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# AP600 DESIGN CHANGE DESCRIPTION REPORT

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## 1.0 Introduction

This report provides a summary description of changes to the AP600 design described in the AP600 Standard Safety Analysis Report (SSAR), Revision 1 (Reference 5.1), AP600 Probabilistic Risk Assessment (PRA), Revision 0 (Reference 5.2) and the February 15, 1994 AP600 Design Change Description Report (Reference 5.3) . The purposes of this document are to:

- Identify changes to the AP600 design,
- Provide an overview of the impacts resulting from the changes,
- Serve as interim documentation until licensing documentation is revised (e.g., SSAR and PRA).

This report covers two design changes to the AP600. The first change is a modification to the design of the reactor vessel head vent system. The second change is the elimination of the line between the Pressurizer and the Core Makeup Tanks.

Section 2 of this report provides a description of each of these changes, including the purpose of the change, impacts (if any) to safety analyses, PRA results, SSAR documentation, and AP600 test program.

Section 3 of this report provides an evaluation of the cumulative impact of the design changes on the AP600 design basis safety analyses.

Section 4 of this report provides a discussion comparing the results of AP600 integral systems tests performed at the SPES-2 test facility, with and without the Pressurizer to Core Makeup Tank pressure balance line.

## 2.0 Description Of Design Changes

This section describes modifications to the AP600 design described in the AP600 Standard Safety Analysis Report (SSAR), Reference 5.1. These modifications are individually discussed in the following subsections.

## 2.1 Reactor Vessel Head Vent Upgrade (DM-12)

### 2.1.1 Description

This design change modifies the reactor vessel head vent portion of the Reactor Coolant System (RCS) to provide redundant, safety-related, remotely operated head vent paths. The previous head vent consisted of one vent path with two remotely-operated isolation valves in series, and one vent path with two manual isolation valves. These vent lines are connected to the top of the reactor vessel head via a common one inch inlet header, and discharge to the IRWST via a common one inch discharge line that connects to one of the ADS discharge headers. The remotely-operated vent path was provided for venting non-condensible gasses that could accumulate in the reactor vessel head as the result of a severe accident. The manual vent path was provided for RCS filling operations during startup. This design modification changes the two manual isolation valves to safety related solenoid-operated valves identical to the valves in the remotely-operated head vent path.

Other changes to the system include:

- removing the 3/8" flow restrictor upstream of the remotely-operated head vent valves, which changes the safety classification of the valves from safety class 2 to safety class 1,
- adding flow limiting orifices downstream of the head vent valves to limit the flow rate from the head vent path, and
- increasing the size of the head vent discharge piping connecting to the ADS discharge header from 1-inch to 2-inch pipe.

Figure 2.1-1 shows a simplified sketch of the revised design. The revised RCS P&ID and SSAR description are provided in Appendix A.

### 2.1.2 Purpose of Modification

This design change provides the plant with a safety-related, single-failure tolerant vent path that could be used to prevent pressurizer overfill during certain design basis events. The design bases for the head vent have been broadened to include the ability to relieve water from the RCS at a flow rate sufficient to prevent pressurizer overfill during an event where the mass addition from the core makeup tanks causes an increase in pressurizer inventory that otherwise might overfill the pressurizer. In addition, the head vent can be used to vent non-condensible gasses that may accumulate in the RCS due to a severe accident.

In order to provide sufficient flow capacity for accident mitigation and for manual startup venting operations, the 3/8" flow restrictor upstream of the remotely-operated head vent valves is removed. A flow limiting orifice downstream of the head vent valves has been incorporated to limit the head vent flow. The size of the discharge piping has been increased from 1" to 2" to provide sufficient vent area.

### 2.1.3 Safety Analysis Impact

During selected design basis non-LOCA events, long-term (> 30 minutes) operation of the core makeup tanks will cause an increase in pressurizer level. Eventually the pressurizer could become water filled, relieving water from the pressurizer safety valves. Failure of the safety valves to reclose would result in a condition II event leading to a condition III event.

The safety analysis previously has assumed that pressurizer overfill following a transent event would be avoided by stopping mass addition to the RCS by isolating the core makeup tanks. However, it is undesirable to isolate the core makeup tanks during these events, and an alternate approach to preventing pressurizer overfill was developed. This approach is to manually open the reactor vessel head vent valves from the control room during a transient event where the pressurizer level increases to a very high level. The head vent valves will vent water from the RCS reducing the water level in the pressurizer, and preventing pressurizer overfill for design basis events that would otherwise lead to pressurizer overfill. When the water level in the pressurizer is reduced to a pre-selected value, the operator would close the valves and stop the venting operation. The level at which the operator would re-close the valves has been selected so that pressurizer overfill could not occur later during the transient. A safety analysis of a design basis event, where head venting operation is modeled, is provided in section 3.1 of this report.

In addition to the safety analysis provided, best-estimate type sensitivity studies have been performed. These studies demonstrate on a realistic best-estimate basis, that no head venting operations would be required to prevent pressurizer overfill during condition II transients. Reactor vessel head venting is only required to meet the success criteria established for conservative, design basis accident analyes.

### 2.1.4 PRA Impact

This change is expected to have little or no effect on the plant core damage frequency. PRA is an evaluation of how the plant is expected to operate, considering realistic conditions. As noted above, sensitivity studies have been performed which show that on a best estimate basis, head vent operation is not required. Furthermore, if venting operations were performed, the probability is high that the operator would re-close the valves when required. Therefore, it is expected that this change will have a minimal effect on the AP600 overall core damage frequency.

### 2.1.5 Test Program Impact

This change does not affect the test program. The AP600 integral tests (OSU, SPES) do not model heatup events that would result in long-term CMT operation and potential pressurizer overfill. The seperate effects tests (CMT, ADS) are not impacted by this change, since the bounding conditions for these tests are not affected by the change in procedures to incorporate head venting.

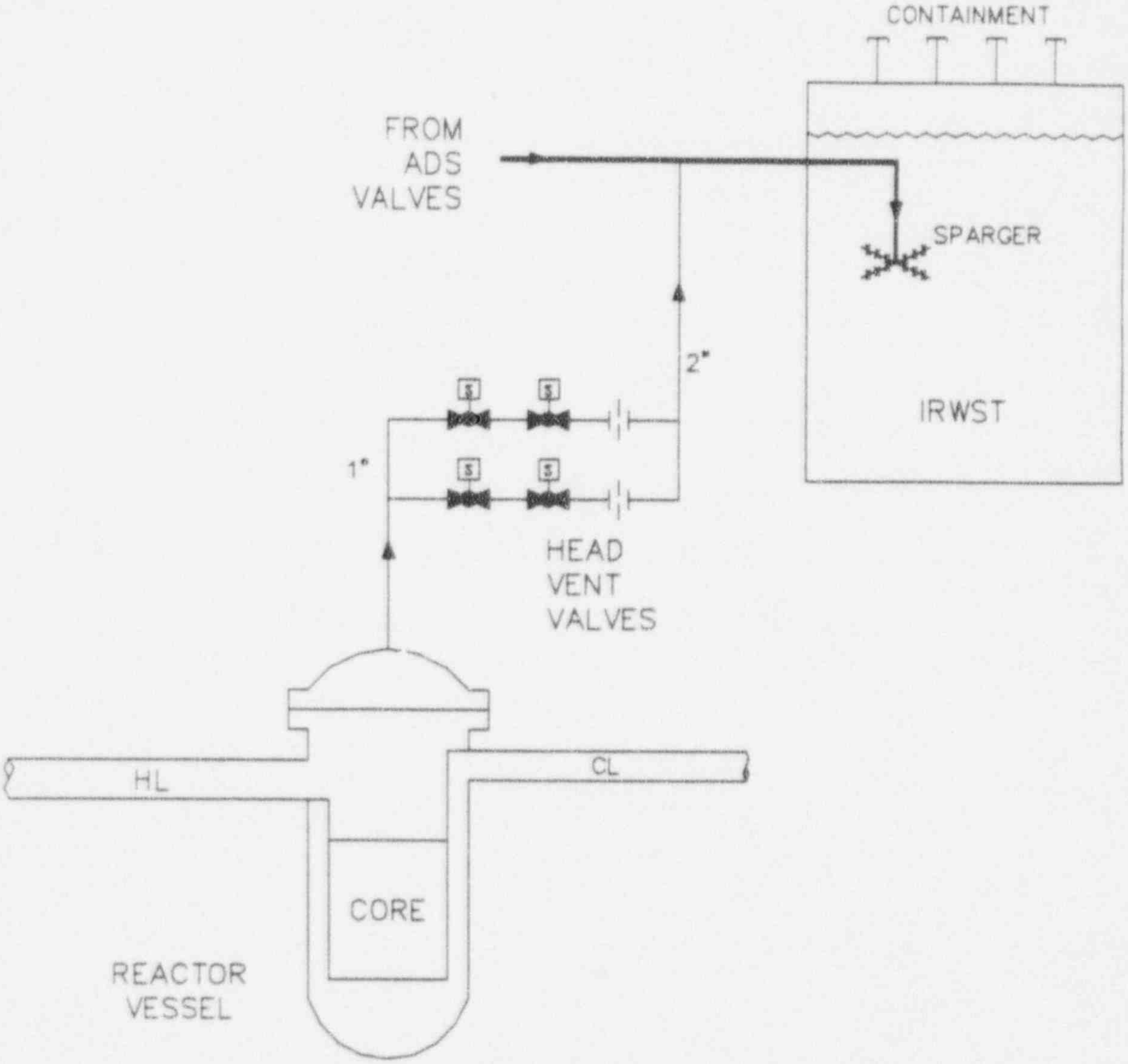



**Figure 2.1-1 AP600 Reactor Vessel Head Vent Subsystem**

## 2.2 Elimination of Pressurizer to CMT Pressure Balance Line (DM-13)

### 2.2.1 Description

This design modification eliminates the pressure balance line connecting the pressurizer and the core makeup tank (CMT) inlet. Also eliminated is the steam trap and drain connections to the steam generator and the reactor coolant drain tank (RCDT). With the revised design, the cold leg balance line contains a single normally open motor operated valve instead of parallel normally closed air operated valves.

A high point gas trap has been added to verify that there are no non-condensables present during normal plant operation. A vent from the top of the gas trap is routed through a orifice to the RCDT. This vent is used to vent off non-condensibles in the unlikely event that they accumulate during normal operation. This line is also used in case the CMT temperature or boron concentration needs to be adjusted.

Figure 2.2-1 shows a simplified sketch of the revised design. The revised PXS P&ID and SSAR description are provided in Appendix A.

### 2.2.2 Purpose of Modification

This design modification is introduced to simplify the plant design; ten remotely operated valves and four manual/check valves are eliminated. It also eliminates approximately 300 feet of pipe and two steam traps. This reduction in equipment simplifies the initial design, construction, startup / inservice testing, maintenance, inspection, and operation. It simplifies the testing and analysis associated with design certification. It also reduces the chance of unnecessary ADS actuation, as discussed below.

### 2.2.3 Safety Analysis Impact

Safety analysis for the AP600 is simplified by this change. As discussed below, there are fewer modes of operation for the CMTs. There are fewer pipe break locations that have to be considered. The potential for hydrogen to accumulate in the CMT, which could affect CMT performance, is minimized.

For non-LOCA events, the CMTs will now operate in one mode instead of two modes. The CMT mode of operation will be water recirculation, with hot water flowing through the line from the CL to the top of the CMT and cold CMT water flowing through the line connecting the bottom of the CMT and the DVI nozzle. This mode of operation provides a larger total CMT flow and a similar net CMT injection flow. The larger total flow provides for a more rapid RCS boration.

The chance of ADS actuation during a steam line break or during a SG tube rupture is greatly reduced because, without the Pzr/CMT line, the cold legs have to void in order for the CMTs to drain.

For LOCA events, section 3.2 show the results of two different break sizes/locations. One case analyzed is a one inch cold leg break and the other is a eight inch double-ended cold leg to CMT pressure balance line break. Both of these analyses show good results with the core remaining covered throughout the accident.

As discussed in section 4.0, SPES-2 test results show that the PXS performs well without the Pzr to CMT pressure balance line. This section discusses three SPES-2 tests. Two of these tests are 2" CL break LOCAs that are identical except one test has the Pzr/CMT line and the other test does not. The third test is a 1" CL break without the Pzr/CMT line. The results from the two 2" LOCA tests are almost identical, which indicates that for CL LOCAs of this size and larger that the Pzr/CMT line has no effect.

### 2.2.4 PRA Impact

This change is expected to improve the CMT/plant reliability. One improvement is that fewer valves have to open to initiate CMT operation since the CL balance line is now normally open instead of closed. Another improvement is that there is less piping and valves that could leak or break and cause an initiating event. There is also a reduced chance that water hammer could occur when the CMT is actuated since the Pzr/CMT line is eliminated.

### 2.2.5 Test Program Impact

**Core Makeup Tank Separate Effects Tests**
This change does impact the CMT test. The CMT test models both the Pzr/CMT and the CL/CMT pressure balance lines. The tests with the Pzr/CMT balance line no longer need to be performed. In addition, a number of tests were intended to investigate the effects of H2 accumulation (prior to CMT actuation) on CMT performance. These tests have been deleted from the test matrix.

**Integral Systems Tests at Oregon State University**
This change does impact the OSU test facility. The OSU tests are integral systems tests intended to obtain thermal-hydraulic data for computer code validation and to investigate long term cooling behavior. The Pzr/CMT line was manually blocked, effectively removing the line. In addition, a test simulating a break in the Pzr/CMT line has been deleted from the test matrix.

