# Attachment 5

# ANP-3316(NP), Revision 0
# MILLSTONE UNIT 2 M5® UPGRADE, REALISTIC LARGE BREAK LOCA ANALYSIS LICENSING REPORT

## (NON-PROPRIETARY)

## DOMINION NUCLEAR CONNECTICUT, INC.
## MILLSTONE POWER STATION UNIT 2

0414-12-F04 (Rev. 001, 03/10/2016)

AREVA

# Millstone Unit 2 M5® Upgrade, Realistic Large Break LOCA Analysis

ANP-3316NP
Revision 0

## Licensing Report

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AREVA Inc.

## Nature of Changes

| Item | Section(s) or Page(s) | Description and Justification |
|---|---|---|
| 1 | All | Initial Issue |

## Contents

## List of Tables

## List of Figures

## Nomenclature

| Acronym | Definition |
|---|---|
| ASI | Axial Shape Index |
| BOCR | Beginning of Core Recovery |
| CCFL | Counter Current Flow Limiting |
| CE | Combustion Engineering |
| CFR | Code of Federal Regulations |
| CHF | Critical Heat Flux |
| CSAU | Code Scaling, Applicability and Uncertainty |
| CWO | Core-Wide Oxidation |
| ECCS | Emergency Core Cooling System |
| ECR | Equivalent Cladding Reacted |
| EM | Evaluation Model |
| EMDAP | Evaluation Model Development and Assessment Process |
| $F_Q$ | Total Peaking Factor |
| $F_r$ | Nuclear Enthalpy Rise Factor |
| FSRR | Fuel Swell Rupture and Relocation |
| GDC | General Design Criteria |
| HPSI | High Pressure Safety Injection |
| LHGR | Linear Heat Generation Rate |
| LPSI | Low Pressure Safety Injection |
| LBLOCA | Large Break Loss of Coolant Accident |
| LOCA | Loss of Coolant Accident |
| LOOP | Loss of Offsite Power |
| MLO | Maximum Local Oxidation |
| No-LOOP | No Loss of Offsite Power |
| NRC | U. S. Nuclear Regulatory Commission |
| PCT | Peak Clad Temperature |
| PWR | Pressurized Water Reactor |

| Acronym | Definition |
|---|---|
| RCP | Reactor Coolant Pump |
| RCS | Reactor Coolant System |
| RLBLOCA | Realistic Large Break Loss of Coolant Accident |
| SE | Safety Evaluation |
| SG | Steam Generator |
| SIAS | Safety Injection Actuation Signal |
| SIT | Safety Injection Tank |
| UTL | Upper Tolerance Limit |
| w/o | Weight Percent |

## ABSTRACT

This report describes and provides results from the RLBLOCA analysis for the Millstone Unit 2 M5®[1] fuel upgrade. The plant is a PWR Combustion Engineering 2x4-loop design with an analyzed thermal power of 2754 MWt (includes power calorimetric uncertainty) and dry atmospheric containment. The loops contain four RCPs, two U-tube steam generators and a pressurizer.

The analysis supports operation for Cycle 25 and beyond with AREVA's 14x14 CE array with HTP™[2] intermediate grids and a lower HMP™[2] grid. The fuel assembly includes a Zirc-4 MONOBLOC™[2] guide tube design, M5® fuel rod design using standard $UO_2$ fuel with 2%, 4%, 6%, and 8% $Gd_2O_3$ and FUELGUARD™[2] debris-resistant lower tie-plate design. The analysis performed is the Millstone Unit 2 plant-specific implementation of the AREVA's RLBLOCA EM in Reference 1 and the methodology amendments in References 2 and 3. The analysis results confirm that the 10 CFR 50.46(b), paragraphs (1) through (3), acceptance criteria (Reference 5) are met and serve as the basis for operation of the Millstone Unit 2 Power Station with Standard CE14 HTP fuel (advanced fuel geometry).

[1] M5 is a registered trademark of AREVA
[2] HTP, HMP, MONOBLOC and FUELGUARD are trademarks of AREVA

## 1.0 SUMMARY

This report describes and provides results from the Realistic Large Break Loss of Coolant (RLBLOCA) for the Millstone Unit 2 M5® fuel upgrade. The plant is a Pressurized Water Reactor (PWR) Combustion Engineering (CE) 2x4-loop design. The parameter specification for this analysis is provided in Table 1. The analysis assumes full-power operation at 2754 MWt (includes power calorimetric uncertainty), a tube plugging level of 5.87 percent per steam generator, a peak linear heat generation rate (LHGR) of 15.1 kW/ft, and a radial peaking factor of 1.854 (includes uncertainty). The analysis supports operation with AREVA Standard CE14 HTP fuel (advanced fuel geometry) design using standard $UO_2$ fuel with 2, 4, 6, and 8 weight percent $Gd_2O_3$. This analysis also addresses typical operational ranges or technical specification limits (whichever is applicable) with regard to pressurizer pressure and level; safety injection tank (SIT) pressure, temperature (containment temperature), and level; core inlet temperature; core flow; containment pressure and temperature; and refueling water storage tank temperature. The analysis explicitly analyzes fresh and once-burned fuel assemblies. The analysis also uses the Fuel Swelling, Rupture, and Relocation (FSRR) model to determine if cladding rupture occurs and evaluate the consequences of FSRR on the transient response.

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The UTL results providing 95/95 simultaneous coverage from this evaluation meet the 10 CFR 50.46(b) criteria with a PCT of 1615°F, a maximum local oxidation of 2.01 percent and a total core-wide oxidation of 0.025 percent. The PCT of 1615°F occurred in a Fresh 4 weight percent $Gd_2O_3$ fuel rod with an assembly burnup of 18.4 GWd/mtU.

## 2.0 RLBLOCA ANALYSIS

### 2.1 *Acceptance Criteria*

The purpose of the analysis is to verify the adequacy of the Millstone Unit 2 Emergency Core Cooling System (ECCS) by demonstrating compliance with the following 10 CFR 50.46(b) criteria (Reference 5):

1. The calculated maximum fuel element cladding temperature shall not exceed 2200°F.

2. The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation.

3. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel excluding the cladding surrounding the plenum volume were to react.

Note: Reference 4 states that the 17% value in the second acceptance criterion for MLO was based on the usage of the Baker-Just correlation. For present reviews on ECCS Evaluation Model (EM) applications, the NRC staff is imposing a limitation specifying that the equivalent cladding reacted (ECR) results calculated using the Cathcart-Pawel correlation are considered acceptable in conformance with 10 CFR 50.46(b)(2) if the ECR value is less than 13%. The limitation is addressed in Table 4.

### 2.2 *Description of LBLOCA Event*

A Large Break Loss of Coolant Accident (LBLOCA) is initiated by a postulated rupture of the Reactor Coolant System (RCS) primary piping. The most challenging break location is in the cold leg piping between the reactor coolant pump and the reactor vessel for the RCS loop. The plant is assumed to be operating normally at full power prior to the accident and the break is assumed to open instantaneously. A worst case single-failure is also assumed to occur during the accident. The single-failure for this analysis is the loss of one ECCS pumped injection train without the loss of containment spray.

The LBLOCA event is typically described in three phases: blowdown, refill, and reflood. Following the initiation of the break, the blowdown phase is characterized by a sudden depressurization from operating pressure down to the saturation pressure of the hot leg fluid. For larger cold leg breaks, an immediate flow reversal and stagnation occurs in the core due to flow out the break, which causes the fuel rods to pass through critical heat flux (CHF), usually within 1 second following the break. Following this initial rapid depressurization, the RCS depressurizes at a more gradual rate. Reactor trip and emergency injection signals occur when either the low pressure setpoint or the containment high-pressure setpoint are reached. However, for LBLOCA, reactor trip and scram are essentially inconsequential, as reactor shutdown is accomplished by moderator feedback. During blowdown, core cooling is supported by the natural evolution of the RCS flow pattern as driven by the break flow.

When the system pressure falls below the SIT pressure, flow from the SIT is injected into the cold legs ending the blowdown period and initiating the refill period. Once the system pressure falls below the respective shutoff heads of the safety injection systems and the system startup time delays are met, flow from the safety injection systems is injected into the RCS. While some of the ECCS flow bypasses the core and goes directly out of the break, the downcomer and lower plenum gradually refill until the mixture in the lower head and lower plenum regions reaches the bottom of the active core and the reflood period begins. Core cooling is supported by the natural evolution of the RCS flow pattern as driven by the break flow and condensation on the emergency coolant being injected. Towards the end of the refill period, heat transfer from the fuel rods is relative low, steam cooling and rod-to-rod radiation being the primary mechanisms.

Once the lower plenum is refilled to the bottom of the fuel rod heated length, refill ends and the reflood phase begins. Substantial ECCS fluid is retained in the downcomer during refill. This provides the driving head to move coolant into the core. As the mixture level moves up the core, steam is generated and liquid is entrained, providing cooling in the upper core regions. The two-phase mixture expands into the

upper plenum and some liquid may de-entrain and flow downward back into the cooler core regions. The remaining entrained liquid passes into the steam generators where it vaporizes, adding to the steam that must be discharged through the break and out of the system. The difficulty of venting steam is, in general, referred to as steam binding. It acts to impede core reflood rates. With the initiation of reflood, a quench front starts to progress up the core. With the advancement of the quench front, the cooling in the upper regions of the core increases, eventually arresting the rise in fuel rod surface temperatures. Later the core is quenched and a pool cooling process is established that can maintain the cladding temperature near saturation, so long as the ECCS makes up for the core boil off.

### 2.3 *Description of Analytical Models*

The RLBLOCA methodology is documented in EMF-2103 *Realistic Large Break LOCA Methodology for Pressurized Water Reactors* (Reference 1) and supplemented in the RAI responses and Errata in References 2 and 3. The methodology follows the Code Scaling, Applicability and Uncertainty (CSAU) evaluation methodology (Reference 6) and the requirements of the Evaluation Model Development and Assessment Process (EMDAP) documented in Reference 7. The CSAU method outlines an approach for defining and qualifying a best-estimate thermal-hydraulic code and quantifies the uncertainties in a LOCA analysis.

The RLBLOCA methodology consists of the following computer codes:

- COPERNIC for computation of the initial fuel stored energy, fission gas release, and the transient fuel-cladding gap conductance.
- S-RELAP5 for the thermal-hydraulic system calculations (includes ICECON for containment response).

The governing two-fluid (plus non-condensable) model with conservation equations for mass, energy, and momentum transfer is used. The reactor core is modeled in S-RELAP5 with heat generation rates determined from reactor kinetics equations (point kinetics) with reactivity feedback, and with actinide and decay heat.

The two-fluid formulation uses a separate set of conservation equations and constitutive relations for each phase. The effects of one phase on the other are accounted for by interfacial friction, and heat and mass transfer interaction terms in the equations. The conservation equations have the same form for each phase; only the constitutive relations and physical properties differ.

The modeling of plant components is performed by following guidelines developed to ensure accurate accounting for physical dimensions and that the dominant phenomena expected during the LBLOCA event are captured. The basic building blocks for modeling are hydraulic volumes for fluid paths and heat structures for heat transfer. In addition, special purpose components exist to represent specific components such as the Reactor Coolant Pumps (RCPs) or the steam generator (SG) separators. All geometries are modeled at the resolution necessary to best resolve the flow field and the phenomena being modeled within practical computational limitations.

The analysis considers blockage effects due to clad swelling and rupture as well as increased heat load due to fuel relocation in the ballooned region of the cladding in the prediction of the hot fuel rod PCT.

A typical calculation using S-RELAP5 begins with the establishment of a steady-state initial condition with all loops intact. The input parameters and initial conditions for this steady-state calculation are chosen to reflect plant technical specifications or to match measured data. Additionally, the COPERNIC code provides initial conditions for the S-RELAP5 fuel models. Specific parameters are discussed in Section 2.6.

Following the establishment of an acceptable steady-state condition, the transient calculation is initiated by introducing a break into one of the loops. The evolution of the transient through blowdown, refill, and reflood is computed continuously using S-RELAP5. Containment pressure is calculated by the ICECON module within S-RELAP5.

A detailed assessment of the S-RELAP5 computer code was made through comparisons to experimental data. These assessments were used to develop quantitative estimates of the ability of the code to predict key physical phenomena in a PWR LBLOCA. The final step of the best-estimate methodology is to combine all the uncertainties related to the code and plant parameters and estimate the first three criteria of 10 CFR 50.46 with a probability of at least 95 percent with 95 percent confidence. The steps taken to derive the uncertainty estimate are summarized below:

1. Base Plant Input File Development

   First, base COPERNIC and S-RELAP5 input files for the plant (including the containment input file) are developed. The code input development guidelines documented in Appendix A of Reference 1, as amended by References 2 and 3, are applied to ensure that model nodalization is consistent with the model nodalization used in the code validation.

2. Sampled Case Development

   The statistical approach requires that many "sampled" cases be created and processed. For every set of input created, each "key LOCA parameter" is randomly sampled over a range established through code uncertainty assessment or expected operating limits (provided by plant technical specifications or data). Those parameters considered "key LOCA parameters" are listed in Table A-6 of 1, as amended by References 2 and 3. This list includes both parameters related to LOCA phenomena, based on the PIRT provided in Reference 1, and to plant operating parameters. The uncertainty ranges associated with each of the model parameters are provided in Table A-7 of Reference 1, as amended by References 2 and 3.

