FRAMATOME TECHNOLOGIES

ENGINEERING INFORMATION RECORD

Document Identifier 51 - 5000519-06

Title Boron Dilution by Hot Leg Injection

PREPARED BY:

Name G J Wissinger

Signature [signature] Date 2/16/98

REVIEWED BY:

Name J A Klingenfus

Signature J A Klingenfus Date 2/16/98

Technical Managers Statement: Initials

Reviewer is Independent.

Remarks:

This revision replaces Revisions 05 entirely. This revision addresses customer comments.

During certain cold leg pump discharge loss-of-coolant accidents, the core liquid through put will cease and boiling will cause the core boron concentration to increase. Control of the core boron concentration post-LOCA is a Nuclear Regulatory Commission issue for the B&W Owner's Group, of which Crystal River Unit 3 is a part. This control can be provided by any passive mechanism or active method that results in a net liquid flow through the core. One of these methods is hot leg injection (HLI). This method provides flow from one low pressure injection pump backward through the other, shutdown LPI pump and through the decay heat drop line into the hot leg inducing a net reverse flow through the core to the break.

Evaluations of core boron concentration have been performed for LBLOCAs and SBLOCAs. Hot leg injection by reverse flows of 500 gpm through the decay heat drop line is sufficient to exceed the gap bypass flow with the remaining flow offering a positive and rapid means for reducing the core boron concentration. The calculations supporting this flow rate consider both 1.2 and 1.0 times the ANS 1971 decay heat standard and conservative core mixing volumes (i.e. 790 and 1200 ft^3 for large and small LOCA, respectively). FTI has reviewed the required flow patterns and hydraulic resistance within the reactor vessel and concluded that there are no problems using HLI for boron concentration control provided it is initiated before the hot leg reaches the boron precipitation mixing limit as defined in Reference 10.

BORON DILUTION BY RCS HOT LEG INJECTION

PREPARED FOR FLORIDA POWER CORPORATION

BY

FRAMATOME TECHNOLOGIES INC.

FEBRUARY 1998

Record of Revision

Rev/Date	DESCRIPTION	Page No.
-01-—Sept. 1997	This revision replaces revision -00- entirely.	
	Section 4: Changes were made to the text discussing methods of detection when boron is concentrating in the core. Boron concentration measurement and incore temperature measurement uncertainty discussion was added to the text.	22-26
	Tables 2 and 3 were modified and renumbered as were Figures 4 and 5. Boron concentration measurement and incore temperature measurement uncertainties were also added to Figures 4A, 4B, 5A, 5B, and 5C.	52
	Section 5.2: Added discussion of impact of Hot leg Injection on the reactor outlet piping, the reactor vessel and the internals	28
	Section 5.4: The parenthesis after 0.00202 should read (about 0.2 % power) rather than (about 0.12 power).	32
	Section 5.4: The word "only" was added after should, to read.... "should only be used in the long term (about 34 days post event)". "Only" was added to clarify the intent of the sentence.	33
	Section 6: A paragraph and a new figure (12) have been added to clarify the dilution flow paths in the reactor vessel before and after the hot leg injection flow is large enough to reverse the direction of core flow.	33
	Section 7:The second paragraph was modified to read the same as the last paragraph on page 20. These paragraphs discuss the sump boron concentration changes if boron is concentrating in the core. This change was made for clarity and continuity.	35
	Section 9: References 13, 14, 15, and 16 were added.	37
	The page numbers in all Appendices were changed from consecutive text page numbers to A1-1, A2-1, A3-1, etc.	A1-1, A2-1, A3-1

	The decay heat relationship should be 1.2 ANS 1971 with the FTI heavy isotopes, rather than 102% ANS 1979 with FTI heavy isotopes.	A1-1
	The tabulation of the results of the hot leg injection dilution calculations is identified as Table 4 in the main body of the document rather than in Appendix 1.	A1-7
	Table A-2 is corrected to Table 5 in the main body of the document.	A1-8
	The units of core power are incorrectly identified as Btu/lbm. The units are corrected to Btu/sec.	A1-10
	Table A-3 is corrected to Table 6 in the main body of the document.	A1-12
	Table A-4 is corrected to Table 7 in the main body of the document.	A1-13
	Appendix A3 was added to evaluate the Boronometer and Incore temperature measurement uncertainties.	A3-1
-02-/Oct 97	Minor editorial changes as requested by Florida Power Corp. (David Rice)	
-03-/Oct'97	Corrected a calculation error and its results on page 32 and 33 in Section 5.4. Changes are on pages 4, 32, and 33.	4, 32 & 33
-04-/Jan'98	This revision replaces Revisions 00 through 03 entirely.	all
	The document was streamlined to include only information pertinent to HLI.	
-05-/Jan'98	Changed HLI inlet temperature to 185 F.	17, 18, 20-27, 31, 32
-06-/Feb'98	This revision replaces revision 05 completely. Addresses CR-3 comments	5, 6, 18, 19, 21, 26, 28

Table of Contents

List of Tables

List of Figures

List of Assumptions

1. In order for hot leg injection to be initiated, the core exit must be saturated, and the decay heat removal/LPI system equipment must be accessible for alignment so that water can be injected in reverse flow through the DHDL to the nozzle on the RCS hot leg piping.

2. FTI considers 1.2 ANS71 decay heat plus B&W heavy isotopes to be conservative by 25 percent, so a value of 0.75 of this decay heat was used to represent some of the realistic decay heat levels in the calculation of the required HLI flows. Other calculations used 1.0 times ANS71 plus B&W heavy actinides. Both of these methods produce similar results.

List of References

1. FTI Document 32-1266110-00, "B&WOG Post-LOCA Core Boron Dilution."

2. FTI Document 51-1266113-00, "Post-LOCA Boron Concentration Management."

3. FTI Document 51-1212232-01, "Key Elevations for All Plants."

4. B&W Drawing 02-142923E-04, "Lower Grid Top Rib Section."

5. B&W Drawing, 02-142917E-04, "Upper Grid Rib Section."

6. FTI Document 51-5000396-00, "RVI Baffle Bolt Safety Assessment."

7. B&W Drawing, 02-27101F-02, "Core Barrel Assembly."

8. FTI Document 32-1258134-00, "Decay Heat for LOCA Analysis."

9.* Florida Power Corporation, Nuclear Operations Engineering, Crystal River Unit 3, "Enhanced Design Basis Document, Decay Heat Removal"

10. FTI Document 32-1266263-01, "Sump Delta Method for Cr-3."

11. FTI Document 32-5000185-01, "CR-3 Heatup and Cooldown PT Limits."

12. FTI Document 32-1266110-01, "B&WOG Post-LOCA Core Boron Dilution."

* These documents are maintained and controlled by Florida Power Corporation. Per FTI procedures, use of these references are allowed in safety-grade calculations with the approval of the cognizant unit manager of contract manager. The signature below authorizes the use of these documents for input to this evaluation.

J Hudlin
(Unit Manager/Contract Manager

2/18/98
(Date)

1. Introduction

During certain cold leg pump discharge (CLPD) loss-of-coolant accidents (LOCAs), the core liquid through put will cease and boiling will cause the core boron concentration to increase. Control of the core boron concentration post-LOCA is a Nuclear Regulatory Commission (NRC) issue for the B&W Owner's Group (BWOG), of which Crystal River Unit 3 (CR-3) is a part. This control can be provided by any passive mechanism or active method that results in a net liquid flow through the core (Ref. 2). One of these methods is hot leg injection (HLI). This method provides flow from one low pressure injection (LPI) pump backward through the other, shutdown LPI pump and through the decay heat drop line (DHDL) into the hot leg inducing a net reverse flow through the core to the break.

This document presents an evaluation of hot leg injection as a means of core boron control. This evaluation includes ECCS flow requirements, plant configuration, HLI DHDL alignments, RV circulation patterns, and verification of boron dilution with HLI.

