NRC1612
Docket 52-006

August 15, 2003

Westinghouse Non-Proprietary Response to DSER Open Item:

"Boron Precipitation During LTC Phase"

DSER Open Item Number: None Assigned, See Below

Original RAI Number(s): na

Summary of Issue:

Section 15.2.7 of the DSER says:

> With regard to the boron precipitation issue, the results presented in DCD transient analysis (1) did not quantify the amount of water exiting the vessel; (2) there was no clear indication of void distribution in the core; (3) did not characterize the water-steam mixture flow regime in the ADS-4; and (4) did not minimize the steam velocity through the ADS-4. At the staff's request, the applicant presented a more conservative case by assuming that all ADS-4 valves are open and the containment pressure is at a maximum. In addition, the applicant presented a qualification of the WCOBRA/TRAC model regarding ADS-4 water-steam flow (RAI responses to 440.091, Revision 1). The staff reviewed this information and (as stated above) found that there is adequate justification for the WCOBRA/TRAC ADS-4 flow model. The applicant demonstrated that the flow regime is the same as in AP600 (annular flow) which would entrain fluid particles to expel water from the vessel as required to avoid boron concentration in the vessel and/or precipitation. The amount of water to be removed from the core was quantified. In addition, literature was cited regarding flow regimes applicable to the conditions of the ADS-4 which reinforced the credibility of the results.

However, based on discussions at the May 29, 2003 meeting with the NRC additional concerns were identified. From NRC meeting minutes letter NRC/DCP1312, 7/15/03:

> Westinghouse presented an analysis demonstrating that adequate entrainment of liquid out ADS-4 would occur to prevent boron precipitation during late stages of the LTC phase. The staff does not agree with Westinghouse's assertion that entrainment would occur indefinitely and requests that the time at which measures should be taken to flush the core be determined and those measures be described.
>
> As the core cools, the increase in coolant boric acid concentration is arrested. However, a high boric acid concentration remains in the core many hours into the event. Westinghouse must demonstrate that as the core becomes increasingly subcooled, these high boric acid concentrations will not result in boron precipitation in the core and that the analysis takes into consideration the effect of coolant temperature on boron solubility. Westinghouse should also demonstrate that the concentrations in the sump also do not approach precipitation limits at the maximum sump temperature subcoolings.
>
> Westinghouse should also address the possible collection of boric acid crystals on the ADS-4 valves and exit piping as these equipment components cool during the event. Justification should be provided to discount the possibility for the ADS-4 valves/piping to become obstructed with boric acid crystals many hours into the event.

Westinghouse Response:

The response to these issues is provided in attachment 1 to this open item response. Attachment 1 is an evaluation of the boron concentrations in the AP1000 in the long-term following a LOCA. Section 2 of this report provides an analysis of the minimum capability of the AP1000 to vent borated water out of the RCS after a LOCA. Section 3 of this report determines the maximum boron buildup in the core considering the minimum capability of the AP1000 to vent water. Section 3 also provides justification that:

- Precipitation of boron in the core is not caused by injection of colder water from the PXS or the containment throughout the transient.
- Precipitation of boron in the containment is not caused by cool down of the containment.
- Precipitation of boron does not occur inside the ADS-4 line and cause obstruction of the flow path.

A new section will be added to the DCD (section 15.6.5.4C.4) to provide more discussion of the analysis that has been performed which demonstrates that the boron concentration will not buildup excessively in the AP1000 during a LOCA.

Design Control Document (DCD) Revision:

The following is a new DCD section that will address the core boron concentration following a LOCA. The current DCD section 15.6.5.4C.4 will become 15.6.5.4C.5.

15.6.5.4C.4 Long-Term Core Boron Concentration

For AP1000, water carryover out the ADS stage 4 lines limits the potential core boron concentration buildup following a cold leg LOCA. The higher the ADS stage 4 vent quality, the higher the core boron concentration buildup. Analyses have been performed to bound the maximum core boron concentration buildup.

These analyses demonstrate that highest ADS stage 4 vent qualities result from the following:

- Highest decay heat levels
- Lowest PXS injection / ADS 4 vent flows, including high line resistances and low containment water levels.

The LTC analysis discussed in DCD section 16.6.5.4C.2 is consistent with these assumptions. The ADS stage 4 vent quality resulting from this analysis is less than 40% at the beginning of IRWST injection and reaches a maximum of less than 50% around the initiation of recirculation. It decreases after this peak, dropping to a value less than 8% at 14 days.

With high decay heat values, the ADS stage 4 vent flows and velocities are high. These high vent velocities result in flow regimes that are annular out through at least 14 days and slug/churn after that time. Such flow regimes can move water up and out the ADS stage 4 lines. These flow regimes are based on the Taitlel-Dukler vertical flow regime map. Lower decay heat levels can also be postulated later in time or just after a refueling outage. Significantly lower decay heat levels result in lower ADS stage 4 vent qualities. They also result in ADS stage 4 vent flows / velocities that are much lower. With very low ADS 4 vent flow velocities, the AP1000 plant will operate as a manometer. The small amount of steam generated in the core is sufficient to reduce the density of the steam/water mixture in the ADS stage 4 line and allow the injection head to push the steam/water mix out the ADS stage 4 line. The limiting condition for core boron buildup is with high decay heat that leads to the highest ADS stage 4 vent qualities.

With the maximum ADS stage 4 vent qualities, the maximum core boron concentration peaks at a value less than 7400 ppm at the time of recirculation initiation. After this time, the core boron concentration decreases as the ADS stage 4 vent quality decreases, reaching 5000 ppm about 6 hours after the accident. The core boron solubility temperature reaches a maximum of 58 F (at 7400 ppm) and quickly drops to 40 F (at 5000 ppm). With these low core boron solubility temperatures, there is no concern with cold PXS injection water causing boron precipitation in the core. With the IRWST located inside containment, its

water temperature is normally expected to be above these solubility temperatures. The minimum core inlet temperature is greater than 120 F considering the minimum IRWST temperature permitted by the Technical Specifications (50 F) and the heatup of the injection by steam condensation and pickup of sensible heat from the reactor vessel, core barrel and lower support plate.

The boron concentration water in the containment is initially about 2980 ppm. As the core boron concentration increases, the containment concentration decreases slightly. The minimum boron concentration in containment is greater than 2950 ppm. The solubility temperature of the containment water at its maximum boron concentration is 32 F.