3. Determination of Adequacy of ECCS

   The RLBLOCA methodology uses a non-parametric statistical approach to determine that the first three criteria of 10 CFR 50.46 are met with a probability higher than 95 percent with 95 percent confidence.

## 2.4 *GDC-35 Limiting Condition Determination*

GDC-35 requires that a system be designed to provide abundant core cooling with suitable redundancy such that the capability is maintained in either the loss of offsite power (LOOP) or the offsite power available (No-LOOP) condition. [

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## 2.5 *Overall Statistical Compliance to Criteria*

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## 2.6 *Plant Description and Summary of Analysis Parameters*

The plant analyzed is the Millstone Unit 2, CE designed PWR, which has 2x4-loop arrangement. There are two hot legs each with an U-tube steam generator and four cold legs each with a RCP. The RCS includes one Pressurizer connected to a hot leg. The ECCS comprises four SITs, one per loop/cold leg, and one full train of Low Pressure Safety Injection (LPSI) and High Pressure Safety Injection (HPSI) (after applying the single failure assumption). The HPSI and LPSI feed into common headers (cross connected) that are connected to the SIT lines. The RLBLOCA transients are of

sufficiently short duration that the switchover to sump cooling water for ECCS pumped injection does not need to be considered.

The S-RELAP5 model explicitly describes the RCS, reactor vessel, pressurizer, and ECCS. The ECCS includes a SIT path and a LPSI/HPSI path per RCS loop. The HPSI and LPSI feed into a common header that connects to each cold leg pipe downstream of the RCP discharge. The ECCS pumped injection is modeled as a table of flow versus backpressure. This model also describes the secondary-side steam generator that is instantaneously isolated (closed main steam isolation valve and feedwater trip) at the time of the break. The analysis includes AREVA fuel with M5® cladding and utilizes the COPERNIC code for fuel calculations within S-RELAP5. The primary and secondary coolant systems for Millstone Unit 2 were nodalized consistent with code input guidelines in Appendix A of Reference 1, and as amended by References 2 and 3.

As described in Appendix A of Reference 1, as amended by References 2 and 3, many parameters associated with LBLOCA phenomenological uncertainties and plant operation ranges are sampled. A summary of those parameters sampled is given in Table A-6 of Reference 1, as amended by References 2 and 3. The LBLOCA phenomenological uncertainties are provided in Table A-7 of Reference 1, as amended by References 2 and 3. Values for process or operational parameters, including ranges of sampled process parameters, and fuel design parameters used in this analysis are given in Table 1. Table 2 presents a summary of the uncertainties used in the analysis. Two parameters (refueling water storage tank temperature and diesel start time) are set at conservative bounding values for all calculations. The passive heat sinks and material properties used in the containment input model are provided in Table 3.

### 2.7 *SE Limitations*

The RLBLOCA analysis for Millstone Unit 2 presented herein is consistent with the submitted RLBLOCA methodology documented in EMF-2103, Revision 3 (Reference 1) and as supplemented in the RAI responses and Errata in References 2 and 3. The

limitation and conditions from the draft NRC Safety Evaluation (SE) (Reference 4) are addressed in Table 4.

## 3.0 REALISTIC LARGE BREAK LOCA RESULTS

[

] For a simultaneous coverage/confidence level of 95/95, the UTL values are a PCT of 1615°F, a maximum local oxidation of 2.01 percent, and a total core-wide oxidation of 0.025 percent. The fraction of total hydrogen generated was not directly calculated; however, it is conservatively bounded by the calculated total core wide percent oxidation, which is well below the 1 percent limit.

This analysis assumes a full core of AREVA Standard CE14 HTP fuel design which incorporates M5® clad fuel rod design among other features. However, at the time of the application of this analysis, the Millstone Unit 2 core will be a mixed core of AREVA Standard CE14 HTP fuel design and the resident fuel design which is a CE 14x14 HTP with Zr-4 cladding. The differences between the two core designs have been assessed. The differences are such that thermal hydraulic performance is not impacted and modeling the core as a full core of M5® is acceptable and no penalty is required for this analysis.

Table 6 is a summary of the major input parameters for the demonstration case. The sequence of event times for the demonstration case is provided in Table 7. The heat transfer parameter ranges for the demonstration case are provided in Table 8. [

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The analysis plots for the case set are shown in Figure 1 through Figure 5. Figure 1 shows linear scatter plots of the key parameters sampled for all cases. Parameter labels appear to the left of each individual plot. These figures illustrate the parameter ranges used in the analysis. Visual examination of the linear scatter plots demonstrates that the spread and coverage of all of the values used is appropriate and within the uncertainty ranges listed in Table 2. Appendix A provides a listing of all the sampled input values for each case. Key results such as the PCT and event timings are also listed for the case set.

Figure 2 and Figure 3 show PCT scatter plots versus the time of PCT and versus break size, respectively. The scatter plots for the maximum local oxidation and total core-wide oxidation are shown in Figure 4 and Figure 5, respectively.

Figure 2 shows a general decreasing trend of PCT with increasing PCT time with two distinctive clusters of high PCTs (>1200°F). The first cluster shows PCT timings of less than 15 seconds (blowdown period); the second cluster shows PCT timings between 15 seconds and 50 seconds (early reflood period). Blowdown PCT cases are dominated by rapid RCS depressurization and stored energy content. Early reflood PCT cases are dominated by decay heat removal capacity, which is highly dependent on SIT liquid volume and pressure setpoint. As shown in Figure 3, there is a strong correlation of PCT to break size. From all sampled parameters, the break size is a dominant effect in PCT because of its high influence in the rate of primary depressurization. As such, the high PCT clusters correlate with the larger end of the break sizes. In general, for this plant design, larger breaks peak at either the blowdown phase or the early reflood

phase of the transient depending on the influence of various phenomena such as blowdown flow reversal/stagnation, ECCS bypass, and steam binding. Large SITs with low pressure setpoints tend towards delayed injection which results in less ECCS bypass. Therefore, the late reflood PCT cases (> 50 seconds, Figure 2) are typically smaller break sizes with slower depressurizations and lower PCTs. An exception to that is the case inFigure 2 with a late reflood peak (~157 seconds) and relatively high PCT (>1500°F). This case falls in the larger end of the break sizes (~4.0 $ft^2$/side). However, it is characterized by a combination of sampling parameters leading to an earlier SIT depletion and a relatively slower reflood rate than the surrounding break size cases.

The demonstration case is a blowdown peak case with a PCT timing of 7.4 seconds. Figure 6 through Figure 17 show key parameters from the S-RELAP5 calculations for the demonstration case. The transient progression for the demonstration case follows that described in Section 2.2.

Figure 4 shows a general increasing trend of MLO with PCT. Since the MLO includes the pre-transient oxidation, the MLO is not only a function of cladding temperature but of time in cycle (burnup), which explains the scatter of the points. A stronger correlation of the CWO to PCT is demonstrated in Figure 5 as higher PCT cases would have a higher oxidation throughout the core.

Figure 18 compares the Beginning of Core Recovery (BOCR) times calculated by S-RELAP5 to the BOCR times predicted using the Counter Current Flow Limiting (CCFL) correlation developed by MPR Associates. Note that Figure 18 uses the total break area, while previous plots use break area per side.

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## 4.0 CONCLUSIONS

This report describes and provides results from the RLBLOCA analysis for the Millstone Unit 2 M5® fuel upgrade. The plant is a PWR Combustion Engineering 2x4-loop design with an analyzed thermal power of 2754 MWt (includes power calorimetric uncertainty) and dry atmospheric containment. The loops contain four RCPs, two U-tube steam generators and a pressurizer. The base model and the design inputs used are representative of the Millstone Unit 2 plant. The application of the AREVA RLBLOCA methodology involves developing input decks, executing the simulations that comprise the uncertainty analysis, retrieving PCT, MLO, and CWO information and determining the simultaneous UTL results for the criteria. [

] The UTL results providing a 95/95 simultaneous coverage/confidence level from this evaluation meet the 10 CFR 50.46(b) criteria with a PCT of 1615°F, a maximum local oxidation of 2.01 percent and a total core-wide oxidation of 0.025 percent.

## 5.0 REFERENCES

1. EMF-2103(P) Revision 3, *Realistic Large Break LOCA Methodology for Pressurized Water Reactors*, AREVA Inc., September 2013.

2. U.S. NRC ADAMS Accession No. ML16054A205, "AREVA, Inc. - Transmittal of Response to First and Second Request for Additional Information Regarding EMF-2103(P), Revision 3, 'PWR Realistic Large Break LOCA Methodology for Pressurized Water Reactors,'" NRC:16:005, February 16, 2016.

3. U.S. NRC ADAMS Accession No. ML16060A062, "Revised Pages for EMF-2103(P), Revision 3, 'Realistic Large Break LOCA Methodology for Pressurized Water Reactors,'" NRC:16:006, February 19, 2016.

4. U.S. NRC ADAMS Accession No. ML16098A366, "Draft Safety Evaluation for AREVA NP Inc. Topical Report EMF-2103(P), Revision 3, 'Realistic Large Break LOCA Methodology for Pressurized Water Reactors,'" April 14, 2016.

5. Code of Federal Regulations, Title 10, Part 50, Section 46, Acceptance Criteria For Emergency Core Cooling Systems For Light-Water Nuclear Power Reactors, August 2007.

6. NUREG/CR-5249, "Quantifying Reactor Safety Margins, Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large Break, Loss-of-Coolant Accident," U.S. NRC, December 1989.

7. Regulatory Guide 1.203, "Transient and Accident Analysis Methods" U.S. NRC, December 2005.

**Table 1**
**RLBLOCA Analysis - Plant Parameter Values and Ranges**

| | Plant Parameter | Parameter Value |
|---|---|---|
| **1.0** | **Plant Physical Description** | |
| | 1.1 Fuel | |
| | a) Cladding outside diameter | 0.440 in. |
| | b) Cladding inside diameter | 0.387 in. |
| | c) Cladding thickness | 0.0265 in. |
| | d) Pellet outside diameter | 0.3805 in. |
| | e) Initial Pellet density | 96 percent of theoretical |
| | f) Active fuel length | 136.7 in. |
| | g) $Gd_2O_3$ concentrations | 2, 4, 6, 8 w/o |
| | 1.2 RCS | |
| | a) Flow resistance | Analysis |
| | b) Pressurizer location | [ ] |
| | c) Hot assembly location | Anywhere in core |
| | d) Hot assembly type | 14x14 |
| | e) SG tube plugging | 5.87 percent |
| **2.0** | **Plant Initial Operating Conditions** | |
| | 2.1 Reactor Power | |
| | a) Analyzed reactor power | 2754 MWt |
| | b) $F_Q$ | 2.385[1,2] |
| | c) $F_r$ | 1.854[2] |
| | 2.2 Fluid Conditions | |
| | a) Loop flow | 132.2 Mlbm/hr $\leq$ M $\leq$ 160.0 Mlbm/hr |
| | b) RCS cold leg temperature | 536°F $\leq$ T $\leq$ 554°F |
| | c) Upper head temperature | ~Thot Temperature[3] |
| | d) Pressurizer pressure | 2190 psia $\leq$ P $\leq$ 2310 psia |
| | e) Pressurizer level | 35 percent $\leq$ L $\leq$ 75 percent |
| | f) SIT pressure | 195 psia $\leq$ P $\leq$ 280 psia |
| | g) SIT liquid volume | 1015 $ft^3 \leq V \leq$ 1255 $ft^3$ |
| | h) SIT temperature | 60°F $\leq$ T $\leq$ 125°F (coupled with containment temperature) |
| | i) SIT resistance fL/D | As-built piping configuration |
| | j) SIT boron | 1720 ppm |

1 The value used for $F_Q$ is derived from the LHGR Technical Specification value
2 Includes measurement uncertainty.
3 Upper head temperature will change based on sampling of RCS temperature.