2. Reactor Vessel Flow Paths for HLI

The HLI method uses one operating LPI pump in an alignment in which the LPI provides suction to one-high pressure injection (HPI) pump, ECCS injection through the core flood tank (CFT) nozzle in the piping run of the operating LPI pump, and flow through the LPI cross-connect line backward through the idle LPI pump into the reactor coolant system (RCS) hot leg. This alignment reverses the typical flow direction in the DHDL. The piping arrangements and flow patterns for CR-3 with the A-LPI and B-LPI pumps operating are shown in Figure 1 and Figure 2, respectively.

A net HLI flow (injection flow minus nozzle gap leakage) into the reactor vessel upper plenum provides dilution of the core boron in two ways. The minimum HLI flow rate to provide boron dilution must match the core boil-off rate with an additional volume to facilitate some reverse flow through the core. This additional flow will mix with the concentrated fluid in the upper plenum, flow down through the core barrel-baffle region, up the downcomer, and out of the RV to the break. Figure 3 shows this process. At higher HLI flows, it is possible to suppress core boiling entirely, thereby defeating the concentrating process. The core throughput is shown in Figure 4. The following discussion details the HLI boron dilution flow path in the reactor vessel prior to complete suppression of core boiling.

The DHDL is connected to the RCS hot leg pipe 4.7 inches above the bottom of the hot leg pipe (Ref. 3). The inner cylinder of the upper plenum assembly directly opposite the hot leg nozzle has 24 three-inch flow holes in addition to the larger flow holes (six 34-inch and four 22-inch) located in the upper parts of the plenum cylinder (Ref. 3). From the small holes opposite the hot leg nozzles, the hot leg injection fluid flows to the upper plenum where it mixes with core outlet steam and water. The resulting saturated, boron rich fluid then flows down, by virtue of static head, to the top of the core where it enters the flow holes that direct flow into the region formed between the core barrel and the former plates. There are 24 flow holes (8-3", 8-2", & 8-4") spaced around the periphery of the upper core plate (Ref. 5) that provide for downflow of the fluid to the core barrel/baffle region. Within the core barrel/baffle region there are eight former plates, each with 80, 1.312-inch flow holes (Ref. 6). From the barrel/baffle region the flow can either exit to the periphery of the lower core plate where there are 64 flow holes (8-3", 8-2.5", 8-2", 8-6", 8-3.5", 16-1.75", & 8-5") arranged around the periphery of the plate (Ref. 4) or exit to the barrel/baffle region through 30, 0.75-inch flow holes in the core barrel wall to the thermal shield annulus (Ref. 7). The fluid needed to remove the core decay heat circulates back into the core. The excess liquid travels to the break via the thermal shield annulus or the downcomer, providing a boron dilution flow path. The dynamic pressure drop through the flow path described above is about 5.4 inches of water (see Appendix 1) for an HLI flow of 500 gpm (the minimum flow identified in Section 3). The head to provide this flow is developed by the injection fluid in the hot leg and the entrance to the upper plenum.

Figure 1: CR-3 DHDL Hot Leg Injection Flow Patterns with the A-LPI Pump.

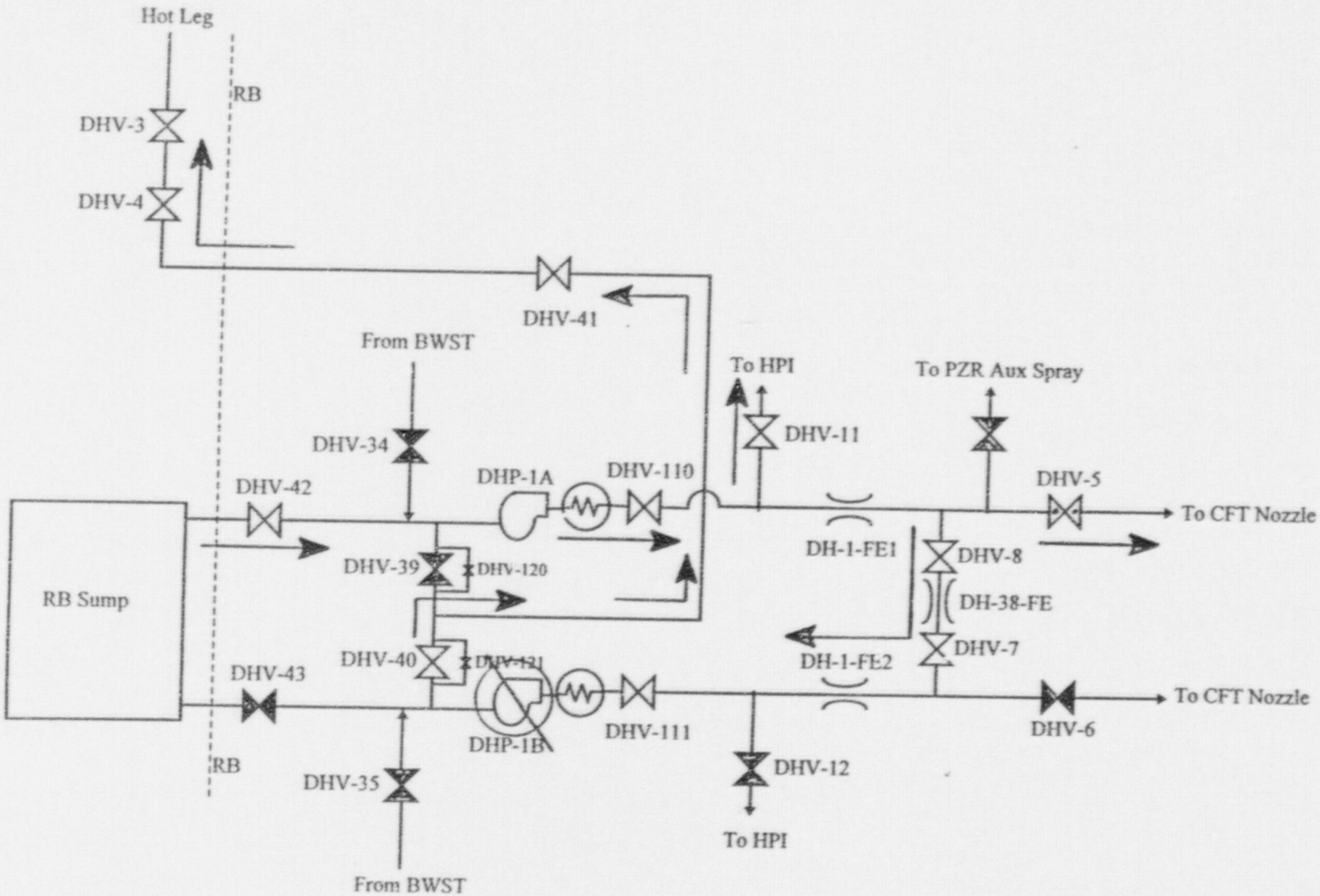


Figure 2: CR-3 DHDL Hot Leg Injection Flow Patterns with the B-LPI Pump .

