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# QUICK-LOOK REPORT ON LOFT NUCLEAR EXPERIMENT SERIES L6-8

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**Idaho National Engineering Laboratory**
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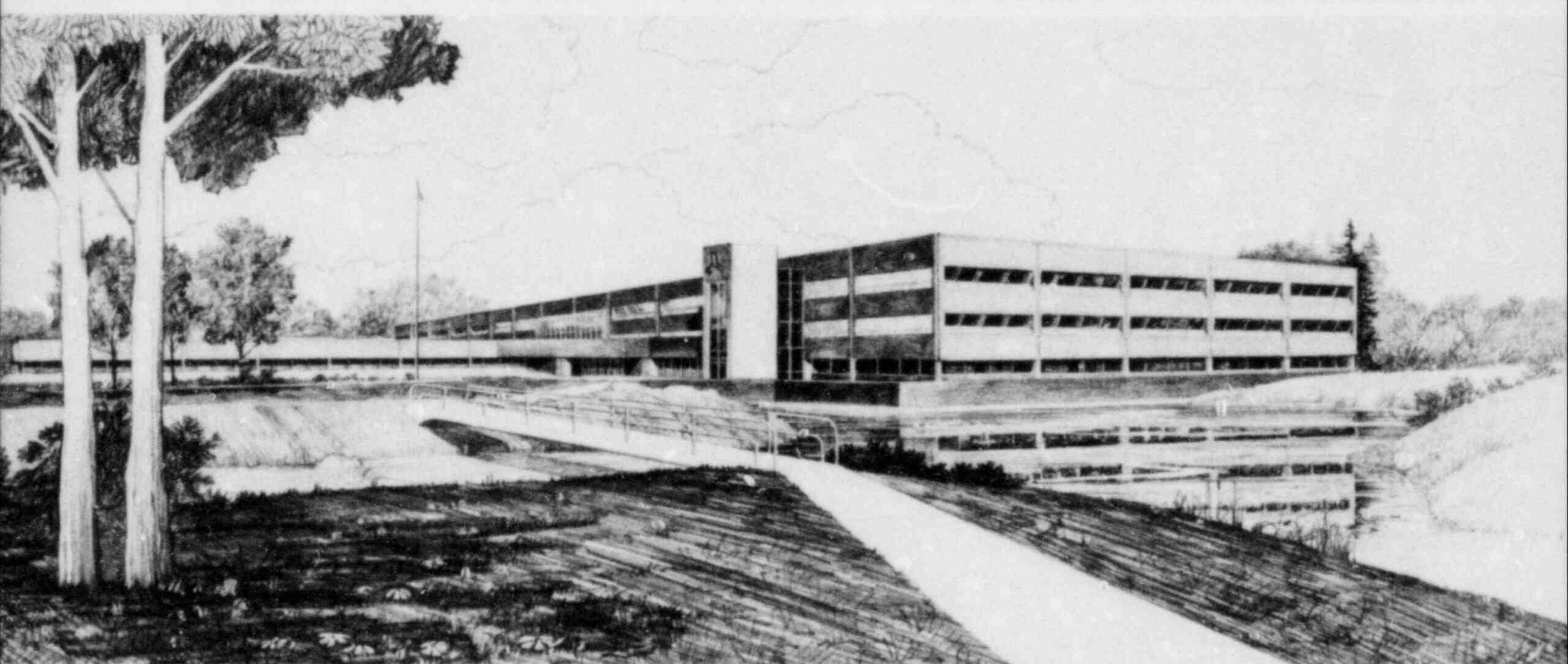

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INTERIM REPORT

QUICK-LOOK REPORT ON LOFT NUCLEAR EXPERIMENT SERIES L6-8

By

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## ABSTRACT

Experiment Series L6-8, which simulated six individual transients that have a high probability of occurrence during the lifetime of a commercial pressurized water reactor (PWR), was successfully conducted in the Loss-of-Fluid Test (LOFT) facility during August 26 through August 31, 1982. The transients were: two control rod withdrawals (L6-8B-1 and B-2); three small break recovery methods (L6-8C-1, C-2, and C-3); and one natural circulation cooldown with low decay heat (L6-8D). The general system response during the two rod withdrawals (L6-8B-1 and L6-8B-2) was as expected, though the time frame involved differed from that in the prediction. The L6-8C results support the hypothesis that continued operation of the primary coolant pumps provides additional information that can remove ambiguities regarding primary system mass inventory and help in diagnosing the type of transient occurring. While the results from the transients demonstrated that the RELAP5/MOD1 computer code can generally calculate the system behavior, results from L6-8B-1 and L6-8C-1 indicate that the code was not able to adequately calculate nonequilibrium conditions in the pressurizer. Primary system voiding, which occurred as intended during L6-8D, did not significantly affect natural circulation. In general, the data obtained from these six simulations will be valuable for qualifying computer codes used to calculate anticipated transients in commercial PWRs.

FIN No. A6048--LOFT Experimental Program

SUMMARY

Loss-of-Fluid Test (LOFT) Experiment Series L6-8 was successfully conducted during August 26 through August 31, 1982. This experiment series consisted of six experiments which simulated transients which have a high probability of occurring during the lifetime of a commercial pressurized water reactor (PWR).

L6-8B-1 and L6-8B-2 simulated two rod withdrawal accidents. In each case, the simulation was initiated from conditions approximately representative of those in a PWR at nominal power. In L6-8B-1, which simulated the lower bound on uncontrolled reactivity insertion rates (average control rod reactivity insertion rate, $\Delta\rho/\Delta t$ = 0.5¢/s), the reactor scram occurred on high hot leg pressure, as expected. However, the scram occurred at 56 s, but was predicted by RELAP5/MOD1 to occur at 106 s. From preliminary analysis, this difference between measured and predicted scram time is attributed to have been caused by nonequilibrium conditions in the pressurizer which were not adequately calculated. The power increased more rapidly than calculated. However, the calculated net energy deposition rate into the primary coolant closely approximated the data; therefore, this difference between measured and calculated power increase did not affect the time of scram. In L6-8B-2, which simulated a fast rod withdrawal accident (control rod reactivity insertion rate $\Delta\rho/\Delta t$ = 5.6¢/s), the negative reactivity feedback was dominated by Doppler feedback, as predicted. Scram occurred in L6-8B-2 on high peak power at 7 s. This scram setpoint parameter is not typical of most commercial PWRs, and caused the scram to occur earlier than if the normal scram setpoint (on high average power) had been reached (calculated at 13.2 s). This nontypical setpoint did not otherwise adversely affect the experiment data which are sufficient to fulfill the experiment objectives.

L6-8C-1, L6-8C-2, and L6-8C-3 simulated recovery procedures for three small, primary coolant system (PCS) breaks. In each case, the simulated break size was identical, and the simulation was initiated from hot standby conditions with approximately 275 kW decay heat. L6-8C-1 simulated a

proposed new recovery procedure for a steam generator tube rupture. The primary coolant pumps were left on throughout L6-8C-1 despite the fact that pressurizer liquid level indications and hot leg subcooling were lost and the primary system pressure was decreasing (normally, the pumps would be turned off in accordance with established procedure). A combination of secondary side cooldown and pressurizer spray reduced the PCS coolant temperature and pressure to the desired values without opening the power-operated relief valve (PORV), and the high-pressure injection system (HPIS) was used to regain and thereafter maintain pressurizer liquid level. The use of primary coolant pumps during the time when pressurizer liquid level indication was lost, removed an ambiguity concerning PCS voiding, since pump current is an indication of the average density. The primary system pressure behavior during pressurizer spray flow and HPIS injection was not correctly calculated. This difference is postulated to have been caused by nonequilibrium conditions in the pressurizer which were not adequately calculated.

L6-8C-2 was based on the steam generator tube rupture recovery procedure similar to that which would be followed in a commercial PWR. When pressurizer liquid level indication was lost, the pumps were turned off and the PORV was opened to reduce pressure in combination with a secondary system cooldown. As in L6-8C-1, HPIS injection was used to recover and maintain pressurizer liquid level. Subsequent to depressurization to the target pressure of 6.8 MPa (988 psia), the pressurizer liquid level response indicated the presence of a steam bubble outside the pressurizer.

L6-8C-3 simulated a proposed procedure involving extended operation of the primary coolant pumps during a recovery from a small break to containment. The pumps were to be operated until a trip setpoint was reached that corresponded to 15% PCS voiding. However, the pumps were not turned off until PCS voiding reached 27%. The pump current was demonstrated to be extremely useful in determining PCS mass inventory during conditions where currently available indications are ambiguous and can, therefore, be used in identifying the type of transient which is occurring.

L6-8D was a slow natural circulation cooldown with low dec y heat input. The PORV was to have been cycled to control hot leg subcooling. Cold leg, instead of hot leg, subcooling was followed, however, and the PORV was left open during most of the transient. This reduced the available data on pressurizer liquid level response to the natural circulation cooldown. However, the data showing the effect of PCS voiding on natural circulation cooling are adequate to fulfill the experiment objective. PCS voiding did occur and persist through most of the cooldown. Natural circulation began immediately upon cessation of forced convection, and was not significantly affected by PCS voiding.

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# QUICK-LOOK REPORT ON LOFT NUCLEAR EXPERIMENT SERIES L6-8

## 1. INTRODUCTION

Experiment Series L6-8 was successfully conducted during August 26 through August 31, 1982, in the Loss-of-Fluid Test (LOFT) facility. Experiment Series L6-8 consisted of six experiments that were independently conducted simulations of transients which have a high probability of occurrence in a commercial pressurized water reactor (PWR).

L6-8B-1 and L6-8B-2 simulated uncontrolled rod assembly withdrawals with reactivity insertion rates of $4 \times 10^{-5}$ $\Delta\rho$/s and $4 \times 10^{-4}$ $\Delta\rho$/s, respectively. These reactivity insertion rates cover approximately the range of rates which are included in the Trojan Final Safety Analysis Report (FSAR).[1] In each case, the rod withdrawal rates were continued until the reactor scram setpoints were reached. Scram occurred on high primary coolant system (PCS) pressure (15.7 MPa, 2277 psia) for L6-8B-1, and on high peak reactor power for L6-8B-2.

Recent steam generator tube rupture events at Prairie Island and Ginna nuclear power stations have emphasized the need to investigate plant recovery procedures for loss-of-coolant accidents (LOCAs) with break flows in the order of 30 to 53 kg/s (400 to 700 gpm). The L6-8C transients investigated three such recovery procedures. L6-8C-1 combined steam generator operation with pressurizer spray actuation to simulate the mitigation of coolant flow from the PCS to the secondary coolant system without challenging the pressurizer power-operated relief valve (PORV). L6-8C-2 utilized a procedure similar to that now in use in operating plants in which the primary coolant pumps were tripped and the PORV was utilized to reduce PCS pressure. L6-8C-3 demonstrated the use of primary coolant pump current to determine PCS inventory during a small break. This experiment had the same size break as L6-8C-1 and C-2, but simulated a break to containment. The PCS inventory was to be allowed to decrease until a 15% void was established at the pump inlet, at which time, the pumps were to be tripped. Use of primary coolant pump operation to assist in accident recognition and management had been proposed in Reference 2.

L6-8D was a natural circulation cooldown with void formation in the PCS outside the pressurizer. This was based on a similar transient that occurred in the St. Lucie nuclear power plant in June 1980.

The programmatic objectives defined for Experiment Series L6-8 were designed to:

1. Assist the Nuclear Regulatory Commission (NRC) in evaluating reactor transient analysis techniques used in reactor licensing by applying the same techniques to transients performed in the LOFT facility

2. Demonstrate that LOFT results can be related to larger PWRs by providing data that can be compared to data obtained from commercial plants (traceability)

3. Provide data for evaluating commercial plant instrumentation and control system response characteristics over a range of transients which could occur in a commerical plant.

To support the above programmatic objectives, specific objectives were defined for each of the Experiment Series L6-8 experiments. These specific objectives are defined as those which can be evaluated shortly after the conduct of the experiments as follows:

1. L6-8B-1 and B-2 will:

    a. Investigate integral plant response to a reactivity insertion event caused by the withdrawal of all four LOFT control rod assemblies

    b. Provide data which can be used to assess the applicability of kinetic models used to predict transient reactor power.

2. L6-8C-1 will:

   a. Evaluate a PCS recovery technique for a primary system-to-secondary system break, which avoids a challenge to the PORV

   b. Determine whether the proposed procedure will enhance plant control

   c. Evaluate the effectiveness of the proposed operator pump current display system in ascertaining PCS inventory.

3. L6-8C-2 will provide a base comparison experiment by employing procedures which use the PORV to mitigate a steam generator tube rupture.

4. L6-8C-3 will:

   a. Evaluate the use of primary coolant pump motor power or current to determine PCS inventory during a small break to containment

   b. Evaluate the effectiveness of a small break recovery procedure in which the primary coolant pumps continue running until a system void fraction of 0.15 is reached

   c. Determine the effectiveness of the proposed operator pump current display system in ascertaining PCS inventory.

5. L6-8D will:

   a. Investigate the pressurizer liquid level response during a natural circulation cooldown in which void formation occurs within the PCS

b. Investigate the effect of void formation on natural circulation when the natural circulation driving forces are low, that is, low decay heat and low steam flow.

An evaluation of plant performance for Experiment Series L6-8 is presented in Section 2, including a summary of specified and measured initial conditions in Tables 1 through 6 and a chronological listing of identifiable significant events in Tables 7 through 12. Section 3 presents a summary of experimental results, and Section 4 contains conclusions based on these results. Data plots are presented in Section 5 to support and clarify the experiment chronologies of events in Section 2 and the results and conclusions in Sections 3 and 4. Also included are comparisons of measured data with preexperiment calculations performed by EG&G Idaho, Inc.,[3,4,5] using the RELAP5[a] computer code.[6] The LOFT system geometry for Experiment L6-8 is shown in Appendix A.

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a. The analysis was performed using RELAP5/MOD1, Cycle 15, a production version of RELAP5/MOD1 which is filed under Idaho National Engineering Laboratory Computer Code Configuration Management Archival Number F00341.

# 2. PLANT EVALUATION

The initial conditions, identifiable significant events, and experimental measurement performance for Experiment Series L6-8 are summarized in this section.

## 2.1 Initial Conditions

Summaries of specified[7] and measured system conditions immediately prior to each of Experiment Series L6-8 experiments are given in Tables 1 through 6. Identification of out-of-specification initial conditions is also included in each table. In L6-8B-1 and L6-8B-2, the hot leg pressure was less than 1% higher than specified. In addition, in L6-8B-2, the control rod position was 1% higher and the pressurizer liquid level was 8% lower than specified. In L6-8D, the hot leg pressure was 1% higher and the cold leg temperature was less than 1% higher than specified. In L6-8C-1, C-2, and C-3, the cold leg temperatures were slightly out of specification (less than 1% in each case), and in L6-8C-1, the pressurizer liquid level was 14% low. In each case, except L6-8B-2 and L6-8C-1 pressurizer liquid levels, the out-of-specification values were too small to affect the transient. The low pressurizer liquid level in L6-8B-2 caused the reactor scram (which occurred on high pressure) to occur later than if the level were correct. Since the predicted scram was much later still, it is considered that the out-of-specification value did not significantly affect the results. The low pressurizer liquid level in L6-8C-1 caused the pressurizer to drain sooner than would have been the case, but did not otherwise affect the transient.