**Table 1**
**RLBLOCA Analysis - Plant Parameter Values and Ranges**
*(Continued)*

| | Plant Parameter | Parameter Value |
|---|---|---|
| **3.0** | **Accident Boundary Conditions** | |
| | a) Break location | Cold leg pump discharge |
| | b) Break type | Double-ended guillotine or split |
| | c) Break size (each side, relative to cold leg pipe area) | $0.05 \le A \le 1.0$ full pipe area (split)<br>$0.05 \le A \le 1.0$ full pipe area (guillotine) |
| | d) ECCS pumped injection temperature | 140°F |
| | e) HPSI pump delay | 10 s (No-LOOP)<br>25 s (LOOP) |
| | f) LPSI pump delay | 30 s (No-LOOP)<br>45 s (LOOP) |
| | g) Initial containment pressure | 14.27 psia |
| | h) Initial containment temperature | 60°F ≤ T ≤ 125°F |
| | i) Containment sprays delay | 0 s |
| | j) Containment spray water temperature | 35°F |
| | k) LPSI Flow | |

| RCS Cold Leg Pressure (psia) | Broken Loop Flow 1A (gpm) | Intact Loop Flow 1B (gpm) | Intact Loop Flow 2A (gpm) | Intact Loop Flow 2B (gpm) |
|---|---|---|---|---|
| 14.7 | 1369 | 1314 | 0 | 0 |
| 50 | 1214 | 1164 | 0 | 0 |
| 100 | 945 | 904 | 0 | 0 |
| 150 | 546 | 519 | 0 | 0 |
| 200 | 0 | 0 | 0 | 0 |
| 300 | 0 | 0 | 0 | 0 |
| 500 | 0 | 0 | 0 | 0 |
| 700 | 0 | 0 | 0 | 0 |
| 900 | 0 | 0 | 0 | 0 |
| 1000 | 0 | 0 | 0 | 0 |
| 1050 | 0 | 0 | 0 | 0 |
| 1100 | 0 | 0 | 0 | 0 |
| 1144.34 | 0 | 0 | 0 | 0 |

## Table 1
## RLBLOCA Analysis - Plant Parameter Values and Ranges
*(Continued)*

| Plant Parameter | Parameter Value |
|---|---|
| l) HPSI Flow | |

| RCS Cold Leg Pressure (psia) | Broken Loop Flow 1A (gpm) | Intact Loop Flow 1B (gpm) | Intact Loop Flow 2A (gpm) | Intact Loop Flow 2B (gpm) |
|---|---|---|---|---|
| 14.7 | 138 | 140 | 139 | 140 |
| 50 | 136 | 138 | 137 | 138 |
| 100 | 133 | 135 | 134 | 135 |
| 150 | 131 | 131 | 131 | 131 |
| 200 | 128 | 128 | 128 | 128 |
| 300 | 121 | 121 | 121 | 122 |
| 500 | 106 | 106 | 106 | 106 |
| 700 | 89 | 89 | 89 | 89 |
| 900 | 68 | 68 | 68 | 68 |
| 1000 | 54 | 54 | 54 | 54 |
| 1050 | 43 | 43 | 43 | 43 |
| 1100 | 30 | 30 | 30 | 30 |
| 1144.34 | 0 | 0 | 0 | 0 |

**Table 2**
**Statistical Distribution Used for Process Parameters**

| Parameter | Operational Uncertainty Distribution | Parameter Range | Measurement Uncertainty Distribution | Standard Deviation |
|---|---|---|---|---|
| Pressurizer Pressure (psia) | Uniform | 2190 - 2310 | Normal | 0 |
| Pressurizer Level (%) | Uniform | 35 - 75 | Normal | 0 |
| SIT Volume ($ft^3$) | Uniform | 1015 - 1255 | N/A | N/A |
| SIT Pressure (psia) | Uniform | 195 - 280 | N/A | N/A |
| Containment/SIT Temperature (°F) | Uniform | 60 - 125 | N/A | N/A |
| Containment Volume ($x10^6$ $ft^3$) | Uniform | 1.899 - 2.125 | N/A | N/A |
| Initial Flow Rate (Mlbm/hr) | Uniform | 132.2 – 160.0 | N/A | N/A |
| Initial Operating Temperature (°F) | Uniform | 536 - 554 | N/A | N/A |

**Table 3**
**Passive Heat Sinks and Material Properties in Containment Geometry**

| Heat Sink | Surface Area, $ft^2$ | Thickness, ft | Material |
|---|---|---|---|
| Containment Shell and Dome | 71870 | 0.02083 | Carbon Steel |
| | | 3.02083 | Concrete |
| Unlined Concrete | 62800 | 2.0 | Concrete |
| Galvanized Steel | 120100 | 0.0003 | Galvanized Steel |
| | | 0.01697 | Carbon Steel |
| Painted Thin Steel | 61850 | 0.01667 | Carbon Steel |
| Painted Steel | 32600 | 0.021667 | Carbon Steel |
| Painted Steel | 25425 | 0.071667 | Carbon Steel |
| Painted Thick Steel | 4630 | 0.245 | Carbon Steel |
| Containment Penetration | 3000 | 0.0625 | Carbon Steel |
| | | 3.8125 | Concrete |
| Stainless Lined Concrete | 8340 | 0.020833 | Stainless Steel |
| | | 2.020833 | Concrete |
| Base Slab | 11130 | 8.0 | Concrete |
| Neutron Shield | 16270 | 0.0154 | Stainless Steel |
| CEDM Cable Support | 1380 | 0.1094 | Stainless Steel |
| Painted Steel | 2891 | 0.031327 | Carbon Steel |
| Painted Steel | 1856 | 0.02083 | Carbon Steel |
| Painted Steel | 624.4 | 0.0374 | Carbon Steel |
| Non Galvanized Carbon Steel | 23564 | 0.02167 | Carbon Steel |
| Galvanized Carbon Steel | 5423.4 | 0.003 | Galvanized Steel |
| | | 0.0112 | Carbon Steel |
| | | 0.0115 | Galvanized Steel |
| Stainless Steel | 6948 | 0.02167 | Stainless Steel |
| Aluminum | 2300 | 0.01333 | Aluminum |
| Lead | 7100 | 0.0325 | Lead |

| Heat Sink Material | Thermal Conductivity Btu/hr-ft-°F | Volumetric Heat Capacity Btu/ft3-°F |
|---|---|---|
| Concrete | 0.92 | 22.62 |
| Carbon Steel | 27.00 | 58.80 |
| Stainless Steel | 8.47 | 58.60 |
| Galvanized Steel | 65.0 | 41.00 |
| Aluminum | 118 | 35.2 |
| Lead | 19.6 | 21.2 |

**Table 4**
**Draft SE Limitations Evaluation**

| | Limitations (Section 4.0 in Ref. [4]) | Response |
|---|---|---|
| 1 | This EM was specifically reviewed, in accordance with statements in the LTR, to determine whether EMF-2103P, Revision 3, is an acceptable EM for determining whether plant-specific results comply with the acceptance criteria set forth in 10 CFR 50.46(b), paragraphs (1) through (3). The vendor did not request, and the NRC staff did not consider, whether this EM would be considered applicable if used to determine whether the requirements of 10 CFR 50.46(b)(4), regarding coolable geometry, or (b)(5), regarding long-term core cooling, are satisfied. Thus, this approval does not apply to the use of SRELAP5-based methods of evaluating the effects of grid deformation due to seismic or LOCA blowdown loads, or for evaluating the effects of reactor coolant system boric acid transport. Such evaluations would be considered separate methods. | This analysis applies only to the acceptance criteria set forth in 10 CFR 50.46(b), paragraphs (1) through (3). |
| 2 | The LTR approval is limited to application for 3-loop and 4-loop Westinghouse-designed nuclear steam supply systems (NSSSs), and to Combustion Engineering-designed NSSSs with cold leg ECCS injection, only. The NRC staff did not consider model applicability to other NSSS designs in its review. | Millstone Unit 2 is a Combustion Engineering-designed NSSS with cold leg ECCS injection. |
| 3 | The evaluation model is approved based on models that are specific to AREVA proprietary M5™ fuel cladding. The application of the model to other cladding types has not been reviewed. | The analysis supports operation with M5® cladding. |
| 4 | Plant-specific applications will generally be considered acceptable if they follow the modeling guidelines contained in Appendix A to EMF 2103, Revision 3. Plant-specific licensing actions referencing EMF 2103, Revision 3, analyses should include a statement summarizing the extent to which the guidelines were followed, and justification for any departures. | The modeling guidelines contained in Appendix A of EMF-2103, Revision 3 were followed completely for the analysis described in this report. |

| | Limitations (Section 4.0 in Ref. [4]) | Response |
|---|---|---|
| 5 | The approach described in 3.1.3.3.7 of EMF-2103, Revision 3, in addition to the guidelines provided on pp. A-67 through A-71 of EMF-2103, Revision 3, regarding the power level assumed for auxiliary rods, will be considered acceptable for generic implementation of the rod-to-rod radiation model. Plant-specific licensing actions referencing EMF-2103, Revision 3, analyses should include a confirmation that these modeling practices bound plant operation. | [ ] |
| 6 | The response to RAI 15 indicates that the fuel pellet relocation packing factor is derived from data that extend to currently licensed fuel burnup limits, i.e., rod average burnup of [ ]. Thus, the approval of this method is limited to fuel burnup below this value. Extension beyond rod average burnup of [ ] would require a revision or supplement to the LTR, or plant-specific justification. | The analysis supports operation with M5® cladding, which has a licensed limit of [ ]. |
| 7 | The response to RAI 15 indicates that the fuel pellet relocation packing factor is derived from currently available data. Should new data become available to suggest that fuel pellet fragmentation behavior is other than that suggested by the currently available database, the NRC may request the vendor to update its model to reflect such new data. | [ ] |
| 8 | The regulatory limit contained in 10 CFR 50.46(b)(2), requiring cladding oxidation not to exceed 17-percent of the initial cladding thickness prior to oxidation, is based on the use of the Baker-Just oxidation correlation. To account for the use of the Cathcart-Pawel correlation, this limit shall be reduced to 13 percent, inclusive of pre-transient oxide layer thickness. | The MLO UTL is less than 13% (Table 5). [ ] |

| | Limitations (Section 4.0 in Ref. [4]) | Response |
|---|---|---|
| 9 | In conjunction with Limitation 8 above, Cathcart-Pawel oxidation results will be considered acceptable, provided plant-specific [ ], or limiting fuel rods with respect to oxidation remain in the first cycle. If second-cycle fuel is identified in a plant-specific analysis, whose [ ], the NRC staff reviewing the plant-specific analysis may request a quantitative assessment, or similar justification, demonstrating that [ ]. | [ ] |
| 10 | The response to RAI 13 states that all operating ranges used in a plant-specific analysis are supplied for review by the NRC in a table like Table B-8 of EMF 2103P, Revision 3. In plant specific reviews, the uncertainty treatment for plant parameters will be considered acceptable if plant parameters [ ]. Alternative approaches may be used, provided they are supported with appropriate justification. | [ ] |
| 11 | The NRC staff review only considered the application of [ ]. Alternate approaches, such as using [ ], require plant-specific justification. Such justification would need to address both the acceptability [ ]. | [ ] |

| | Limitations (Section 4.0 in Ref. [4]) | Response |
|---|---|---|
| 12 | Plant-specific applications must adhere to the processes described in the response to RAIs 22 and 23, regarding the determination of the sample size, and dispositioning outlying or unacceptable results. More specifically:<br>• The minimum sample size for the statistical analysis shall be [ ] cases.<br>• The exact sample size shall be selected prior to the initiation of production safety analysis.<br>• When re-analysis is necessary for any purpose other than a significant plant change such as the analysis for an extended power uprate:<br>o The random number seed and sample size from the initial statistical analysis shall be preserved.<br>o Prior analyses shall be documented in calculation files at a level of documentation that allows full reproducibility.<br>Any submittal to the NRC, based on EMF-2103P, Revision 3, which is based on other than a first statistical calculation must specify that re-analysis has been performed, and must identify what changes were made to the evaluation model and/or input to obtain the submitted, final analysis. | [ ] |

**Table 5**
**Compliance with 10 CFR 50.46(b)**

| UTL for 95/95 Simultaneous Coverage/Confidence | | |
|---|---|---|
| **Parameter** | **Value** | **Case Number** |
| PCT, °F | 1615 | 123 |
| MLO, % | 2.01 | 174 |
| CWO, % | 0.025 | 96 |

| Characteristics of Case Setting the PCT UTL | |
|---|---|
| PCT, °F | 1615 |
| PCT Rod Type | Fresh 4% Gad Rod |
| Time of PCT, s | 7.44 |
| Elevation within Core, ft | 9.36 |
| Local Maximum Oxidation, % | 1.98 |
| Total Core-Wide Oxidation, % | 0.006 |
| PCT Rod Rupture Time, s | No rod rupture |
| Rod Rupture Elevation within Core, ft | No rod rupture |

**Table 6**
**Summary of Major Parameters for the Demonstration Case**

| Parameter | Value |
|---|---|
| Core Power (MWt) | 2754 |
| Time in Cycle (hrs) | 11619 |
| Limiting Rod Assembly Burnup (GWd/mtU) | 18.4 |
| Limiting Rod LHGR (kW/ft) | 13.25 |
| Limiting Rod Equivalent $F_Q$ | 2.09 |
| Limiting Rod Radial Peak, $F_r$ | 1.71 |
| Limiting Rod Axial Shape Index | -0.076 |
| Break Type | Split |
| Break Size ($ft^2$/side) | 3.6942 |
| Offsite Power Availability | LOOP |

**Table 7**
**Calculated Event Times for the Demonstration Case**

| Event | Time (sec) |
|---|---|
| Break Opens | 0.0 |
| RCP Trip | 0.0 |
| SIAS Issued | 0.7 |
| PCT Occurred | 7.4 |
| Start of Broken Loop SIT Injection | 16.6 |
| Start of Intact Loop SIT Injection (Loop 2,3 and 4 respectively) | 17.3, 17.3 and 17.3 |
| HPSI Available | 25.7 |
| Broken Loop HPSI Delivery Began | 25.7 |
| Intact Loops HPSI Delivery Began | 25.7, 25.7 and 25.7 |
| Beginning of Core Recovery (Beginning of Reflood) | 26.8 |
| LPSI Available | 45.7 |
| Broken Loop LPSI Delivery Began | 45.7 |
| Intact Loops LPSI Delivery Began | 45.7, N/A and N/A |
| Intact Loop SIT Emptied (Loop 2, 3 and 4 respectively) | 62.0, 62.1 and 61.5 |
| Broken Loop SIT Emptied | 63.3 |
| Transient Calculation Terminated | 900.0 |