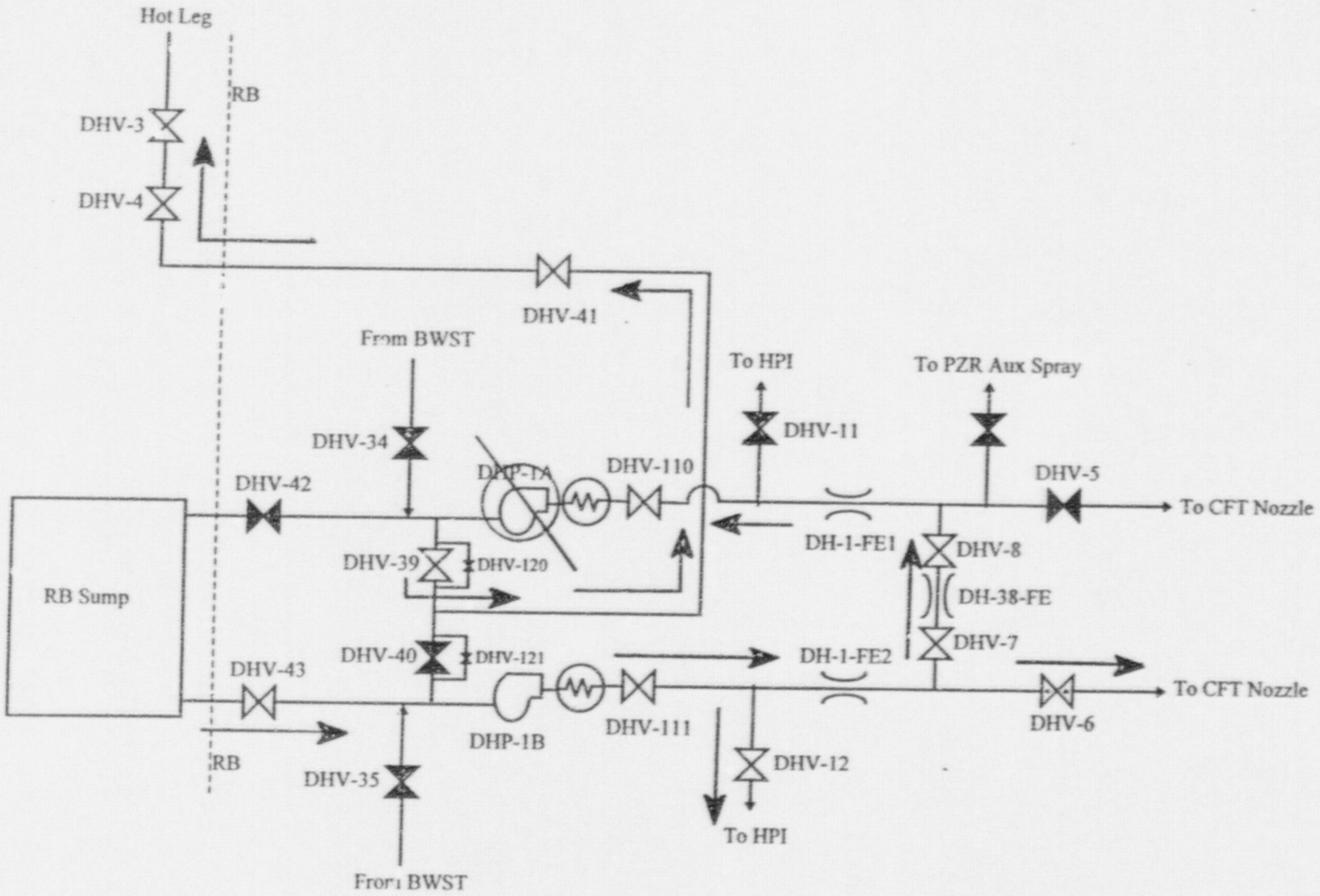


Figure 3: HLI Flow Paths in the RV Before Core Boiling Suppression

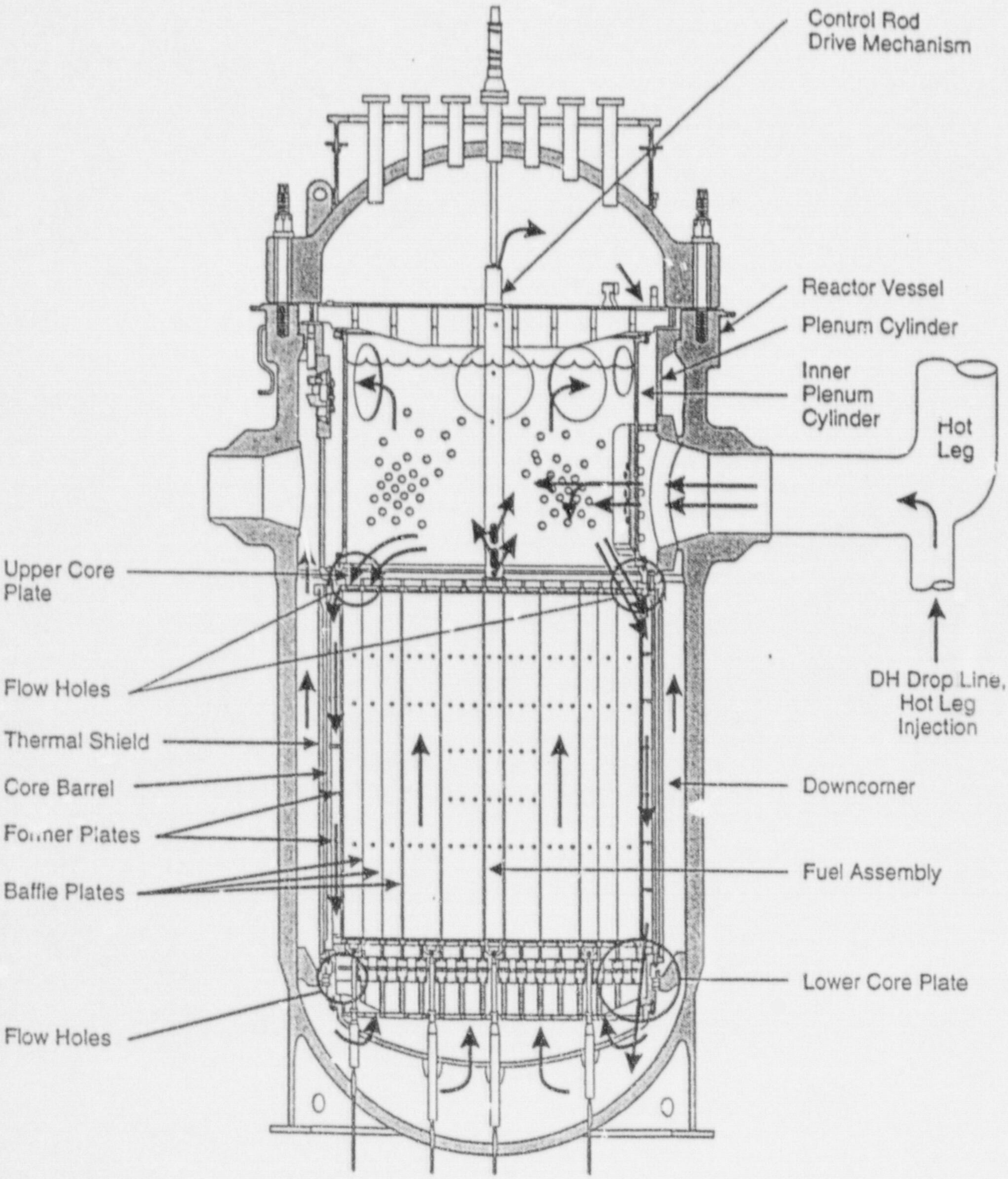
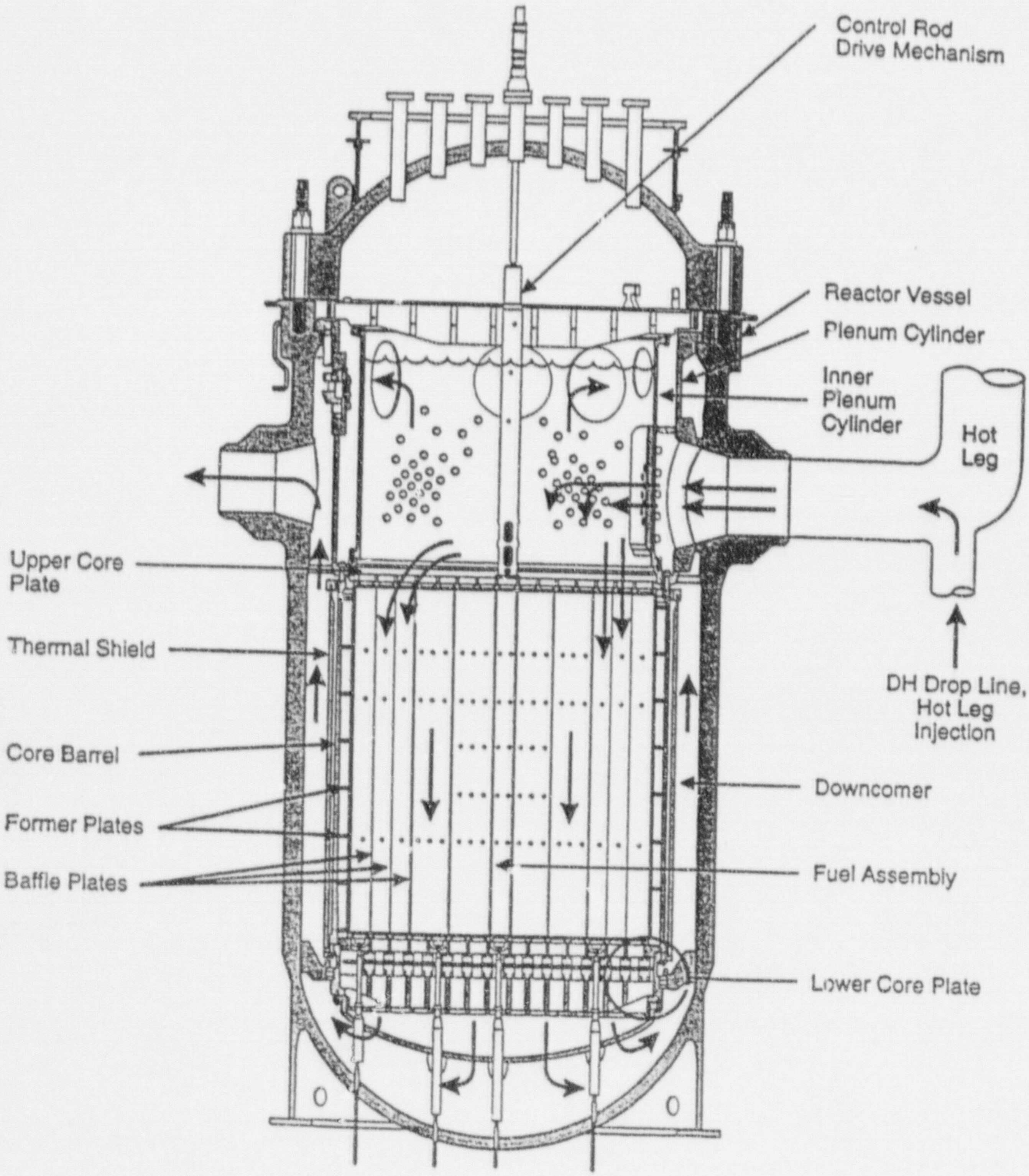