**Integral Systems Tests at SPES-2 Test Facility**
This change does impact the SPES-2 test facility. The SPES-2 tests are integral systems tests to obtain thermal-hydraulic data for computer code validation and to investigate systems interactions during high pressure transients. The first matrix test at SPES-2, the 2 inch SBLOCA SSAR reference case, was completed with the Pzr/CMT line in place. The next matrix was a repeat of the first test except that the Pzr/CMT line was removed. All of the other SPES-2 tests will be performed without the Pzr/CMT line.

**ADS Phase B Tests**
This design change has no impact on the ADS Phase B tests. The ADS Phase B tests are performed by depressurizing the test facility through the ADS valve piping package, downstream piping and sparger. The conditions of the test are determined by the facility supply tank initial conditions (supply tank pressure and temperature) and the position of the facility control valve, which determines the fluid conditions upstream of the ADS valve piping package. The CMT is not explicitly modeled in the test facility. This change does not affect the range of conditions required to be tested.

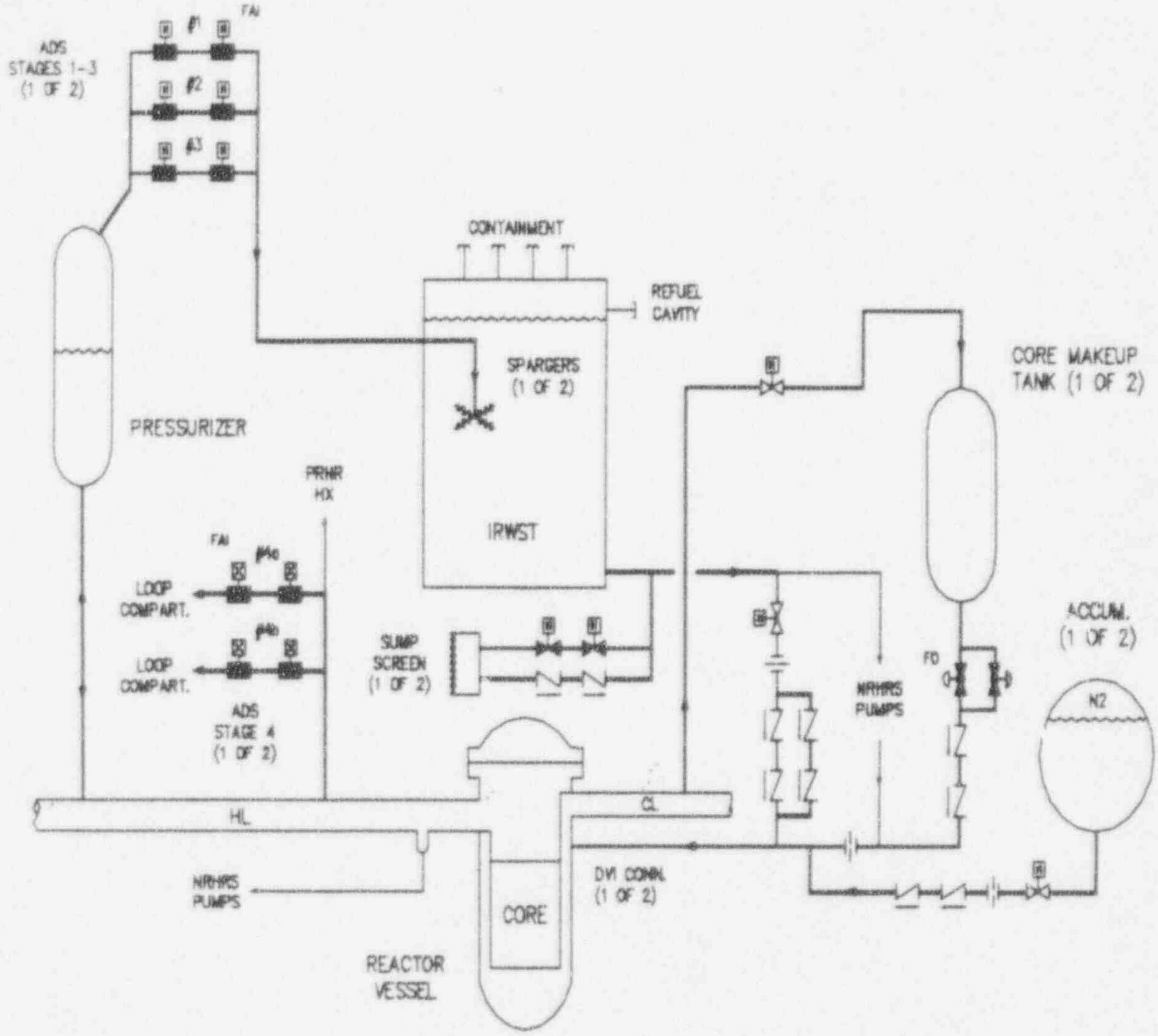



Figure 2.2-1  Passive Core Cooling System

## 3.0 Integrated Evaluation of Safety Analysis Impact

Chapter 15 of the SSAR (Reference 5.1) presents the design basis accident analyses performed for the AP600. Accidents are classified therein according to the type of event: increase in heat removal from the primary system, decrease in heat removal by the secondary system, etc. The SSAR Chapter 15 analyses were reviewed with respect to the design changes described in Section 2 of this report, and those events which were determined to be significantly affected have been reanalyzed, modeling the design changes discussed in Section 2 and the design changes discussed in Reference 5.3. The results of these reanalyses are presented in the following sections.

## 3.1 Spurious ECCS Events

The impact of the proposed design changes on the following Condition II events are presented in this section:

1) Inadvertent operation of the core makeup tanks (CMT) during power operation

2) Chemical and volume control system (CVS) malfunction that increases reactor coolant inventory

3) Inadvertent operation of the passive residual heat removal (PRHR) system

Analyses of the first two events listed above are presented in AP600 SSAR Section 15.5. These Condition II events cause an increase in reactor coolant inventory. For this effort, the analysis of these design basis events incorporates the changes made to the AP600 design. The two major design changes which affect these analyses are the actuation of the PRHR system on any CMT actuation signal (Reference 5.3), and the modification of the reactor vessel head vent system (Section 2.1). Two solenoid operated valves and a flow restrictor have been added to the head vent path in order to allow the operator to relieve RCS inventory during a transient if necessary to prevent pressurizer overfill.

### 3.1.1 Inadvertent Operation of the Core Makeup Tanks (CMT) During Power Operation

#### 3.1.1.1 Identification of the Causes and Accident Description

Spurious CMT operation at power could be caused by operator error, a false electrical actuation signal or a valve malfunction. A spurious actuation signal could be an "S" signal which actuates the CMTs. The event described below is a spurious "S" signal with the conservative assumption that both CVS pumps operate at maximum injection rates until they are isolated.

A spurious "S" signal results in a reactor trip. Following the reactor trip, the reactor power drops and the average RCS temperature decreases with subsequent coolant shrinkage. A few seconds after the trip, the two CVS pumps actuate, the CMT discharge valves open, the RCPs trip, and the PRHR system actuates. The CMTs and CVS pumps then start injecting cold, highly borated water into the RCS. After the initial shrinkage due to the reactor trip, the primary coolant system shrinkage is counteracted by the CMT and CVS injection and the pressurizer volume starts to increase because of the heat up of the cold injected fluid by the decay heat. The CVS pumps are automatically isolated on a high pressurizer level signal. The operator will be alerted by status lights in the main control room and can take action to terminate the event. For analysis purposes, the operator is assumed to take action 30 minutes after the transient is initiated. The operator ensures that the CVS pumps are isolated and opens the head vent valves. The operator waits to close the head vent valves until the pressurizer water level is reduced below a low level control setpoint. After the head vent valves have been closed, the CMTs continue to inject for some time, and the expansion of the cold water injected causes the pressurizer water level to increase. The CMTs operate in a recirculating mode where hot water from the cold leg is drawn into the CMT tanks, while cold, highly borated water is injected into the RCS. As the water in the CMTs heats up, the available driving head slowly decreases, and eventually the recirculating flow stops. The amount of expansion which occurs after the head vent valves are closed is not sufficient to cause the pressurizer water level to increase above nominal. Once the CMTs stop recirculating, the plant stabilizes and the operator follows the appropriate recovery procedure.

### 3.1.1.2 Method of Analysis

The plant response to a spurious "S" signal is analyzed by employing a modified version of the computer program LOFTRAN described in AP600 SSAR Section 15.B. Additional modifications were made to model the relief path from the reactor vessel head. The code simulates the neutron kinetics, RCS, pressurizer, pressurizer safety valves, pressurizer spray, steam generator, steam generator safety valves, and the passive residual heat removal (PRHR) and CMT systems. The program computes pertinent plant variables including temperatures, pressures and power level.

Reactor power and average temperature drop immediately following the trip, and the operating conditions never approach the core limits.

For conservatism, control systems except for the CVS charging pumps are not assumed to function during the transient. Cases with the turbine bypass (steam dump) and feedwater control systems working result in lower secondary and primary temperatures and in greater margin to pressurizer overfill prior to the time of operator action. CVS, CMT, and PRHR system performance are conservatively simulated (CVS and CMT flow rates to the RCS are maximized, and minimum heat transfer from only one PRHR heat exchanger is modeled).

The major assumptions are as follows:

- Initial operating conditions

  The initial reactor power, RCS pressure and average temperature are assumed to be at their nominal values. The initial pressurizer water level is assumed to be 10% above nominal.

- Moderator and Doppler coefficients of reactivity

  A least negative moderator temperature coefficient is used. A low (absolute value) Doppler power coefficient is assumed. Reactivity parameters are not important for this analysis, since the core is shutdown by the boron injection from the CMTs and CVS.

- Control Systems

  The CVS level control system is assumed not to function. Instead, the CVS charging pumps are assumed to deliver maximum flow upon recipt of an "S" signal. The other control systems are not assumed to function since their operation results in a better behaved transient.

- Reactor Control

  Rod control is not modeled.

- Pressurizer Heaters

  Pressurizer heaters are assumed to be shut off throughout the transient. In the AP600 design, the pressurizer heaters are blocked on receipt of an "S" signal. Since an "S" signal is the initiating event in this case, the amount of residual heat input from the heaters is negligible.

- Boron Injection

  The transient is initiated by a spurious "S" signal. This signal opens the CMT discharge valves. This signal is also assumed to actuate two CVS pumps at full flow. The CMTs are assumed to be filled with 3500 ppm borated water and the water from the CVS contains 4375 ppm boron.

- Reactor Trip

Reactor trip is initiated by the "S" signal.

### 3.1.1.3 Results

Figures 3.1.1-1 through 3.1.1-7 show the transient response to the inadvertent operation of the CMT during power operation. The spurious "S" signal occurs at 10 seconds accompanied by the actuation of the two CVS pumps. The nuclear power is shown in Figure 3.1.1-1. After a two second delay the neutron flux starts decreasing due to the reactor trip which is immediately followed by the turbine trip. The CVS and CMT injection flows are shown in Figure 3.1.1-2, and the PRHR heat flux is shown in Figure 3.1.1-3. The CMT valves are assumed to open at 17 seconds followed by a trip of the reactor coolant pumps at 25 seconds, and actuation of the PRHR at 30 seconds. As shown in Figures 3.1.1-4 and 3.1.1-5, the RCS temperature and pressure initially increase when the RCPs are tripped and the $\Delta T$ across the core is increased. As the CVS and passive safety features cool the plant, the RCS temperature and pressure are reduced. The RCS begins to repressurize as the cold injected water expands and begins to fill the pressurizer (pressurizer water volume is shown in Figure 3.1.1-6). The CVS pumps are automatically isolated on high pressurizer level at 1381 seconds, but the CMTs continue to recirculate until the driving head is sufficiently reduced at about 25,600 seconds. Once the cold CVS flow is terminated, the RCS temperature stops decreasing. The RCS mass and pressurizer level increase until the reactor vessel head vent valves are assumed to be manually opened at 1800 seconds.

At 1800 seconds, the pressurizer pressure is at the safety valves setpoint (2500 psia) and the fluid in the pressurizer is subcooled. As the RCS inventory is relieved through the head vent path, the pressurizer is drained and the pressurizer pressure is reduced quickly. At about 4600 seconds, the pressurizer pressure is reduced sufficiently such that the fluid in the pressurizer becomes saturated. Once there is no subcooling, the pressurizer fluid begins flashing to steam which increases the pressurizer steam space. The additional increase in steam space reduces the rate at which the primary system pressure is reduced and increases the rate at which the pressurizer water volume is reduced. The head vent flow rate, which is dependent on the primary system pressure, is shown in Figure 3.1.1-7. Once pressurizer level has been reduced to the low level control setpoint, the head vent valves are assumed to be manually closed. Eventually, the CMTs stop recirculating and a stable condition is reached. No discharge of primary water through the pressurizer safety valves is predicted.

The calculated sequence of events is shown in Table 3.1-1. Recovery from the accident is discussed in Section 3.1.1.1.
In addition to the conservative design basis analysis, an evaluation was performed using "Best Estimate" assumptions. The major differences from the design basis assumptions are as follows:

- 1979 ANS decay heat model + 0 sigma is modeled.

- Two PRHR heat exchangers are assumed available. Nominal heat transfer is modeled.
- Nominal CMT flow rates and boron concentrations are assumed.
- After receipt of an "S" signal, flow is not initiated by the CVS if the pressurizer level remains above the control system setpoint of 10% of span.