## Table 8
## Heat Transfer Parameters for the Demonstration Case

| Time (s) | [ | | | | | ] |
|---|---|---|---|---|---|---|
| LOCA Phase | Early Blowdown | Blowdown[1] | Refill | Reflood | Quench | Long Term Cooling[2] |
| Heat Transfer Mode | [ | | | | | |
| Heat Transfer Correlations | | | | | | |
| Maximum LHGR kW/ft | | | | | | |
| Pressure (psia) | | | | | | |
| Core Inlet Mass Flux ($lb/s\text{-}ft^2$) | | | | | | |
| Vapor[4] Reynolds Number | | | | | | |
| Liquid Reynolds Number | | | | | | |
| Vapor Prandtl Number | | | | | | |
| Liquid Prandtl Number | | | | | | |
| Vapor[5] Superheat (°F) | | | | | | ] |

[1] End of blowdown considered as beginning of refill.
[2] Quench to End of Transient
[ ]
[4] Not important in pre-CHF heat transfer
[5] Vapor superheat is meaningless during blowdown and system depressurization

**Table 9**
**Fuel Rod Rupture Ranges of Parameters**

[ ]

**Figure 1**
**Scatter Plot Operational Parameters**

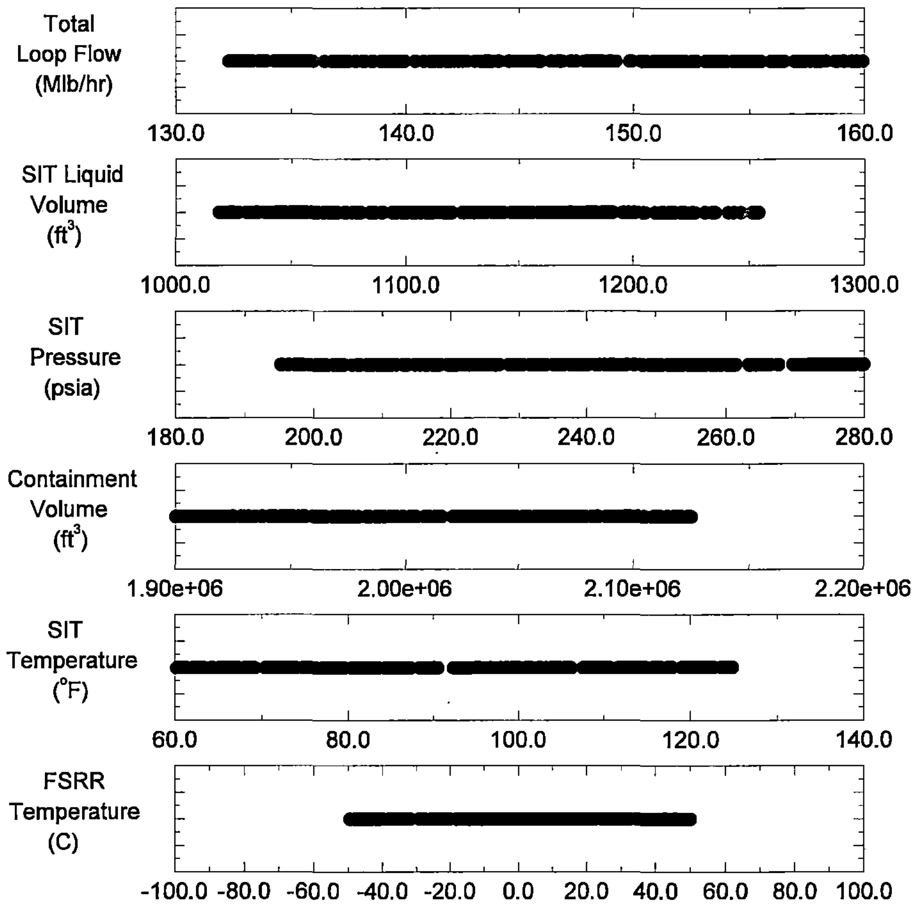

**Figure 2**
**PCT versus PCT Time Scatter Plot**

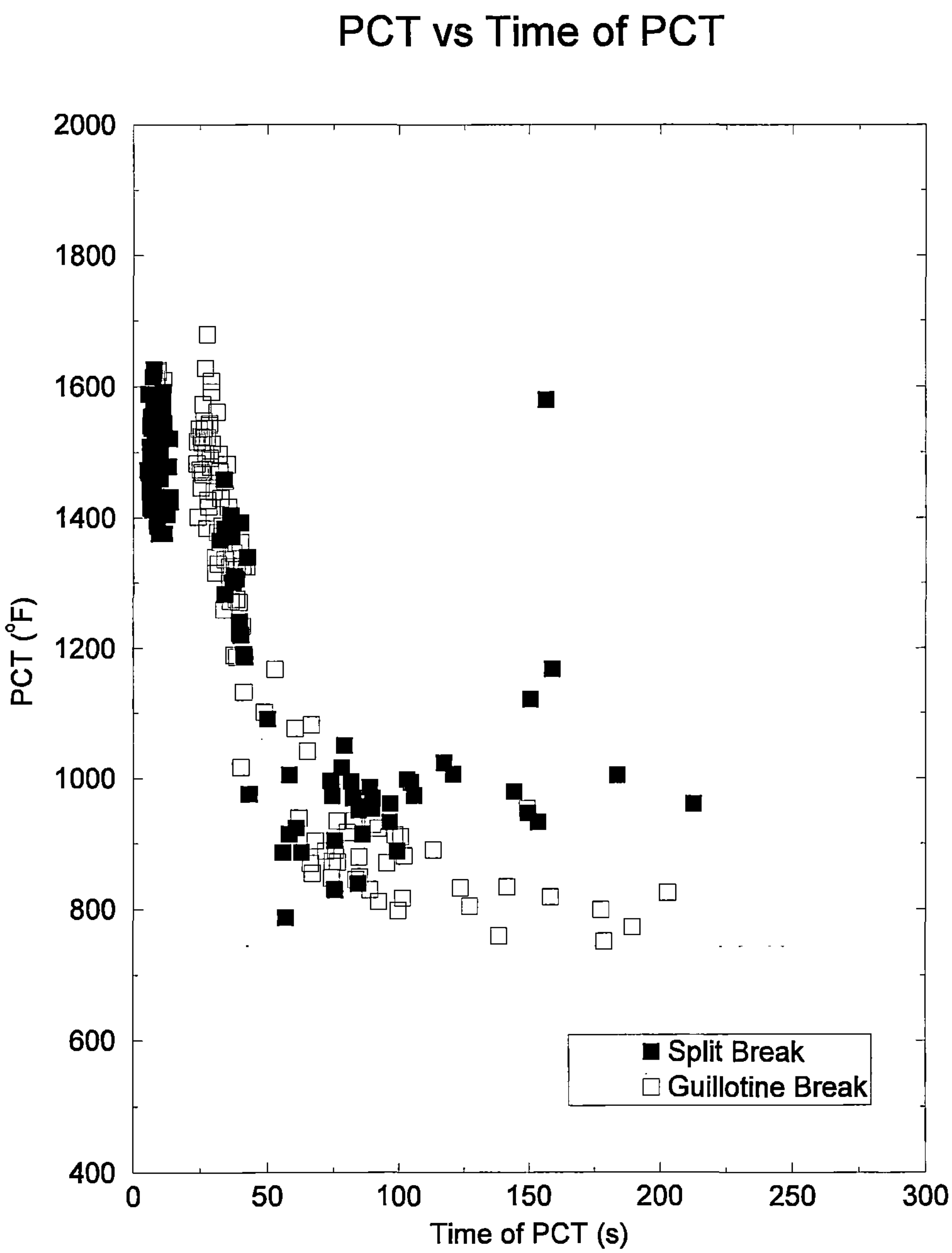

**Figure 3**
**PCT versus Break Size Scatter Plot**

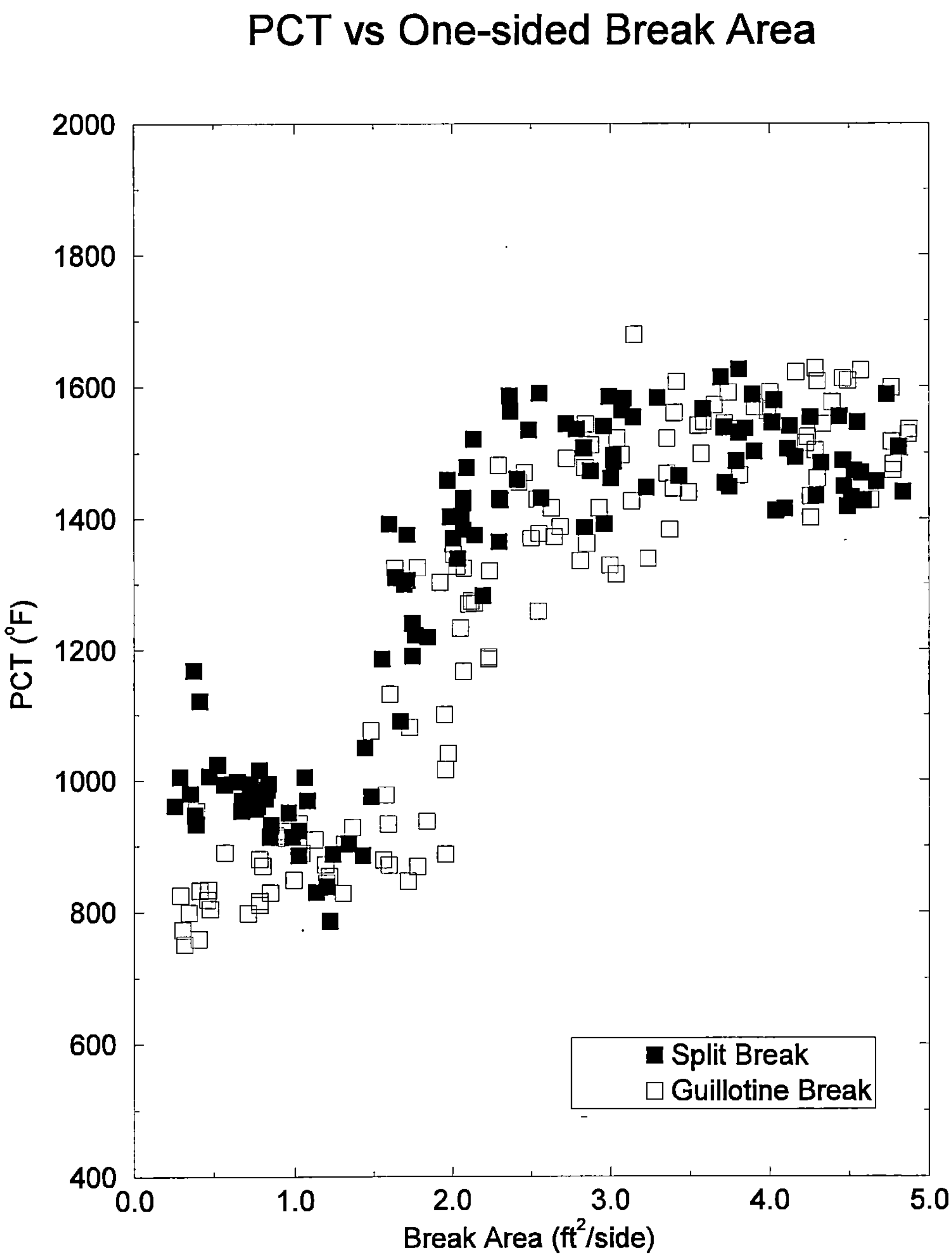

**Figure 4**
**Maximum Local Oxidation versus PCT Scatter Plot**

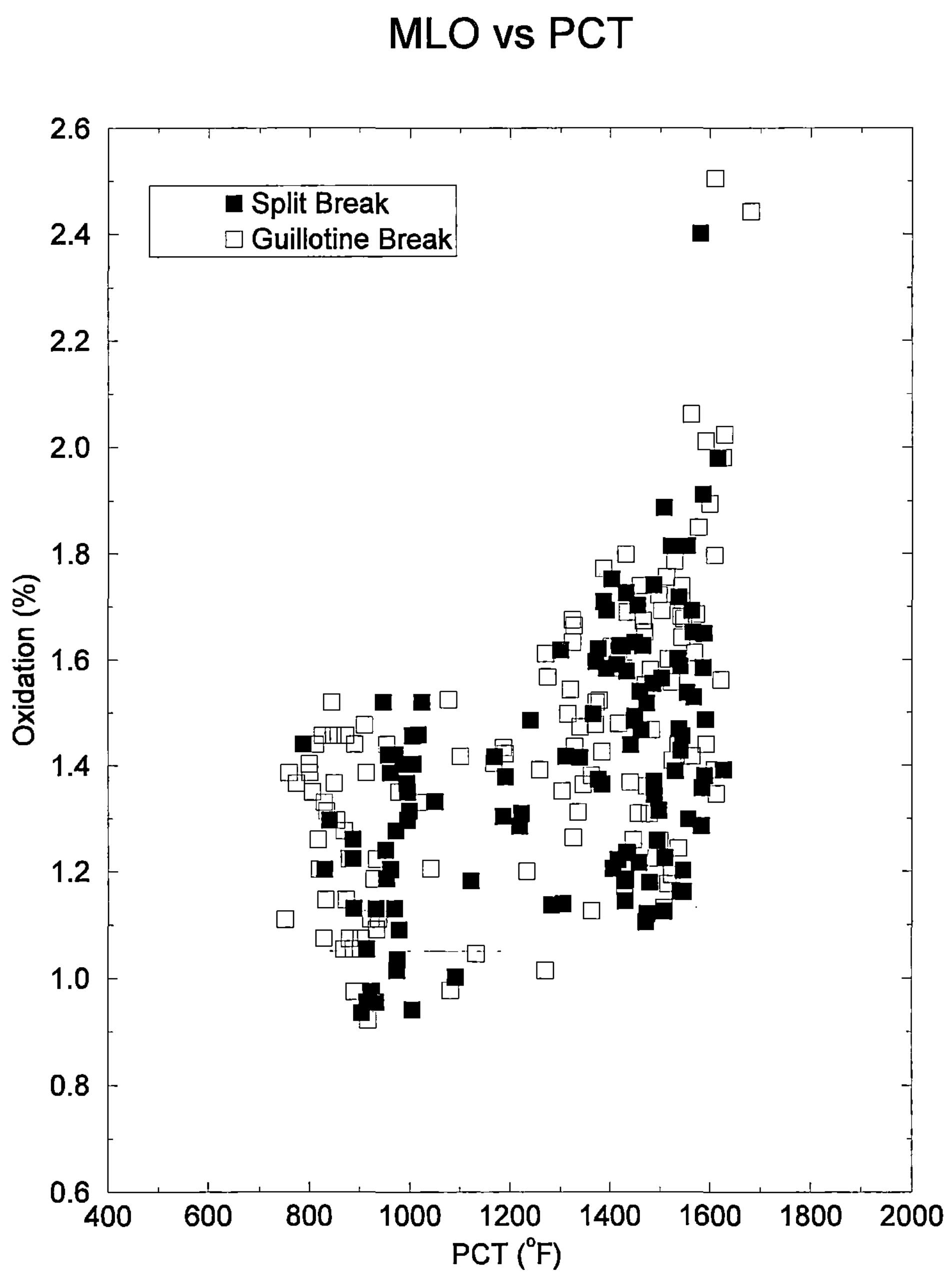

**Figure 5**
**Total Core Wide Oxidation versus PCT Scatter Plot**

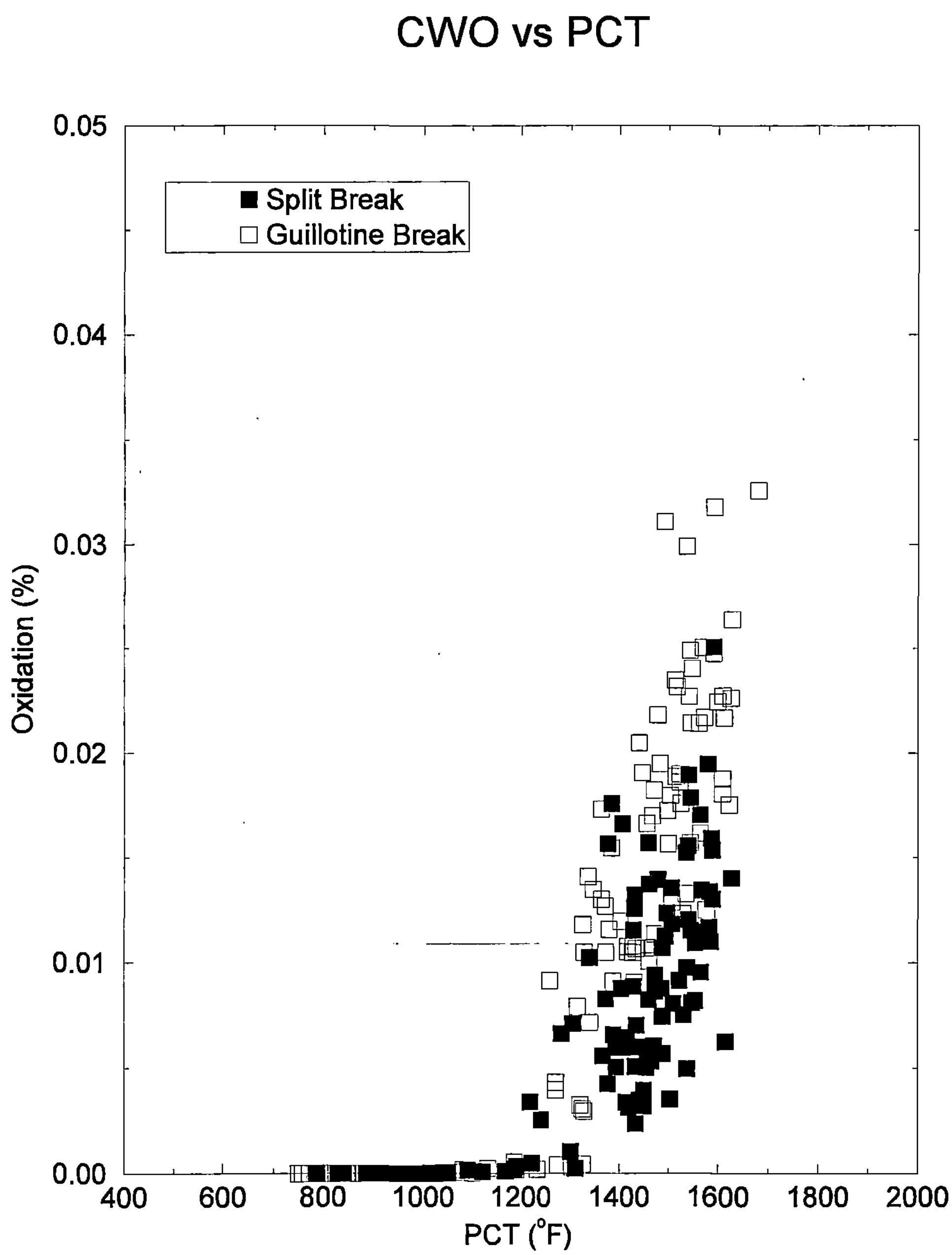