Figure 4: HLI Flow Paths in the RV After Core Boiling Suppression



3. ECCS Requirements for HLI

The HLI method involves either shutting down an operating LPI pump if both are available or throttling the only available LPI pump (if the other one was lost because of a single failure). Use of this method therefore requires a definition of an acceptable ECCS flow split that will provide both core cooling and boron dilution. Since the pumped injection flow increases with decreasing system pressure, this evaluation should be performed at the highest appropriate pressure. The solubility limit increases with temperature, and since the system will be saturated, the limit will increase with pressure. At an RCS pressure of 72 psia, calculations have shown that boron precipitation will not occur, even for a scenario with all of the available system boron in the core (Ref. 1). At this pressure, the LPI pump is capable of providing at least 2700 gpm of flow (Ref. 9) for all of the ECCS and HLI.

$$\text{ECCS flow} = 2700\text{ gpm} = W_{HPI} + W_{LPI} + W_{HLI}.$$

If a maximum flow of 600 gpm is assumed for one HPI pump, the remaining flow is available to be split between the LPI nozzle and the HLI path.

$$W_{LPI} + W_{HLI} = W_{ECCS} - W_{HPI} = 2100\text{ gpm}.$$

Some of the HLI flow may bypass the core via the hot leg nozzle gaps. The remaining flow is used to match core decay heat and provide an excess flow for boron dilution via throughput to the break. If the excess throughput is sufficiently large, it can possibly suppress core boiling and eliminate the concentrating mechanism entirely. So,

$$W_{HLI} = W_{gap} + W_{DH} + W_{excess}.$$

Post-small break LOCA, the system cool down is slow such that the internals and RV shell remain nearly isothermal. At 300 F, the CR-3 total nozzle gap flow was calculated to be 103 gpm (Ref. 1, Table 7A). Only one nozzle gap would directly bypass the hot leg injection flow, so only one-half of gap flow should be considered.

$$W_{gap,\,SBLOCA} = 0.5\ (103\ \text{gpm}) = 51.5\ \text{gpm}\ .$$

Post-large break LOCA, the cooldown is more rapid and the thick RV shell will remain hotter than the internals (i.e. non-isothermal). The internals are at the RCS saturation temperature, while the reactor vessel is still at a higher temperature. At 14.7 psia with the RV internals at 212 F and the RV at 400 F five hours post-LOCA, the maximum single gap flow is estimated to be

$$W_{gap,\,LBLOCA} = 199\ \text{gpm}\ .$$

The ECCS injection rates needed to match the decay heat boiloff rate and to totally suppress core boiling can be determined with the following equations.

$$W_{DH,\,match} = DH\ /\ (h_g - h_{in})\ \text{and}$$
$$W_{DH,\,no\ boil} = DH\ /\ (h_f - h_{in})$$

where DH is the decay heat, h_g is the saturated steam enthalpy, h_{in} is the ECCS liquid enthalpy, and h_f is the saturated liquid enthalpy. Calculations were performed using 1.2 times the 1971 ANS decay heat standard (tabulated in Ref. 8) at 5 hours, 24 hours, and 1 week post LOCA for various RCS pressures. The calculation was repeated for best-estimate decay heat. (FTI considers 1.2 ANS71 decay heat to be conservative by 25 percent, so a decay heat of 0.75 times 1.2 ANS71 was used.) The results are shown in Table 1.

For small break loss of coolant accidents (SBLOCAs), the required HLI flow to overcome the gap flow and to match 1.2 times the ANS 1971 decay heat at 5 hours post-LOCA and 72 psia is 52 gpm plus 202 gpm, or approximately 255 gpm. An additional hot leg flow of 245 gpm in excess of the decay heat match up flow plus gap flow should be adequate for core boron dilution. That is, a total hot leg injection flow of 500 gpm is adequate to provide boron dilution 5 hours post-SBLOCA and beyond.

For large break loss of coolant accidents (LBLOCAs), the required HLI flow to overcome the gap flow and to match 1.2 times the ANS 1971 decay heat at 5 hours post-LOCA and 14.7 psia[1] is 199 gpm plus 209 gpm, or approximately 410 gpm. In this case, the recommended 500-gpm HLI flow still exceeds the flow needed for boiloff and gap flow considerations. This example only has 90-gpm excess flow for boron dilution versus the 245 gpm recommended previously. The excess will increase with time as the decay heat boiloff and gap size and flow decrease. At 24 hours, the boiloff is 130 gpm and the gap flow is extrapolated from the nozzle gap data of Reference 1 to be less than 100 gpm. The excess hot leg flow at this time will be greater than 245 gpm. For LBLOCA the excess ECCS flow can be smaller, since the boron concentration does not have to be reduced to compensate for possible solubility decreases due to subsequent RCS depressurization after 5 hours. Therefore, the recommended 500 gpm is adequate for LBLOCA concentration control as well.