PRA Revision:

None

Attachment 1: AP1000 Long Term Boron Concentration Evaluation

1.0 Background

The evaluation in Section 2 determines the minimum capability of the AP1000 to vent water out of the RCS through the ADS stage 4 lines following a cold leg LOCA and thereby limit the buildup of boron in the core region. In addition, the maximum core boron concentration is determined in Section 3 as a function of time. Section 3 also addresses the potential for boron precipitation in the core and containment as decay heat levels decrease and the core / containment cool down. Finally, Section 3 also addresses the possibility of boric acid crystals forming in and obstructing the ADS 4 lines.

2.0 Capability of AP1000 to Vent Water After a LOCA

The AP1000 PXS injection is provided through a cold leg direct vessel injection (DVI) line. With this injection arrangement, the boron concentration will tend to buildup in the core region following a cold leg LOCA. This buildup is limited by the ability of the ADS stage 4 valves to vent water from the RCS following their opening. This venting of water continues in the long-term during IRWST injection and containment recirculation operation. Figure 1 shows a simplified sketch of the AP1000 PXS. Figure 2 shows a section view of the containment illustrating the long-term cooling operation following a LOCA. This figure illustrates the LTC flow path from the water in the containment, through the PXS recirc lines into the reactor vessel via the DVI connections, with venting of steam / water out the ADS 4 lines.

The following provides an evaluation of the amount of water that will be vented through this path. Consideration is given to variations in plant parameters and assumptions that could affect the venting of water.

A simplified model has been developed to provide an estimate of the ADS 4 vent quality under specific conditions. Although the model is a steady state model, it has been exercised at different times to provide the ADS 4 vent quality as a function of time.

The simplified model considers the plant operation during containment recirculation conditions, starting as early as several hours after a LOCA out through many days / weeks. The model calculates the PXS injection / ADS 4 vent quality that will remove core decay heat. The model is setup to calculate a conservatively high quality in order to minimize the ADS 4 water removal and therefore maximize the core boron buildup.

Simplified LTC model assumptions:

1. Energy balance is applied such that PXS injection / ADS 4 venting removes decay heat. Sensible heat from the reactor metal components is assumed to have been removed by the time this analysis starts several hours after the LOCA.
2. Mass balance is applied such that PXS injection equals the ADS venting. Although OSU testing and WCOBRA-TRAC analysis both indicate that the flows tend to be cyclical, this calculation approach should approximate the actual performance using average flow rates.
3. ADS 123 flow is assumed to be insignificant relative to the ADS 4 flow. This assumption is considered reasonable and conservative. It is reasonable since in the long-term the HL tends to be filled by the PXS which cuts off the path to the Pzr. In addition, it is conservative since its operation would reduce the ADS vent pressure loss which would allow more PXS injection and result in a lower ADS 4 vent quality.
4. The downcomer is assumed to be filled up to the DVI connection. The fluid elevation heads are tracked from the containment water level down through the downcomer to the bottom of the core, up through the core and the ADS 4 vent lines. WCOBRA-TRAC analysis indicates that this is a good assumption for the time frame of interest for this calc (days/weeks).
5. The core exit quality is assumed to be equal to the ADS 4 vent quality with an adjustment to account for the higher pressure at the core exit. The core exit pressure is higher because of the head of steam / water in the upper plenum / HL. Since the core exit pressure is higher, the core exit quality will be slightly lower.
6. The region above the core up to the top of the hot legs is assumed to be filled with water except for the steam venting from the core. The steam is assumed to bubble up through this water. The bubble rise velocity is calculated to determine the resident time and the effective quality in this region. This assumption increases the backpressure on the PXS injection which tends to reduce the PXS injection flow and increase the ADS 4 quality.
7. The ADS 4 line pressure drop is calculated using a 2-phase flow multiplier. The multiplier is the maximum of Homogeneous and Martinelli-Nelson as shown in Table 1. This multiplier is applied to the resistance of the line which includes the f L/D for entrance/exits, straight pipe, elbows, tees, and valves (everything except velocity head and elevation head).
8. The velocity head differences are included in the calculation for the ADS 4 line. The HL velocity is assumed to be negligible. The velocity at the ADS 4 line discharge is taken at the ADS 4 valve minimum inside diameter. Homogeneous flow conditions are assumed.
9. Flow pressure losses are ignored in the reactor between the DVI discharge point and the ADS 4 inlet point. This is reasonable considering the relatively low flows that exist in these later times and the large flow areas in these sections compared to the PXS injection lines and the ADS 4 vent lines.
10. The 2-phase flow regime is determined at the entrance to the ADS 4 lines where they connect to the HL. This location is considered limiting because the orientation is vertical with upward flow and the velocities at this point are less than those in the individual ADS 4 lines. As a result, if the water can be lifted into the ADS 4 inlet the water will be more easily

pushed out the individual, horizontal ADS 4 lines. The Taitlel-Dukler vertical flow regime map (Figure 3) is used to determine the flow regime in the ADS 4 inlet lines.

Inputs provided to the model:

1. Containment pressure is taken from WGOTHIC analysis performed to determine the minimum containment pressure possible after a LOCA. Sensitivity studies are done to evaluate higher containment pressures.
2. The partial pressure of steam in the containment is calculated by hand as a function of the total containment pressure.
3. The PXS recirc and ADS 4 line resistances are taken from the maximum, best estimate, and minimum values that have been established for the AP1000. In addition, for maximum line resistance cases "resident" debris is assumed to be transported to the recirc screens and add to their pressure drop. For BE resistance cases the debris DP is assumed to be 50% of the maximum value. For Min resistance cases the debris DP is assumed to be zero.
4. The maximum decay heat is based on the AP1000 operating at 101% power and Appendix K decay heat values. Best estimate and minimum decay heat values are also evaluated. Best estimate decay heat is based on operation at 100% power and ANS'79 plus 0 sigma margin. Minimum decay heat is based on 2/3 of a core having operated at 100% power and shutdown for 20 days (for refueling) and ANS'79 minus 2 sigma margin.
5. The containment water level is determined by hand calculation. This calculation applies margins/conservatisms to the containment volumes and the water supply volumes as well as the break location. A DVI break in a PXS room results in more of the containment flooding and a lower containment water level. In addition, in the very long-term (days/weeks) the containment level decreases as rooms (PXS rooms and CVS) that didn't initially flood, flood due to leakage.