## 2.2 Chronology of Events

Tables 7 through 12 contain the lists of identifiable significant events for each of the Experiment L6-8 transients. Anotated primary system pressure responses for each experiment are shown in Figures 1 through 6 in Section 5.

## 2.3 Instrument Performance

The instrumentation used for Experiment Series L6-8 was the same as that described in Reference 8 for Experiment L2-5. During the conduct of the experiments, several parameters were monitored in real time in the control room, visitor display room, and technical support center to determine the thermal and hydraulic state of the plant. This was done as part of the augmented operator control program. The monitored systems included:

1. Primary coolant pump current versus fluid temperature

2. PCS pressure and temperature

3. Automated data qualification (ADQ).

TABLE 1. INITIAL CONDITIONS FOR EXPERIMENT L6-8B-1

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Primary Coolant System | | |
| Hot leg pressure (MPa) | 14.7 ± 0.1 | 14.9 ± 0.2[b] |
| (psia) | 2132 ± 15 | 2161 ± 23 |
| $T_{ave}$ (K) | -- | 564 ± 2 |
| (°F) | | 556 ± 4 |
| Hot leg temperature (K) | -- | 570 ± 1 |
| (°F) | | 566 ± 2 |
| Cold leg temperature (K) | 555 ± 1 | 556 ± 2 |
| (°F) | 539 ± 2 | 541 ± 4 |
| Mass flow rate (kg/s) | 479 ± 63 | 482 ± 3 |
| (lbm/hr x $10^6$) | 3.8 ± 0.5 | 3.83 ± 0.02 |
| Reactor Vessel | | |
| Power level (MW) | 37.5 ± 0.5 | 37.6 ± 1.2 |
| Maximum linear heat generation rate (kW/m) | -- | 42.6 ± 3 |
| (kW/ft) | -- | 13.0 ± 0.9 |
| Control rod position (above full-in position) (m) | $1.30^{+0.03}_{-0.0}$ | 1.30 ± 0.01 |
| (in.) | $51.0^{+1}_{-0}$ | 51.2 ± 0.4 |
| Pressurizer | | |
| Water temperature (K) | -- | 616 ± 4 |
| (°F) | | 648 ± 7 |
| Liquid level (m) | 1.12 ± 0.05 | 1.09 ± 0.04 |
| (in.) | 44 ± 2 | 43 ± 2 |

TABLE 1. (continued)

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Steam Generator Secondary Side | | |
| Water level (m) | -- | 0.28 ± 0.06 |
| (in.) | | 11.0 ± 2.4 |
| Water temperature (K) | -- | 539 ± 2 |
| (°F) | | 510 ± 4 |
| Pressure (MPa) | -- | 5.6 ± 0.1 |
| (psia) | | 812 ± 15 |
| Mass flow rate (kg/s) | -- | 22.1 ± 0.7 |
| (lbm/s) | | 48.7 ± 1.5 |

a. Listed values are specified in the Experiment Operating Specification (EOS). If no value is listed, that parameter is not specified by the EOS.

b. These values are out of specification, but are not considered to have adversely affected the results of this experiment.

TABLE 2. INITIAL CONDITIONS FOR EXPERIMENT L6-8B-2

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Primary Coolant System | | |
| Hot leg pressure (MPa) | 14.7 + 0 - 0.2 | 14.8 ± 0.1[b] |
| (psia) | 2132 + 0 - 30 | 2146 ± 15 |
| $T_{ave}$ (K) | -- | 565 ± 2 |
| (°F) | | 558 ± 4 |
| Hot leg temperature (K) | -- | 570 ± 1 |
| (°F) | | 566 ± 2 |
| Cold leg temperature (K) | 554.8 ± 1.1 | 555 ± 2 |
| (°F) | 539 ± 2 | 540 ± 4 |
| Mass flow rate (kg/s) | 478.8 ± 62.9 | 475.0 ± 2.6 |
| (lbm/hr x $10^6$) | 3.8 ± 0.5 | 3.77 ± 0.02 |
| Reactor Vessel | | |
| Power level (MW) | 38.0 | 37.3 ± 1.2 |
| Maximum linear heat generation rate (kW/m) | -- | 49.1 ± 3 |
| (kW/ft) | | 15.0 ± 0.9 |
| Control rod position (above full-in position) (m) | 0.97 ± 0.01 | 0.99 ± 0.01[b] |
| (in.) | 38.2 ± 0.5 | 39.0 ± 0.4 |
| Pressurizer | | |
| Water temperature (K) | -- | 615 ± 2 |
| (°F) | | 647 ± 4 |
| Liquid level (m) | 1.12 ± 0.05 | 0.98 ± 0.04[b] |
| (in.) | 44 ± 2 | 39 ± 2 |

TABLE 2. (continued)

| Parameter | Specified Value[a] | Measured Value |
| --- | --- | --- |
| Steam Generator Secondary Side | | |
| Water level (m) | -- | 0.18 ± 0.06 |
| (in.) | | 7 ± 2 |
| Water temperature (K) | -- | 541 ± 2 |
| (°F) | | 514 ± 4 |
| Pressure (MPa) | -- | 5.64 ± 0.08 |
| (psia) | | 818 ± 12 |
| Mass flow rate (kg/s) | -- | 22.23 ± 0.67 |
| (lbm/s) | | 49.0 ± 1.5 |

a. Listed values are specified in the Experiment Operating Specification (EOS). If no value is listed, that parameter is not specified by the EOS.

b. These values are out of specification, but are not considered to have adversely affected the results of this experiment.

TABLE 3. INITIAL CONDITIONS FOR EXPERIMENT L6-8C-1

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Primary Coolant System | | |
| Hot leg pressure (MPa) | 15.5 ± 0.1 | 15.5 ± 0.1 |
| (psia) | 2248 ± 15 | 2248 ± 15 |
| $T_{ave}$ (K) | -- | 561 ± 2 |
| (°F) | | 550 ± 4 |
| Hot leg temperature (K) | -- | 561 ± 1 |
| (°F) | | 550 ± 2 |
| Cold leg temperature (K) | 559 ± 1 | 561 ± 2[b] |
| (°F) | 547 ± 2 | 550 ± 4 |
| Mass flow rate (kg/s) | 478.8 ± 62.9 | 476.5 ± 2.7 |
| (lbm/hr x $10^6$) | 3.8 ± 0.5 | 3.78 ± 0.02 |
| Pressurizer | | |
| Water temperature (K) | -- | 619 ± 3.7 |
| (°F) | | 655 ± 7 |
| Liquid level (m) | 0.48 ± 0.05 | 0.36 ± 0.04[b] |
| (in.) | 19 ± 2 | 14 ± 2 |

a. Listed values are specified in the Experiment Operating Specification (EOS). If no value is listed, that parameter is not specified by the EOS.

b. These values are out of specification, but are not considered to have adversely affected the results of this experiment.

TABLE 4. INITIAL CONDITIONS FOR EXPERIMENT L6-8C-2

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Primary Coolant System | | |
| Hot leg pressure (MPa) | 15.5 ± 0.1 | 15.5 ± 0.06 |
| (psia) | 2248 ± 15 | 2251 ± 9 |
| $T_{ave}$ (K) | -- | 561 ± 2 |
| (°F) | | 551 ± 4 |
| Hot leg temperature (K) | -- | 561 ± 1 |
| (°F) | | 551 ± 2 |
| Cold leg temperature (K) | 559.3 ± 1.1 | 561 ± 2[b] |
| (°F) | 547 ± 2 | 550 ± 4 |
| Mass flow rate (kg/s) | 479 ± 63 | 475 ± 3 |
| ($lbm/hr \times 10^6$) | 3.8 ± 0.5 | 3.77 ± 0.02 |
| Pressurizer | | |
| Water temperature (K) | -- | 618 ± 4 |
| (°F) | | 652 ± 7 |
| Liquid level (m) | 0.48 ± 0.05 | 0.489 ± 0.04 |
| (in.) | 19 ± 2 | 19 ± 2 |

a. Listed values are specified in the Experiment Operating Specification (EOS). If no value is listed, that parameter is not specified by the EOS.

b. These values are out of specification, but are not considered to have adversely affected the results of this experiment.

TABLE 5. INITIAL CONDITIONS FOR EXPERIMENT L6-8C-3

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Primary Coolant System | | |
| Hot leg pressure (MPa) | 15.5 ± 0.1 | 15.6 ± 0.06 |
| (psia) | 2248 ± 15 | 2258 ± 9 |
| $T_{ave}$ (K) | -- | 560 ± 2 |
| (°F) | | 548 ± 4 |
| Hot leg temperature (K) | -- | 561 ± 1 |
| (°F) | | 549 ± 2 |
| Cold leg temperature (K) | 559 ± 1 | 561 ± 2[b] |
| (°F) | 547 ± 2 | 550 ± 4 |
| Mass flow rate (kg/s) | 479 ± 63 | 482 ± 3 |
| (lbm/hr x $10^6$) | 3.8 ± 0.5 | 3.82 ± 0.02 |
| Pressurizer | | |
| Water temperature (K) | -- | 618 ± 4 |
| (°F) | | 652 ± 7 |
| Liquid level (m) | 0.48 ± 0.05 | 0.47 ± 0.04 |
| (in.) | 19 ± 2 | 19 ± 2 |

a. Listed values are specified in the Experiment Operating Specification (EOS). If no value is listed, that parameter is not specified by the EOS.

b. These values are out of specification, but are not considered to have adversely affected the results of this experiment.

TABLE 6. INITIAL CONDITIONS FOR EXPERIMENT L6-8D

| Parameter | Specified Value[a] | Measured Value |
|---|---|---|
| Primary Coolant System | | |
| Hot leg pressure (MPa) | 6.98 ± 0.1 | 7.17 ± 0.06[b] |
| (psia) | 1012 ± 15 | 1040 ± 9 |
| $T_{ave}$ (K) | -- | 532 ± 2 |
| (°F) | | 499 ± 4 |
| Hot leg temperature (K) | -- | 533 ± 1 |
| (°F) | | 500 ± 2 |
| Cold leg temperature (K) | 530 ± 1 | 534 ± 2[b] |
| (°F) | 495 ± 2 | 501 ± 4 |
| Mass flow rate (kg/s) | -- | 484 ± 3 |
| (lbm/hr x $10^6$) | | 3.84 ± 0.02 |
| Pressurizer | | |
| Water temperature (K) | -- | 559 ± 4 |
| (°F) | | 547 ± 7 |
| Liquid level (m) | 1.12 ± 0.05 | 1.13 ± 0.04 |
| (in.) | 44 ± 2 | 45 ± 2 |

a. Listed values are specified in the Experiment Operating Specification (EOS). If no value is listed, that parameter is not specified by the EOS.

b. These values are out of specification, but are not considered to have adversely affected the results of this experiment.

TABLE 7. CHRONOLOGY OF EVENTS FOR EXPERIMENT L6-8B-1

| | Time After Initiation (s) | |
|---|---|---|
| Event | Prediction[a] | Data |
| Initiated[b] | 0 | 0 |
| Pressure reached scram setpoint | 105.6 | 56.4 ± 1 |
| Reactor power reached maximum | 105.6 | 58.4 ± 0.5 |
| Reactor scrammed | 105.6 | 58.5 ± 0.1 |
| Secondary feed stopped | 108.9 | 60.3 ± 0.2 |
| Steam control valve closed | 117.5 | 69.4 ± 0.1 |
| Pressurizer level reached minimum | 130.5 | 77.5 ± 2 |
| Terminated | -- | 198.6 ± 0.1 |

a. When no time is listed, the event was not calculated.

b. Initiation defined as when control rod withdrawal began.

TABLE 8. CHRONOLOGY OF EVENTS FOR EXPERIMENT L6-8B-2

| Event | Time After Initiation (s) Prediction[a] | Data |
|---|---|---|
| Initiated[b] | 0 | 0 |
| Power reached scram setpoint | 13.2 | 7.4 ± 0.2 |
| Reactor scrammed | 13.2 | 7.41 ± 0.1 |
| Primary pressure reached maximum | 14.0 | 7.86 ± 0.5 |
| Secondary feed stopped | 15.5 | 9.1 ± 0.5 |
| Steam control valve closed | 25.0 | 17.6 ± 0.2 |
| Pressurizer level reached minimum | 36.0 | 26.5 ± 2 |
| Terminated | -- | 254 ± 0.2 |

a. When no event time is listed, it was not calculated.

b. Initiation defined as when control rod withdrawal began.

TABLE 9. CHRONOLOGY OF EVENTS FOR EXPERIMENT L6-8C-1

| Event | Time After Initiation (s) Prediction[a] | Data |
|---|---|---|
| Initiated[b] | 0 | 0 |
| Specified cooldown rate established | 0 | 72.0 ± 5 |
| Pressurizer level reached bottom of indicating range | 144.0 | 115 ± 3 |
| Pressurizer spray initiated | 204.0 | 200 ± 2 |
| Pressurizer level increased into indicating range | 210.0 | 202 ± 5 |
| HPIS flow initiated | 204.0 | 219.2 ± 0.7 |
| HPIS flow decreased to maintain pressurizer level | 238.0 | 302.2 ± 2.5 |
| Primary pressure reached 6.8 MPa (988 psia) | 432.0 | 877 ± 1 |
| Terminated | -- | 958.4 ± 2.9 |

a. When no time is listed, the event was not calculated.

b. Initiation defined as when letdown flow valve began to open.

TABLE 10. CHRONOLOGY OF EVENTS FOR EXPERIMENT L6-8C-2

| Event | Time After Initiation (s) Prediction[a] | Data |
|---|---|---|
| Initiated[b] | 0 | 0 |
| Specified cooldown rate established | 0 | 20 ± 5 |
| Pressurizer level reached bottom of indicating range | 144 | 157 ± 3 |
| Primary coolant pumps tripped | 204 | 217.5 ± 0.4 |
| PORV latched open | 204 | 219.4 ± 1.0 |
| HPIS flow initiated | 204 | 220 ± 0.3 |
| Pressurizer level increased into indicating range | 223 | 232.5 ± 2.0 |
| HPIS flow decreased to maintain pressurizer level | 243 | 270.7 ± 1.0 |
| Primary pressure reached 6.8 MPa (988 psia) | 247 | 281 ± 2 |
| Letdown valve closed | -- | 317.7 ± 0.3 |
| PORV closed | -- | 325.9 ± 0.2 |
| HPIS flow increased | -- | 337 ± 1 |
| HPIS flow increased | -- | 397 ± 1 |
| HPIS flow increased | -- | 433 ± 1 |
| HPIS flow decreased | -- | 517.5 ± 1 |
| Terminated | -- | 581 ± 2 |

b. When no time is listed, the event was not calculated.

a. Initiation defined as when letdown flow valve began to open.