With a minimum of 500 gpm of HLI flow and 600 gpm for HPI flow, the flow available for LPI nozzle flow and instrument uncertainty is

$$\begin{aligned} W_{LPI} &= \text{ECCS flow} - W_{HPI} - W_{HLI} \\ &= 2700 - 600 - 500 = 1600 \text{ gpm.} \end{aligned}$$

---

[1] The LBLOCA is expected to depressurize to 14.7 psia by five hours post-LOCA. The difference in the LPI flow between 72 psia and 14.7 psia is not considered in this calculation, but the result presented is conservative.

Historically, 1000 gpm per LPI nozzle has been assumed to be the target value for securing the HPI pumps. When using the HLI alignment, it is reasonable to target 1000 gpm for the one flowing LPI line, which leaves 600 gpm of real pump flow for instrument uncertainty or flow imbalance at 72 psia. Below 72 psia, the pump flow will increase and additional flow may be available to the hot leg injection path, such that, once initiated, the flow may be adequate to suppress core boiling with best-estimate or realistic decay heat levels.

In summary, FTI recommends that the HLI alignment provide flow for one HPI pump (up to 600 gpm), a minimum reverse flow of at least 500 gpm through the decay heat drop line for boron dilution, and approximately 1000 gpm into one CFT nozzle. It should be emphasized that the suppression of core boiling eliminates the mechanism that concentrates the boron, thereby addressing the boron concentration control for the duration of the transient. Therefore, the highest possible HLI flow rates should be targeted. For example, if hot leg injection flow is 900 gpm, core boiling will be suppressed and the core boron concentration mechanism will be removed if realistic decay heat contributions are considered.

Table 1: HLI Flow to Match Decay Heat and Suppress Core Boiling

		1.2 ANS71 DH			0.75*(1.2 ANS71 DH)		
Time Post LOCA	Pressure, psia	Decay Heat, Btu/s	$W_{DH\ match}$, gpm	$W_{no\ boil}$, gpm	Decay Heat, Btu/s	$W_{DH\ match}$, gpm	$W_{no\ boil}$, gpm
6 hours	100	28,084	201	1437	21,063	151	1078
	72		202	1708		152	1281
	14.7		209	7717		157	5788
24 hours	72	17,457	126	1062	13,093	94	796
	14.7		130	4797		97	3598
1 week	72	9535	69	580	7151	52	435
	14.7		71	2620		53	1965

NOTE: The HLI liquid is injected at 185 F.

4. Verification of HLI Effectiveness

The previous sections have identified the HLI flow paths and minimum required flow rate for core boron dilution. The effectiveness of HLI as a boron dilution mechanism has also been demonstrated by analyses performed in Reference 12 for both large and small LOCA scenarios. These analyses do not necessarily represent the most limiting cases or identify necessary HLI activation times. They simply demonstrate the effectiveness of the HLI method in reversing the core boron concentration buildup.

The LBLOCA cases were run with 100 gpm of net HLI flow (at 185 F) beginning five hours post-LOCA. Two cases were examined, the first case using 1.2 times ANS 1971 decay heat, and the second using 1.0 times ANS 1971 decay heat. The results from Appendix G of Reference 12 are shown in Figure 5 and Figure 6. It can be seen from the figures that even this small amount of HLI is effective in diluting the core boron concentration very quickly.

The SBLOCA cases were run with 100 gpm of net HLI flow (at 185 F) beginning 100 hours post-LOCA. Two cases were examined, the first case using 1.2 times ANS 1971 decay heat, and the second using 1.0 times ANS 1971 decay heat. The results from Appendix G of Reference 12 are shown in Figure 7 and Figure 8. Again, it is obvious that HLI is an effective core boron dilution mechanism once it is initiated.

The core boron dilution flows used in these analyses were very conservative (i.e. high gap bypass flow). If the gaps were open and passing liquid, the core concentration at the beginning of the dilution would be much lower, although the dilution mechanism would be as effective. Further, if the gaps were closed, the net core throughput would be significantly higher. With larger core flows, the core boron concentration decrease would be faster.

Figure 5: **LBLOCA Boron Concentations Versus Time for the 2568 MWt LL Plant. CLPD Break at 1.2 ANS 71 (With No Gaps, 100 gpm net HLI, 790.5 ft3 Vol).**

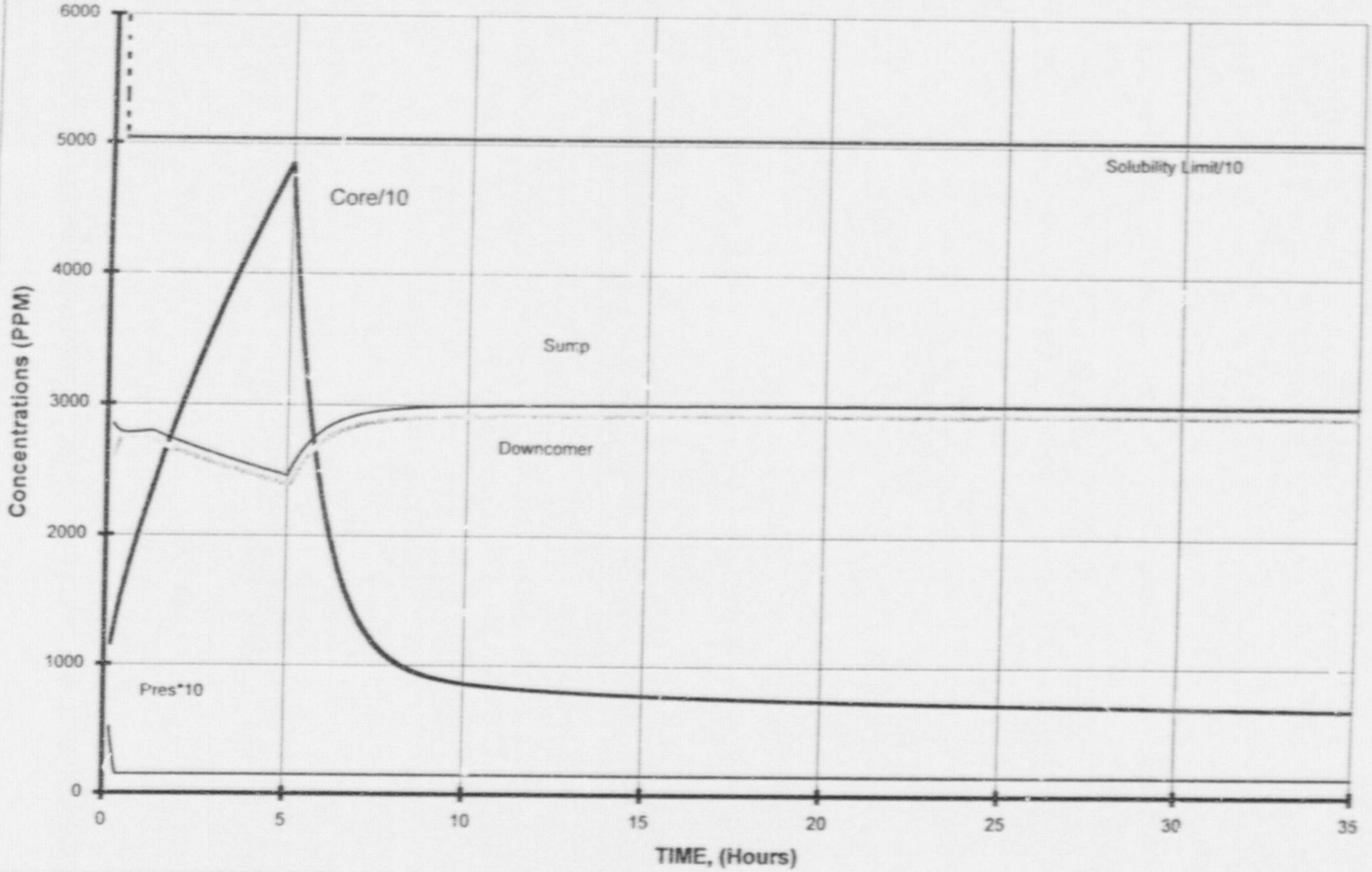


Figure 6: LBLOCA Boron Concentations Versus Time for the 2568 MWt LL Plant.
CLPD Break at 1.0 ANS 71 (With No Gaps, 100 gpm net HL', 790.5 ft3 Vol).