The calculation method is iterative. An ADS 4 vent quality is guessed. The PXS injection flow is then calculated based on the energy balance. The pressure drop through the system is calculated. The ADS 4 discharge pressure is compared with the containment pressure. If the ADS 4 discharge pressure is higher, then the ADS 4 vent quality is reduced. This results in an increase in the injection / vent flows, an increase in the pressure losses in the lines and a decrease in the ADS 4 discharge pressure. Table 2 illustrates this process. Case 1a has an ADS 4 vent quality that is too high (20%) for this set of conditions and results in an ADS 4 discharge pressure that is greater than the containment pressure (27.4 psia > 24.4 psia). Case 1b has an ADS 4 vent quality that is too low (3%) which results in a ADS 4 discharge pressure that is less than the containment pressure (21.1 psia < 24.4 psia). Case 1c has an ADS 4 vent quality (7.7%) which results in an ADS 4 discharge pressure that equals the containment pressure. The difference between these pressures is shown in Table 2 as the "Calc Error (ADS4 pres – cont pr)" and is very small (8.5E-7). In addition, this result was compared with the COBRA-TRAC LTC analysis (Ref. 5.1) performed at this same time (14 days). The COBRA-TRAC analysis was also performed with maximum decay heat and maximum

PXS line resistances. The ADS 4 vent quality calculated in WCOBRA-TRAC is 7.5%, which is slightly less than the result from the simplified hand calculation.

A number of sensitivity cases have been made to determine the conditions / inputs that result in the highest ADS 4 vent qualities. Table 3 shows a sample of these cases. This table demonstrates that maximum decay heat and minimum PXS flow capability result in the highest ADS 4 vent qualities. The highest ADS 4 vent quality (Case 2) is achieved with:

- Max decay heat
- Min containment flood level
- Max containment pressure
- Max PXS line resistances

Another issue of concern is the ability of the plant to move water out the ADS 4 line. To evaluate this concern, three sets of analysis were performed. These analyses were performed as a function of time using the following three sets of inputs:

	Max Quality	BE Quality	Min Quality
• Decay heat	Max	BE	Min
• Cont flood level	Min	BE	Max
• Cont pressure	Max	BE	Min
• PXS line resis	Max	BE	Min

For each analysis, the ADS 4 vent quality and the flow regime at the inlet to the ADS 4 line is shown in Table 4. For the maximum quality set, the ADS 4 flow regime is annular out through 14 days and then changes to slug/churn. For the best estimate quality set, the ADS 4 flow regime is annular out through 1 day, is slug/churn out through 14 days and then changes to slug flow. The minimum quality set has bubble flow from early on; the main driver for this is the very low decay heat assumed (just after refueling).

For the maximum and best estimate sets, the flow regime (annular, slug/churn, slug) is sufficient to move the water out the ADS 4 flow path. However, for the minimum set it is not obvious that bubble flow can move water out the ADS 4 vent.

Figure 4, illustrates how the plant will operate with very low decay heat / steam flow rates typical of the minimum quality set of cases. There is sufficient head available from the containment water / downcomer water to push the steam / water mix into the ADS 4 line. The steam flow in the ADS 4 line serves to displace water and reduce the density of the mixture. This displacement allows the system to work as a manometer. As a result, even in these minimum decay heat cases with very low steaming rates, the plant will be able to move water out the ADS 4 line and limit the buildup of boron.

In conclusion, the limiting case for boron concentration in the AP1000 core following a LOCA is with maximum decay heat and minimum PXS flows. Table 4 shows the maximum ADS 4 vent quality as a function of time. The ADS 4 vent qualities used for the earlier times are taken from the WCOBRA-TRAC LTC analysis (Ref. 5.1). This analysis indicates that the ADS 4 vent quality will vary from about 40% during the initial IRWST injection and to about 50% when containment recirculation begins. To add conservatism, the ADS 4 vent quality is assumed to be 60% out through recirculation start and then decrease to 29% at 12 hours. The ADS 4 vent qualities from 12 hours and later are based on the simplified hand calculation. The ADS 4 vent qualities in Table 4 are used in section 3.0 to calculate the maximum core boron concentration buildup in the AP1000.

3.0 Post-LOCA Core Boron Concentration Buildup in AP1000

The purpose of this evaluation is to calculate the maximum boron concentration buildup in the AP1000 core following a cold leg LOCA. Water leaving the RCS through ADS stage 4 limits the buildup of boron in the core following a cold leg LOCA. The minimum amount of water occurs with the maximum ADS 4 vent quality, which is taken from the results of section 2 of this report, as shown in Table 4.

The analysis of the boron concentration in the core is based on the following assumptions:

1. The core is assumed to only mix with the water in the upper plenum. A minimum mass of 27,490 lb is used in this analysis. This mass is based on WCOBRA-TRAC analysis (Ref. 5.1).
2. The only boron that leaves the core is that carried out of the RCS in water in the ADS 4 vent flow. Because of the low volatility of boron, very little boron will be present in the vapor phase. Based on test results (ref. 5.2), the amount of boron present in the vapor phase is only about 1% of the concentration of boron in the water. This data is applicable to water that is partially neutralized with lithium hydroxide (typical PWR practice). For the purposes of calculating the maximum core boron concentration, the volatility of boron is ignored.
3. The maximum initial post accident boron concentration is calculated based on the following:
    - RCS – minimum volume, maximum boron concentration
    - CMTs, Accumulator, IRWST – maximum volume and boron concentration
    - BATs, Cask Loading Pit - maximum volume and boron concentration

   The minimum RCS volume is used because its maximum concentration is less than the concentration after mixing with the other volumes. The BATs (both) are assumed to be injected by the CVS makeup pumps and the Cask Loading Pit is assumed to be injected by the RNS pumps. Although neither the CVS nor the RNS pumps are safety related, their operation is likely and it makes the initial mixed boron concentration higher.

For design purposes, the maximum core boron concentration is set at 35,000 ppm. The basis for this concentration is the solubility limit at a temperature of 180 F. This temperature was selected to conservatively bound the minimum boiling temperature of 212 F.

The core concentration starts at about 2980 ppm and reaches a maximum value of 7400 ppm in about 2.4 hours. By 6 hours the concentration has dropped below 5000 ppm. Figure 5 shows the calculated AP1000 core boron concentration as a function of time. This figure also shows the solubility temperature of the boron solution in the core. When the core is at its maximum concentration of 7400 ppm the solubility temperature is 58 F. The core inlet temperature will be well above this temperature based on several considerations.