**Figure 6**
**Peak Cladding Temperature (Independent of Elevation) for the Demonstration Case**

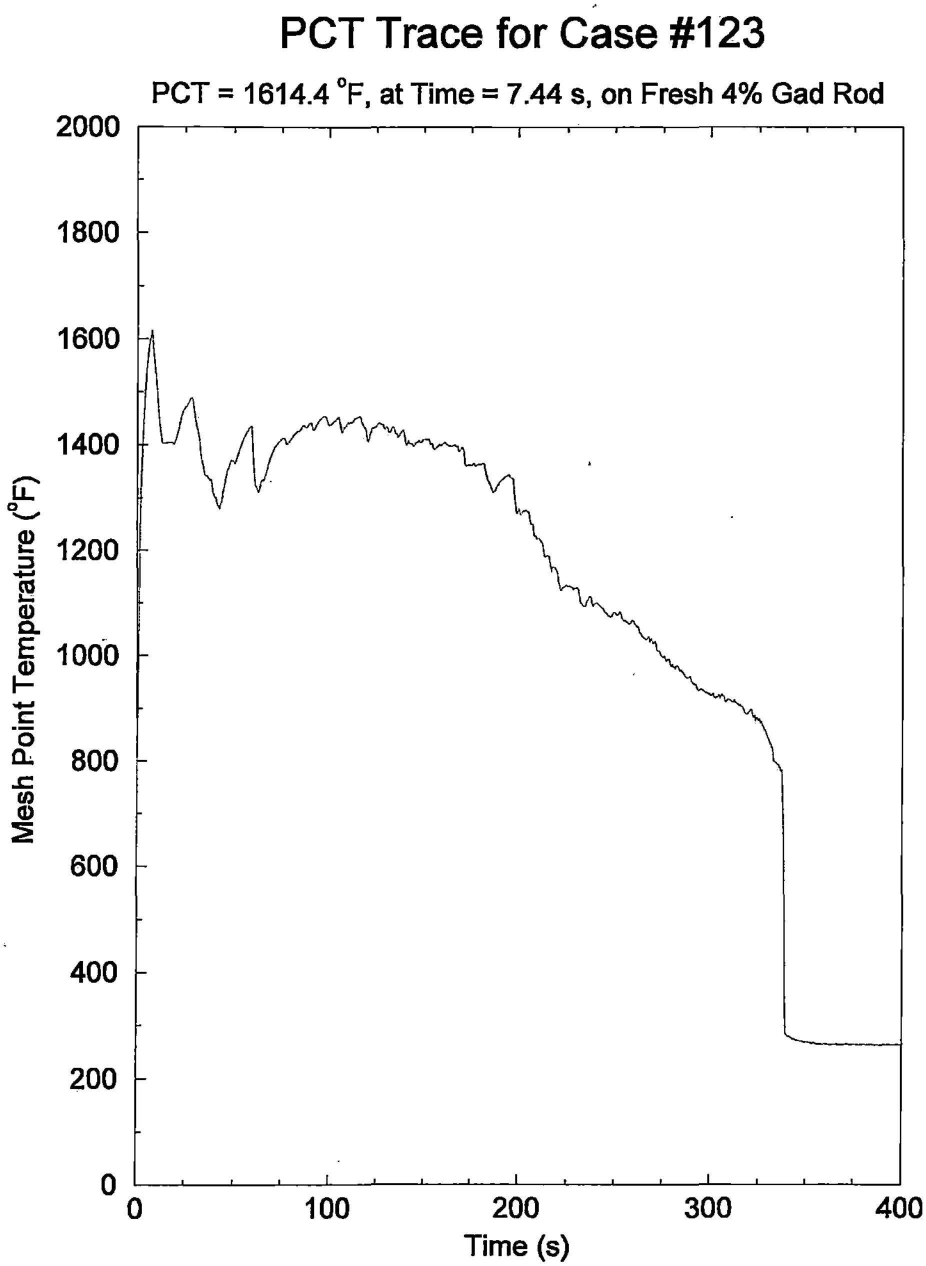

**Figure 7**
**Break Flow for the Demonstration Case**

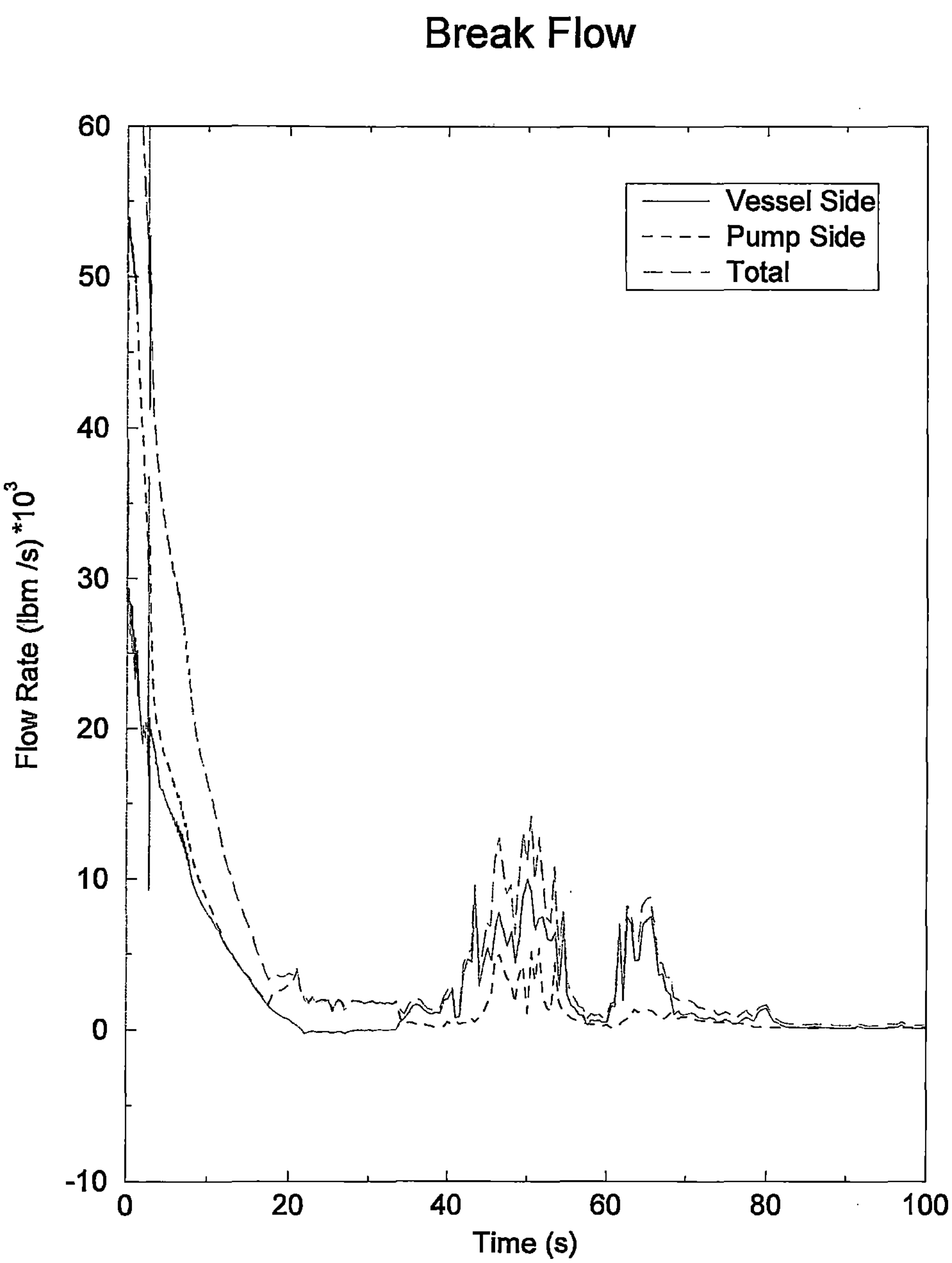

**Figure 8**
**Core Inlet Mass Flux for the Demonstration Case**

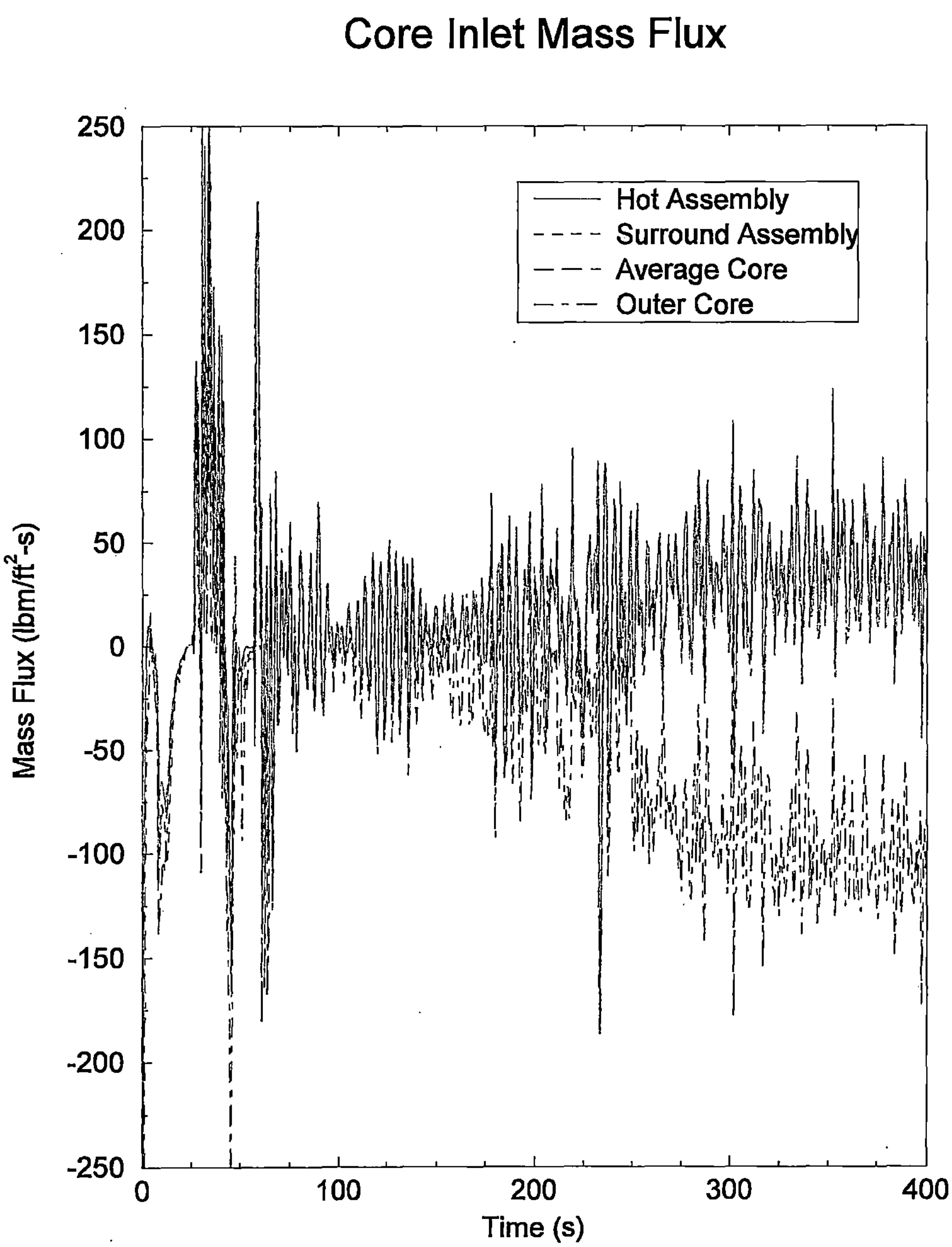

**Figure 9**
**Core Outlet Mass Flux for the Demonstration Case**

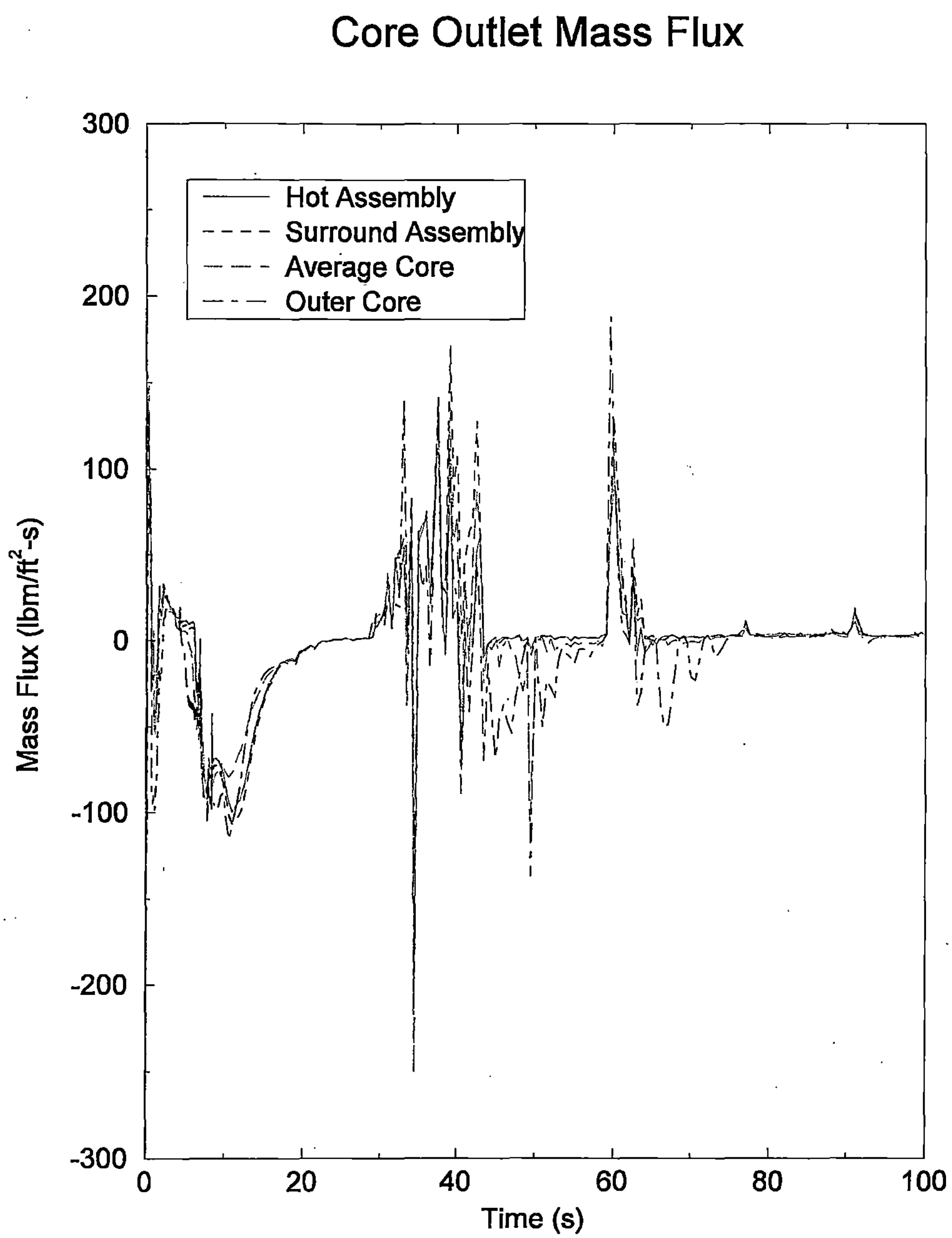

**Figure 10**
**Void Fraction at RCS Pumps for the Demonstration Case**

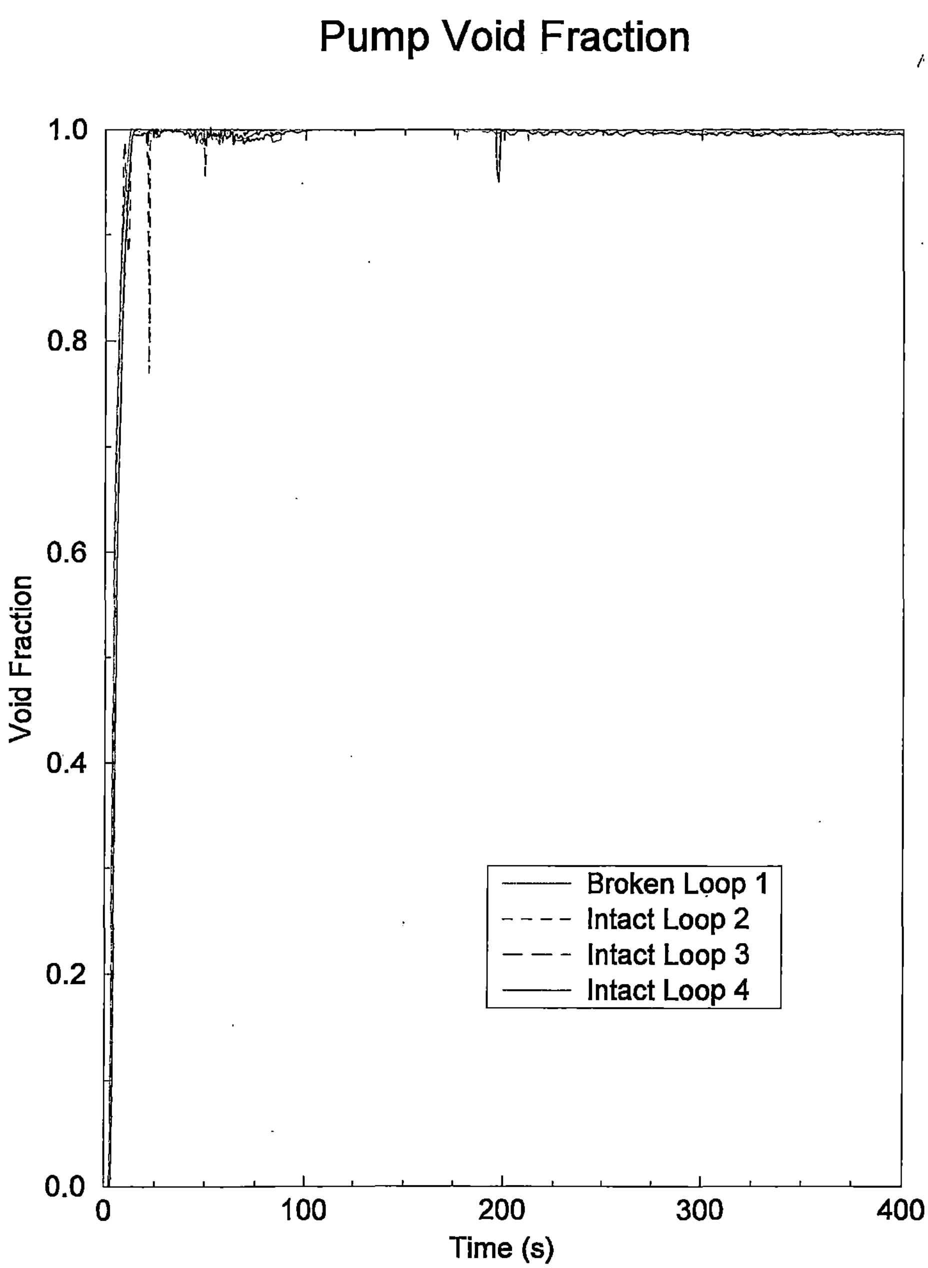