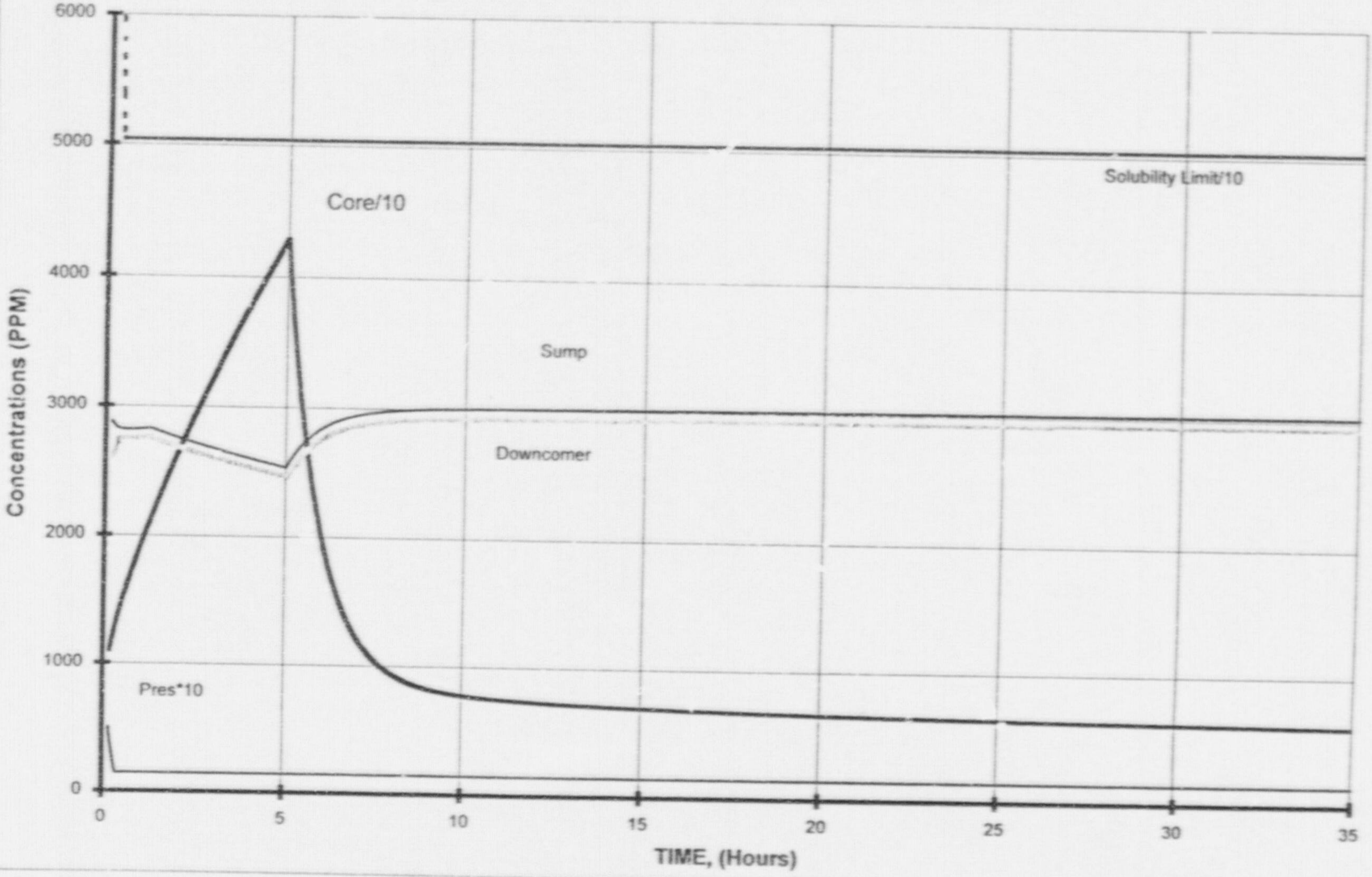


Figure 7: 0.05 ft2 SBLOCA Boron Concentations Versus Time for the 2568 MWt LL Plant. CLPD Break at 1.2 ANS 71 (With No Gaps, 100 gpm net HLI, 1200 ft3 Vol).