First the IRWST is located inside containment and is expected to normally be above this temperature, although the Technical Specifications allows the IRWST to be as cold as 50 F. Second, the IRWST injection water will heatup significantly between the time it enters the RCS and the time it enters the core region, especially in this earlier time frame. IRWST flow will heat up because it sprays through steam as it drops down from the DVI injection connection to the water level in the downcomer. The IRWST water also heats up because it comes in contact with the hot metal surfaces of the reactor vessel, the core barrel and the core support plate. The LTC WCOBRA-TRAC analysis (Ref. 5.1) shows that the minimum heatup of the IRWST water is 70 F (120 F to 190 F) during the initial IRWST injection phase. This analysis also shows that the temperature of water entering the core gradually increases to about 240 F as the IRWST drains. This further increase is due to a reduction in the IRWST flow (as the IRWST water level decreases) and IRWST heat up due to ADS stage 1/2/3 operation. Even with only a 70 F heatup and the minimum Tech Spec IRWST temperature of 50 F, the minimum core inlet temperature would be 120 F. This temperature is comfortably above the solubility temperature of 58 F. After recirculation starts, the margin becomes even greater because of the increase in the injection water temperature and because the solubility temperature begins to decrease (as the quality decreases).

Note that later on in the IRWST injection phase, as the IRWST level decreases, the IRWST injection temperature will increase. This increase is due to ADS 1/2/3 operation and to steam condensation returned to the IRWST by the gutter. For a DVI LOCA the ADS 1/2/3 operation admits less mass / energy into the IRWST because of the rapid sequencing of the ADS 4 valves. For a DVI LOCA the top portion of the IRWST is calculated to heatup ~ 20 F. Note that ADS 1/2/3 operation is only assumed to affect the top portion of the IRWST from the bottom of the sparger up. This hotter IRWST water is calculated to start entering the RCS at about 2.2 hours after a DVI LOCA.

The boron concentration of the water in the containment is initially about 2980 ppm. As the core boron concentration increases, the containment concentration decreases slightly. The minimum boron concentration in containment is about 2960 ppm. The solubility temperature of the containment water at its maximum boron concentration is 32 F.

No buildup of boron is expected in the RCS hot legs and ADS 4 vent paths because these areas always see a flow of hot water and steam. Note that although the hot water contains boron, its concentration is far below the solubility limit; when the core is at its maximum boron concentration of 7400 ppm the water is capable of holding about 80,000 ppm boron (at 240 F). Even assuming that the inside surface of the ADS 4 piping is at the containment temperature of 176 F, the water could still hold 33,000 ppm boron. Boron in the steam will be at a much lower concentration (about 1% of that in the water, or about 74 ppm in this case). The only way that the boron in the steam could plate out would be for the steam to be condensed and then have the water evaporate. Such a process could not happen inside the ADS piping with the continued high flow of hot water.

4.0 Summary and Conclusions

The maximum ADS stage 4 vent quality has been calculated in a conservative fashion. A quality of 60% bounds the ADS 4 vent quality out through the start of containment recirculation. After that time the quality decreases eventually dropping to less than 8% after 14 days. With high decay heat levels, the resulting velocities in the ADS 4 vent lines are capable of carrying water out these lines; the flow regime is annular or slug flow. With low decay heat levels (later in time or after a refueling outage), water is pushed out the ADS 4 lines using a manometer mode of operation.

The maximum core boron concentration will be less than 7,400 ppm using the maximum ADS 4 vent quality and the maximum initial core / containment boron concentrations. This core boron concentration is far below the solubility limit (35,000 ppm). In addition, the solubility temperature (58 F) at the maximum boron concentration is significantly lower than the minimum core inlet temperature (120 F). In addition, the core boron concentration quickly drops to lower values (less than 5000 ppm in 6 hours) which further increases margin.

There is no mechanism to cause boron to plate out inside the RCS or ADS 4 lines and adversely affect core cooling or the limiting of the core boron concentration buildup.

5.0 References

5.1 AP1000 DCD, Section 15.6.5.4C, Post-LOCA Long Term Cooling

5.2 Byrnes, D.E., "Some Physicochemical Studies of Boric Acid Solutions at High Temperatures", WCAP-3713 (Proprietary), September 1962