The results of the "Best Estimate" evaluation show that the CVS pumps would not be actuated for at least 10 hours for this event, because the pressurizer level would not decrease below 10% of span. Furthermore, the two PRHR heat exchangers have sufficient heat removal capability to prevent the expansion of the cold water injected from the CMTs from pressurizing the system to the safety valves setpoint or filling the pressurizer. Thus, operator action is not required to prevent overfill for this event on a "Best Estimate" basis.

#### 3.1.1.4 Conclusions

The results of the design basis inadvertent ECCS operation (CMT and CVS actuation) analysis show that the plant operating conditions never approach the core limits. Pressurizer pressure always remains below 110 percent of the design limit, and the operator can open the head vent valves to prevent the discharge of primary water through the pressurizer safety valves. The results of the "Best Estimate" evaluation show that operator action is not required to prevent overfill for this event on a "Best Estimate" basis.

## 3.1.2 Chemical and Volume Control System Malfunction That Increases Reactor Coolant Inventory

### 3.1.2.1 Identification of Causes and Accident Description

The increase of RCS inventory due to the addition of borated water is analyzed here. This increase may be due to the spurious operation of one or both of the CVS pumps or by the closure of the letdown path with CVS pump(s) running. If the CVS is injecting highly borated water into the RCS, the reactor experiences a negative reactivity excursion due to the injected boron, causing a decrease in reactor power and subsequent coolant shrinkage and pressurizer pressure and water level decrease. The load decreases due to the effect of reduced steam pressure after the turbine throttle valve fully opens. If the automatic rod control system is used, these effects are lessened by the rods moving out of the core. More mass accumulates in the RCS. While the reactor is eventually tripped by the reactor protection system (low pressurizer pressure, high pressurizer water level, low steam line pressure "S", or low $T_{cold}$ "S" signal), the RCS pressure and volume transient is not over until the CVS is isolated and the CMTs stop injecting into the RCS. Using conservative design basis assumptions, the transient analysis shows that the operator must take action to avoid filling the pressurizer by manually opening the reactor vessel head vent valves.

The time of the trip is affected by initial operating conditions, including core burnup history, which affects initial boron concentration, rate of change of boron concentration, and doppler and moderator coefficients.

If an "S" signal is not generated during the transient, the PRHR and CMTs will not be actuated, and CVS isolation terminates the accident. If the CMTs are actuated during the transient, the transient proceeds like a spurious "S" signal actuation transient analyzed in Section 3.1.1. The only difference is the lower average temperature and pressure associated with the power mismatch during the first part of the transient. The operator determines if conditions exist to isolate the CVS and terminates the accident in the same manner as the spurious "S" signal actuation accident discussed in Section 3.1.1.

### 3.1.2.2 Method of Analysis

The malfunction of the CVS system is analyzed by employing a modified version of the computer program LOFTRAN discussed in Section 3.1.1.2.

The time until an "S" signal is reached was conservatively minimized in order to initiate CMT injection earlier. This has the effect of maximizing the CMT injection flow and minimizing the margin to pressurizer overfill prior to the time of assumed operator action. For the purposes of this analysis, operator action was assumed at 30 minutes.

CVS, CMT, and PRHR system performance are conservatively simulated (CVS and CMT flow rates to the RCS have been maximized, and minimum heat transfer from only one PRHR heat exchanger is modeled).

The major assumptions are as follows:

- Initial Operating Conditions

  The initial reactor power, RCS pressure and average temperature are at their nominal values. The initial pressurizer water level is assumed to be 10% above nominal.

- Moderator and Doppler coefficients of reactivity

  A least negative moderator temperature coefficient is used. A low (absolute value) Doppler power coefficient is assumed. Reactivity parameters are not important for this analysis, since the core is shutdown by the boron injection from the CMTs and CVS.

- Control Systems

  The CVS level control system is assumed not to function. A malfunction in the CVS is assumed to cause the CVS centrifugal charging pumps to begin injecting maximum flow into the RCS. The other control systems are not assumed to function since their operation results in a better behaved transient.

- Reactor Control

  Rod control is not modeled.

- Pressurizer Heaters

  Pressurizer heaters are assumed to be shut off throughout the transient. In the AP600 design, the pressurizer heaters are blocked on receipt of an "S" signal. Since an "S" signal is generated within one minute of the transient initiation, the amount of residual heat input from the heaters is negligible.

- Boron Injection

  After 10 seconds at steady state, two CVS pumps start injecting 4375 ppm borated water at full flow into the RCS. Generation of an "S" signal actuates the CMTs. The CMT discharge valves are opened, and the CMTs are assumed to be filled with 3500 ppm.

- Reactor Trip

  Reactor trip is initiated by either a low pressurizer pressure, high pressurizer water level, low steam line pressure "S", or low $T_{cold}$ "S" signal.

### 3.1.2.3 Results

Figures 3.1.2-1 through 3.1.2-7 show the transient response to a CVS malfunction that results in an increase of RCS inventory. The nuclear power is shown in Figure 3.1.2-1. Neutron flux starts decreasing immediately due to boron injection, but steam flow does not decrease until later in the transient when the turbine throttle valves are wide open.

The mismatch between load and nuclear power causes the RCS average temperature and pressure, and the pressurizer water level to drop. When the low $T_{cold}$ "S" signal set point is reached at about 49 seconds, the reactor trips and the control rods start moving into the core after a two second delay. A few seconds after the trip, the CMTs discharge valves open, the RCPs trip, and the PRHR actuates. The CVS and CMT injection flows are shown in Figure 3.1.2-2, and the PRHR heat flux is shown in Figure 3.1.2-3. As the CVS and passive safety features cool the plant, the RCS temperature and pressure are reduced as shown in Figures 3.1.2-4 and 3.1.2-5. The RCS begins to repressurize as the cold injected water expands and begins to fill the pressurizer (pressurizer water volume is shown in Figure 3.1.2-6). The CVS pumps are automatically isolated on high pressurizer level at 1381 seconds, but the CMTs continue to recirculate until the driving head is sufficiently reduced at about 26,300 seconds. Once the cold CVS flow is terminated, the RCS temperature stops decreasing. The RCS mass and pressurizer level increase until the reactor vessel head vent valves are assumed to be manually opened at 1800 seconds.

At 1800 seconds, the pressurizer pressure is at the safety valves setpoint (2500 psia) and the fluid in the pressurizer is subcooled. As the RCS inventory is relieved through the head vent path, the pressurizer is drained and the pressurizer pressure is reduced quickly. At about 6230 seconds, the fluid in the pressurizer becomes saturated. The rate at which the primary system pressure is reduced is decreased, and the rate at which the pressurizer water volume is reduced is increased. The head vent flow rate, which is dependent on the primary system pressure, is shown in Figure 3.1.2-7. Once pressurizer level has been reduced to the low level control setpoint, the head vent valves are assumed to be manually closed. Eventually, the CMTs stop recirculating and a stable condition is reached. No discharge of primary water through the pressurizer safety valves is predicted.

The calculated sequence of events is shown in Table 3.1-2. Recovery from the accident is done in the same manner as the spurious "S" signal accident discussed in Section 3.1.1.

In addition to the conservative design basis analysis, an evaluation was performed using "Best Estimate" assumptions. The major differences from the design basis assumptions are as follows:

- 1979 ANS decay heat model + 0 sigma is modeled.
- Two PRHR heat exchangers are assumed available. Nominal heat transfer is modeled.
- Nominal CMT flow rates and boron concentrations are assumed.

On a "Best Estimate" basis, a single failure will most likely not result in the delivery of maximum flow from both CVS pumps at maximum boron concentration. Instead, a more reasonable estimation of the expected CVS delivery is about 100 gpm flow at approximately 185°F and RCS boron concentration. If this flowrate is initiated spuriously, the results of the "Best Estimate" evaluation show that the protection system will automatically isolate the CVS flow before an "S" signal is generated. If an "S" signal is not generated during the transient, the PRHR and CMTs will not be actuated, and CVS isolation terminates the accident. If a significant boration does occur, the protection system may still terminate the event without generating an "S" signal if the reactor is in the automatic control mode.

### 3.1.2.4 Conclusions

Results of the analysis show that CVS malfunction represents no hazard to the integrity of the RCS. If the reactor does not trip immediately, it will be initiated by either the low pressurizer pressure, the high pressurizer water level, the low steam pressure "S", or the low $T_{cold}$ "S" signal. This signal also trips the turbine preventing excess cooldown.

The plant operating conditions never approach the core limits during this transient. Pressurizer pressure always remains below 110 percent of the design limit, and the operator can open the head vent valves to prevent the discharge of primary water through the pressurizer safety valves. The results of the "Best Estimate" evaluation show that operator action is not required to prevent overfill for this event on a "Best Estimate" basis.

### 3.1.3 Inadvertent Operation of the Passive Residual Heat Rmoval (PRHR) System

#### 3.1.3.1 Identification of Causes and Accident Description

The potential for the inadvertent operation of the PRHR system leading to a departure from nucleate boiling ratio (DNBR) less than the safety analysis limit was addressed in AP600 SSAR Subsection 15.1.6. In the SSAR, a short term transient analysis was performed with conservative assumptions made to minimize the departure from nucleate boiling ratio. The design changes do not affect the results of this SSAR transient with respect to minimum DNBR.

The long term effects of this transient are analyzed here. This accident can result in the generation of an "S" signal, which causes CMT and CVS actuation, after which the event proceeds similarly to the spurious "S" signal and spurious CVS transients. Assumptions are made in this analysis to maximize the increase in reactor coolant inventory.

The inadvertent actuation of the passive residual heat removal system can be caused by operator error or a false actuating signal. Actuation of the passive residual heat removal system involves opening the isolation valves, which establishes a flow path from one reactor coolant system hot leg, through the passive residual heat removal system heat exchangers, and back into the associated steam generator cold leg plenum.

The passive residual heat removal system heat exchangers are located above the core to promote natural circulation flow when the reactor coolant pumps are not operating. With the reactor coolant pumps in operation, flow through the passive residual heat removal system is enhanced. The heat sink for the passive residual heat system is provided by the in-containment residual water storage tank, in which the passive residual heat removal system heat exchangers are submerged. Since the passive residual heat removal system is connected to only one reactor coolant system loop, the cooldown resulting from its actuation is asymmetric with respect to the core.

The following reactor protection system functions provide protection (reactor trip, "S" signal) in the event of an inadvertent passive residual heat removal system actuation:

- The overpower reactor trips (neutron flux and $\Delta T$)
- Two out of four low pressurizer pressure signals
- Two out of four low $T_{cold}$ signals in any one loop
- Two out of four low pressurizer level signals.
- Two out of four low steamline pressure signals in any one loop

### 3.1.3.2 Method of Analysis

The inadvertent operation of the PRHR system event is analyzed by employing a modified version of the computer program LOFTRAN discussed in Section 3.1.1.2.

The effects of this accident with respect to minimum DNBR are addressed in AP600 SSAR Subsection 15.1.6 . The long term effects are addressed here. The time until an "S" signal is reached was conservatively minimized in order to initiate CMT injection earlier. This has the effect of maximizing the CMT injection flow and minimizing the margin to pressurizer overfill prior to the time of assumed operator action. For the purposes of this analysis, operator action was assumed at 30 minutes.

CVS, CMT and PRHR system performance are conservatively simulated (CVS and CMT flow rates to the RCS have been maximized, and minimum heat transfer from only one PRHR heat exchanger is modeled).

The major assumptions are as follows:

- Initial Operating Conditions

  The initial reactor power, RCS pressure and average temperature are at their nominal values. The initial pressurizer water level is assumed to be 10% above nominal.

- Moderator and Doppler coefficients of reactivity

  A least negative moderator temperature coefficient is used. A low (absolute value) Doppler power coefficient is assumed. Reactivity parameters are not important for this analysis, since the core is shutdown by the boron injection from the CMTs and CVS.

- Control Systems

  The CVS level control system is assumed not to function. Instead, the CVS charging pumps are assumed to deliver maximum flow upon receipt of an "S" signal. The other control systems are not assumed to function since their operation results in a better behaved transient.

- Reactor Control

  Rod control is not modeled.

- Pressurizer Heaters

  Pressurizer heaters are assumed to be inoperable throughout the transient. In the AP600 design, the pressurizer heaters are blocked on receipt of an "S" signal. Since an "S" signal is generated within one minute of the transient initiation, the amount of heat input from the heaters is negligible.

- Boron Injection

  The inadvertent actuation of the PRHR system results in the generation of an "S" signal. This signal is also assumed to actuate two CVS pumps at full flow. The CMTs are assumed to be filled with 3500 ppm borated water and the water from the CVS contains 4375 ppm boron.

- Reactor Trip

  Reactor trip is initiated by either a low pressurizer pressure, high pressurizer water level, low steam line pressure "S", or low $T_{cold}$ "S" signal reactor trip.

### 3.1.3.3 Results

Figures 3.1.3-1 through 3.1.3-7 show the transient response to the inadvertent operation of the PRHR system during power operation. The heat removal from the PRHR causes the RCS average temperature and pressure, and the pressurizer water level to drop. When the low $T_{cold}$ "S" signal set point is reached at about 17 seconds, the CVS pumps are assumed to begin delivering flow immediately. The reactor trips and the control rods start moving into the core after a two second delay. The nuclear power is shown in Figure 3.1.3-1. A few seconds after the trip, the CMTs discharge valves open, and the RCPs trip. The CVS and CMT injection flows are shown in Figure 3.1.3-2. The PRHR heat flux (shown in Figure 3.1.3-3) is initially about 7.5% of nominal core heat flux with the RCPs running. Once the reactor and RCPs are tripped upon receipt of an "S" signal, the flow through the PRHR system is reduced, and the PRHR heat flux just matches decay heat. As the CVS and passive safety features cool the plant, the RCS temperature and pressure are reduced as shown in Figures 3.1.3-4 and 3.1.3-5. The RCS begins to repressurize as the cold injected water expands and begins to fill the pressurizer (pressurizer water volume is shown in Figure 3.1.3-6). The CVS pumps are isolated on high pressurizer level at 1381 seconds, but the CMTs continue to recirculate until the driving head is sufficiently reduced at about 25,700 seconds. Once the cold CVS flow is terminated, the RCS temperature stops decreasing. The RCS mass and pressurizer level increase until the reactor vessel head vent valves are assumed to be manually opened at 1800 seconds.