TABLE 11. CHRONOLOGY OF EVENTS FOR EXPERIMENT L6-8C-3

| Event | Time After Initiation (s) Prediction[a] | Data |
|---|---|---|
| Initiated[b] | 0 | 0 |
| Pressurizer level reached bottom of indicating range | 162 | 178 ± 1 |
| Voiding in primary system outside pressurizer detected | 280 | 300.0 ± 50 |
| Primary coolant pumps tripped | 655 | 1387.5 ± 0.5 |
| HPIS flow initiated (letdown flow adjusted to lower rate) | 655 | 1389.6 ± 0.4 |
| Hot leg subcooling exceeded 11 K (20°F) | 860 | 1771 ± 2 |
| Pressurizer level increased into indicating range | 895 | 2110 ± 8 |
| HPIS flow decreased to maintain pressurizer level | 904 | 2325 ± 2 |
| Primary coolant pumps restarted | 905 | 2751.5 ± 0.5 |
| Primary pressure reached 6.8 MPa (988 psia) | -- | 3103 ± 2 |
| Terminated | -- | 3192.8 ± 0.2 |

a. When no value is given, event was not calculated.

b. Initiation defined as when letdown flow valve began to open.

TABLE 12. CHRONOLOGY OF EVENTS FOR EXPERIMENT L6-8D

| Event | Time After Initiation (s) Prediction[a] | Data |
|---|---|---|
| Initiated[b] | 0 | 0 |
| Hot leg temperature reached maximum | -- | 142.5 ± 3 |
| HPIS flow initiated | -- | 170 ± 2 |
| PORV opened | -- | 308.7 ± 1 |
| HPIS flow terminated | - | 491 ± 2 |
| Specified cooldown rate established | -- | 900 ± 50 |
| Voiding occurred in primary system outside pressurizer | -- | 1300 ± 50 |
| PORV closed | -- | 5399 ± 1 |
| Pressurizer level cycling started | -- | 5400.0 ± 3.5 |
| HPIS flow initiated | -- | 5482 ± 5 |
| Terminated | -- | 5721 ± 140 |

a. No comparison to prediction possible due to PORV operation.

b. Initiation defined as when pumps were tripped.

# 3. RESULTS FROM EXPERIMENT SERIES L6-8

The preliminary analysis presented in this section is based on data processed and available within the first 2 weeks following the completion of Experiment Series L6-8. In certain instances, the results discussed herein reflect a degree of incompleteness in the analysis consistent with the short time elapsed since the experiments. Analysis of the data will continue, and complete analysis results of the experiments will be reported in future documents.

## 3.1 Results from Experiments L6-8B-1 and B-2

This section describes the experimental results from control rod withdrawal Experiments L6-8B-1 and B-2. Preliminary comparison of results with predictions are also included.

### 3.1.1 L6-8B-1 Results

As the control rods were withdrawn, at a rate of 2 x $10^{-3}$ m/s (4.8 in./min), the reactor power responded by increasing at a linear rate of approximately 0.1 MW/s, as shown in Figure 7. Since the steam flow control valve position was held constant, this resulted in a PCS energy imbalance and a concomitant increase in PCS temperature. The increasing coolant temperature in turn caused a coolant swell and surge into the pressurizer. The resultant pressure increase is shown in Figure 1.

When the hot leg pressure reached the scram setpoint of 15.7 MPa (2277 psia) at 56 s after experiment initiation, the reactor automatically scrammed. During the rest of the transient, the plant responded to the normal postscram transient, that is, the primary coolant shrank due to decreasing fluid temperature and the pressurizer liquid level and PCS pressure decreased.

The average PCS heatup rate was calculated to be 6 K/s (11°F/s), compared to 7 K/s (12°F/s) measured, a 14% discrepancy. This difference resulted at least in part from a calculated power increase of 0.06 MW/s, compared to a measured power increase rate of 0.1 MW/s. However, the net energy deposition rate into the coolant, as indicated by pressurizer liquid level (see Figure 8), resulted in a calculated swell which was almost identical to the measured data. Thus, the difference in power increase between measured and predicted data did not have a large effect on the resultant scram time, since it is the swell into the pressurizer that dominated the PCS pressure response. As shown in Figure 9, the calculated PCS pressure increase due to the pressurizer liquid level increase was much less than measured. Thus, the difference between measured and calculated scram times was caused by inadequate calculation of the pressurizer response to the insurge. The nonequilibrium conditions which resulted in the pressurizer as a result of the insurge are postulated to have been inadequately calculated.

### 3.1.2 L6-8B-2 Results

In L6-8B-2, the control rods were withdrawn at a rate of 1.07 x $10^{-2}$ m/s (25.2 in./min), a rate more than 5 times as fast as that in L6-8B-1. In addition, the rods were initially at 0.99 m (39 in.) in L6-8B-2. In this position, the rod worth was higher. The resultant average reactivity insertion rate during L6-8B-2 was 5.6¢/s versus 0.49¢/s in L6-8B-1, or 11 times as much. Because of this rapid reactivity insertion rate, the PCS coolant did not have time to respond to the energy imbalance, and the transient was dominated by reactor kinetics. Reactor scram occurred on high peak core power, instead of pressure as in L6-8B-1.

The PCS temperature had increased approximately 2 K (3.6°F), and the pressure had increased 0.3 MPa (46 psia) at the time of reactor scram. However, the fuel temperature increased at a much more rapid rate in L6-8B-2 than in L6-8B-1, as shown in Figure 10. The measured fuel centerline temperature had increased 155 K (279°F) when scram occurred in L6-8B-2, an average rate of 20 K/s (36°F/s). By comparison, in L6-8B-1, the increase was 88 K (16°F) and the rate was 1.5 K/s (2.7°F/s). Thus, the moderator feedback did not significantly affect the L6-8B-2 reactor power, and the Doppler feedback (which is a function of fuel temperature) dominated along with the reactivity insertion of the control rods.

The reactor scram occurred when the high peak power setpoint was reached (unique LOFT trip), instead of high average power as would occur in a commercial PWR. The peak power measurement is taken at the high power elevation of the core. Because of the control rod axial position (lower than normal), the flux peaking was more pronounced than during normal operation. (Note, the control rods were positioned lower initially so that their worth was greater and a higher reactivity insertion rate could be achieved.) This was recognized prior to the transient initiation, and the peak power scram setpoint was raised to its maximum allowed value. Despite this, the peak power setpoint was reached prior to the average power setpoint, and scram occurred just prior to the average power setpoint. The data collected are valid, however, and the objectives for L6-8B-2 were achieved, since the only effect of the scram setpoint was the time at which scram occurred.

Figure 11 compares the measured and calculated reactor power for L6-8B-2. Until approximately 1 s prior to scram, the calculated and measured power responses to the combined control rod and Doppler reactivity insertions were virtually identical. The difference at scram was approximately 1 MW, or less than 10% of the total power increase. It is, however, not known at this time whether this difference would have continued to increase had the scram not occurred when it did.

### 3.2 Results from Experiments L6-8C-1, C-2, and C-3

This section describes the experiment results from small break recovery simulations L6-8C-1, C-2, and C-3.

#### 3.2.1 L6-8C-1 Results

L6-8C-1 was initiated by opening the letdown valve to match a predetermined flow rate which approximated rupture of a single steam generator tube. In addition, an operator-controlled 56-K/h (100°F/h) cooldown of the PCS using secondary system feed and bleed was started. Under the combined effects of the simulated break flow and secondary cooldown, the PCS started to depressurize (see Figure 3). At 110 s (1.8 min), the pressurizer was empty and the depressurization increased. At approximately 200 s (3.3 min), the pressurizer spray was turned on causing a more rapid depressurization. When emergency coolant injection from the high-pressure injection system (HPIS) started (219 s, 13.7 min), the PCS mass inventory started to increase. This increase in PCS mass was sufficient to overcome the depressurization effect of pressurizer spray, and the pressure began to increase. After the pressurizer liquid level indication was restored, the HPIS flow was reduced to maintain the liquid level near the bottom of the pressurizer (balancing both letdown flow and cooldown-induced coolant shrink). The pressure again started to decrease, and this decrease continued until the desired termination pressure of 6.8 MPa (988 psia) was reached.

The primary coolant pumps were operated throughout the transient and were used to monitor the PCS mass inventory. After the pressurizer was empty, the operator had to rely on pump current to know that the PCS did not void during the depressurization. This was especially important during the short time when subcooling in the intact loop hot leg was also lost. Throughout L6-8C-1, the fluid void fraction did not exceed 0.1, as shown in Figure 12.

Figure 13 shows a comparison of measured and predicted PCS pressure. As shown, the calculated pressure response followed the measured data very closely for the first 200 s, or until pressurizer spray and HPIS flows were started. The initial spray-induced depressurization was somewhat greater than calculated, possibly because HPIS flow was not actually initiated until nearly 20 s later. In the prediction, HPIS flow initiated simultaneously with pressurizer spray. The major difference between the measured and predicted data, however, occurred when HPIS flow was initiated in the transient. The measured pressure trend reversed and a slight repressurization occurred, followed by a long quasi-steady state period and only then a resumption of the depressurization. The calculated pressure continued to decrease monotonically, and thus the time at which the primary pressure reached the predetermined pressure of 6.8 MPa (988 psia) was calculated to be reached nearly 500 s earlier than measured. The precise cause of this difference has not yet been determined, though it is felt that nonequilibrium in the pressurizer was not being adequately calculated. Also, the effectiveness of pressurizer spray with low fluid subcooling may not be fully understood.

### 3.2.2 L6-8C-2 Results

L6-8C-2 was initiated, in a manner similar to L6-8C-1, by opening the PCS letdown valve (approximating rupture of a single steam generator tube) and establishing a secondary system controlled cooldown rate. L6-8C-2 was, by design, qualitatively similar to L6-8C-1 for the first 200 s. Quantitative differences between the two transients during this time were the result of differences in the boundary conditions imposed on the system (for example, initial pressurizer liquid level was higher in L6-8C-2 which resulted in a longer time to drain than in L6-8C-1). Figure 4 shows the PCS pressure behavior during L6-8C-2. After pressurizer liquid level indication had been lost for approximately 1 min, the primary coolant pumps were turned off, HPIS flow was initiated, and the PORV was latched open. The depressurization continued until the termination pressure (6.8 MPa, 988 psia) was reached, approximately 1 min thereafter.

Figure 14 shows the response of the pressurizer liquid level during the L6-8C-2 transient. As noted on the figure, level was restored 16 s after HPIS and PORV flows were initiated. The level continued to rise, despite reduction of the HPIS flow, until the PORV was closed. The level immediately decreased, in response to the closing of the PORV, until approximately 500 s (8.3 min) when increased HPIS again started to refill the pressurizer. HPIS flow was subsequently decreased again, but the pressurizer liquid level continued to rise, seemingly unaffected by the reduced HPIS flow. It appears that PCS voiding outside the pressurizer caused this latter level response.

The calculated pressure response of the plant during the L6-8C-2 transient compared closely with the measured data, as shown in Figure 15 and in

Table 10. There were some minor differences between the measured and predicted data such as the more rapid than measured PCS depressurization after the pressurizer emptied. These differences will be examined in the postexperiment analysis.

### 3.2.3 L6-8C-3 Results

L6-8C-3 was initiated, as with L6-8C-1 and C-2, by opening the letdown valve. L6-8C-3, however, simulated a small break to containment (lower back pressure). However, there was no secondary side-induced cooldown. In addition, the PORV was shut throughout the transient and pressurizer spray was not turned on until after 2900 s (48 min). The primary pump currents were monitored versus cold leg temperature, and it was specified that the pump should be turned off when the current indicated 15% voiding. However, the pumps were not turned off until the cold leg voiding was approximately 27% due to a combination of instrumentation problems (see Figures 16 and 17). Since this event was used as a reference for turning on HPIS flow, the entire transient was extended in time relative to the prediction. When HPIS flow was initiated, the PCS began to refill and, subsequent to recovery of both the pressurizer liquid level indication and a predetermined hot leg subcooling, the primary pumps were turned back on. The PCS pressure then started to decrease (see Figure 5). The PCS depressurization continued, aided subsequently by pressurizer spray, until the termination pressure of 6.8 MPa (988 psia) was reached at 3125 s (52 min).

The use of primary pump current to monitor PCS fluid conditions supports the hypothesis that this parameter can be used in accident recognition and recovery procedures. Hot leg subcooling and pressurizer liquid level were lost for an extended period of time. During this time the pump current was the only real-time measurement of PCS fluid inventory.

The cold leg voiding, as measured by the gamma densitometer, reached 15% at approximately 550 s (9.2 min). The predicted time to reach 15% voiding was calculated to be 655 s (11 min). During this time, when the boundary conditions in the calculation approximated those in the measured data, a comparison of measured and predicted data can be made. Figure 18 shows the comparison of calculated and measured hot leg pressures. As shown, the depressurization after the pressurizer emptied was calculated to be greater than measured. This was caused, at least in part, by the letdown flow which was somewhat less than specified (see Figure 19). More detailed comparison between measured data and calculated data will be made during the postexperiment analysis.

### 3.3 Results from Experiment L6-8D

The final experiment (L6-8D) conducted in Experiment Series L6-8 was a slow natural circulation cooldown. The intent of L6-8D was to maintain pressurizer liquid level by cycling HPIS flow to control PCS fluid inventory, and to obtain a low hot leg subcooling by cycling the PORV to control PCS pressure. Under these conditions, it was expected that hot, stagnant fluid (for example, in the reactor vessel upper head region) would flash to steam as the PCS pressure decreased, creating a steam bubble outside the pressurizer. The pressurizer liquid level response to a continued natural circulation cooldown under these conditions would then be measured. In actuality, cold leg subcooling was monitored instead of hot leg subcooling and the PORV was left in an open position throughout nearly all of the transient. Thus, though voiding outside the pressurizer did occur and persist throughout most of the transient, and although natural circulation cooling was established, the pressurizer liquid level response was altered significantly by the PORV flow during most of the transient. There was one time interval, for approximately 80 s, beginning at 5400 s (90 min) when the PORV was closed and no HPIS flow existed. During this time, the pressurizer liquid level continued to decrease in response to the PORV having been shut and to the continued PCS cooldown-induced coolant shrink (see Figure 20). There were no pressurizer liquid level oscillations during this time.

Natural circulation started as forced convection stopped (see Figure 21). Natural circulation continued throughout the transient, and was not noticeably affected by voiding outside the pressurizer. Changes in the indicated fluid velocity, as seen in Figure 20, may have been caused by sudden changes in the fluid density, for example, loop voiding around 2500 s (42 min) due to shrink and PORV flow and loop refill at 5500 s (92 min) due to the PORV being shut and the pressurizer liquid level dropping.