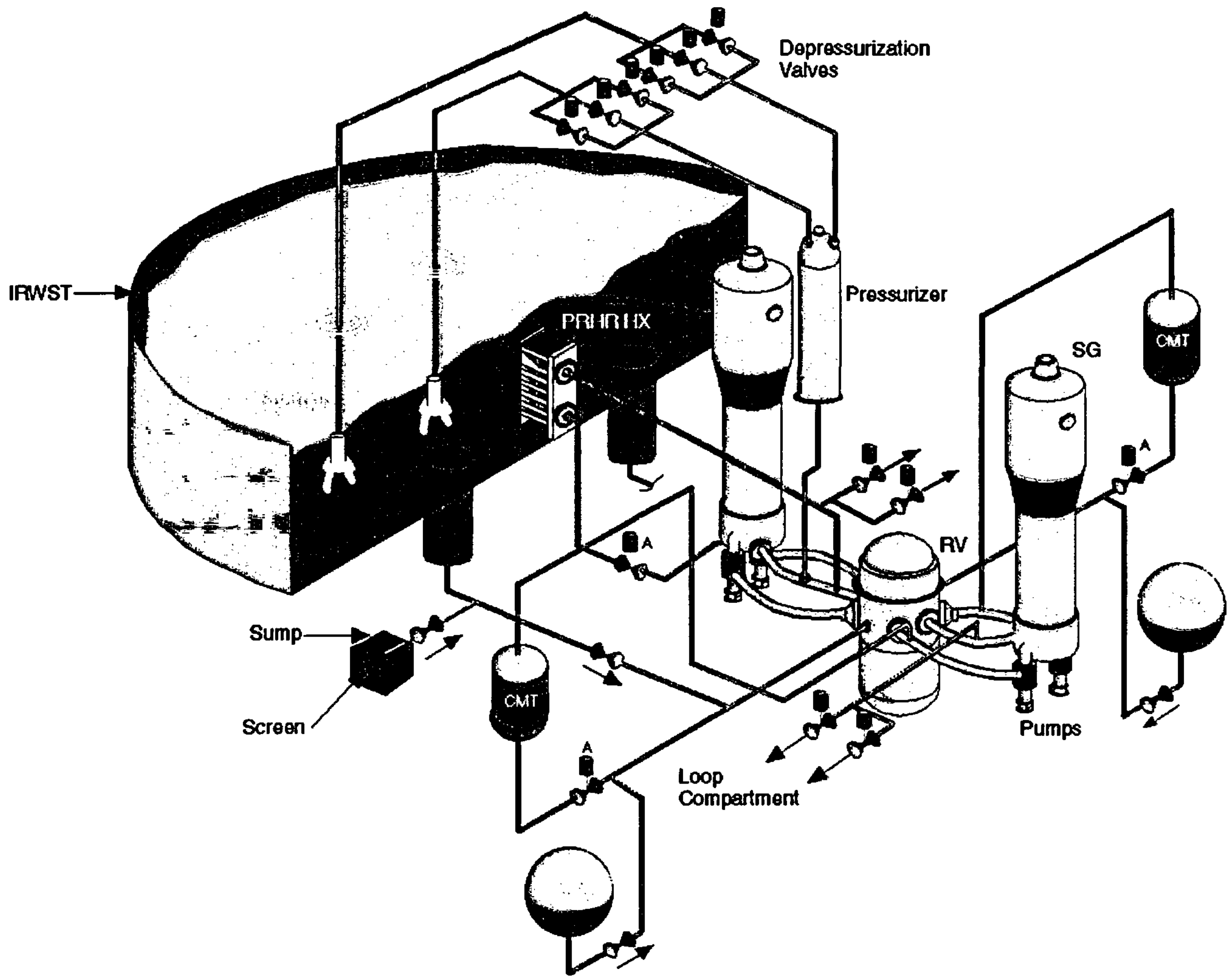

Figure 1 – AP1000 PXS System Sketch

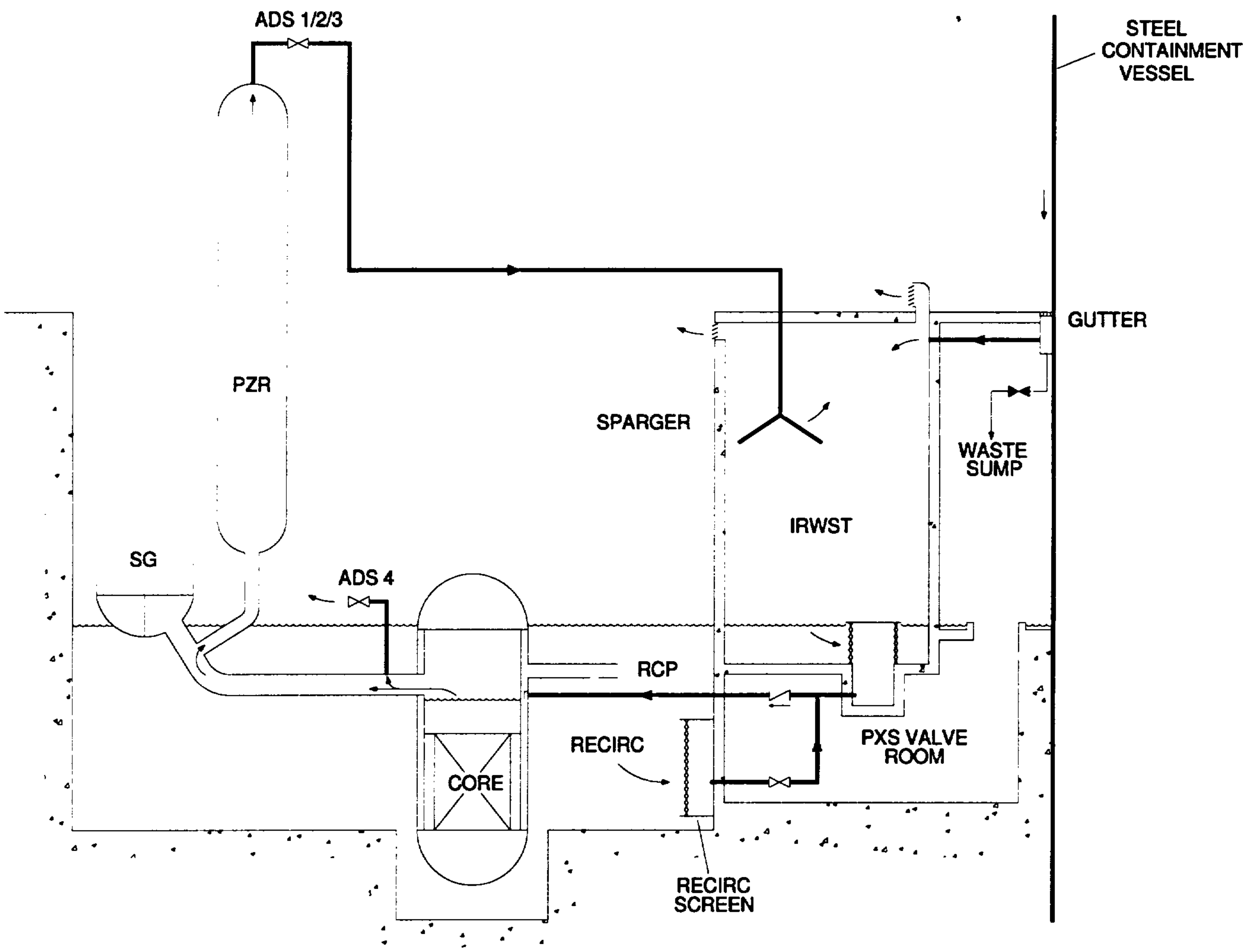

Figure 2 – AP1000 Long-Term Cooling Post LOCA

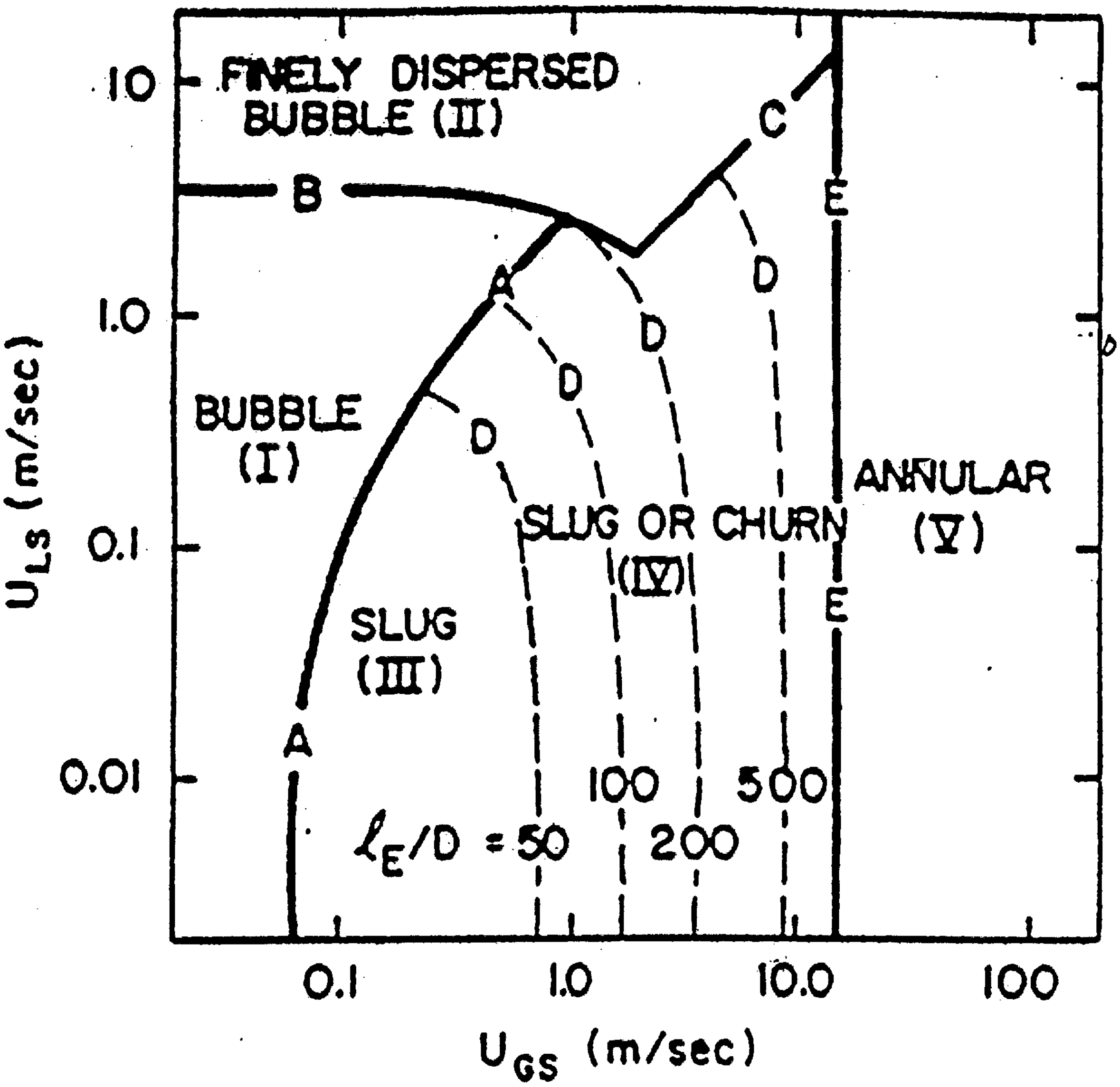

Figure 3 – Vertical Flow Regime Map (Taitlel-Dukler)

	(ft)	(lb/ft³)	(psi)	(ft)	(lb/ft³)	(psi)	
ADS 4	9.46	9.30	0.61				
HL	8.32	58.88	3.40	3.74	61.49	1.60	PXS
Core	14.00	60.19	5.85	19.36	61.49	8.27	RV
			9.87			9.87	