At 1800 seconds, the pressurizer pressure is at the safety valves setpoint (2500 psia) and the fluid in the pressurizer is subcooled. As the RCS inventory is relieved through the head vent path, the pressurizer is drained and the pressurizer pressure is reduced quickly. At about 4700 seconds, the fluid in the pressurizer becomes saturated. The rate at which the primary system pressure is reduced is decreased, and the rate at which the pressurizer water volume is reduced is increased. The head vent flow rate, which is dependent on the primary system pressure, is shown in Figure 3.1.3-7. Once pressurizer level has been reduced to the low level control setpoint, the head vent valves are manually closed. Eventually, the CMTs stop recirculating and a stable condition is reached. No discharge of primary water through the pressurizer safety valves is predicted.

The calculated sequence of events is shown in Table 3.1-3. Recovery from the accident is done in the same manner as the spurious "S" signal accident discussed in Section 3.1.1.

In addition to the conservative design basis analysis, an evaluation was performed using "Best Estimate" assumptions. The major differences from the design basis assumptions are as follows:

- 1979 ANS decay heat model + 0 sigma is modeled.
- Two PRHR heat exchangers are assumed available. Nominal heat transfer is modeled.
- Nominal CMT flow rates and boron concentrations are assumed.
- After receipt of an "S" signal, flow is not initiated by the CVS if the pressurizer level remains above the control system setpoint of 10% of span.

The results of the "Best Estimate" evaluation show that the CVS pumps would not be actuated for at least 10 hours for this event, because the pressurizer level would not decrease below 10% of span. Furthermore, the two PRHR heat exchangers have sufficient heat removal capability to prevent the expansion of the cold water injected from the CMTs from pressurizing the system to the safety valves setpoint or filling the pressurizer. Thus, operator action is not required to prevent overfill for this event on a "Best Estimate" basis.

### 3.1.3.4 Conclusions

Results of the design basis analysis show that inadvertent operation of the PRHR system represents no hazard to the integrity of the RCS.

If the reactor does not trip immediately, it will be initiated by either the overpower trips (neutron flux and $\Delta T$), the low pressurizer pressure signal, the low pressurizer water level signal, or an "S" signal from the low steam pressure or low $T_{cold}$. This signal also trips the turbine preventing excess cooldown.

The plant operating conditions never approach the core limits during the transient. Pressurizer pressure always remains below 110 percent of the design limit, and the operator can open the head vent valves to prevent the discharge of primary water through the pressurizer safety valves.

Table 3.1-1

Time Sequence of Events
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

| Event | Time (s) |
|---|---|
| Spurious "S" signal | 10. |
| Two CVS pumps actuate | 10. |
| Rod motion begins | 12. |
| CMTs actuate | 17. |
| RCPs trip | 25. |
| PRHR system actuates | 30. |
| High pressurizer level setpoint reached | 1,369. |
| CVS pumps isolated | 1,381. |
| Operator manually opens reactor vessel head vent valves | 1,800. |
| Operator manually closes reactor vessel head vent valves | 10,293. |
| CMTs stop recirculating | ~25,600. |

**Table 3.1-2**

Time Sequence of Events
CVS Malfunction That Increases RCS Inventory

| Event | Time (s) |
|---|---|
| CVS started | 10. |
| Low $T_{cold}$ "S" signal | 49. |
| Rod motion begins | 51. |
| CMTs actuate | 56. |
| RCPs trip | 64. |
| PRHR system actuates | 69. |
| High pressurizer level setpoint reached | 1,610. |
| CVS pumps isolated | 1,622. |
| Operator manually opens reactor vessel head vent valves | 1,800. |
| Operator manually closes reactor vessel head vent valves | 11,473. |
| CMTs stop recirculating | ~26,300. |

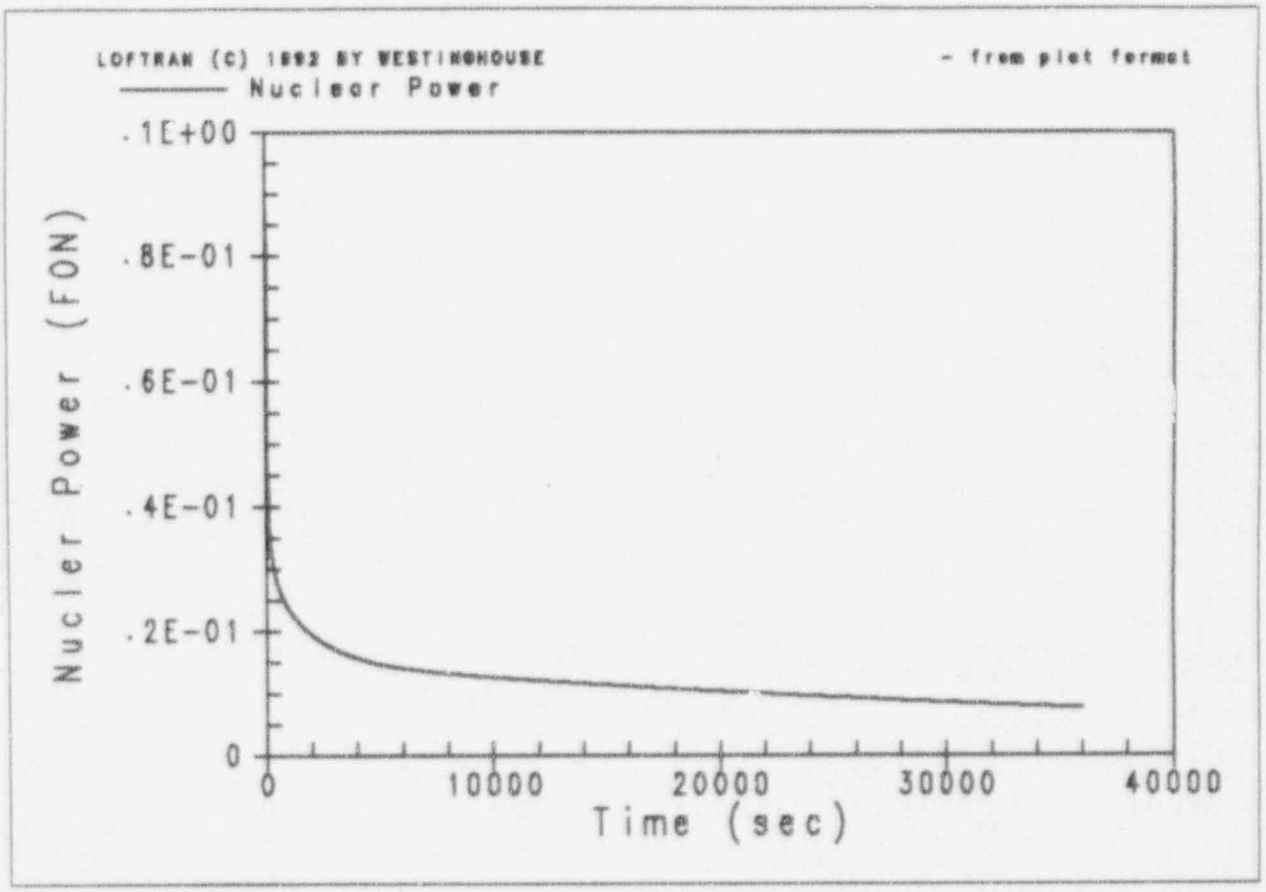
Table 3.1-3

Time Sequence of Events
Inadvertent Operation of the PRHR System

| Event | Time (s) |
|---|---|
| Inadvertent PRHR system actuation | 10. |
| Low $T_{cold}$ "S" signal | 17. |
| Two CVS pumps actuate | 17. |
| Rod motion begins | 19. |
| CMTs actuate | 24. |
| RCPs trip | 32. |
| High pressurizer level setpoint reached | 1,385. |
| CVS pumps isolated | 1,397. |
| Operator manually opens reactor vessel head vent valves | 1,800. |
| Operator manually closes reactor vessel head vent valves | 10,375. |
| CMTs stop recirculating | ~25,600. |

Figure 3.1.1-1
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

Nuclear Power






Westinghouse

Figure 3.1.1-2
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

CVS and CMT Injection

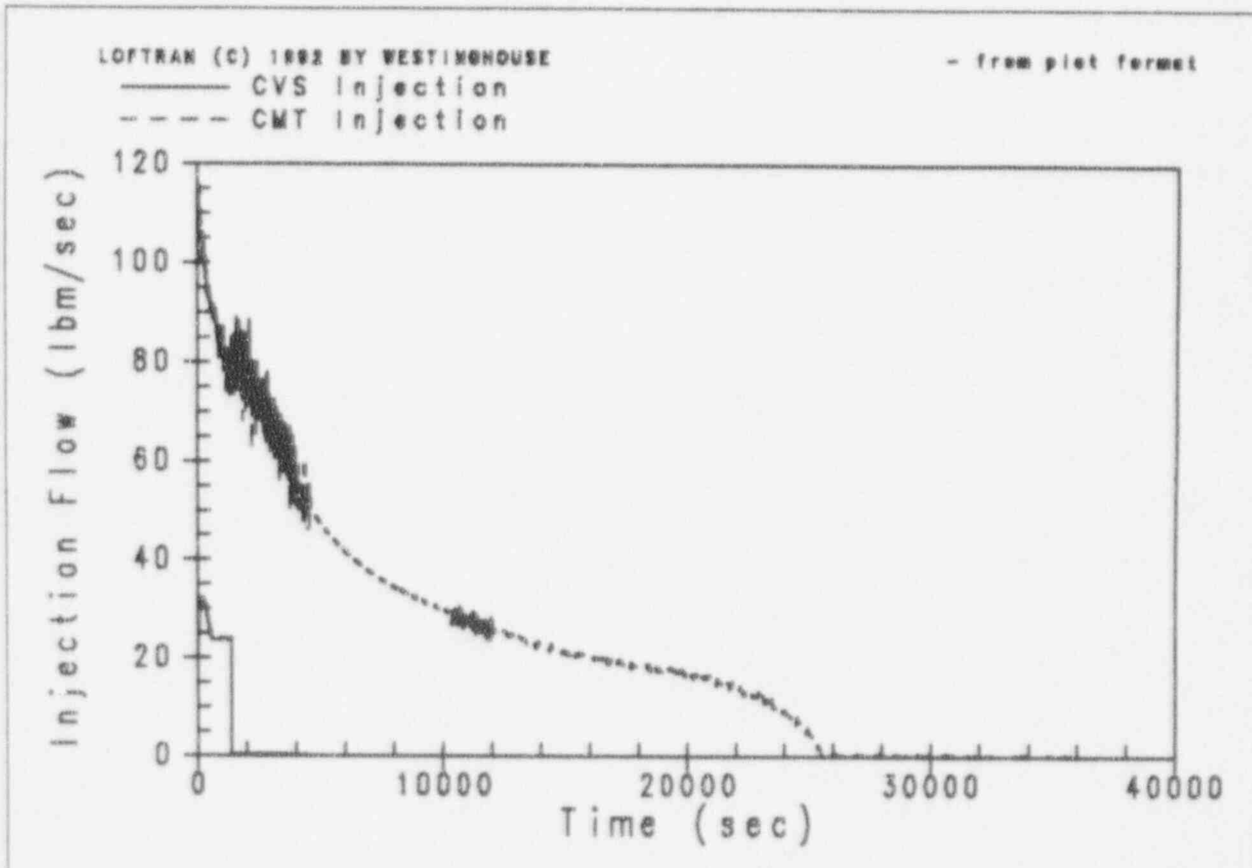
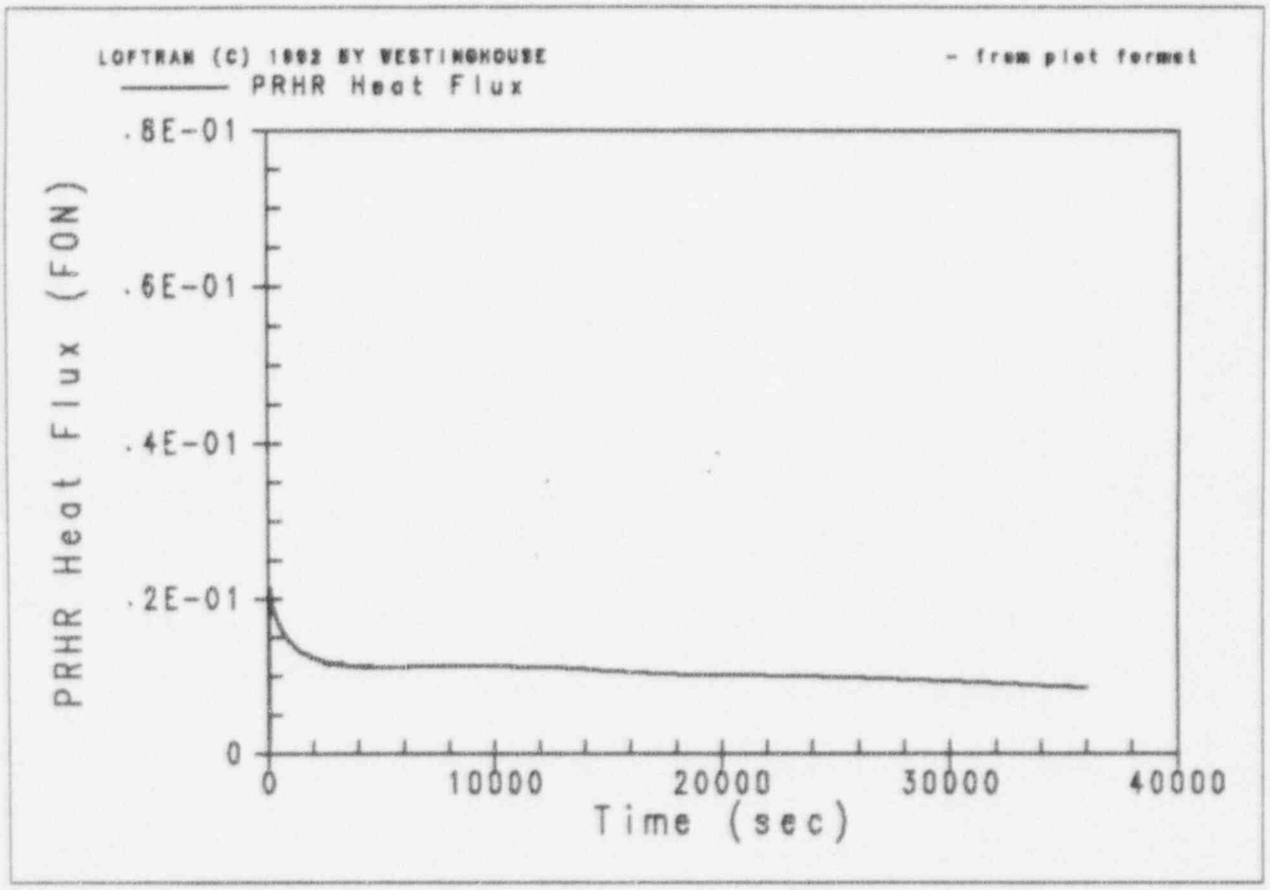