Since the PORV was open throughout most of the transient, it is not possible to compare the preexperiment calculations with the measured data. Calculation of the experiment will be performed during the postexperiment analysis. L6-8D provided valuable data on natural circulation cooling with PCS voiding, meeting the second experiment objective.

## 4. CONCLUSIONS

The conduct of Experiment Series L6-8 and the data acquired concerning integral system response are considered to have met the specific objectives as defined by Reference 7 with the exception of Objective (a) for L6-8D. Specific conclusions based on the preliminary analysis and experiment assessment are as follows for each of the three types of transients:

### L6-8B-1 and B-2

Doppler dominated the L6-8B-2 negative reactivity feedback as predicted. In L6-8B-2, the reactor scrammed due to a high peak power setpoint which is not typical in most commercial PWRs. However, the data obtained prior to scram in L6-8B-2 are considered sufficient to meet the stated objectives.

The thermal and hydraulic response of the plant during these rod withdrawal simulations were as expected based on preexperiment calculations. The scram on high pressure in L6-8B-1 occurred earlier than predicted, and it is believed this difference was caused by nonequilibrium conditions in the pressurizer which were not adequately calculated.

### L6-8C-1, C-2, and C-3

The continued operation of the primary coolant pumps during L6-8C-1 and L6-8C-3 provided the operator with information on PCS mass inventory which would otherwise have been lacking due to loss of pressurizer liquid level and hot leg subcooling. This removed some ambiguity during these transients that was present during a similar time frame in L6-8C-2.

During the later portion of L6-8C-2, there was an indication of the presence of a persistent steam bubble outside the pressurizer. This steam bubble caused the pressurizer liquid level to increase even through PCS charging via HPIS flow was reduced.

In general, the preexperiment calculations of these three transients agreed well with the data during those times when the boundary conditions were similar. One exception to this was the pressure response after pressurizer spray and HPIS flows were started in L6-8C-1. As with L6-8B-1, it is felt that the predicted calculations were not adequate to correctly calculate this pressure response. Pressurizer spray with low fluid subcooling was not at as effective as expected.

L6-8D

The PORV was open during most of the transient which was not as had been intended. This compromised experiment objective (a) for L6-8D. However, the data obtained on natural circulation cooling in the presence of voiding are considered to have met the second experiment objective. Because of the difference between actual and intended PORV operation, no direct comparisons between measured and predicted data were possible.

## 5. DATA PRESENTATION

This section presents selected preliminary data from Experiment Series L6-8. Experimental data are overlayed with results from the pretest calculations made using the RELAP5/MOD1 computer code.[3,4,5] A listing of the data plots is presented in Table 13. Table 14 gives the nomenclature system used in instrumentation identification. A complete list of the LOFT instrumentation and data acquisition requirements for the experiment is given in Reference 7.

The maximum (2 $\sigma$) uncertainties in the report data are:

1. Fluid temperature -- ±4 K (±7°F)
2. Pressure -- ±0.26 MPa (±38 psi)
3. Liquid level -- ±0.17 m (±0.56 ft)
4. Pump current -- ±25 amps
5. Break mass flow -- ±0.5 kg/s (±1.1 lbm/s)
6. Reactor power -- ±2 MW.

TABLE 13. LIST OF DATA PLOTS

TABLE 13. (continued)

TABLE 14. NOMENCLATURE FOR LOFT INSTRUMENTATION

Designations for the Different Types of Transducers[a]

| | | | |
|---|---|---|---|
| TE | -- Temperature element | FE | -- Coolant flow transducer |
| PE | -- Pressure transducer | DE | -- Densitometer |
| PdE | -- Differential pressure transducer | DiE | -- Displacement transducer |
| | | ME | -- Momentum flux transducer |
| LE | -- Coolant level transducer | FT | -- Flow rate transducer |

Designations for the Different Systems, Except the Nuclear Core

| | | | |
|---|---|---|---|
| PE | -- Primary coolant intact loop | LP | -- Lower plenum |
| BL | -- Broken loop | ST | -- Downcomer stalk |
| RV | -- Reactor vessel | P120 | -- Emergency core coolant system |
| SV | -- Suppression tank | P128 | -- Primary coolant addition and control |
| UP | -- Upper plenum | | |

Designations for Nuclear Core Instrumentation

Transducer location (inches from bottom of fuel rod)

Fuel assembly row

Fuel assembly column

Fuel assembly number

Transducer type

TE-3B11-28

a. Includes only instruments discussed in this report.

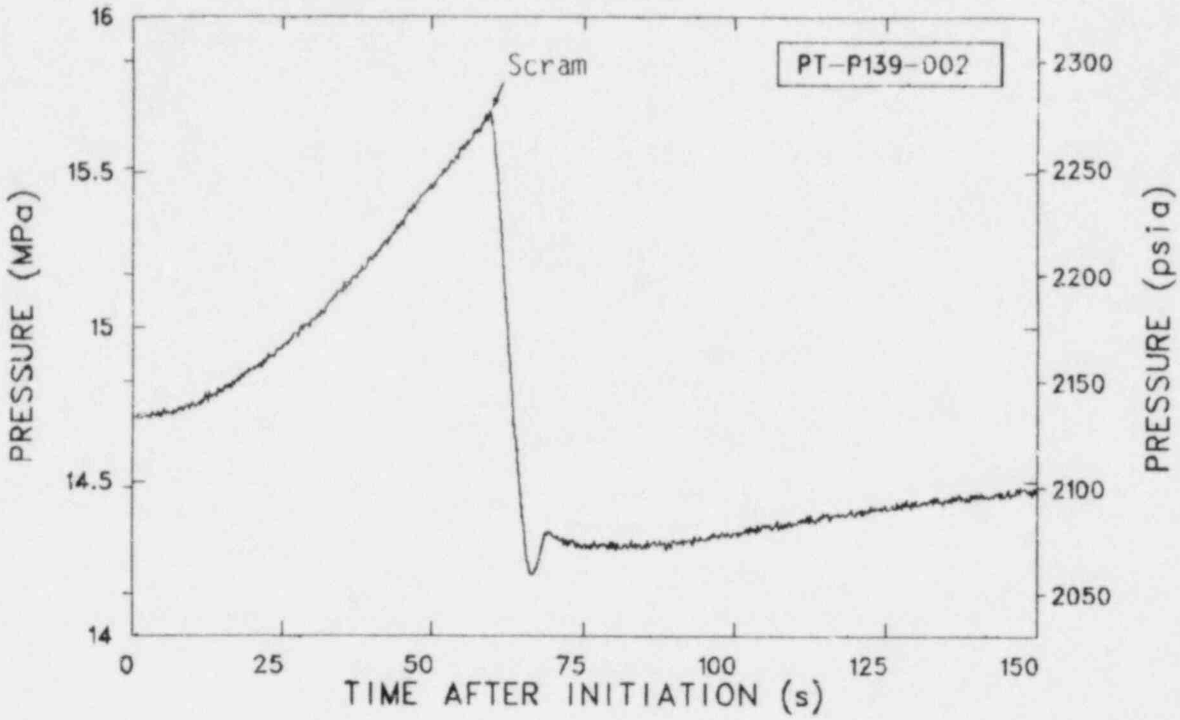


Figure 1. Primary system pressure during L6-8B-1.

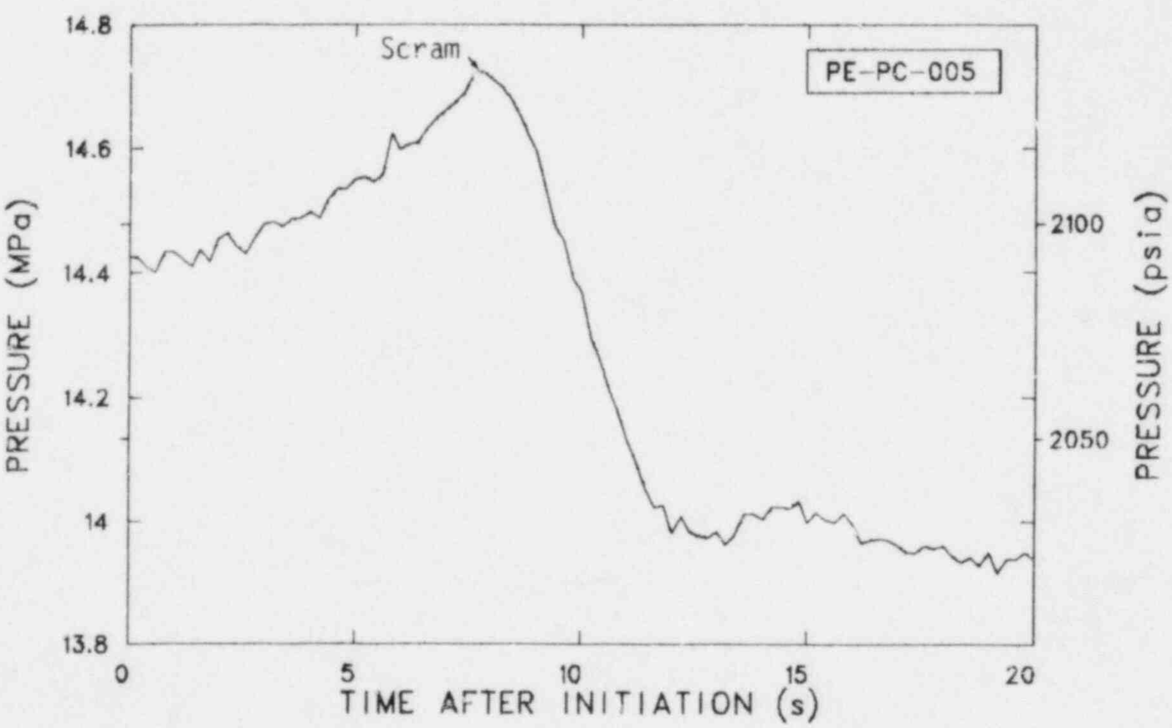


Figure 2. Primary system pressure during L6-8B-2.

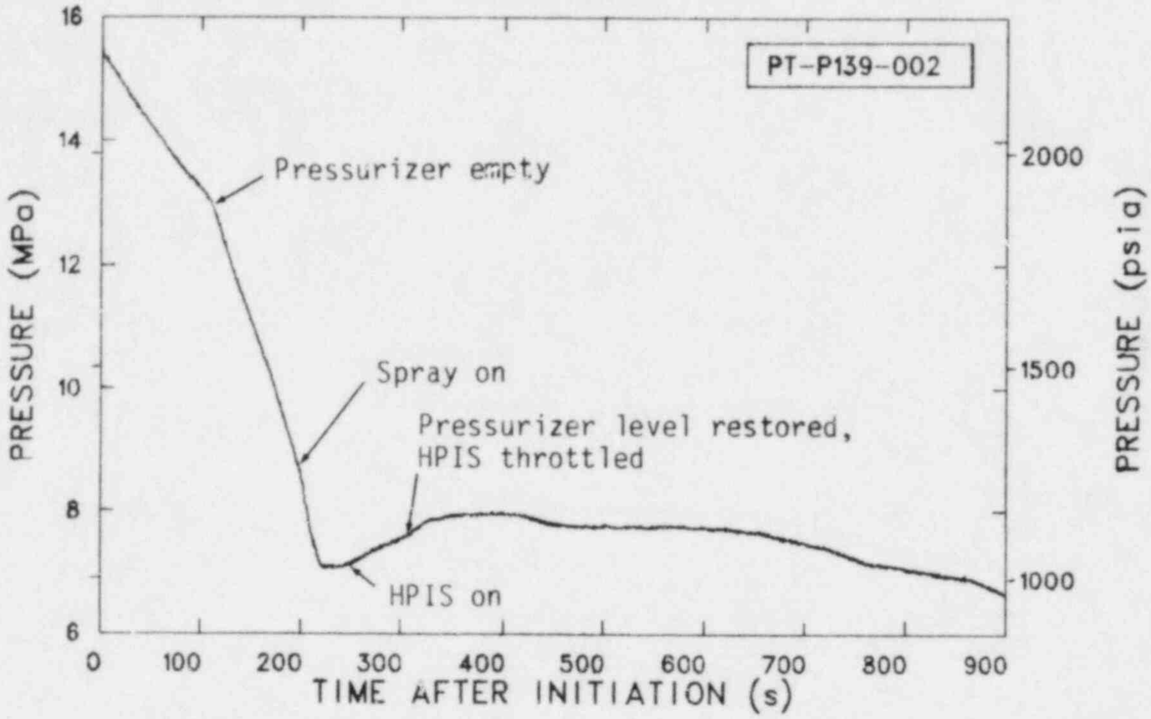


Figure 3. Primary system pressure during L6-8C-1.

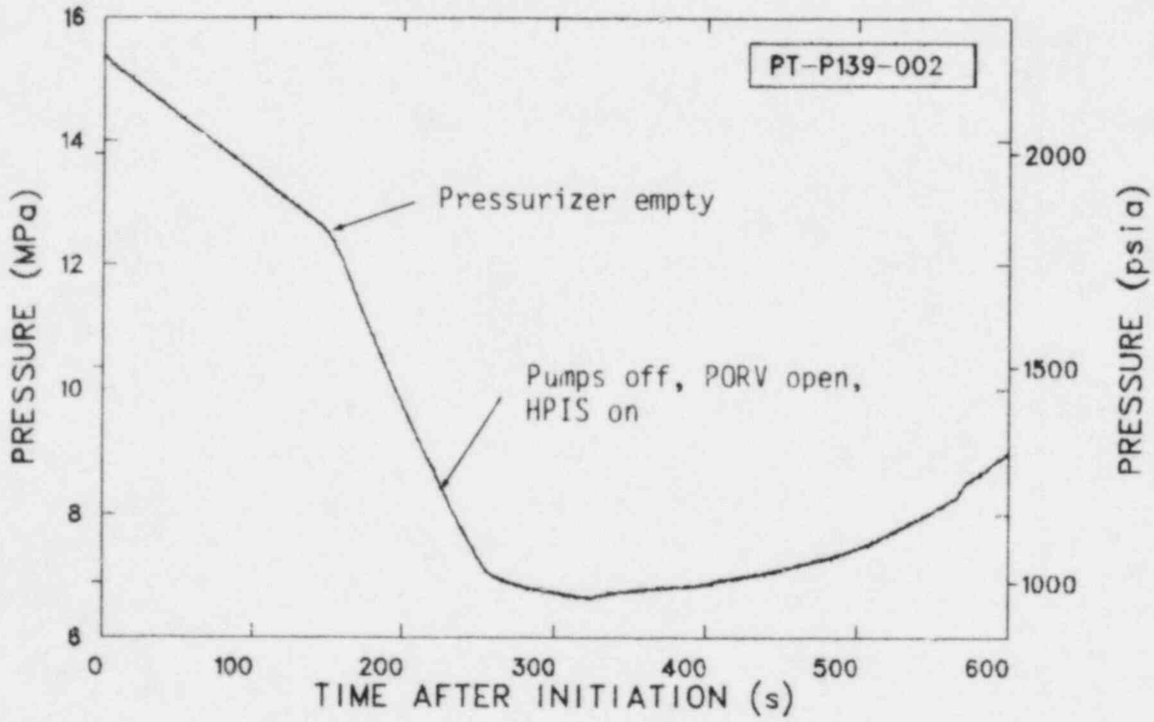


Figure 4. Primary system pressure during L6-8C-2.