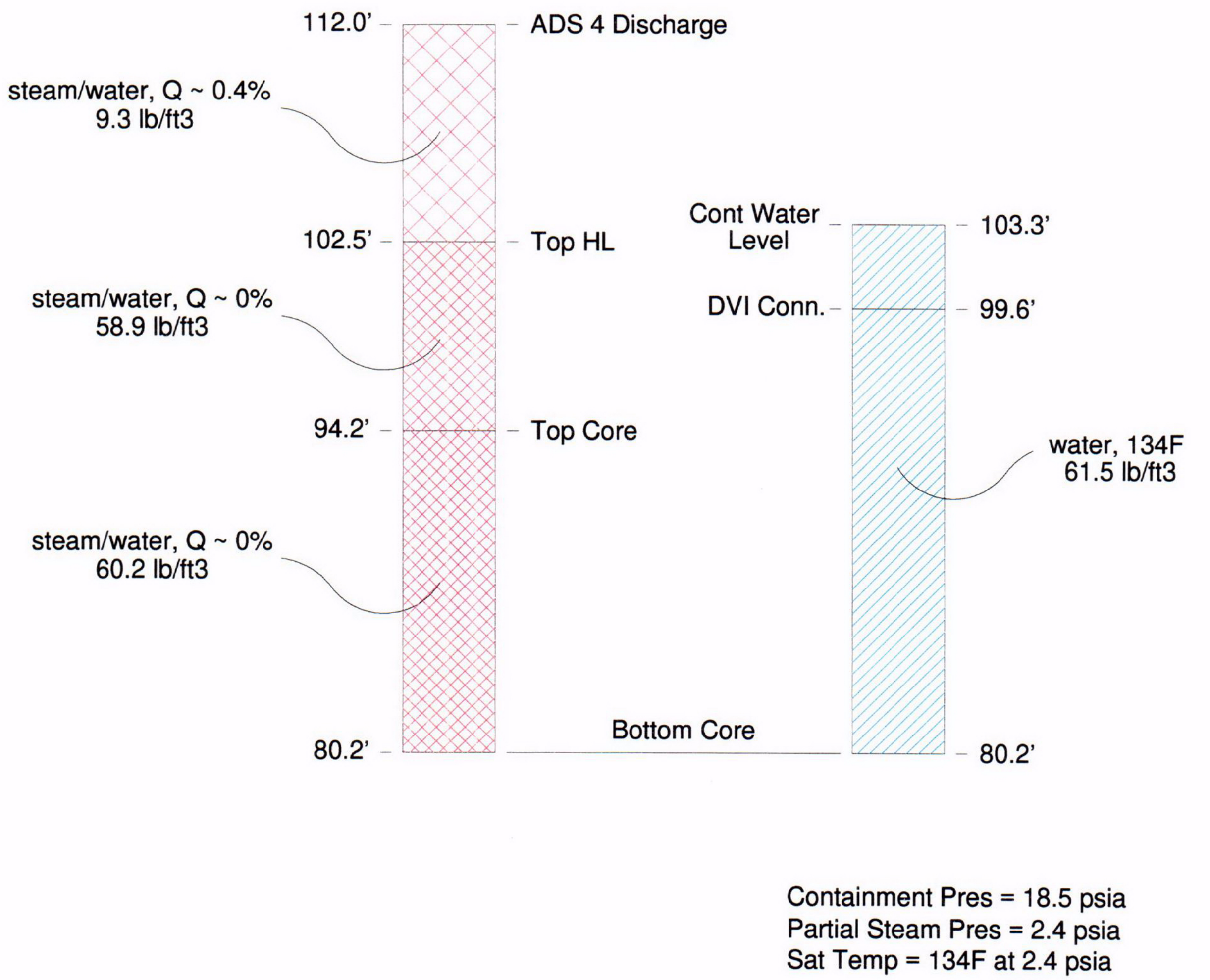

Figure 4 – Long-Term Cooling With Very Low Decay Heat

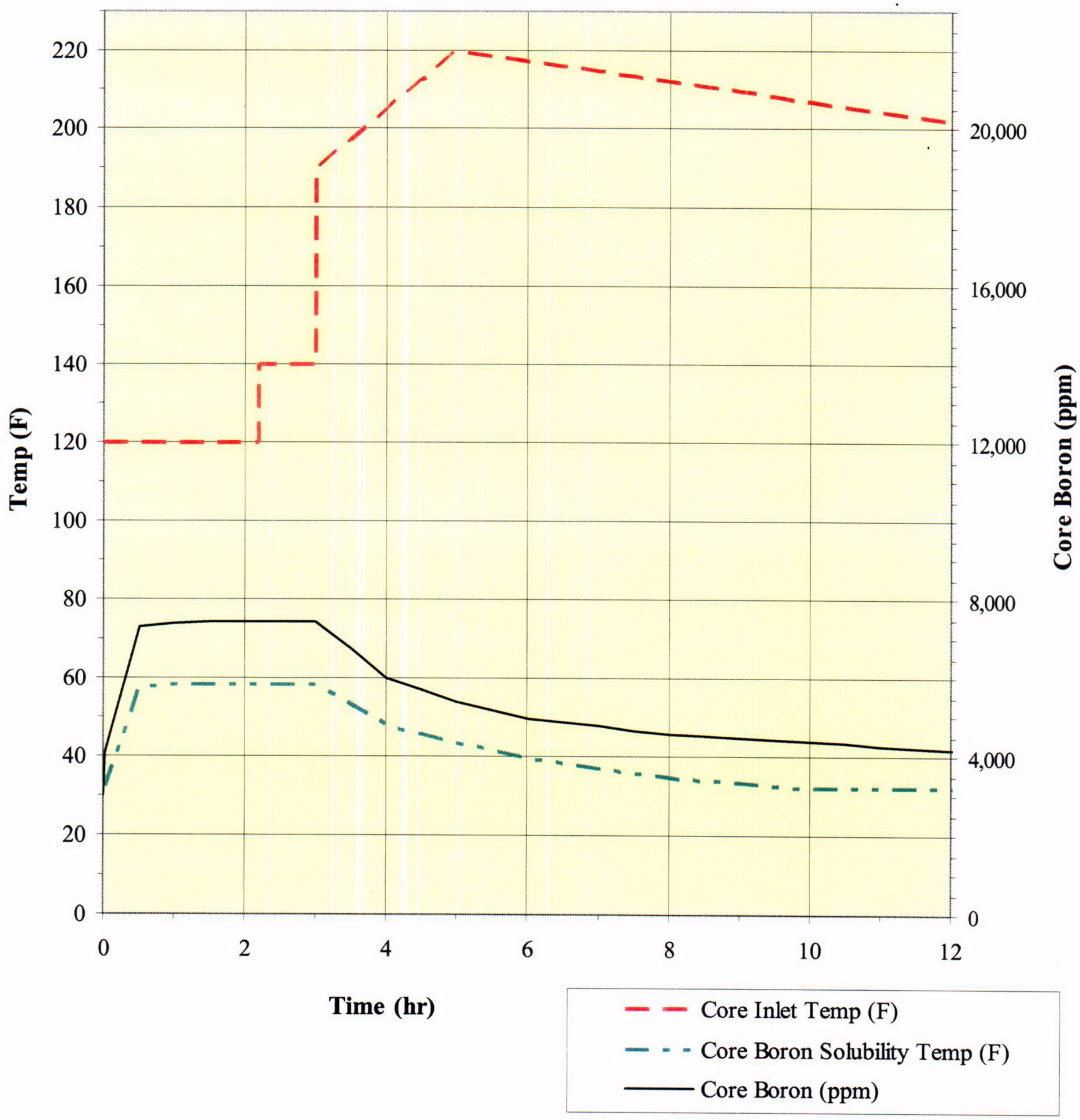

Figure 5 – AP1000 Post LOCA Boron Concentration

Note: This figure uses a conservative maximum ADS 4 vent quality based on WCOBRA-TRAC and hand calculations. The quality is 60% for the first 3 hours and then decreases.

Steam Quality	Pressure (psia)							
	14.7	100	500	1000	1500	2000	2500	3000
1%	16.2	3.5	1.8	1.6	1.4	1.2	1.1	1.1
5%	67.0	15.0	5.3	3.6	2.4	1.8	1.4	1.2
10%	121	28.0	8.9	5.4	3.4	2.5	1.8	1.3
20%	212	56.0	16.2	8.6	5.1	3.3	2.2	1.5
30%	292	83.0	23.0	11.6	6.8	4.0	2.6	1.7
40%	366	115	29.2	14.4	8.4	4.8	3.0	1.8
50%	450	145	34.9	17.0	9.9	5.6	3.4	2.0
60%	545	174	40.0	19.4	11.1	6.3	3.7	2.1
70%	625	199	44.6	21.4	12.1	7.1	4.0	2.2
80%	685	216	48.6	22.9	12.8	7.7	4.2	2.4
90%	720	210	48.0	22.3	13.0	8.0	4.2	2.4
100%	525	130	30.0	15.0	8.6	5.9	3.7	2.2

Note: Based on Martinelli-Nelson 2-Phase Multipler, except for 1% to 40% qualities at 14.7 psia where Homogeneous Multiplier is used to be more conservative.