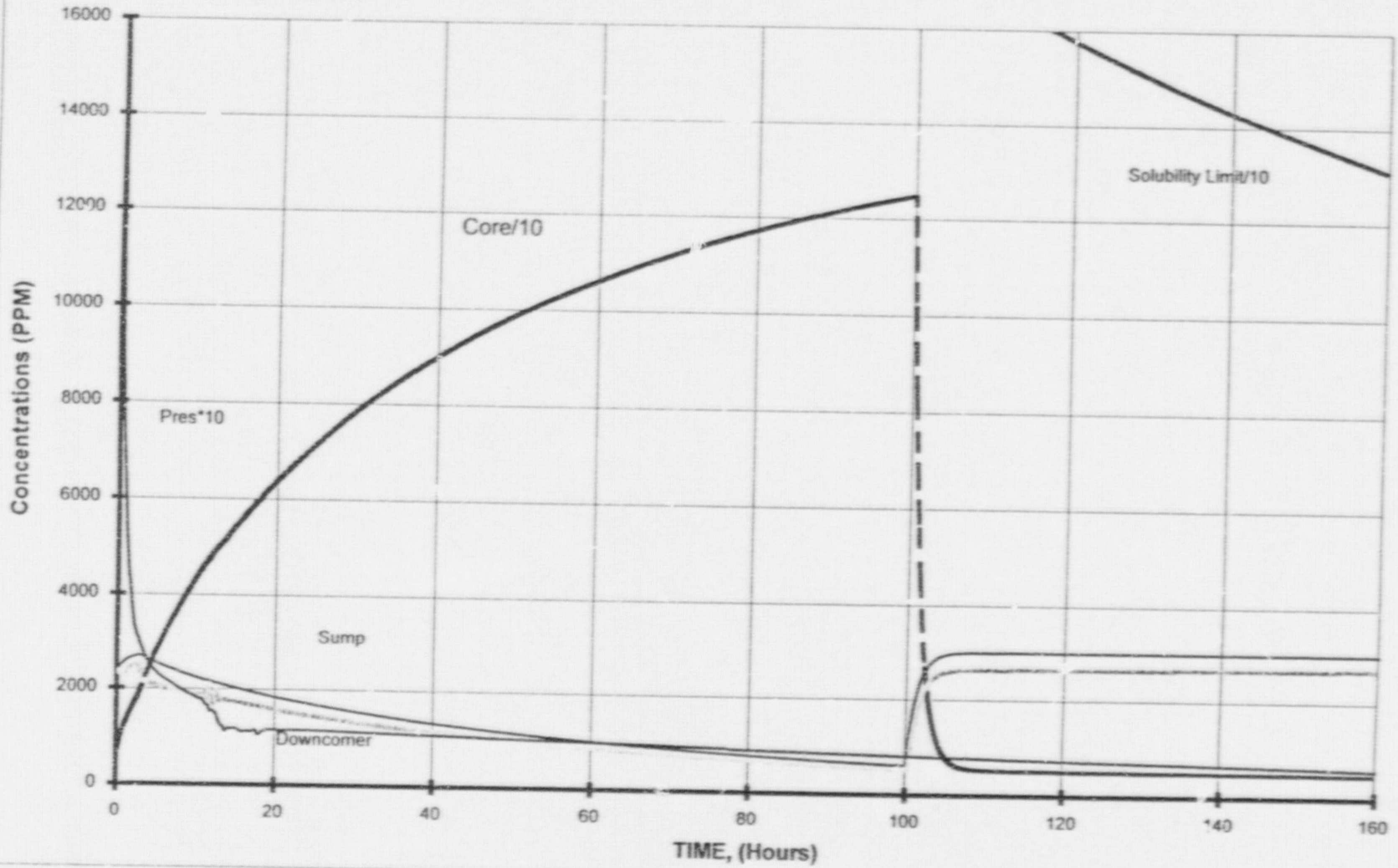
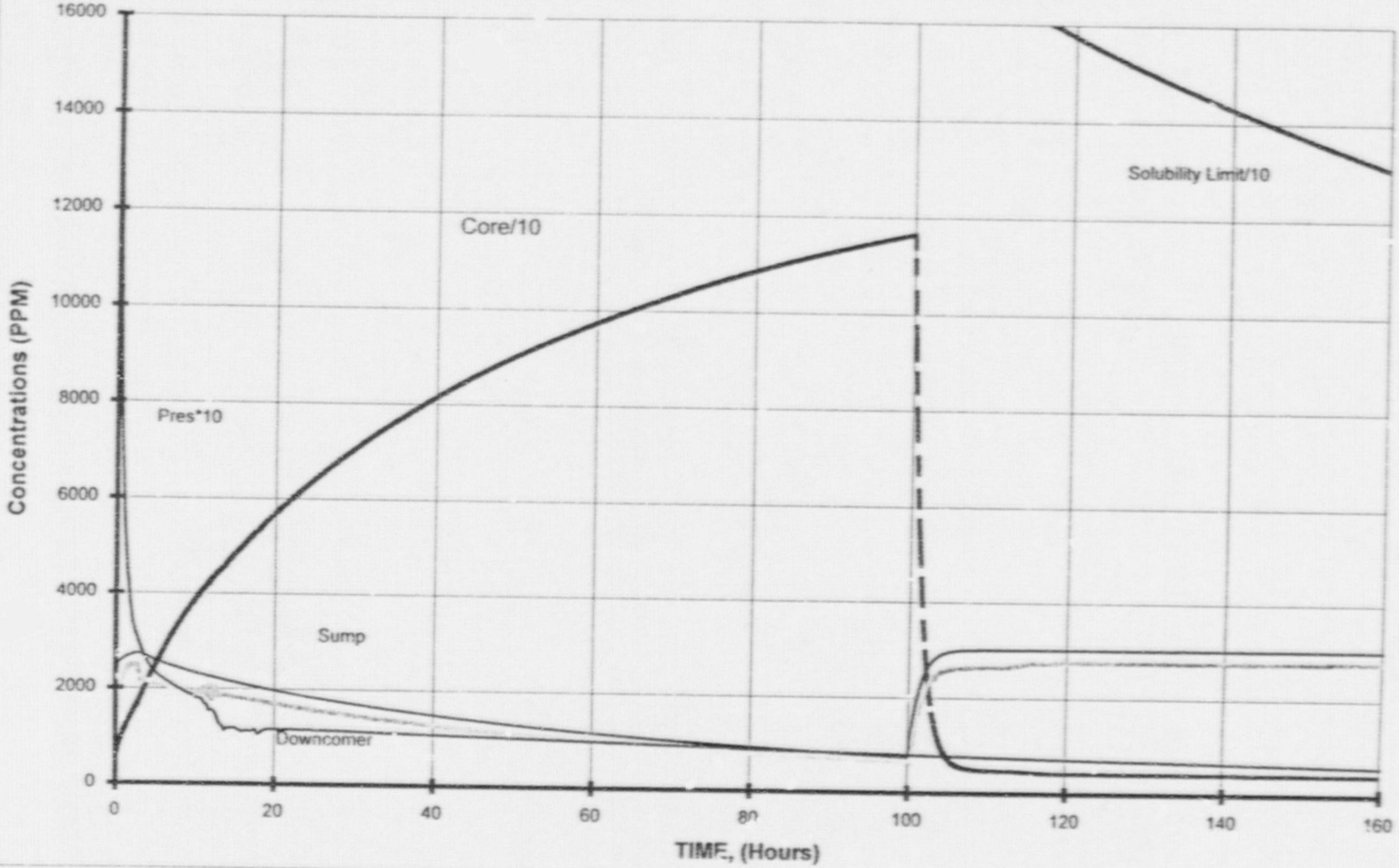


Figure 8: 0.05 ft2 SBLOCA Boron Concentations Versus Time for the 2568 MWt LL Plant. CLPD Break at 1.0 ANS 71 (With No Gaps, 100 gpm net HLI, 1200 ft3 Vol).



5. Effect of HLI on Hot Leg Piping

In addition to the boron dilution evaluations discussed above, FTI also evaluated the impact of the HLI on the hot leg near the RV nozzles, the reactor vessel, and the reactor vessel internals. The evaluation includes:

- Steam-water interaction and or cold water-hot water interactions (water hammer),
- Stratified liquid flow in the hot leg pipe,
- Temperature rates of change for the RV and the RV internals,
- Operation within the pressure-temperature (P-T) limits, and
- Reverse flow in the core.

The following paragraphs describe these evaluations in detail.

5.1 Water Hammer

The injection of sump water, assumed cooled to 185 F by the operating decay heat cooler, into the reactor vessel hot leg is not expected to result in steam-water interactions ("water hammer"), because the HLI fluid is introduced into a water-to-water interface in the hot leg. The hot leg pipe will have a water level consistent with, but deeper than the water level in the cold leg pipe for the assumed CLPD break. The hot leg injection flow velocity is relatively low (less than about 0.25 ft/s) in the hot leg pipe and is expected to run along the bottom of the hot leg pipe under the saturated fluid in the pipe, gradually mixing with the hotter water in the hot leg pipe until the injection fluid reaches the upper plenum cylinder. This fluid injection into the hot leg is similar to the injection sites of the HPI into the RCS cold legs, and to the core flood line (CFL) nozzles on the reactor vessel. Direct contact of colder HLI water with steam and the resultant water hammer is not expected to occur.

5.2 Thermal Stratification

The HLI flow velocity is relatively low (less than about 0.25 ft/sec) in the hot leg pipe and is expected to run along the bottom of the hot leg pipe under the saturated fluid in the pipe, gradually mixing with the hotter water in the hot leg pipe until the injection fluid reaches the upper plenum cylinder. At the reactor vessel, the injection fluid flows through the holes in the inner plenum cylinder and is expected to begin vigorous mixing with the steam-water mixture in the plenum. The injection fluid begins at 185 F and is expected to reach the saturation temperature for the pressure in the reactor vessel (212 to 305 F).

Since the hot leg injection fluid is expected to flow under the saturated fluid in the hot leg pipe and reactor outlet nozzle, thermal stratification of the hot leg injection fluid between the DHDL nozzle and the reactor internals can occur. However, there is no significant pressure on the system (less than approximately 200 psia saturated) and the temperature difference between the HLI fluid and the RCS fluid is relatively small, between 72 and 242 F. Any stresses generated by this thermal stratification are expected to be insignificant for this LOCA event.

5.3 Rates Of Temperature Change

As the core decay heat decreases with time, HLI fluid is expected to eventually remove the core decay heat by reverse flow through the core with sensible heat removal (delta-T cooling). The suppression of core boiling is accompanied by a temperature reversal in the vessel wherein the colder (185 F) HLI water enters at the top of the core, flows downward through the core removing heat by subcooled heat transfer, and exits the core at a higher temperature but below the boiling point. Since the decay heat will be slowly decreasing, the change in the decay heat removal process is expected to take place over a long period of time (days) so that the changes in temperature in the reactor vessel and the internals are slow and insignificant relative to the temperature changes in the reactor vessel and internals immediately post-LBLOCA.