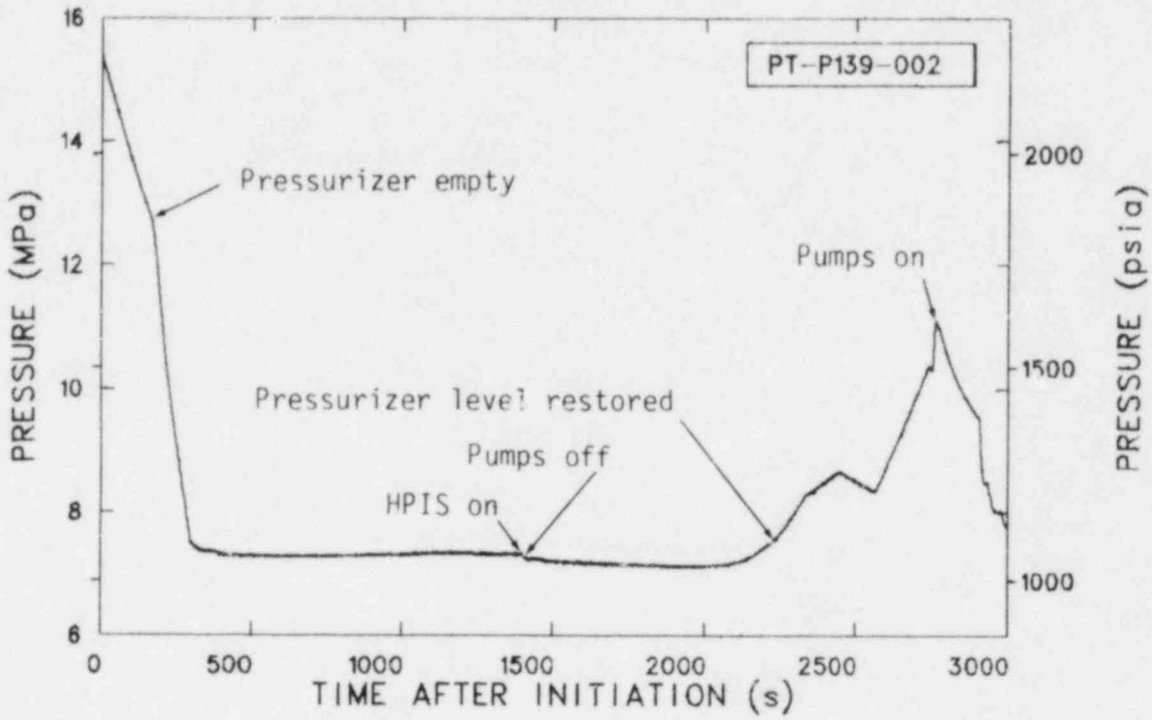


Figure 5. Primary system pressure during L6-8C-3.

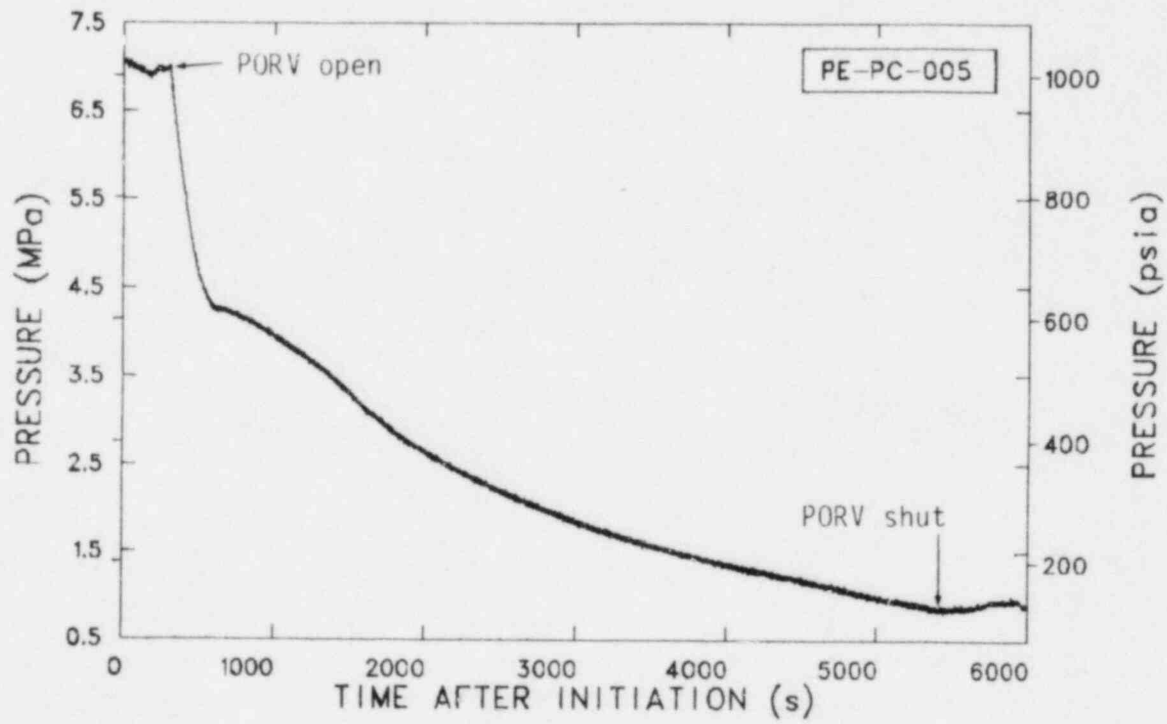


Figure 6. Primary system pressure during L6-8D.

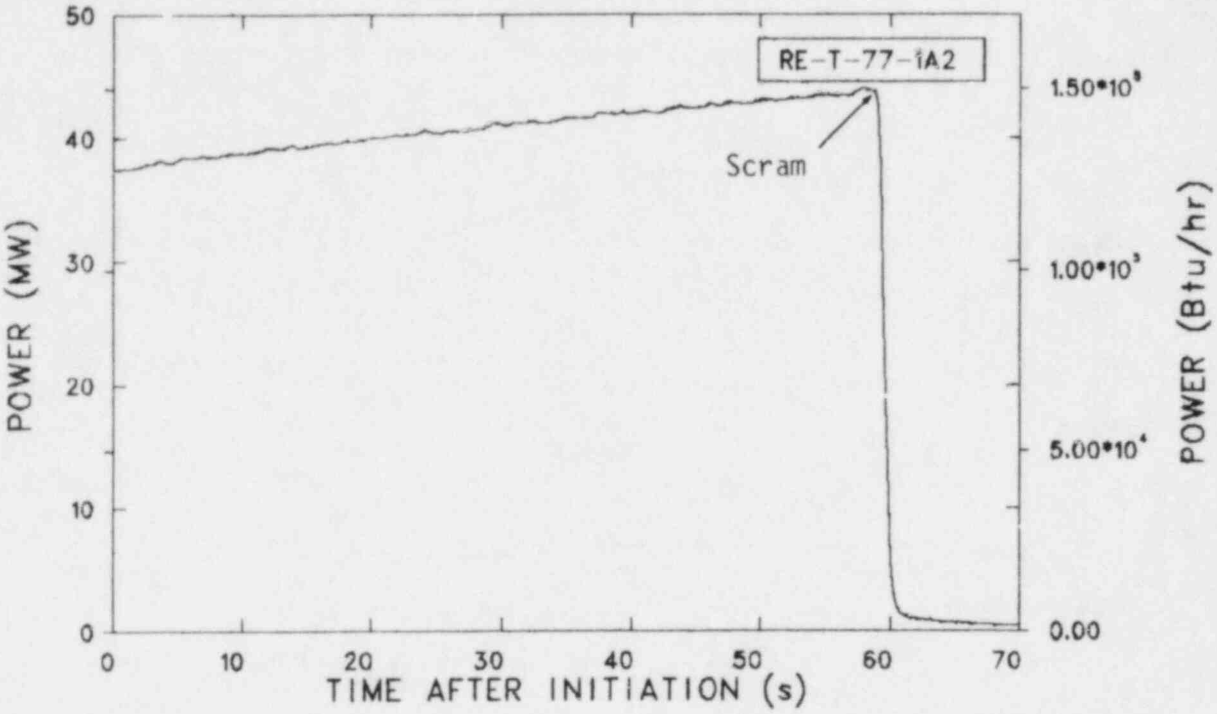


Figure 7. Reactor power during L6-8B-1.

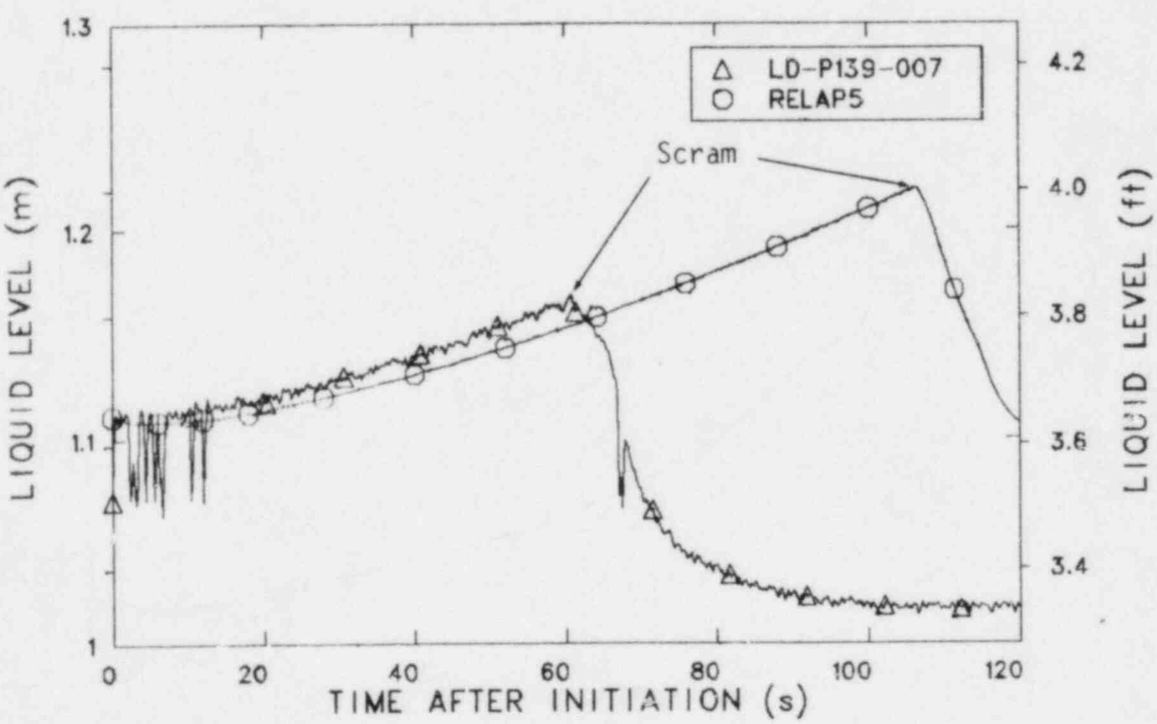


Figure 8. Pressurizer liquid level during L6-8B-1 compared to prediction.

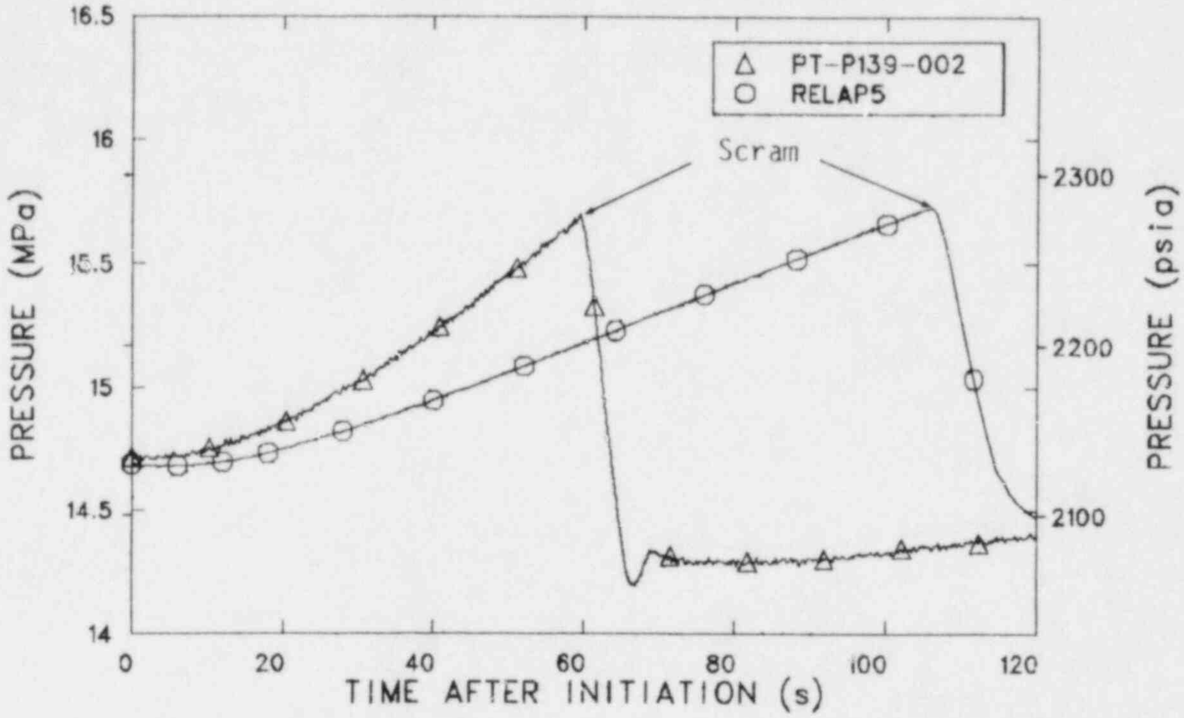


Figure 9. Hot leg pressure during L6-8B-1 compared to prediction.