**Figure 11**
**ECCS Flows (Includes SIT, HPSI and LPSI) for the Demonstration Case**

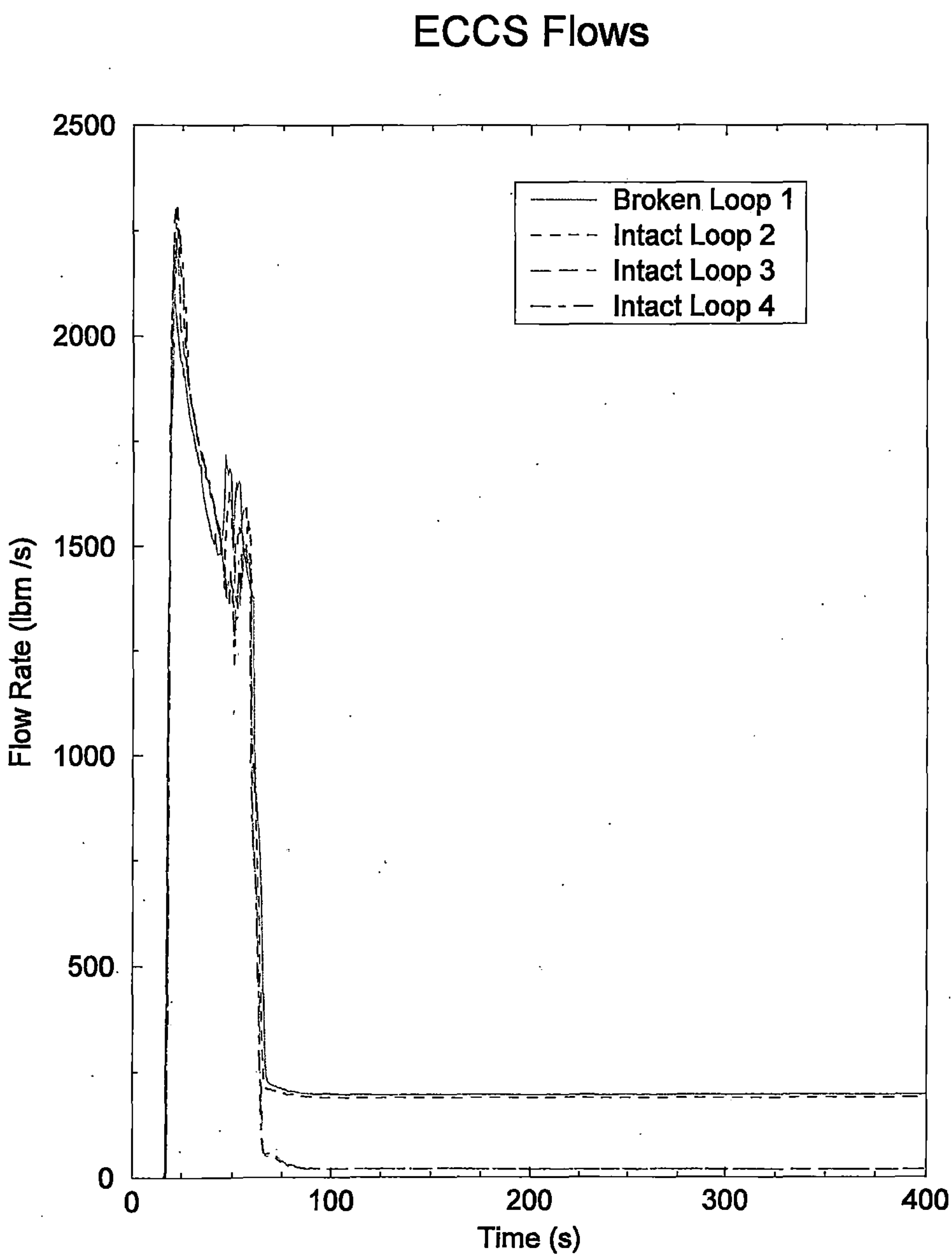

**Figure 12**
**Upper Plenum Pressure for the Demonstration Case**

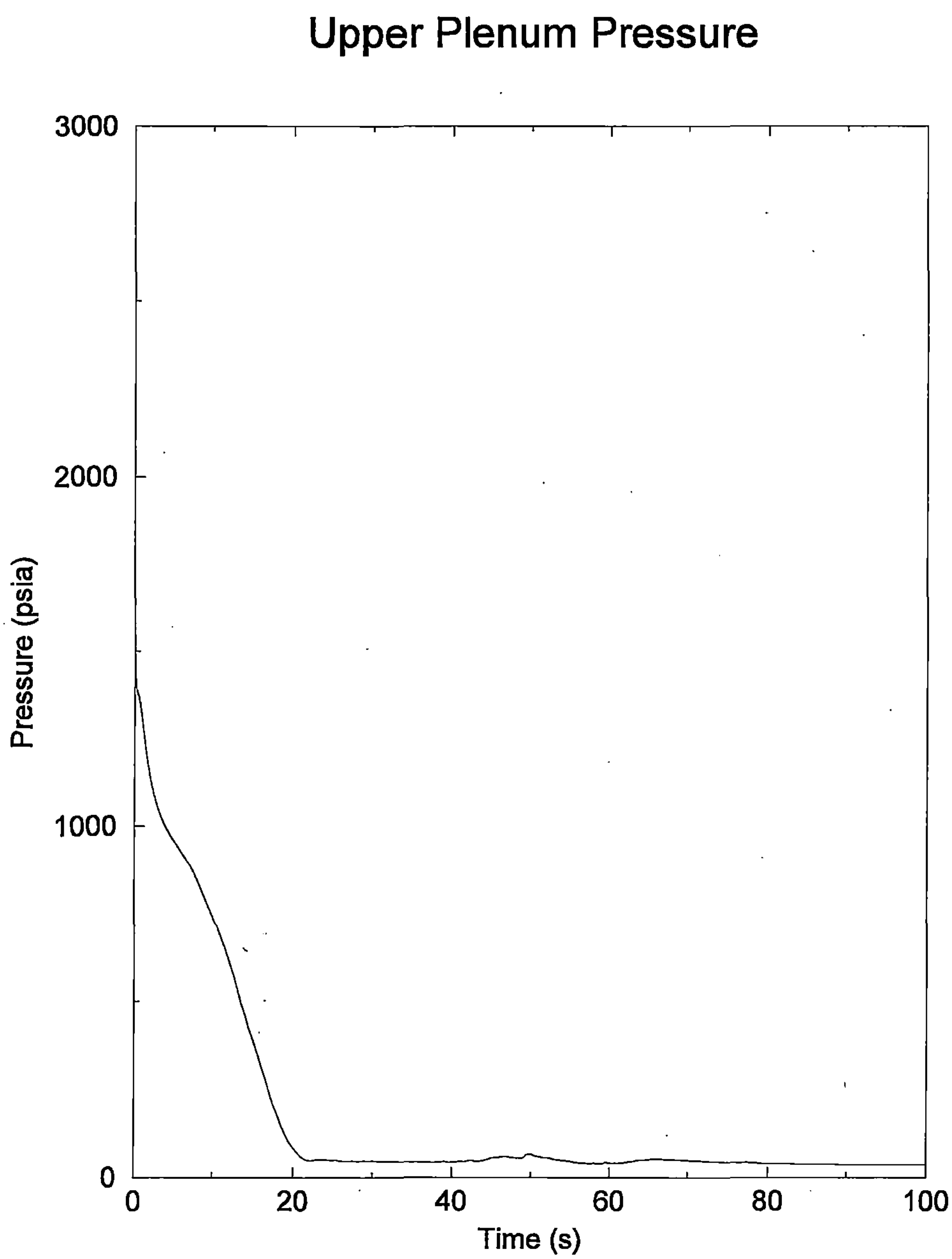

**Figure 13**
**Collapsed Liquid Level in the Downcomer for the Demonstration Case**

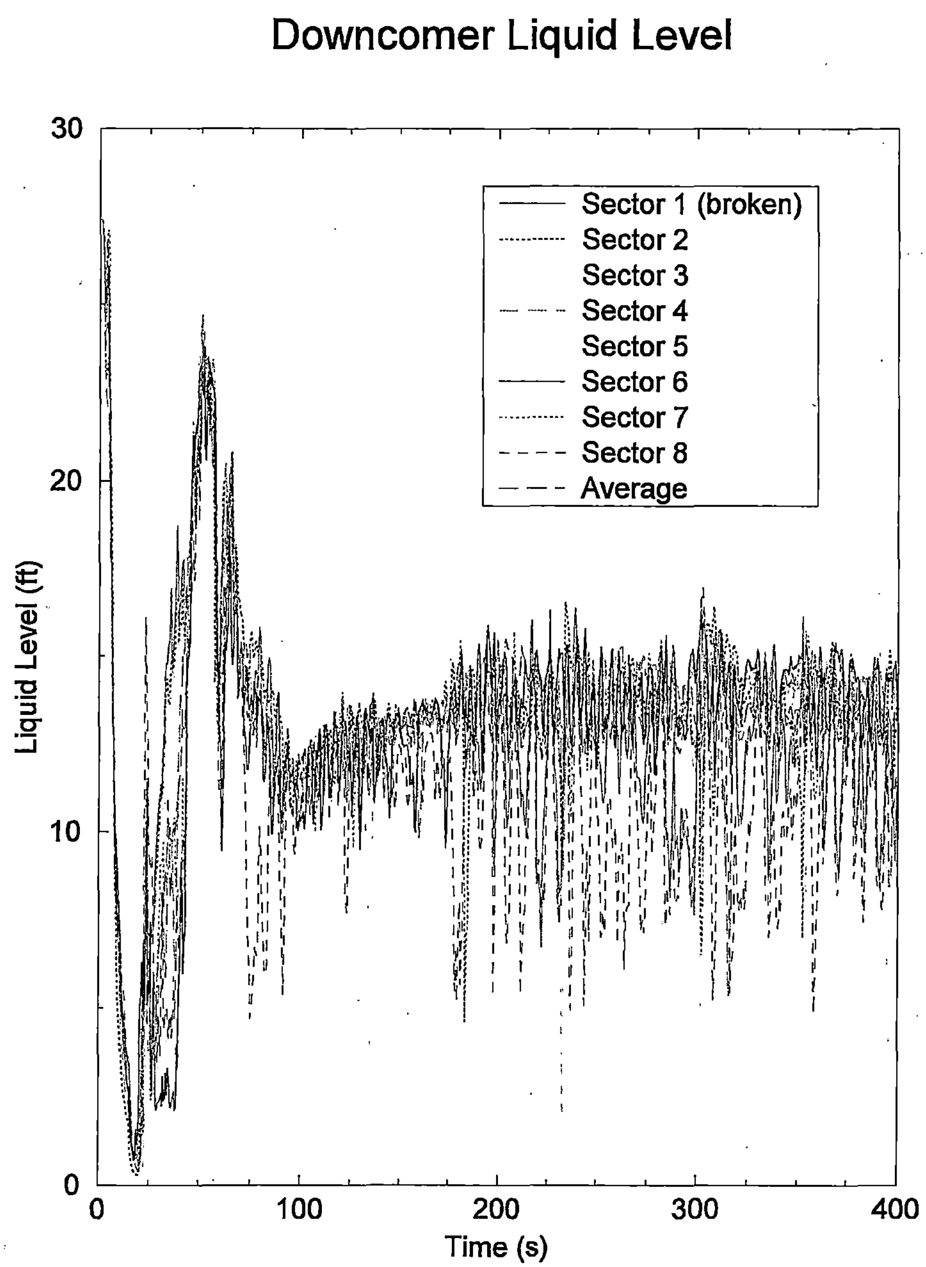

**Figure 14**
**Collapsed Liquid Level in the Lower Plenum for the Demonstration Case**

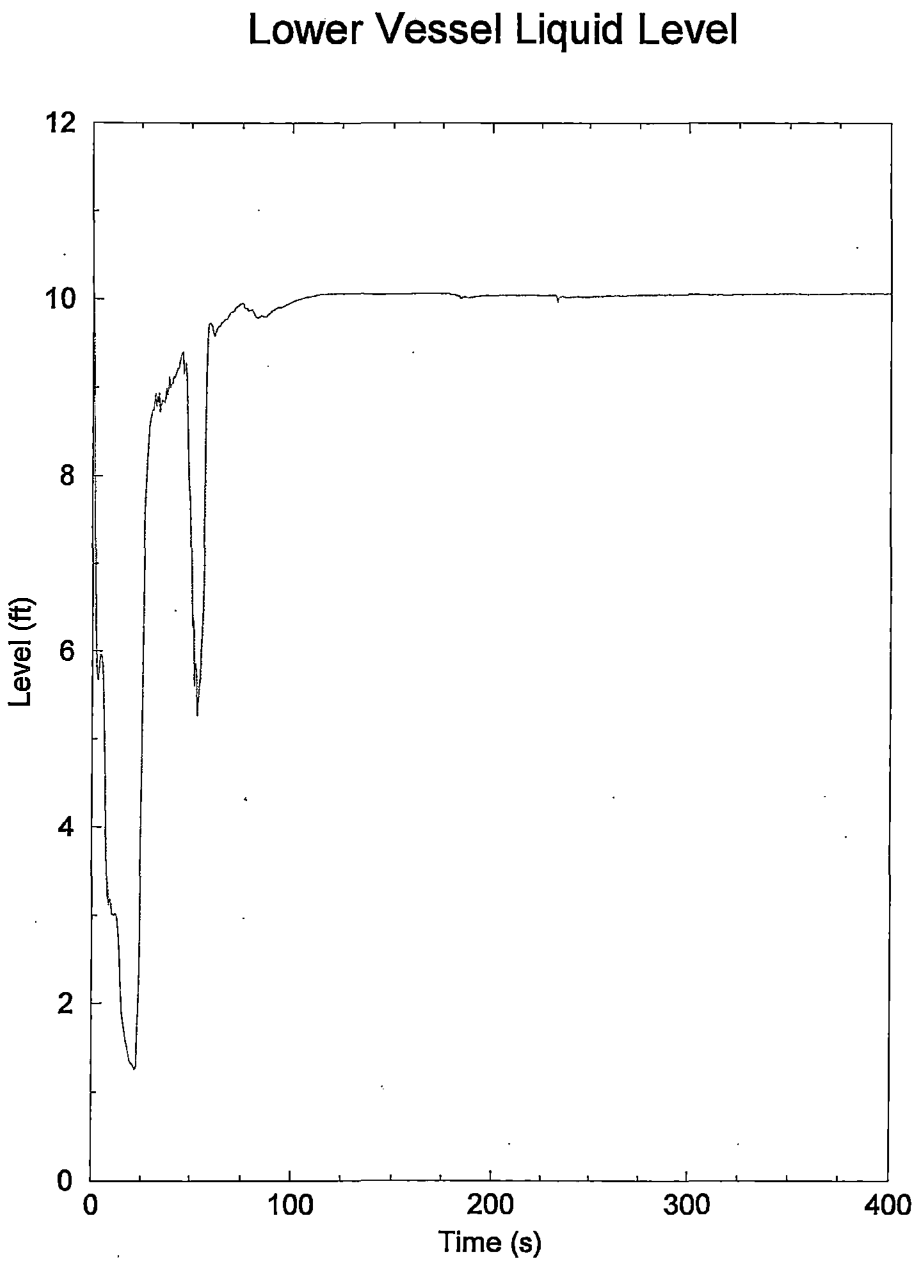

**Figure 15**
**Collapsed Liquid Level in the Core for the Demonstration Case**

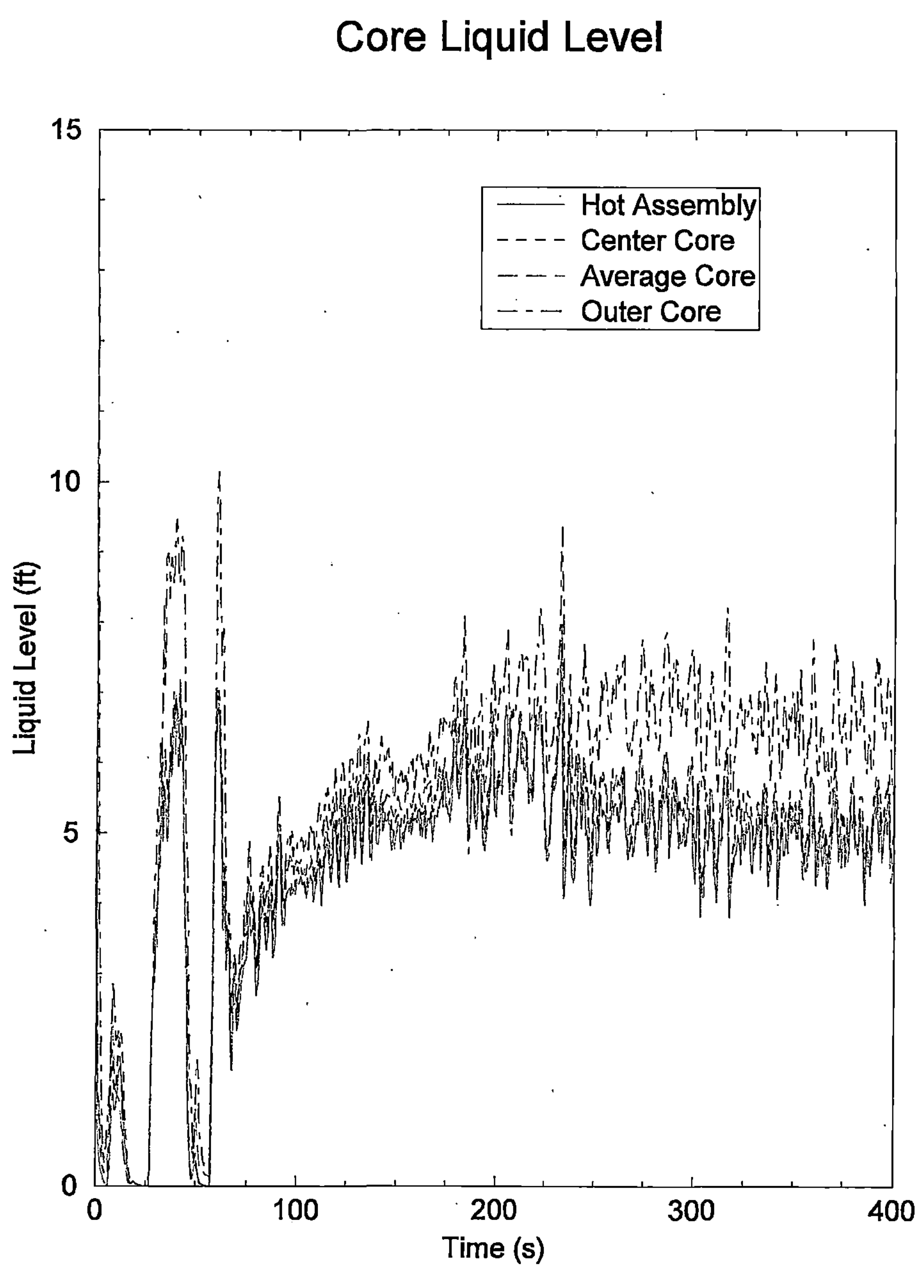

**Figure 16**
**Containment and Loop Pressures for the Demonstration Case**

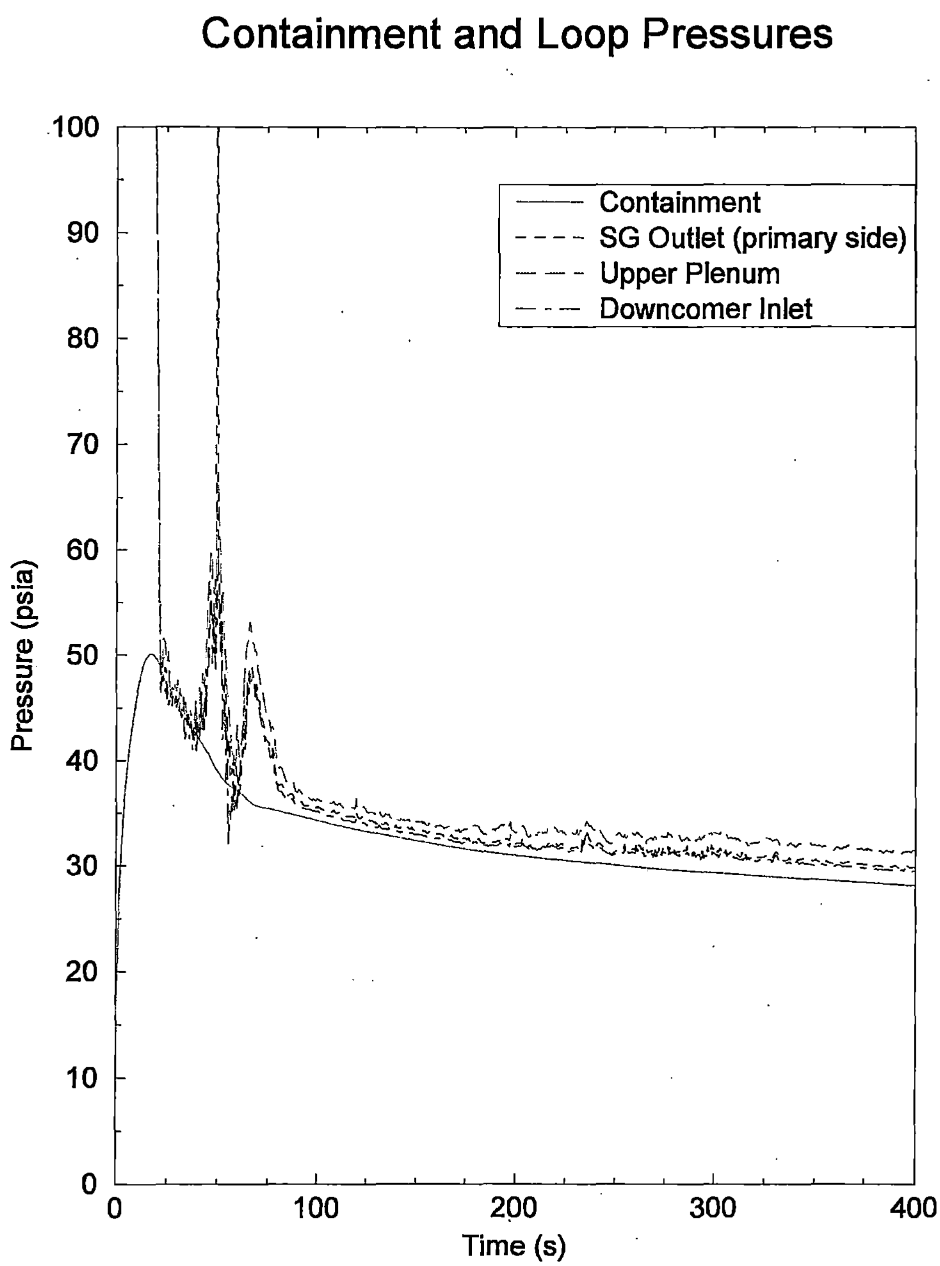