Figure 3.1.1-3
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

PRHR Heat Flux






Westinghouse

Figure 3.1.1-4
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

RCS Indicated Tavg

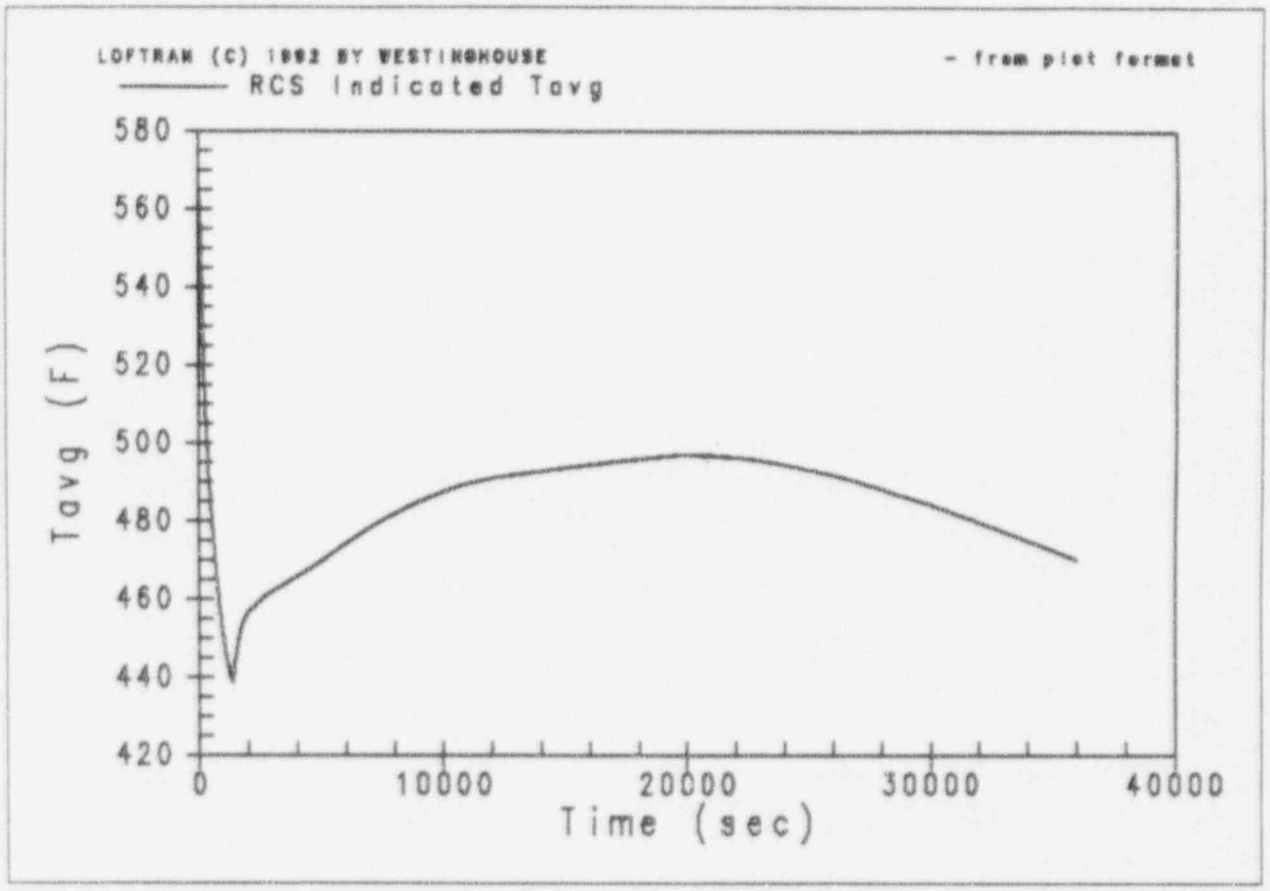
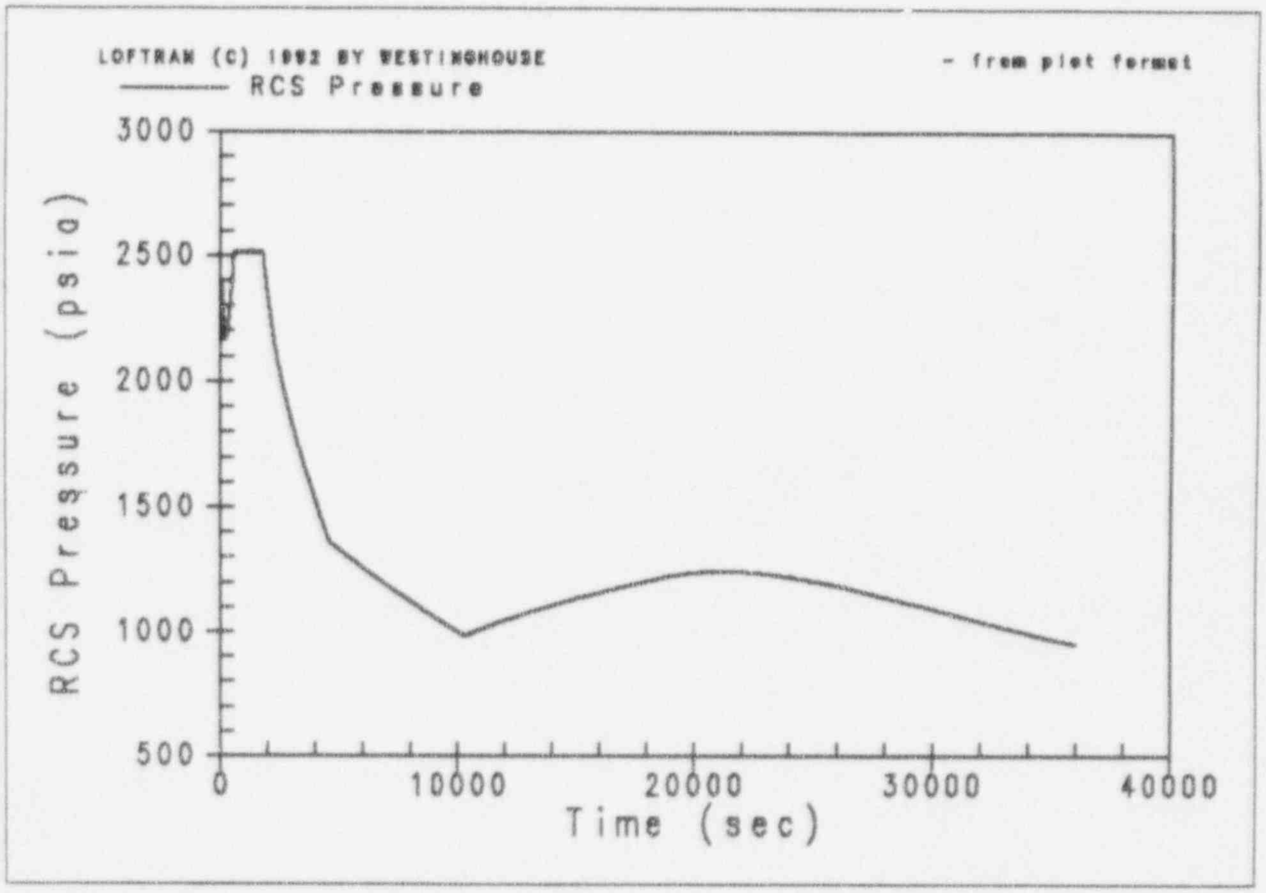


Figure 3.1.1-5
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

RCS Pressure






Westinghouse

Figure 3.1.1-6
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

Pressurizer Water Volume

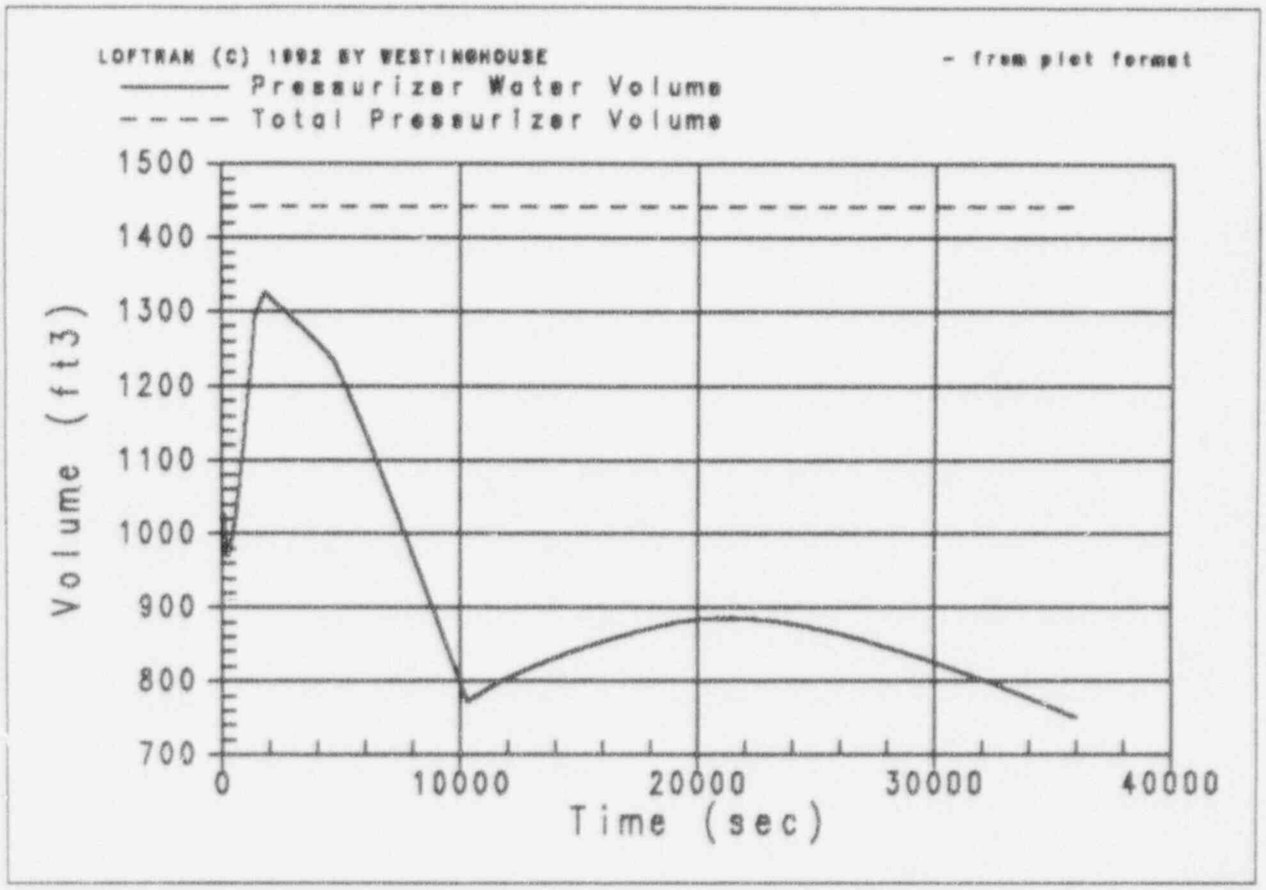


Figure 3.1.1-7
Inadvertent Operation of the ECCS (CMT and CVS Actuation)
Due to a Spurious "S" Signal