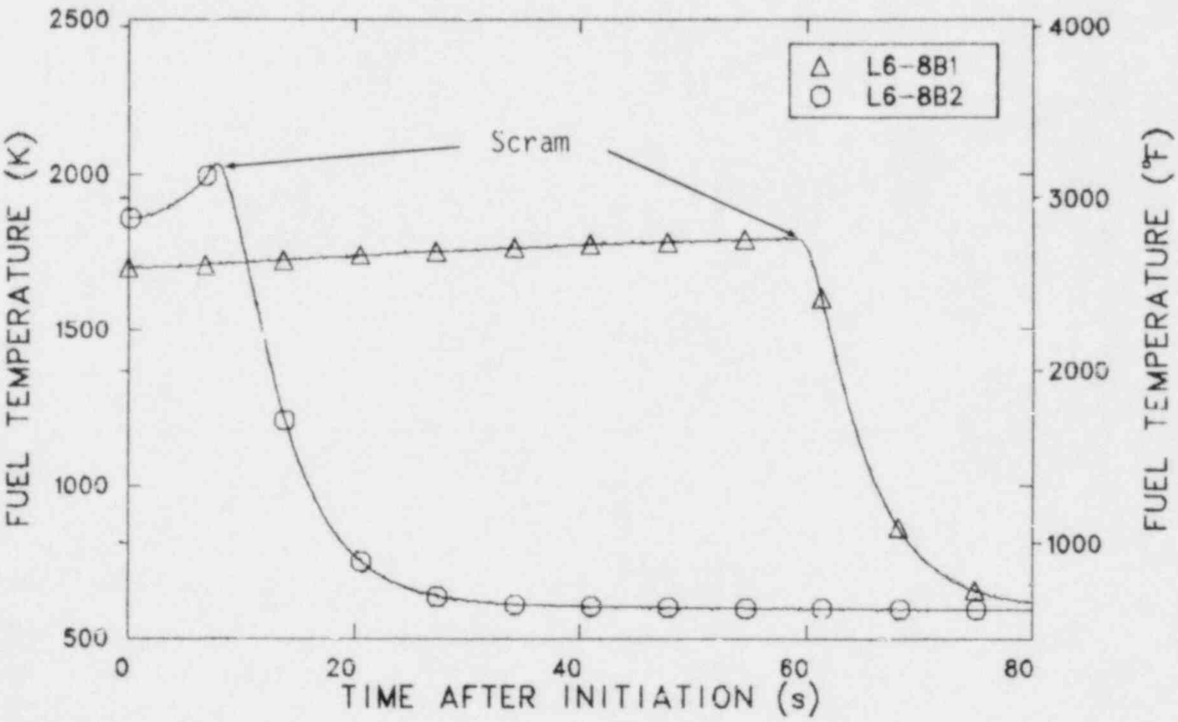


Figure 10. Fuel centerline temperatures during L6-8B-1 and L6-8B-2.

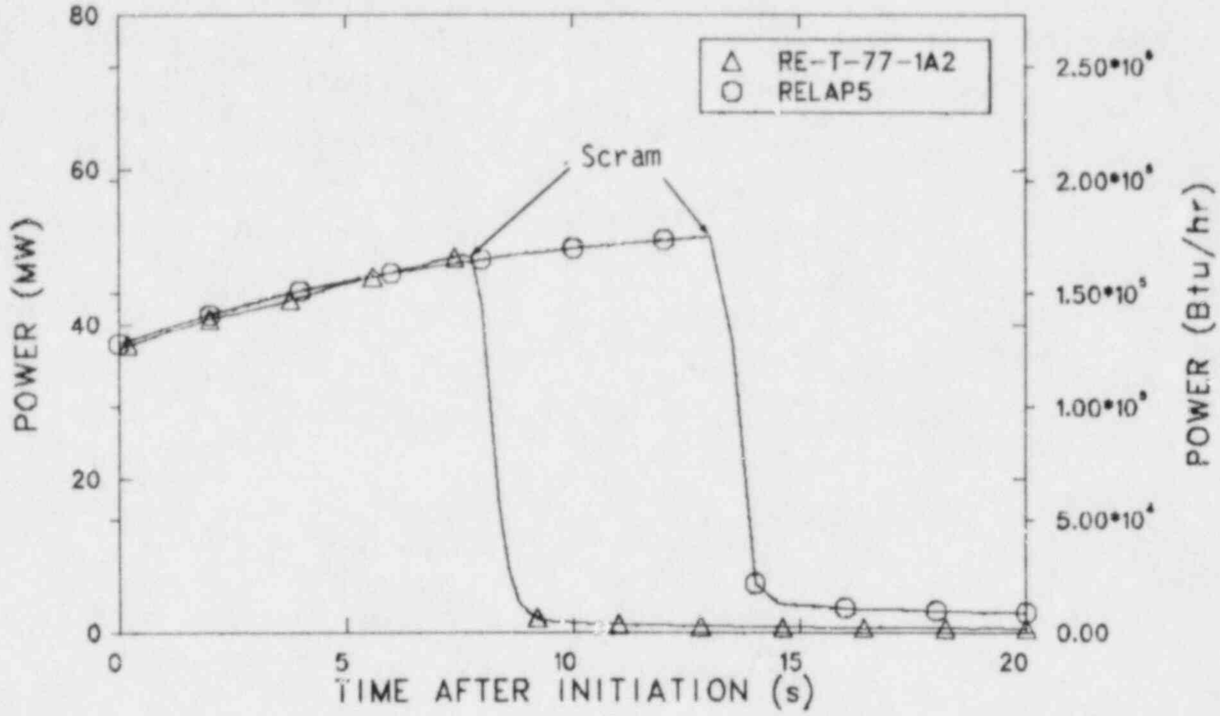


Figure 11. Reactor power during L6-8B-2 compared to prediction.

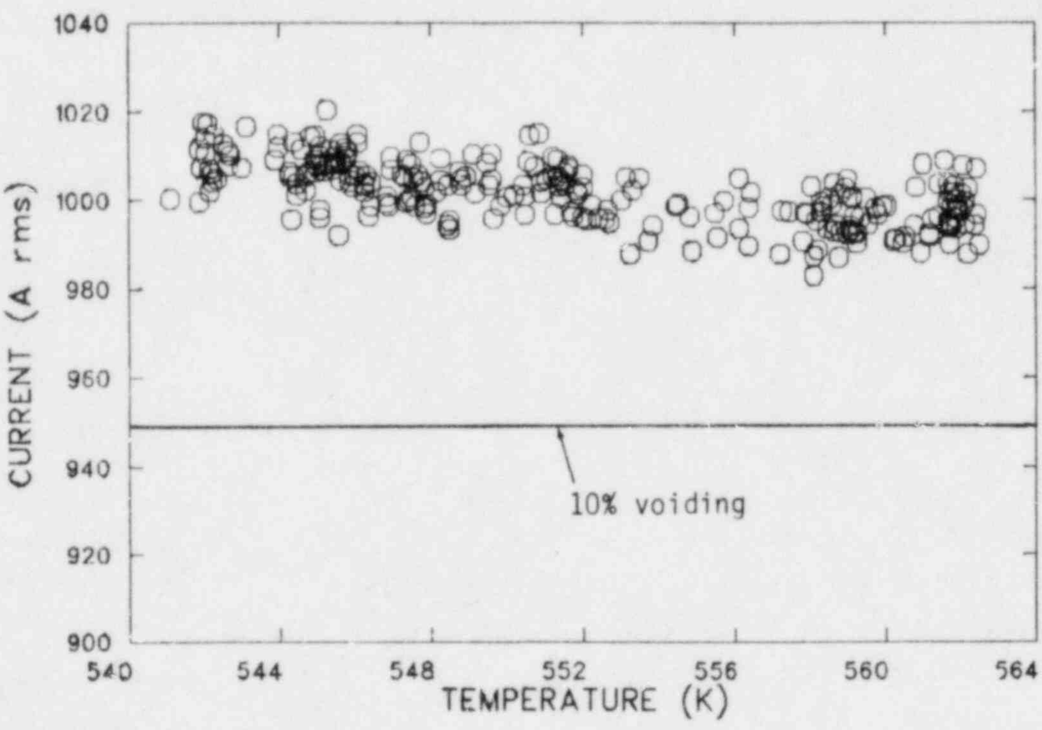


Figure 12. Primary pump current versus cold leg temperature during L6-8C-1.

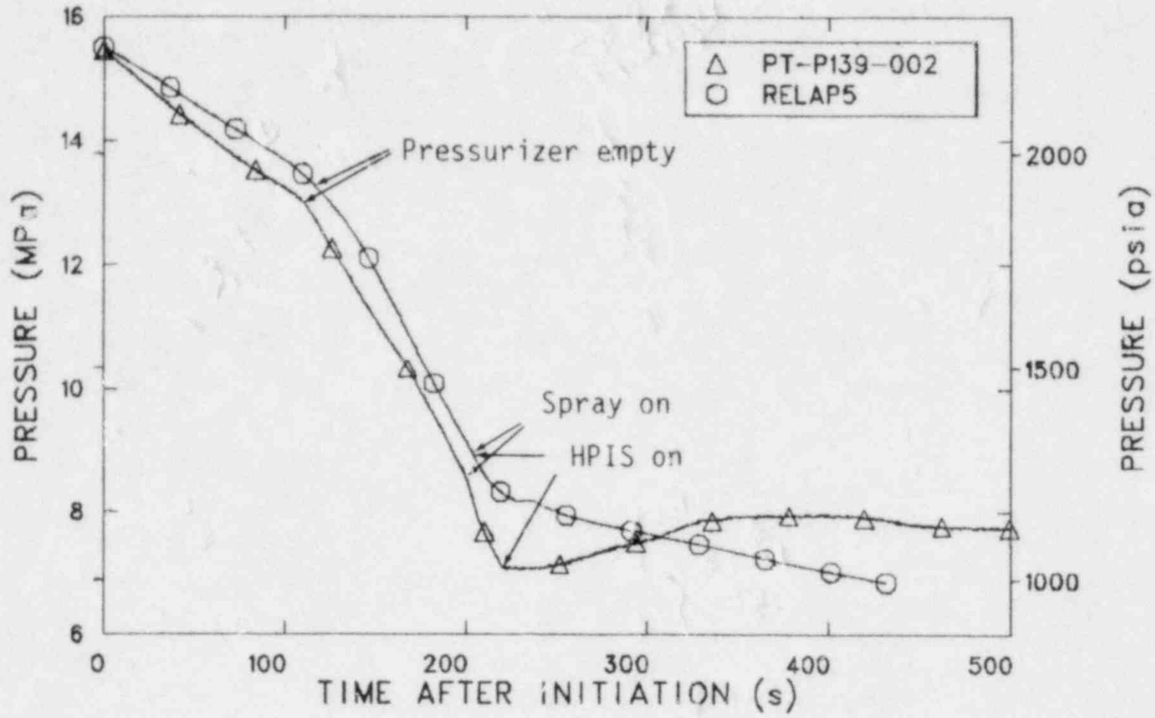


Figure 13. Hot leg pressure during L6-8C-1 compared to prediction.

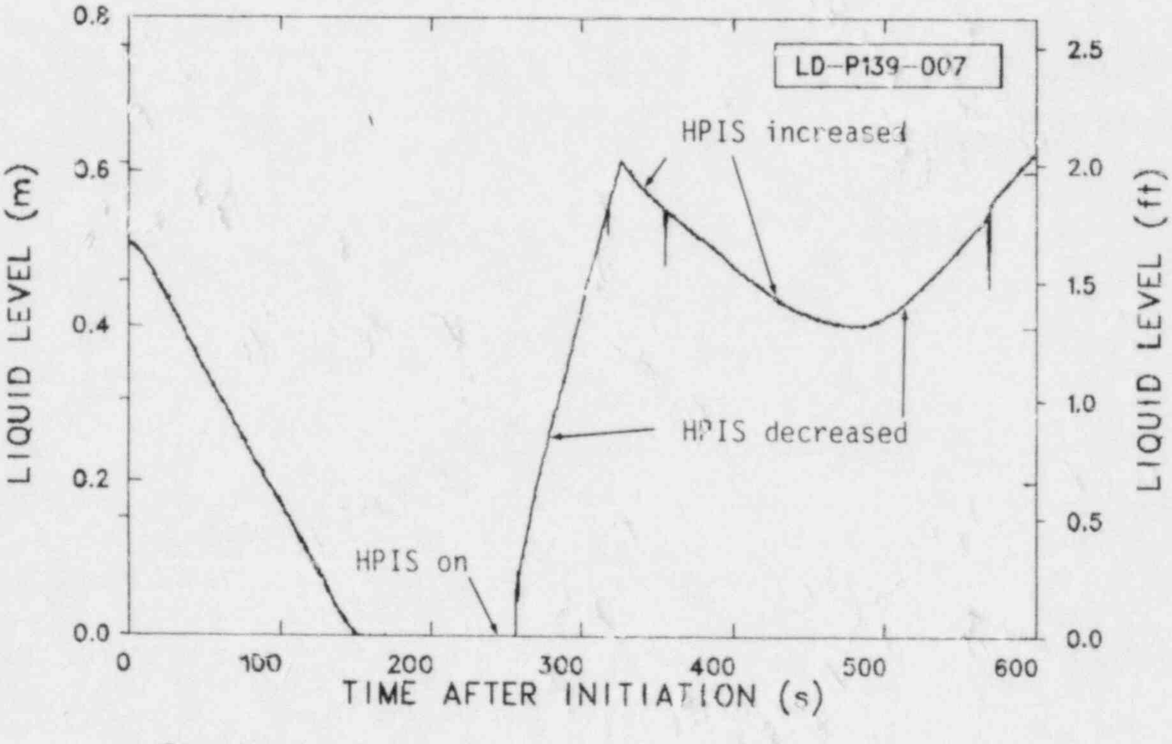


Figure 14. Pressurizer liquid level during L6-8C-2.

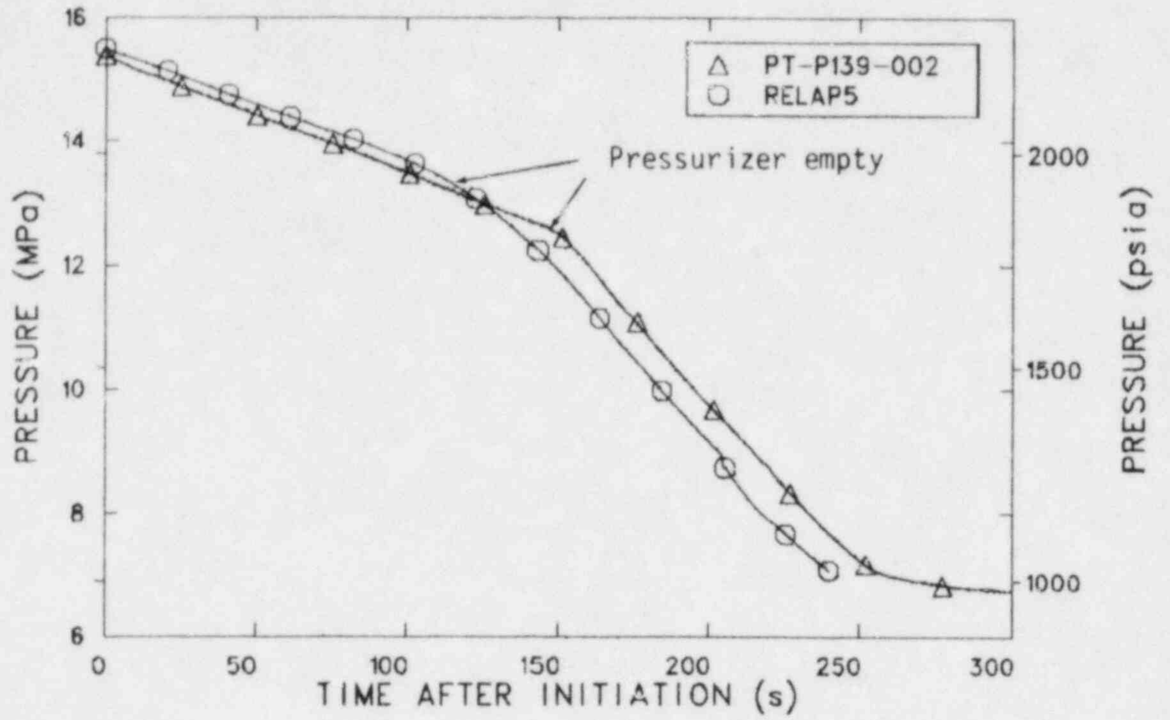


Figure 15. Hot leg pressure during L6-8C-2 compared to prediction.