**Figure 17**
**Pressure Differences between Upper Plenum and Downcomer for the Demonstration Case**

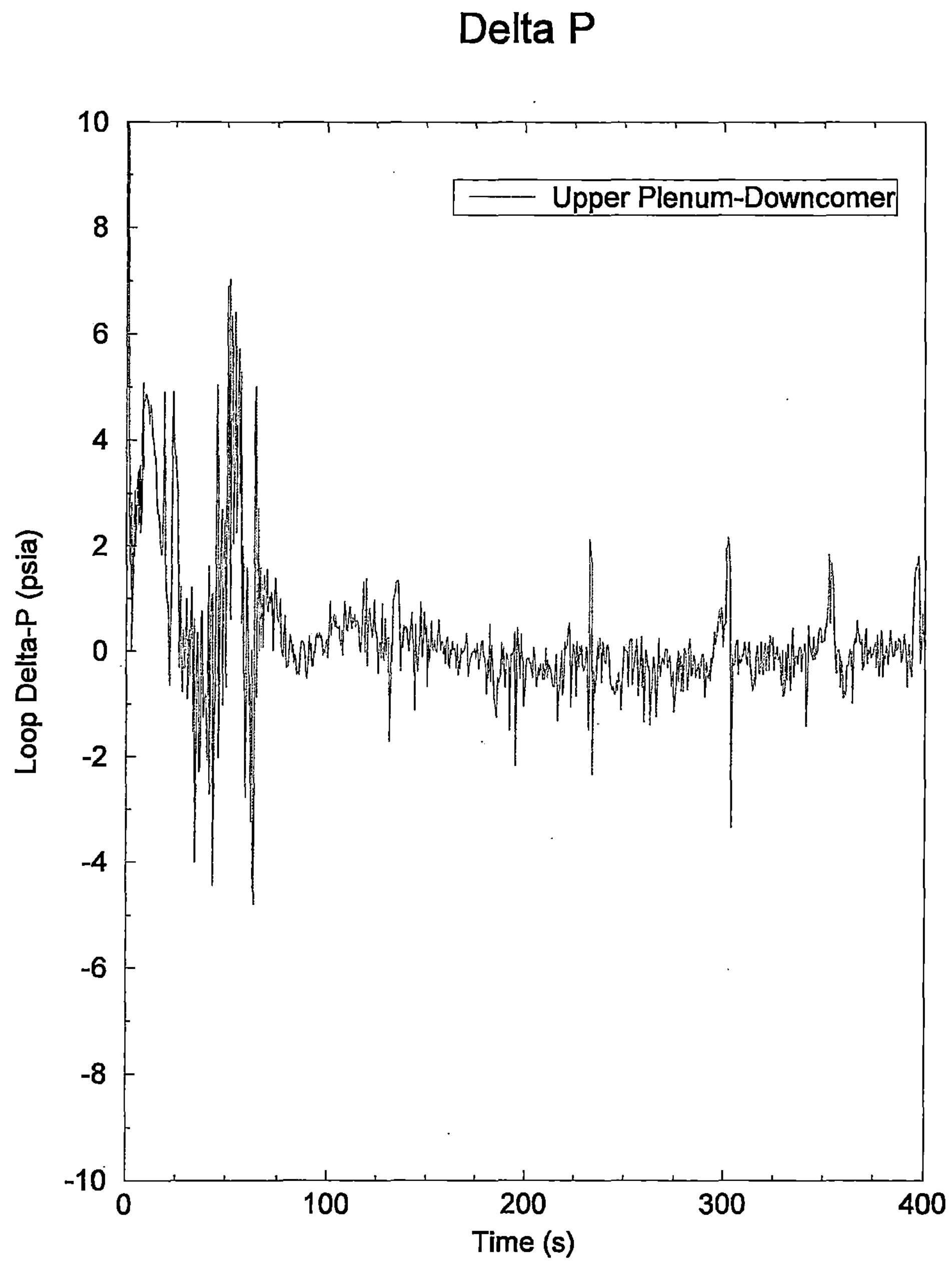

**Figure 18**
**Validation of BOCR Time using MPR CCFL Correlation**

[

]

[ **Figure 19** ]

[ ]

# APPENDIX A: SUMMARY OF KEY INPUT AND OUTPUT PARAMETERS

The following tables contain the sampled input values for all cases analyzed. Key results are also included in columns 2 through 6 in Table A-1 for the case set. In all cases, the core power is 2754 MWth with a decay multiplier of 1.0.

**Table A-1 Summary of Key Input and Output Parameters, Part 1**

**Table A-2 Summary of Key Input and Output Parameters, Part 2**

[ ]

[

]