Head Vent Flow Rate

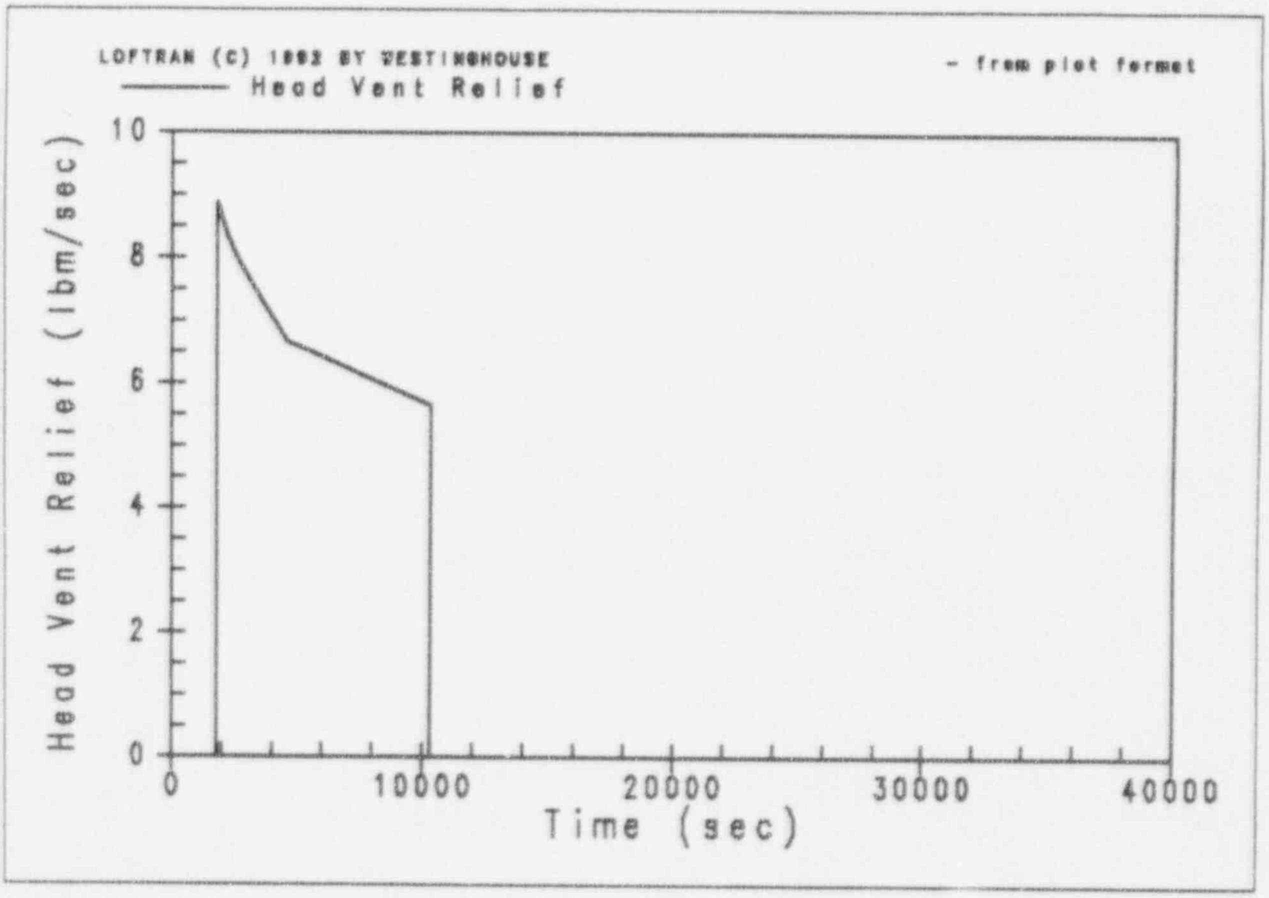


Figure 3.1.2-1
CVS Malfunction That Increases RCS Inventory

Nuclear Power

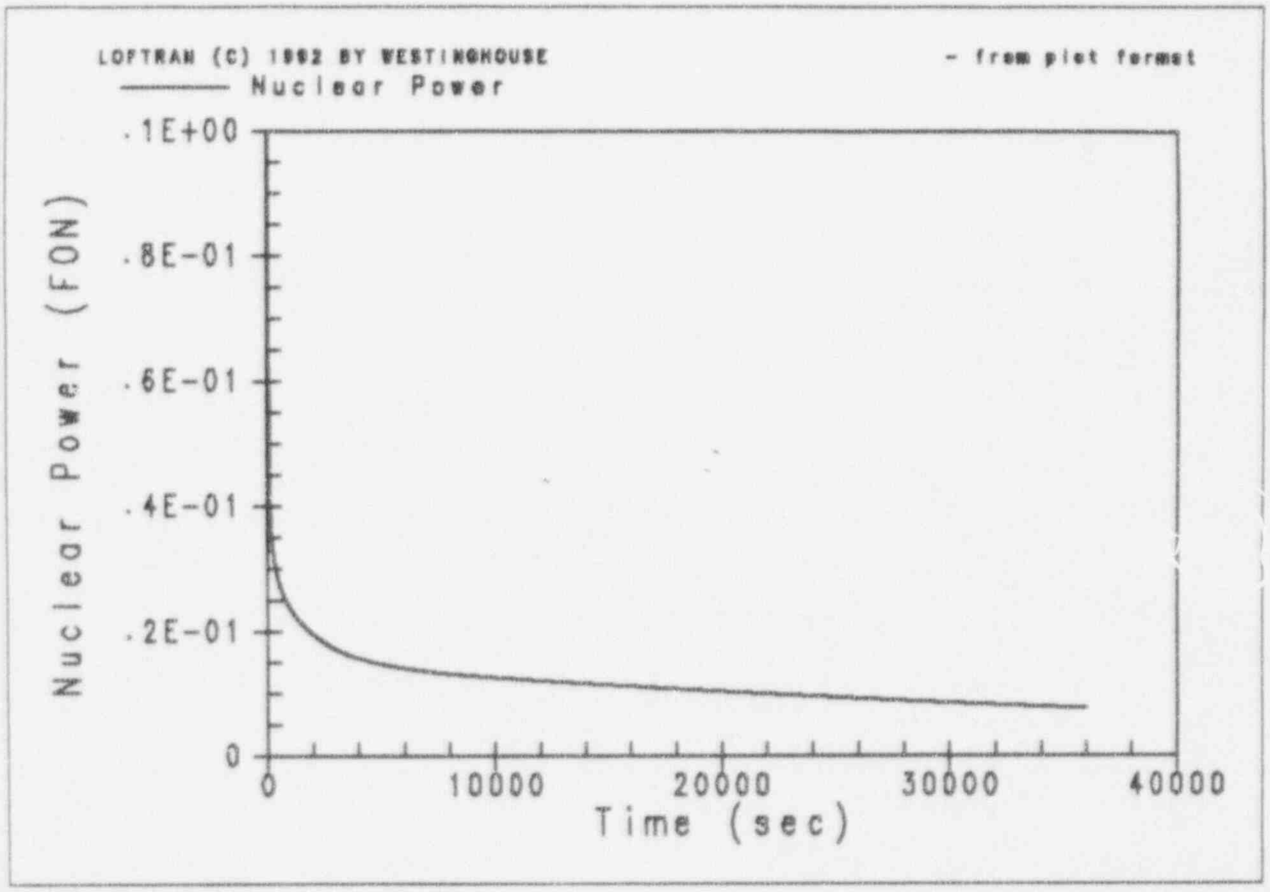


Figure 3.1.2-2
CVS Malfunction That Increases RCS Inventory

CVS and CMT Injection

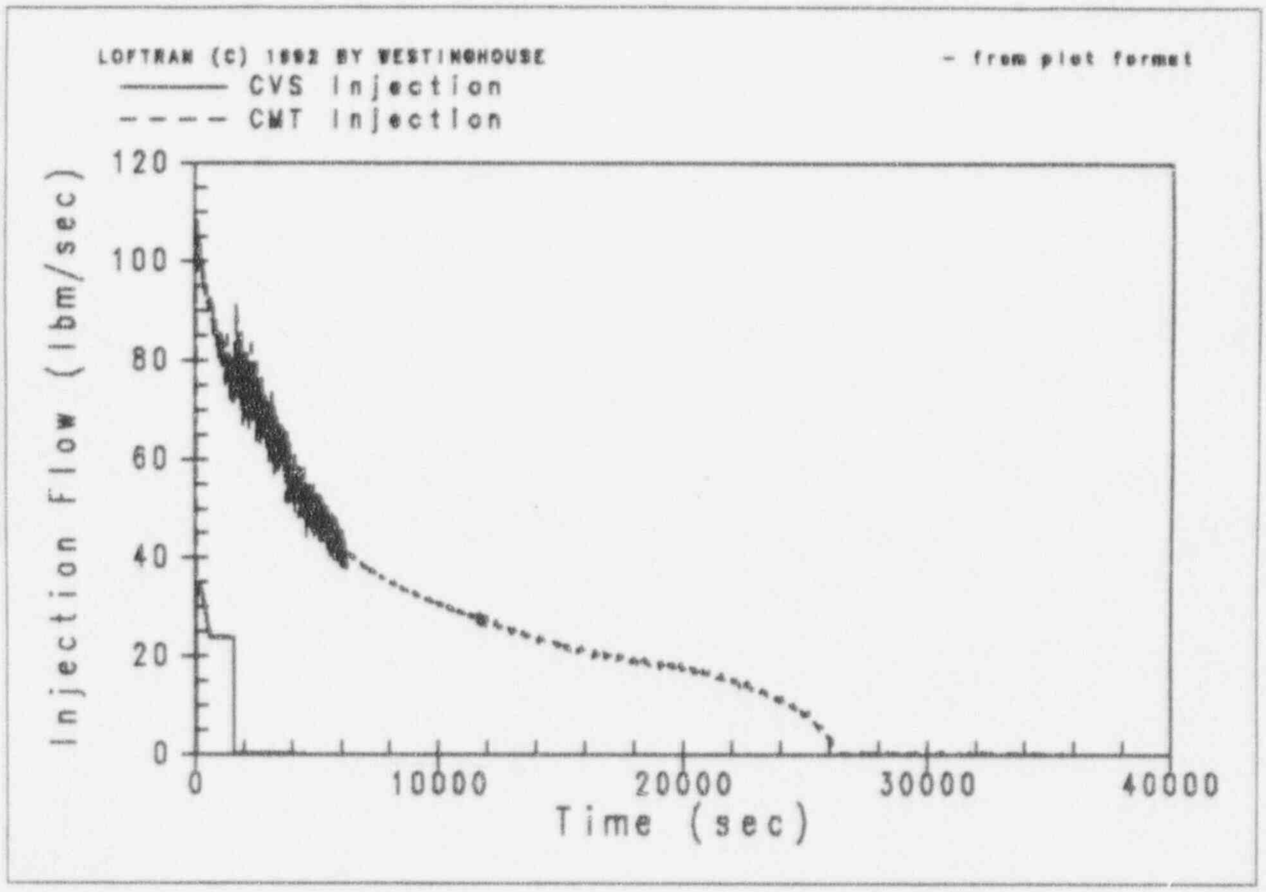


Figure 3.1.2-3
CVS Malfunction That Increases RCS Inventory