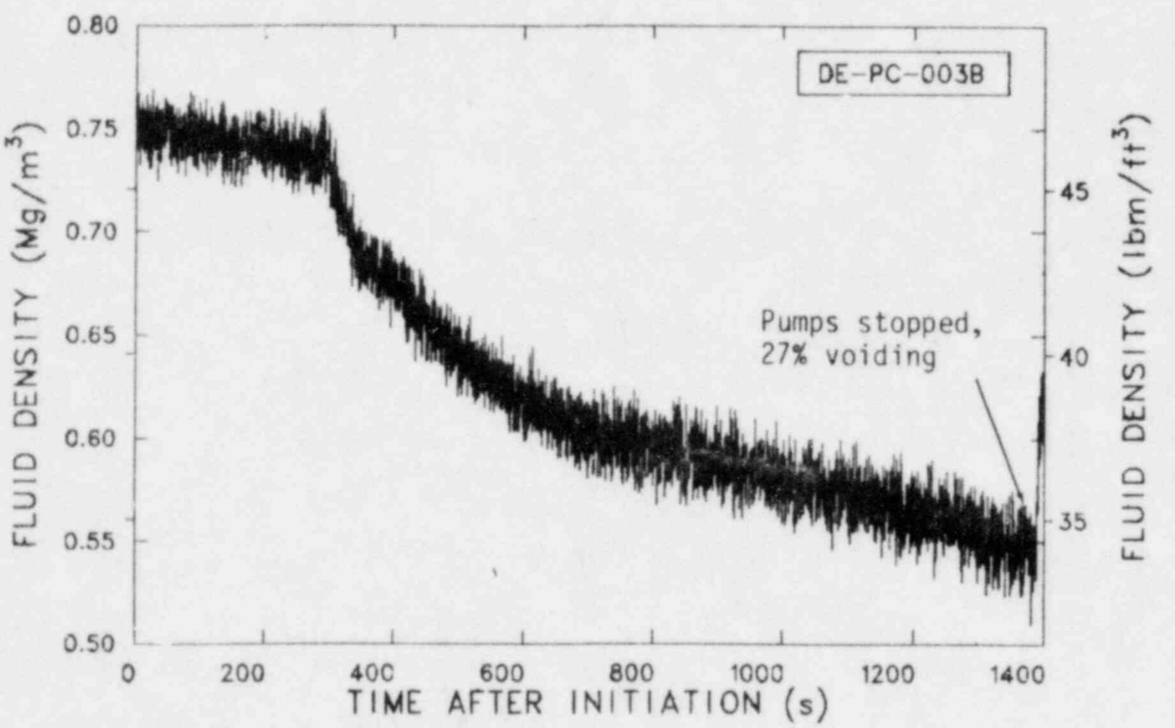


Figure 16. Steam generator outlet density during L6-8C-3.

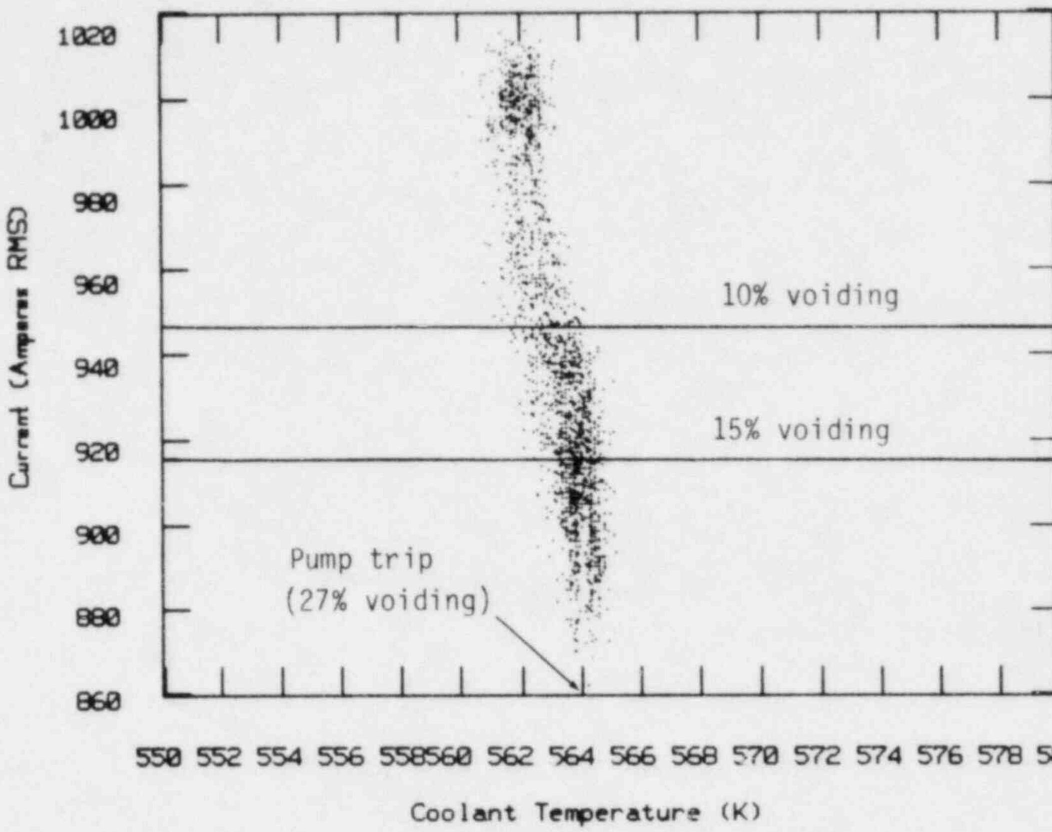


Figure 17. Primary pump current versus cold leg temperature during L6-8C-3.

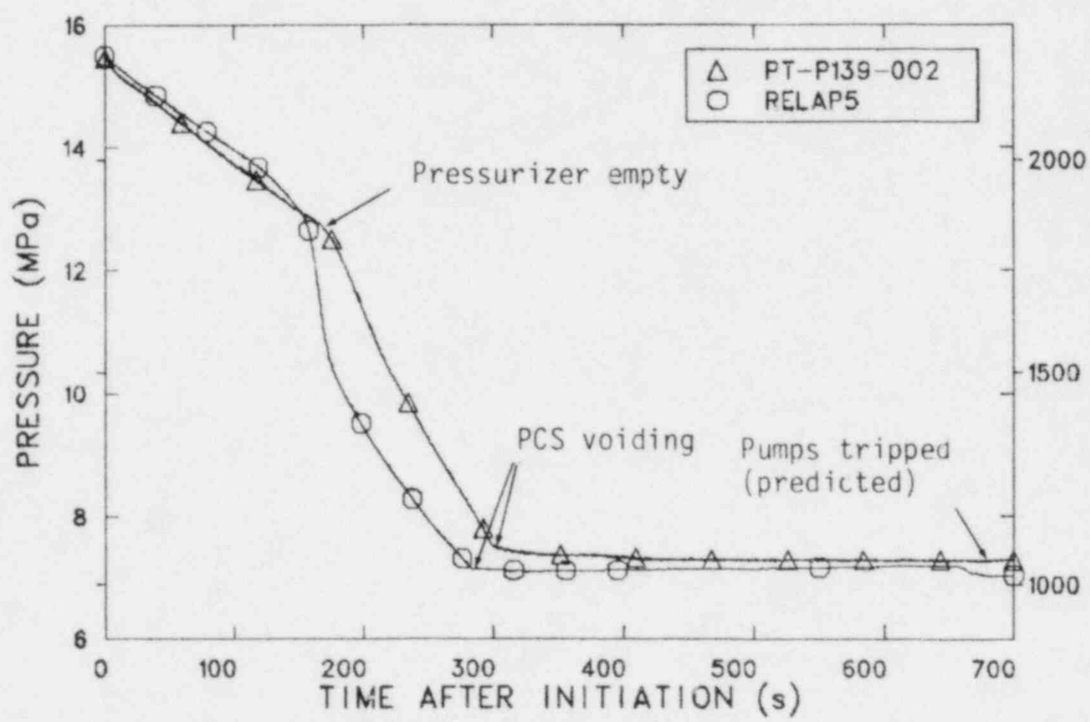


Figure 18. Hot leg pressure during L6-8C-3 compared to prediction.

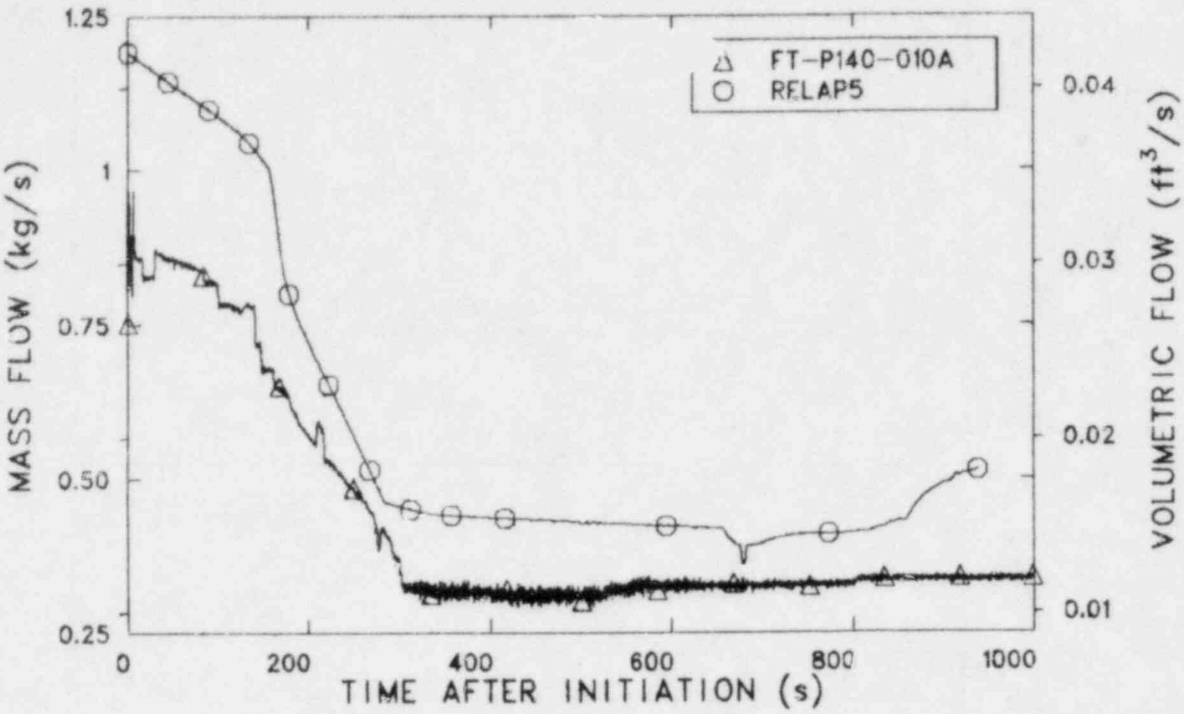


Figure 19. Letdown flow during L6-8C-3 compared to prediction.

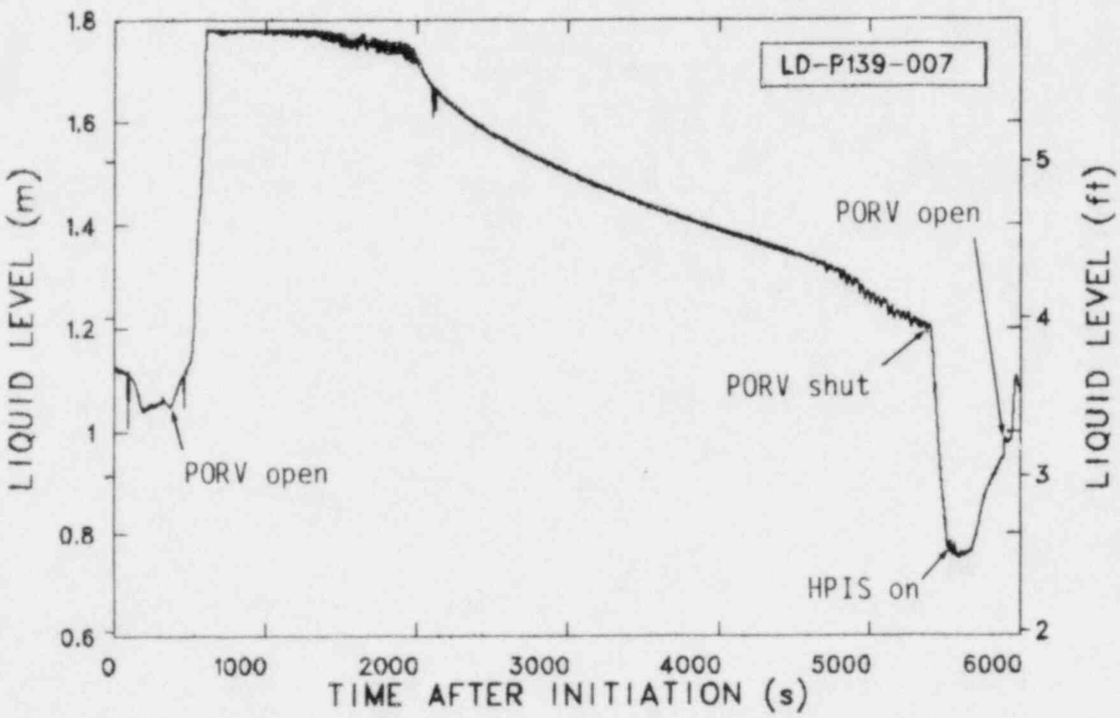


Figure 20. Pressurizer liquid level during L6-8D.