Table 1 – Two Phase Flow Multiplier

		Case 1a	Case 1b	Case 1c
Basis for decay heat		Max	Max	Max
for containment flood level		MinMin	MinMin	MinMin
for containemnt pressure		Max	Max	Max
for flow resistance		Max	Max	Max
Time after accident (days)		14.00	14.00	14.00
Total containment pres (psia)		24.4	24.4	24.4
Recirc water temp (F)		177.9	177.9	177.9
Recirc water elev. (ft)		103.3	103.3	103.3
ADS 4 vent quality		20.00%	3.00%	7.73%
Core exit quality		18.48%	2.28%	6.40%
PXS Flows				
Recirc flow	(lb/sec)	38.56	108.11	71.97
ADS 4 water vent	(lb/sec)	30.85	104.86	66.40
ADS 4 steam vent	(lb/sec)	7.71	3.24	5.57
ADS 4 gas vel	(m/sec)	22.89	9.63	16.52
ADS 4 flow regime		annular	slug/churn	annular
Pressures				
Containment		24.38	24.38	24.38
ADS 4 Discharge		27.43	21.09	24.38
Calc Error (ADS-cont pres)		3.1E+00	-3.3E+00	-1.7E-08
Pressure losses				
Cont Recirc line	(psi)	0.51	3.36	1.57
ADS 4 line	(psi)	0.72	1.15	1.15

Table 2 – LTC Calculation Iteration

		Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Basis for decay heat		Max	BE	Max	Max	Max	BE
for containment flood level		MinMin	MinMin	BE	MinMin	MinMin	BE
for containemnt pressure		Max	Max	Max	BE	Max	BE
for flow resistance		Max	Max	Max	Max	BE	BE
Number ADS 4 valves open		3	3	3	3	4	4
recirc valves open		2	2	2	2	4	4
Time after accident (days)		14.00	14.00	14.00	14.00	14.00	14.00
Decay power (fraction full power)		0.30%	0.24%	0.30%	0.30%	0.30%	0.24%
Total containment pres (psia)		24.4	24.4	24.4	21.9	24.4	21.9
Partial Cont.Steam pres (psia)		7.2	7.2	7.2	5.2	7.2	5.2
Recirc water temp (F)		177.9	177.9	177.9	163.5	177.9	163.5
Press base for recirc water temp		partial	partial	partial	partial	partial	partial
Recirc water elev. (ft)		103.3	103.3	106.9	103.3	103.3	106.9
ADS 4 vent quality		7.73%	5.70%	5.22%	7.48%	3.57%	0.18%
Core exit quality		6.40%	4.51%	4.00%	6.03%	2.51%	0.04%
PXS Flows							
Recirc flow	(lb/sec)	71.97	67.11	87.52	68.69	101.91	108.32
ADS 4 water vent	(lb/sec)	66.40	63.29	82.95	63.56	98.27	108.13
ADS 4 steam vent	(lb/sec)	5.57	3.82	4.57	5.14	3.64	0.20
ADS 4(A) gas vel.	(m/sec)	8.38	5.76	6.88	8.54	7.98	0.48
ADS 4(B) gas vel.	(m/sec)	16.52	11.35	13.55	16.83	8.31	0.50
ADS 4(A) flow regime		slug/churn	slug/churn	slug/churn	slug/churn	slug/churn	slug/churn
ADS 4(A) flow regime		annular	slug/churn	slug/churn	annular	slug/churn	slug/churn
Pressures:							
Containment	(psia)	24.38	24.38	24.38	21.94	24.38	21.94
DVI connection	(psia)	24.38	24.57	25.21	22.09	25.27	24.29
Bottom core	(psia)	32.53	32.72	33.36	30.28	33.42	32.48
Top core	(psia)	28.97	28.59	29.01	26.46	28.43	26.67
Top HL	(psia)	25.58	25.20	25.63	23.06	25.04	23.28
ADS 4 discharge	(psia)	24.37	24.38	24.37	21.94	24.37	21.94
ERROR (Cont pres-ADS 4 pres)		-1.7E-08	3.2E-07	-1.6E-07	3.4E-07	-5.0E-07	2.5E-07
Pressure losses							
Cont Recirc line	(psi)	1.33	1.16	1.97	1.21	0.51	0.58
(screen debris)	(psi)	0.23	0.22	0.29	0.22	0.17	0.18
ADS 4 line (friction)	(psi)	0.78	0.51	0.80	0.72	0.36	0.02
(velocity head)	(psi)	0.37	0.24	0.38	0.36	0.20	0.02
Fluid Densities:							
Recirc water	(lb/ft3)	60.62	60.62	60.62	60.92	60.62	60.92
DVI conn.	(lb/ft3)	60.62	60.62	60.62	60.93	60.62	60.93
Fuel inlet	(lb/ft3)	60.62	60.62	60.62	60.93	60.62	60.93
Avg fuel	(lb/ft3)	36.66	42.52	44.71	39.28	51.32	59.80
Fuel to top HL	(lb/ft3)	58.66	58.65	58.62	58.78	58.62	58.66
ADS 4	(lb/ft3)	0.77	1.03	1.13	0.72	1.63	19.77

Table 3 – LTC Importance of Decay Heat, Containment Level / Pressure, PXS Resistances

	Max Quality	BE Quality	Min Quality
Decay Heat	Max	BE	Min
Cont Flood Level	Min	BE	Max
Cont Pressure	Max	BE	Min
PXS Line Resis.	Max	BE	Min
Time	Quality / Regime	Quality / Regime	Quality / Regime
0.5 days	29.0% / annular	6.7% / annular	0.02% / bubble
1.0 days	21.9% / annular	4.5% / annular	0.02% / bubble
3.0 days	14.7% / annular	2.4% / slug/churn	0.04% / bubble
7.0 days	10.7% / annular	0.6% / slug/churn	0.06% / bubble
14.0 days	7.7% / annular	0.2% / slug/churn	0.05% / bubble
30.0 days	5.0% / slug/churn	0.1% / slug	0.04% / bubble

Table 4 – ADS 4 Vent Quality / Flow Regime vs Time

Time	Max Quality
0.00 days	60.0%
0.12 days	60.0%
0.5 days	29.0%
1.0 days	21.9%
3.0 days	14.7%
7.0 days	10.7%
14.0 days	7.7%
30.0 days	5.0%

Table 5 – ADS 4 Maximum Vent Quality