PRHR Heat Flux

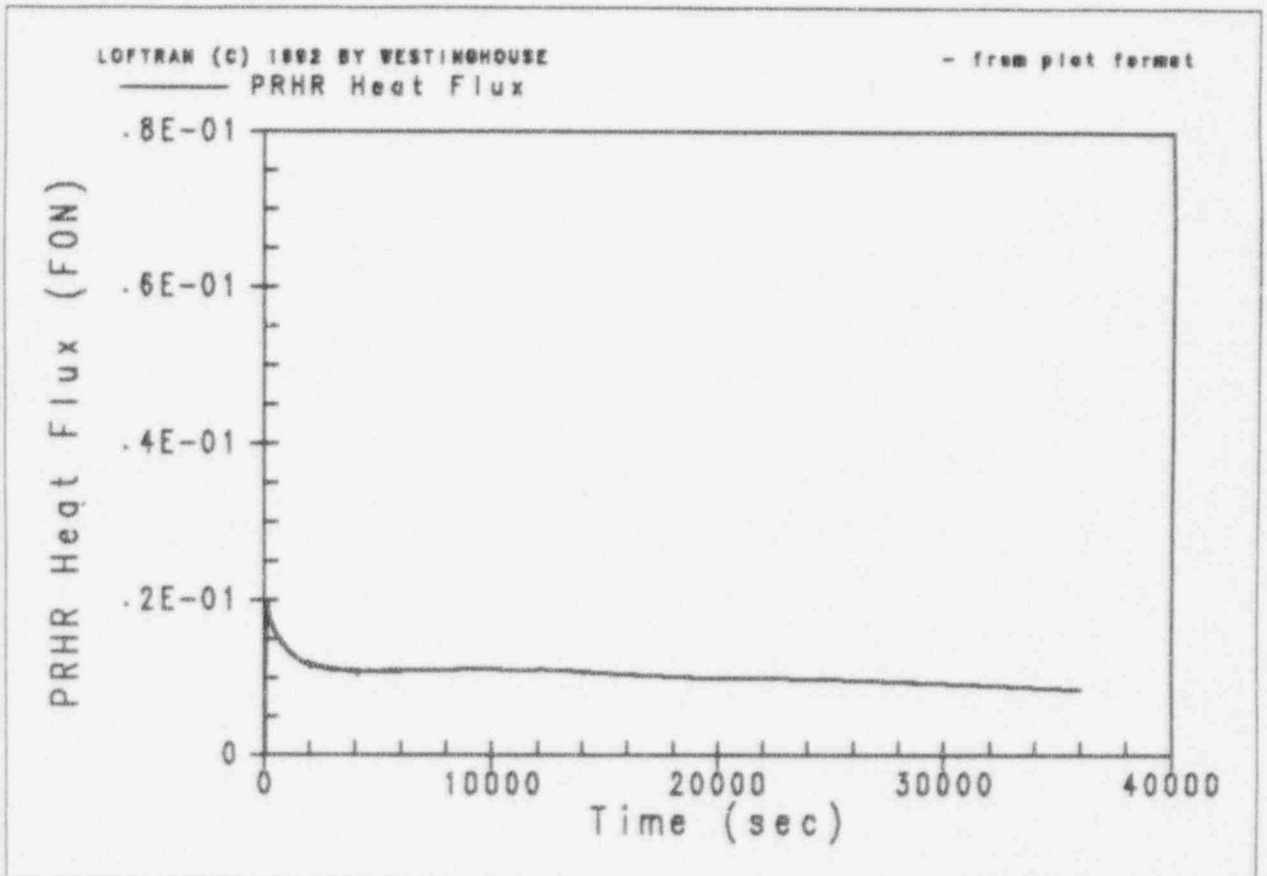


Figure 3.1.2-4
CVS Malfunction That Increases RCS Inventory

RCS Indicated Tavg

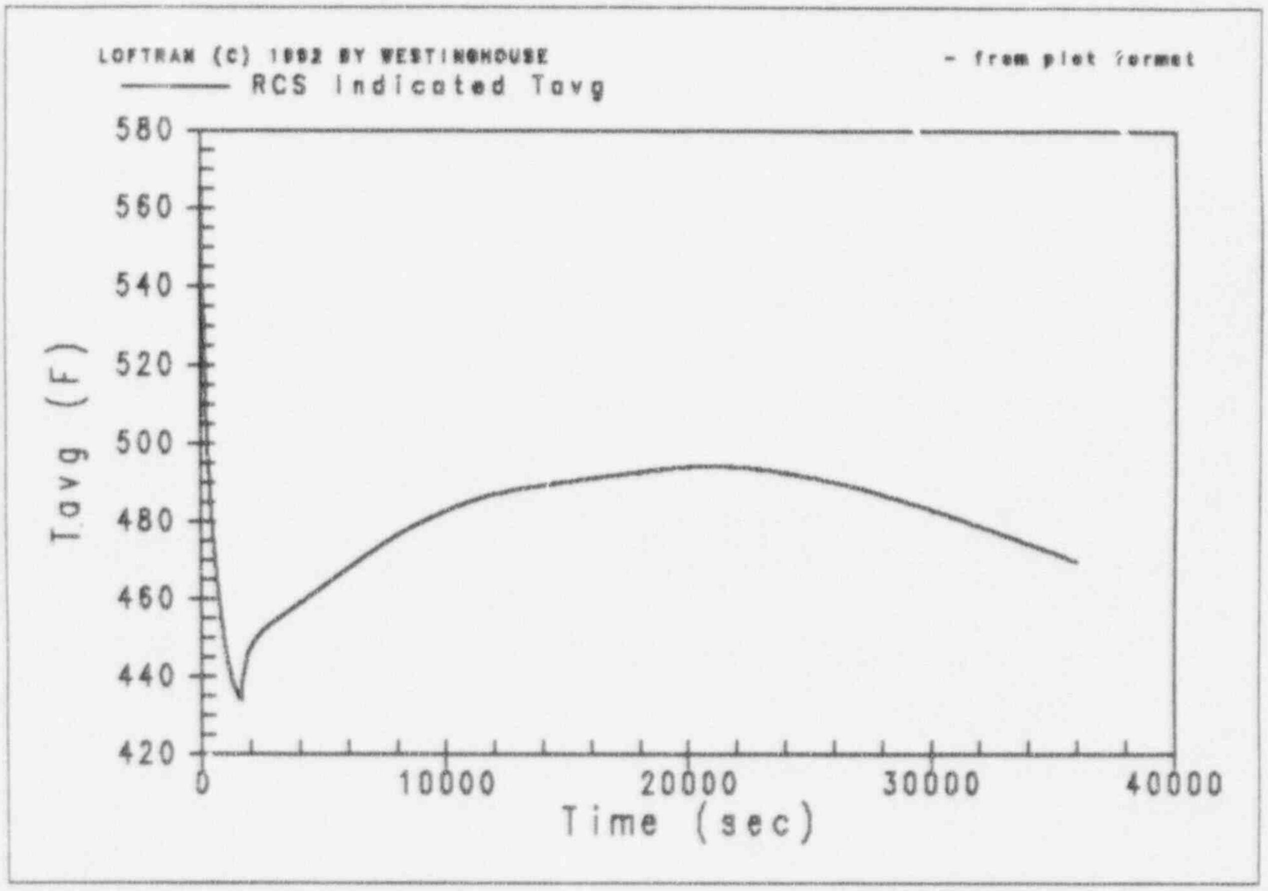


Figure 3.1.2-5
CVS Malfunction That Increases RCS Inventory

RCS Pressure

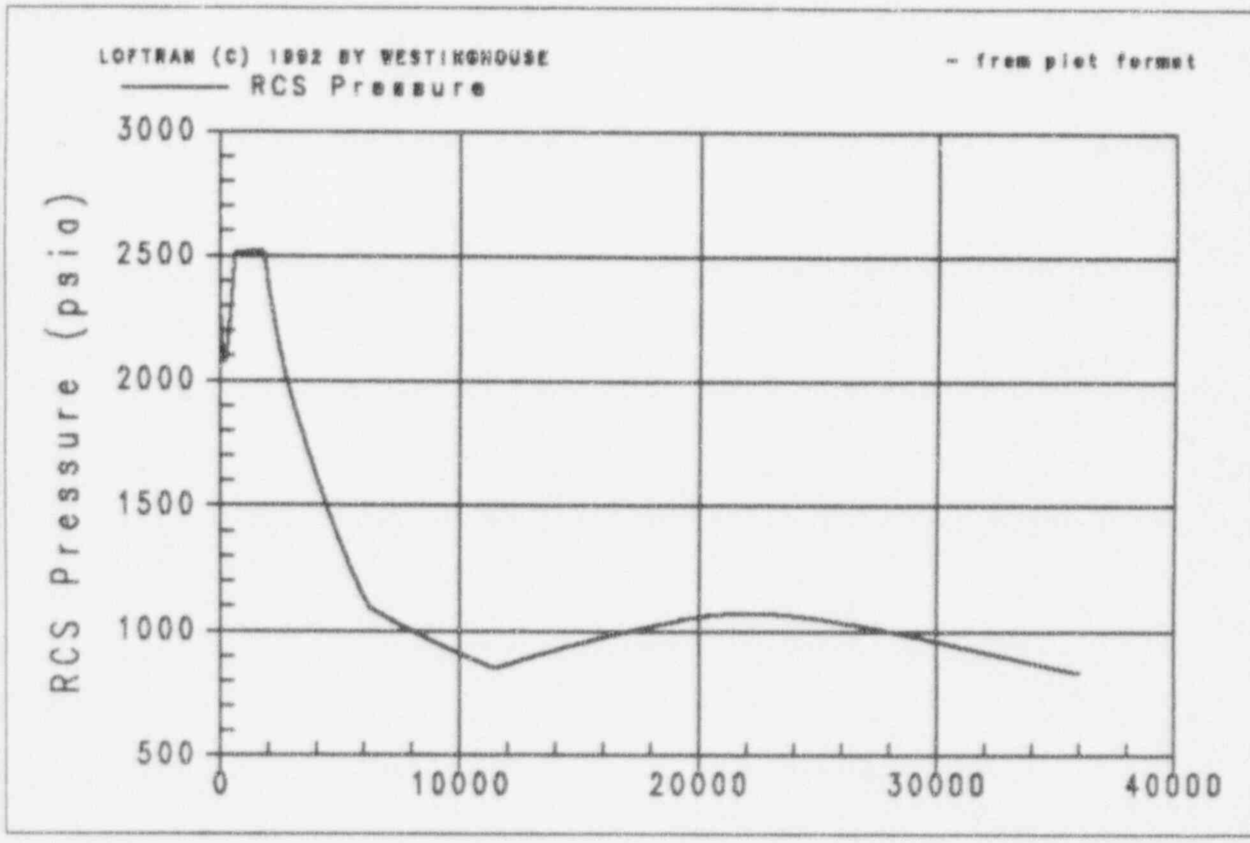
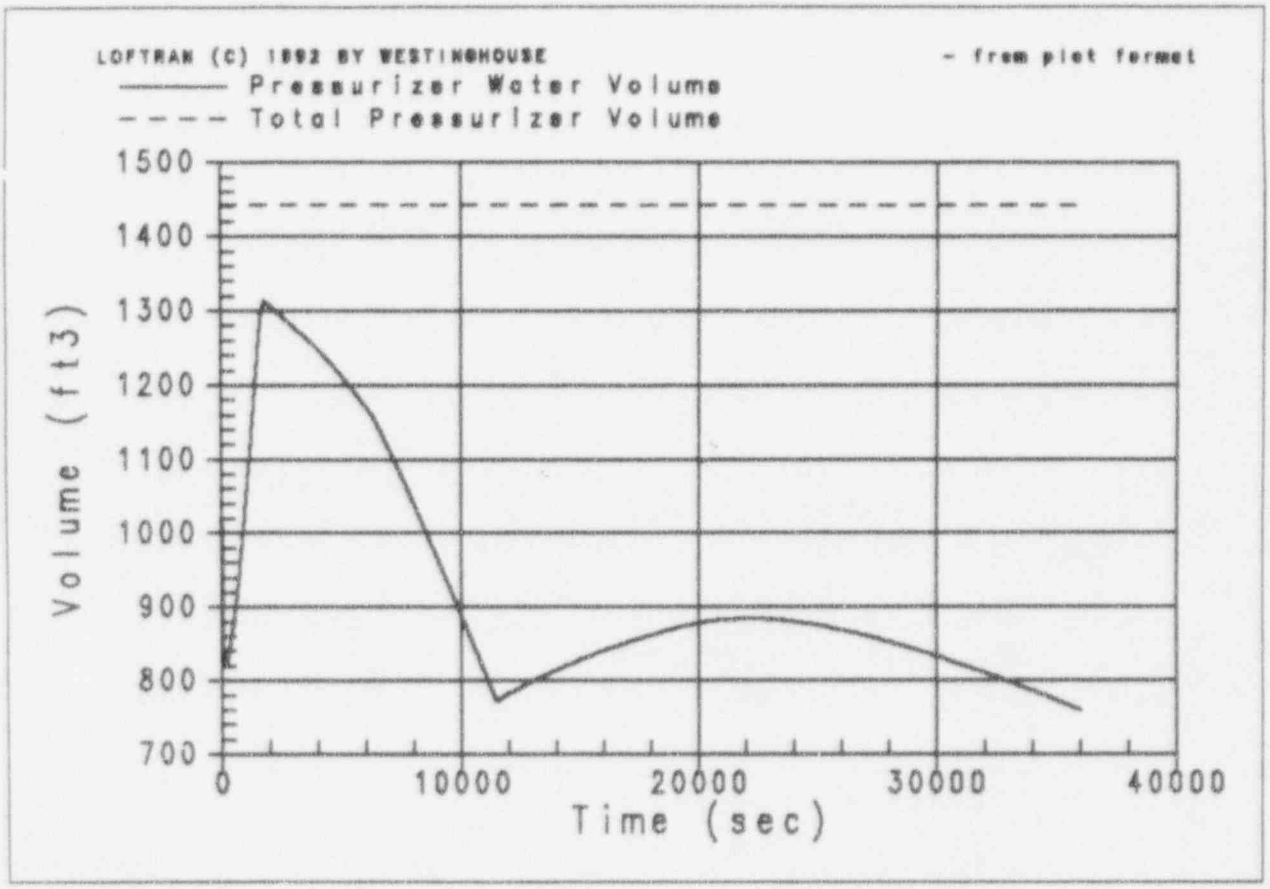