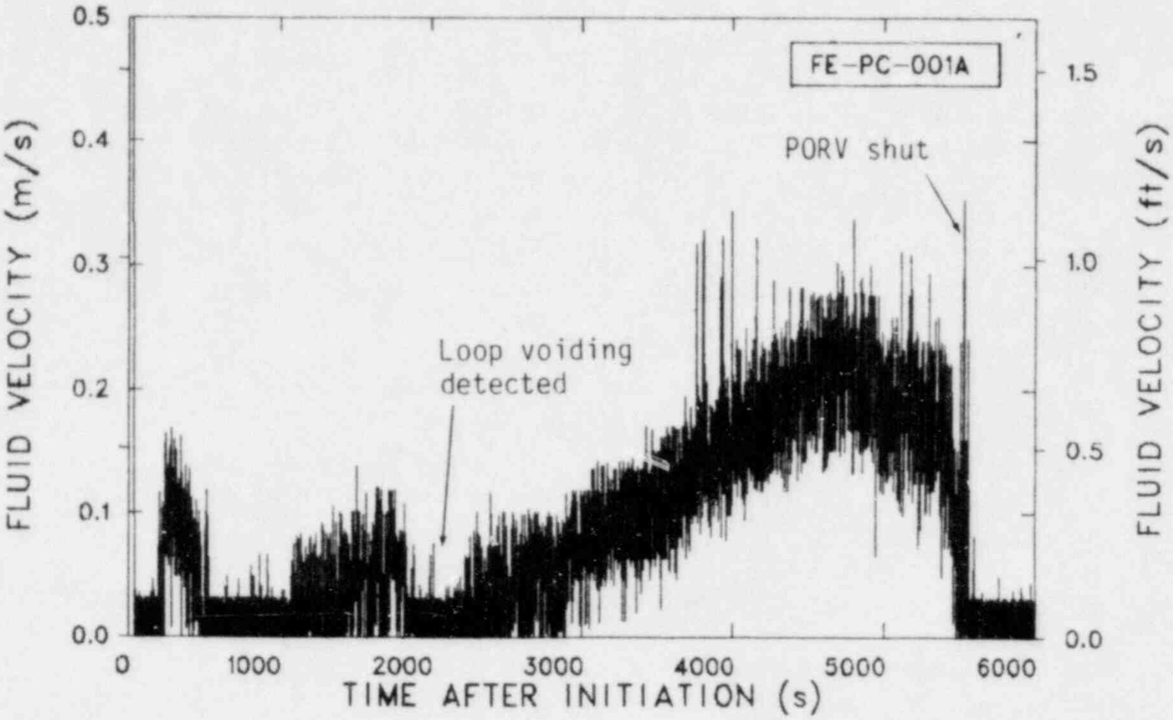


Figure 21. Cold leg fluid velocity during L6-8D.

## 6. REFERENCES

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2. J. H. Linebarger et al., "Reactor Coolant Pump Motor Power or Current Criteria for Reactor Coolant System Inventory Management in Commercial PWRs During Accidents," LOFT Research Memorandum, March 1982.

3. H. Ollikkala, Best Estimate Prediction for LOFT Anticipated Transient Slow and Fast Rod Withdraw Experiment L6-8B, EGG-LOFT-5983, August 1982.

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# APPENDIX A
# LOFT SYSTEM GEOMETRY

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# LOFT SYSTEM GEOMETRY

The LOFT system geometry is shown in Figure A-1. Figure A-2 shows the pressurizer with operating liquid levels, volumes, and instrument locations. Figure A-3 shows the LOFT steam generator and instrumentation. For complete information on the LOFT system, refer to Reference A-1.

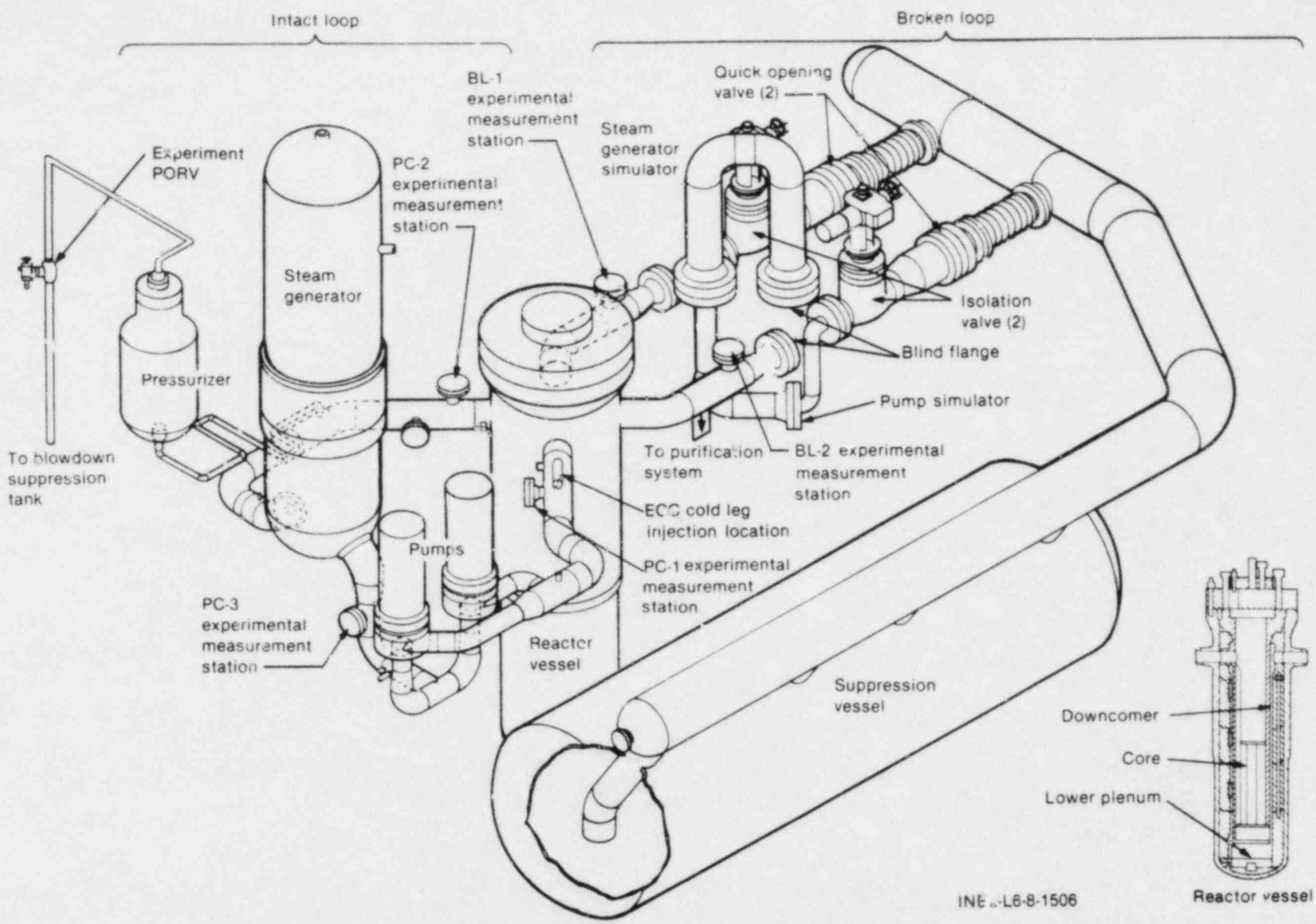


Figure A-1. LOFT system geometry.

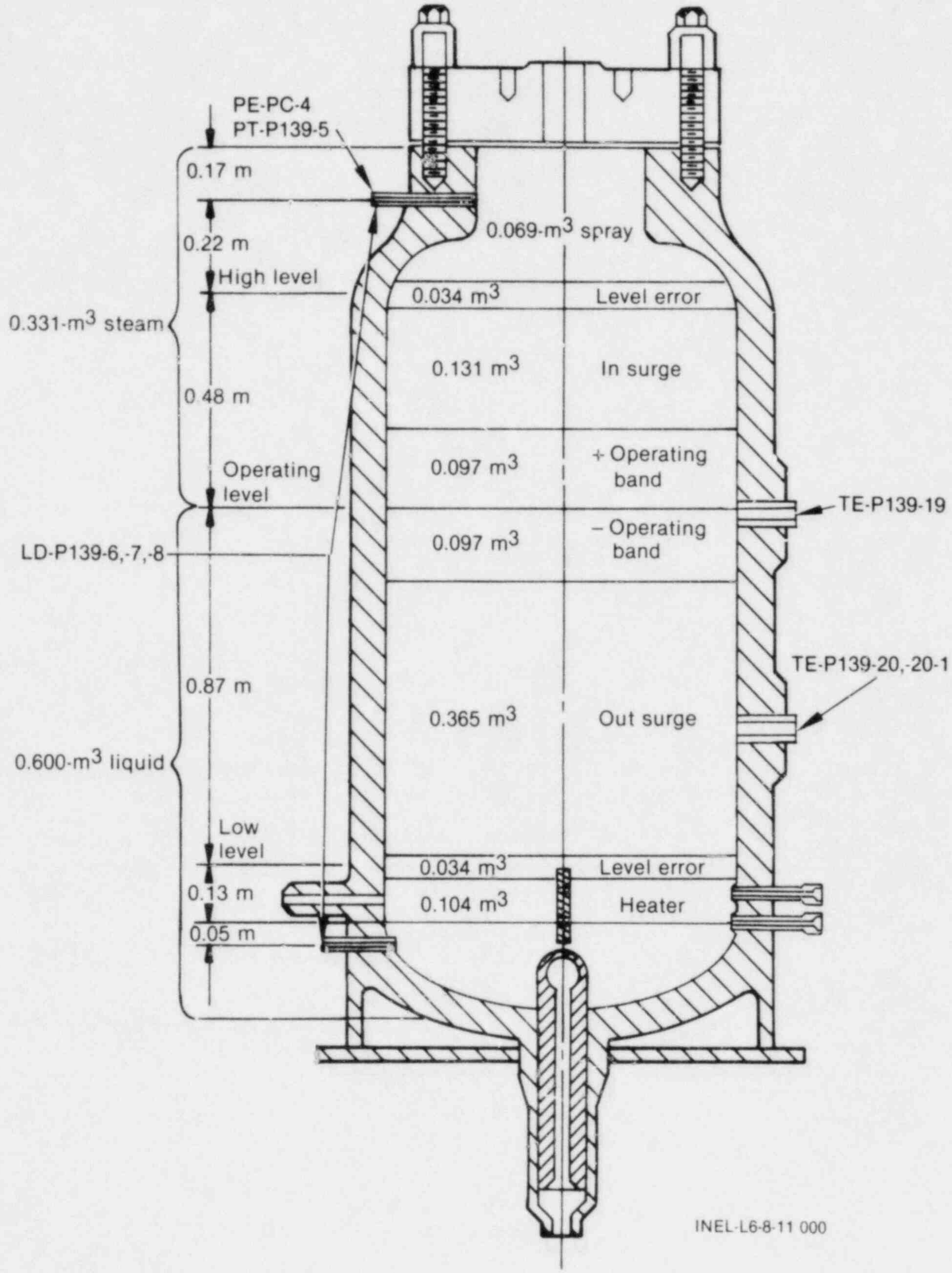


Figure A-2. LOFT pressurizer with operating levels and volumes.

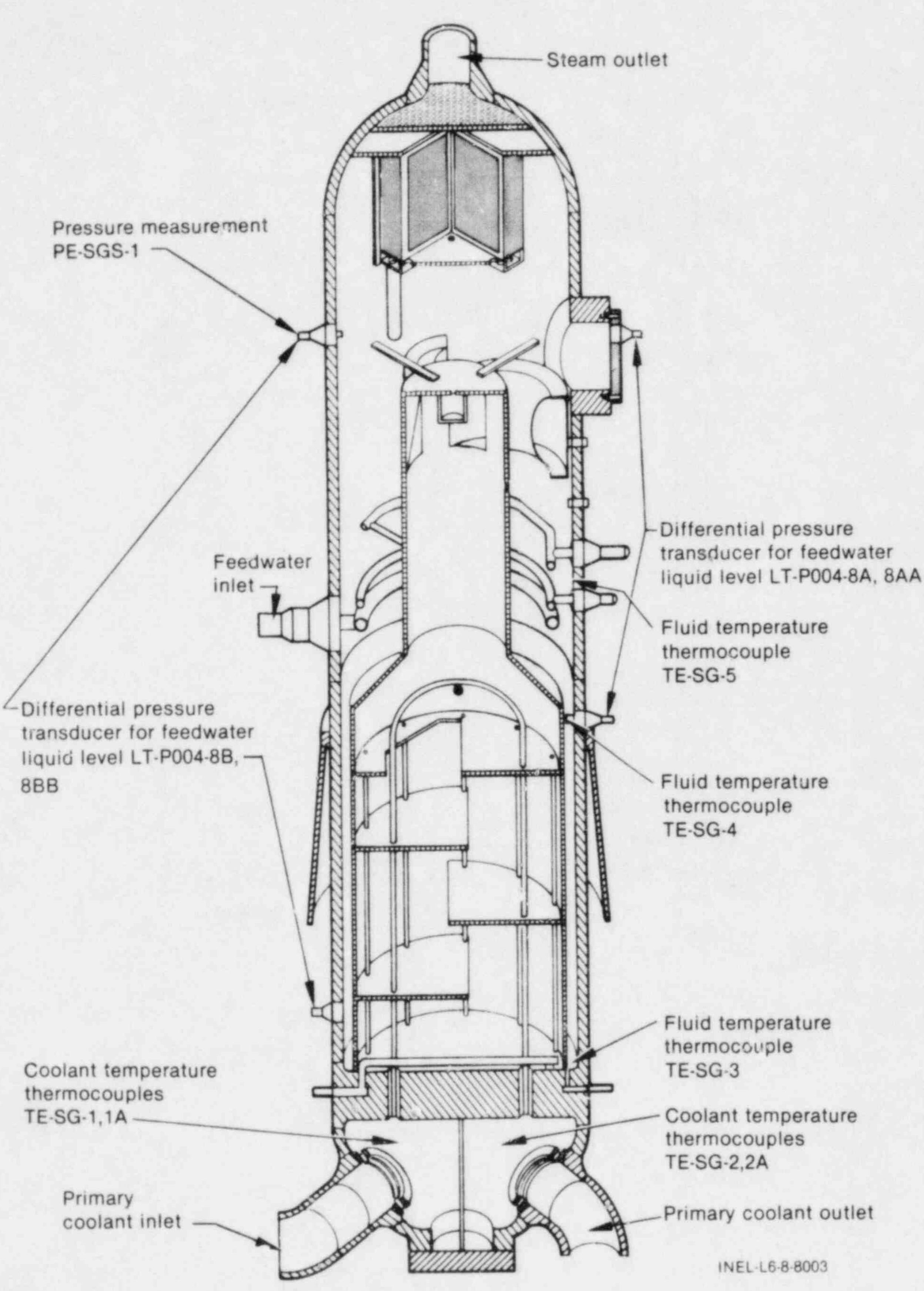


Figure A-3. LOFT steam ge.erator and instrumentation.

## Reference

A-1. D. L. Reeder, LOFT System and Test Description (5.5-Ft Nuclear Core 1 LOCEs), NUREG/CR-0247, TREE-1208, July 1978.