5.4 Pressure-Temperature Limits

In the temperature pressure range where hot leg injection is expected to operate, (saturated water in the range from 212 F to 305 F), the temperature and pressure conditions are well below the temperature-pressure limits (Ref. 11) for Crystal River Unit 3. No additional significant pressure or thermal stresses are expected for these operating conditions.

5.5 Reverse Flow In The Core

The eventual reversal of flow direction in the core will have no impact on the fuel assemblies or their support structures, because the downward flow velocity for flow rates in the range of 500 to 900 gpm is less than about 0.05 ft/s. This velocity is insignificant compared to the normal core velocity (about 15 ft/s). There will essentially be no additional loads on the fuel assemblies above their own weight.

6. Summary of Results and Conclusions

Evaluations of core boron concentration have been performed for LBLOCAs and SBLOCAs. Hot leg injection by reverse flows of 500 gpm through the decay heat drop line is sufficient to exceed the gap bypass flow with the remaining flow offering a positive and rapid means for reducing the core boron concentration. The calculations supporting this flow rate consider both 1.2 and 1.0 times the ANS 1971 decay heat standard and conservative core mixing volumes (i.e. 790 and 1200 ft^3 for large and small LOCA, respectively). FTI has reviewed the required flow patterns and hydraulic resistance within the reactor vessel and concluded that there are no problems using HLI for boron concentration control provided it is initiated before the hot leg reaches the boron precipitation mixing limit as defined in Reference 10.

Appendix 1: Reactor Vessel HLI Flow Path Pressure Losses

Calculation of the pressure losses through the several plate flow holes in the hot leg injection flow path is performed below.

1.1 Identification of Flow Holes

a) Plenum Cylinder Flow Holes (Reference 3)

There are 24- 3-inch flow holes in the plenum cylinder adjacent to the hot leg nozzle. These holes are arranged in rows as follows:

Row	Number of flow holes
1	2
2	2
3	4
4	2
5	4
6	2
7	4
8	2
9	2
	24

The flow area of these holes is:

$24*0.785*(3.0\ in)^2/144\ in^2/ft^2=1.1775\ ft^2$. Use 1.18 ft^2

b) Upper Core Plate Flow Holes (Reference 5)

There are 24 flow holes in the upper core plate. Their numbers and dimensions are:

8-3 inch dia holes: $8*0.785*(3.0\ in)^2/144\ in^2/Ft^2= 0.392\ ft^2$
8-2 inch dia holes: $8*0.785*(2.0\ in)^2/144\ in^2/Ft^2= 0.174\ ft^2$
8-4 inch dia holes: $8*0.785*(4.0\ in)^2/144\ in^2/Ft^2= 0.70\ ft^2$
$1.266\ ft^2$

c) Former Plate Flow Holes (Reference 6)

The former plates have 80-1.312 in dia flow holes.
The flow area per former plate is:

$$80*.785*(1.312\ in)^2/144\ in^2/ft^2=0.75\ ft^2$$

d) Lower Core Plate flow holes: (Reference 4)

There are:

8-3	in dia holes-----$8*.785*(3\ in)^2/144\ in^2/ft^2 =$	$0.392\ ft^2$
8-2.5	in dia holes-----$8*.785*(2.5\ in)^2/144\ in^2/ft^2 =$	$0.273\ ft^2$
8-2.0	in dia holes-----$8*.785*(2.0\ in)^2/144\ in^2/ft^2 =$	$0.174\ ft^2$
8-6.0	in dia holes-----$8*.785*(6.0\ in)^2/144\ in^2/ft^2 =$	$1.57\ ft^2$
8-3.5	in dia holes-----$8*.785*(3.5\ in)^2/144\ in^2/ft^2 =$	$0.534\ ft^2$
16-1.75	in dia holes---$16*.785*(1.75\ in)^2/144\ in^2/ft^2 =$	$0.267\ ft^2$
8-5.0	in dia holes-----$8*.785*(5.0\ in)^2/144\ in^2/ft^2 =$	$1.090\ ft^2$
	Total-----------------	$4.30\ ft^2$

e) Summary of Flow hole areas in the hot leg injection flow path

Plenum cylinder adjacent to hot leg nozzle---------------$1.18\ ft^2$
Upper core plate inlet to core barrel/baffle area---------$1.26\ ft^2$
Former Plate--$0.75\ ft^2$
Outlet holes in lower core plate------------------------------$4.30\ ft^2$

1.2 Calculation of Velocities in the Flow Holes

velocity = flow/area/density

Flow = 500 gpm
Density of water at 185 F=$1/0.01654\ ft^3/lbm=60.46\ lbm/ft^3$
Mass flow =$500\ g/min*60.46\ lbm/ft^3/7.48\ gal/ft^3/60\ sec/min=67.4\ lbm/sec$

a) velocity in plenum cylinder flow holes =

$$67.4\ lbm/sec/1.18\ ft2/60.46\ lbm/ft^3=0.945\ ft/sec$$

b) velocity in upper core plate flow holes =

67.4 lbm/sec/1.26 ft2/60.46 lbm/ft^3=0.88 ft/sec

c) velocity in former plate flow holes;

67.4 lbm/sec/0.75 ft2/60.46 lbm/ft^3=1.49 ft/sec

d) velocity in lower core plate flow holes;

67.4 lbm/sec/4.30 ft2/60.46 lbm/ft^3=0.26 ft/sec

1.3 Calculation of pressure drops in the several flow holes:

delta p= DP = k*rho*v^2/144/2g

k = is assumed to be 1.5 velocity heads entrance (k=0.5) and exit loss (k=1.0) at each plate (Total loss factor =0.5 +1.0 velocity heads)

rho is water density = taken as 60.46 lbm/ft^3 as above. This value of density is used for cons_ atism (higher DP) of the pressure losses in hot leg injection flow path.

g= gravitational constant=32.2 ft/sec/sec

a) DP plenum cylinder flow holes =

1.5*60.46 lbm/ft^3*(0.945 ft/sec)^2/(144 in^2/ft2*2*32.2 ft/sec^2)=0.00873 psi

b) DP upper core plate:

1.5*60.46 lbm/ft^3*(0.88 ft/sec)^2/(144 in^2/ft^2*2*32.2 ft/sec^2)=0.00757 psi

c) DP former plates:

8 plates*1.5*60.46 lbm/ft^3*(1.49 ft/sec)^2/(144 in^2/ft^2*2*32.2 ft/sec^2)
=0.174 psi

d) DP lower core plate:

1.5*60.46 lbm/ft^3*(.026 ft/sec)^2/(144 in^2/ft^2*2*32.2 ft/sec^2)=0.0000066 psi

ATTACHMENT E

ACRONYMS AND ABBREVIATIONS

APS . . . . Auxiliary Pressurizer Spray
B&W . . . . Babcock and Wilcox
BWST . . . . . . Borated Water Storage Tank
CFT . . . . Core Flood Tank
CR-3 . . . . Crystal River Unit 3
DL-RB Sump . . Drop Line to Reactor Building Sump (mitigation method)
ECCS . . . . . . Emergency Core Cooling System
FPC . . . . Florida Power Corporation
FTI . . . . Framatome Technologies Incorporated
gpm . . . . gallons per minute
HLI-RF . . . . . Hot leg injection via Reverse Flow (mitigation method)
HPI . . . . High Pressure Injection system
LAR . . . . License Amendment Request
LBLOCA . . . . Large Break LOCA
LOCA . . . . . . Loss of Coolant Accident
LPI . . . . Low Pressure Injection system
NRC . . . . U.S. Nuclear Regulatory Commission
ppm . . . . parts per million
RB . . . . Reactor Building
RCS . . . . Reactor Coolant System
RV . . . . Reactor Vessel
RVVV . . . . . . Reactor Vessel Vent Valve
SBLOCA . . . . Small Break LOCA
TSC . . . . Technical Support Center