Figure 3.1.2-6
CVS Malfunction That Increases RCS Inventory

Pressurizer Water Volume






Westinghouse

Figure 3.1.2-7
CVS Malfunction That Increases RCS Inventory

Head Vent Flow Rate

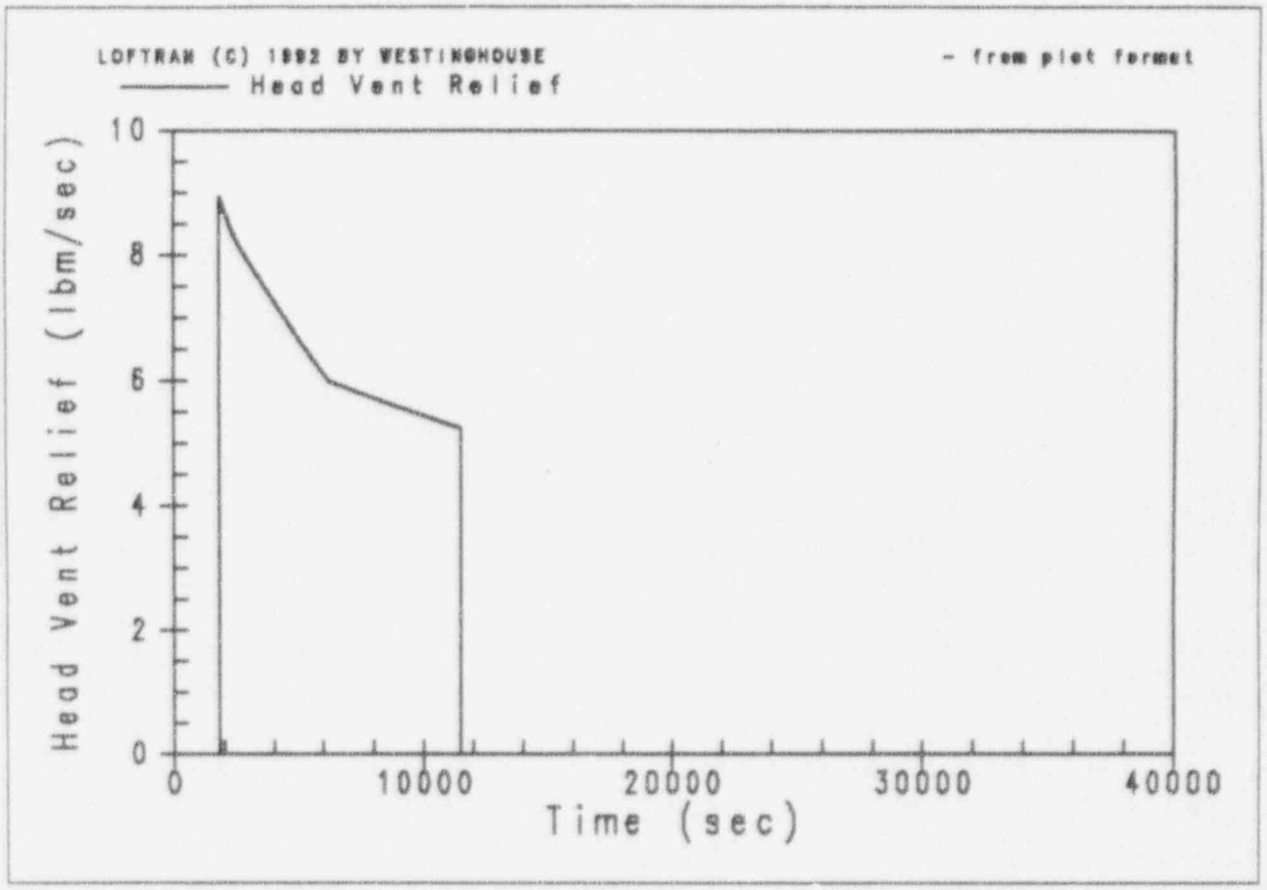


Figure 3.1.3-1
Inadvertent Operation of the PRHR System

Nuclear Power

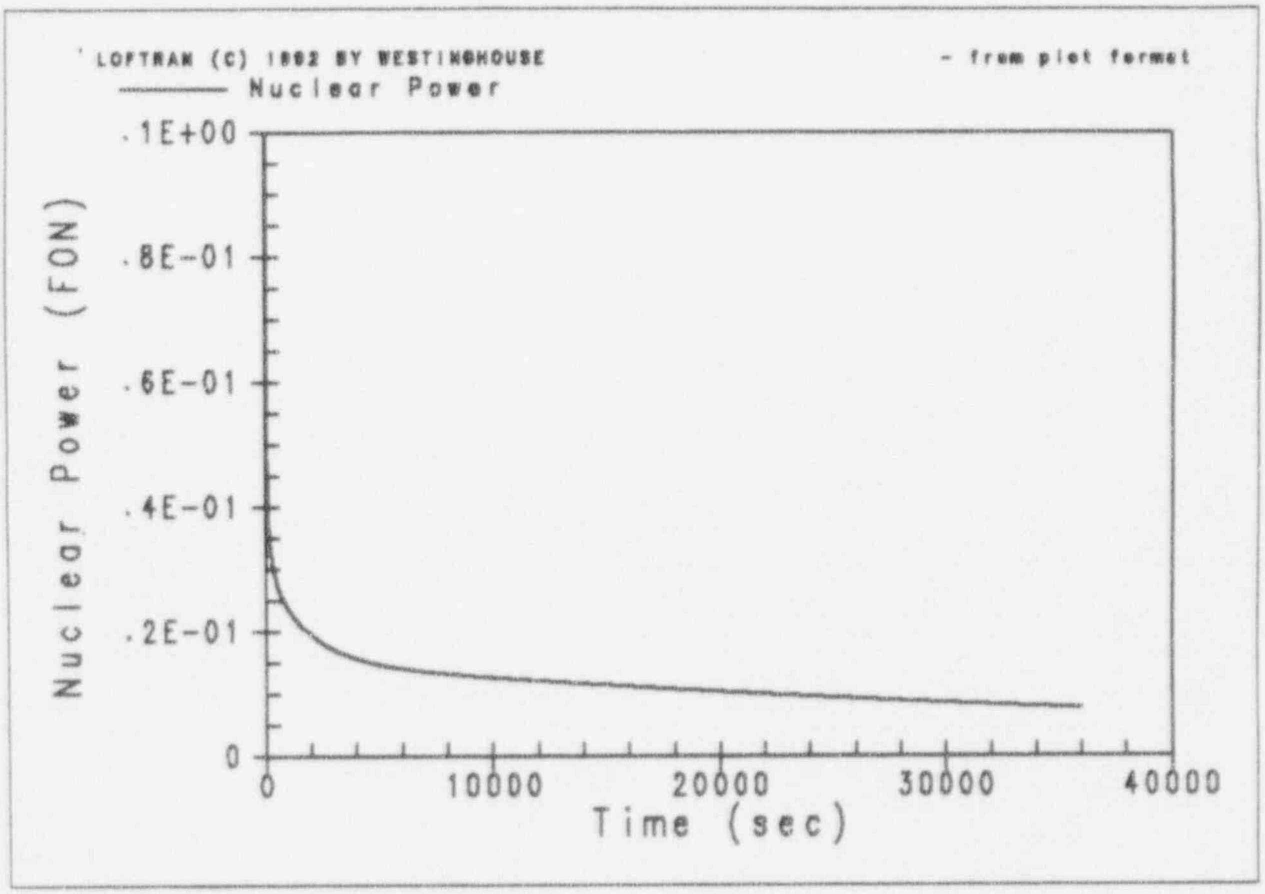


Figure 3.1.3-2
Inadvertent Operation of the PRHR System

CVS and CMT Injection

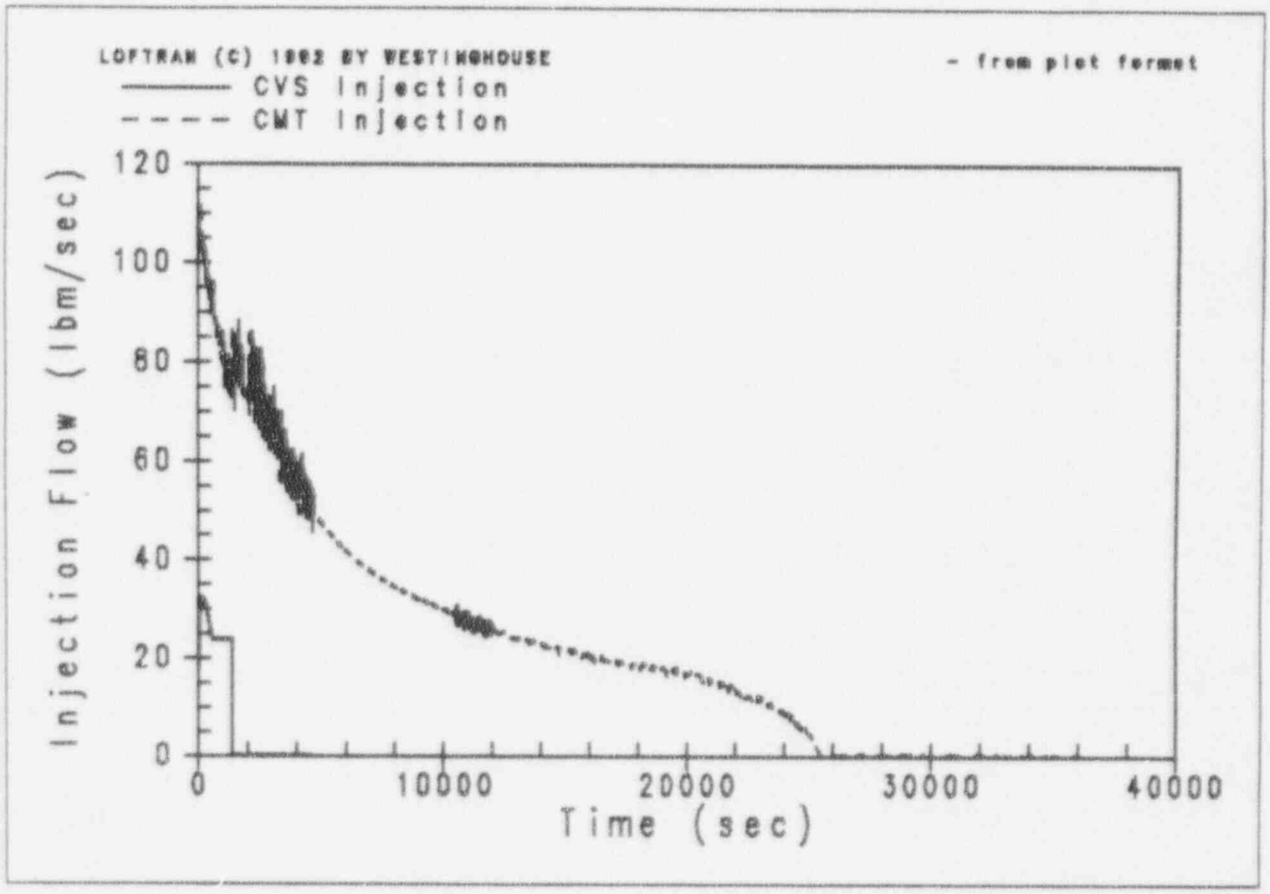
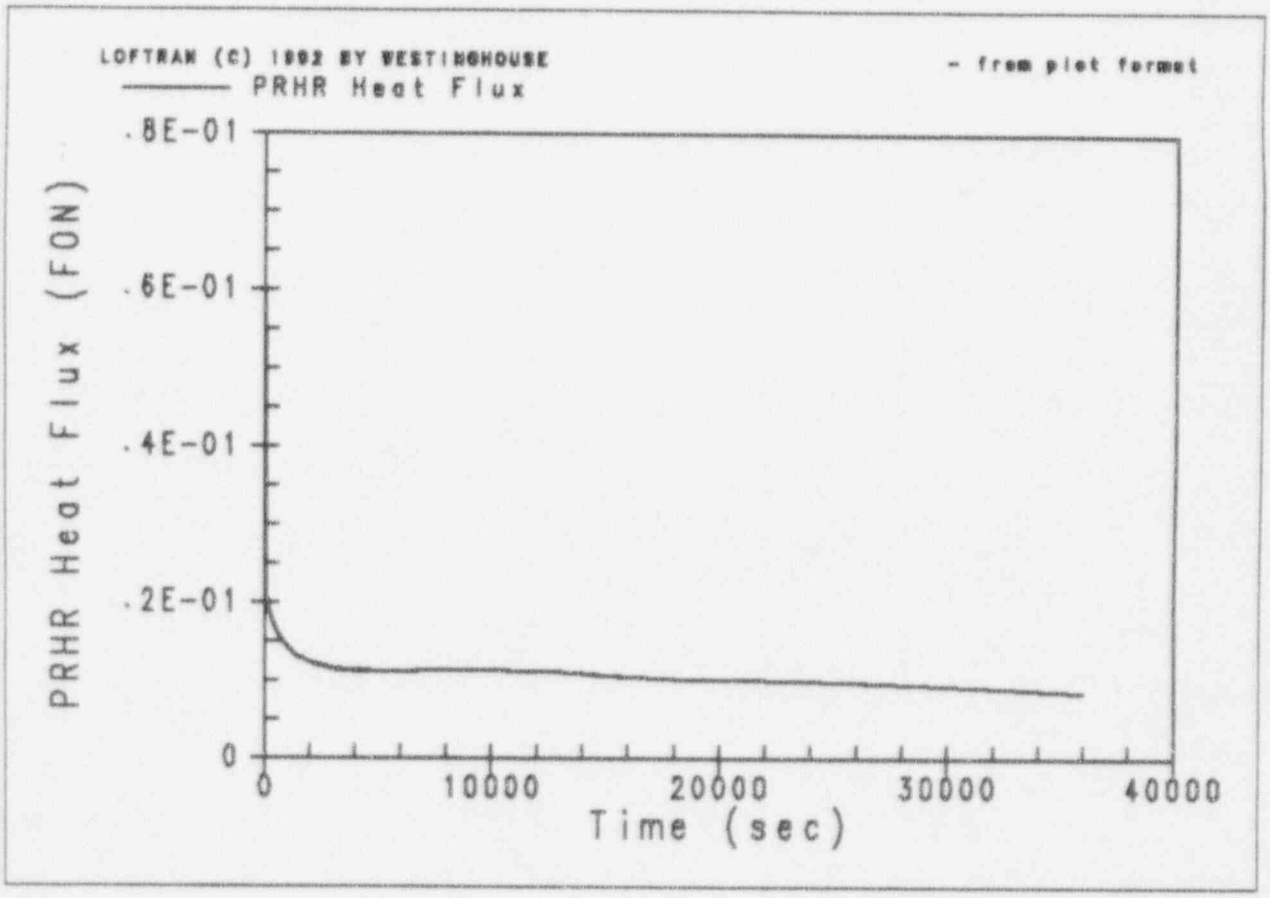


Figure 3.1.3-3
Inadvertent Operation of the PRHR System

PRHR Heat Flux






Westinghouse

Figure 3.1.3-4
Inadvertent Operation of the PRHR System

RCS Indicated Tavg

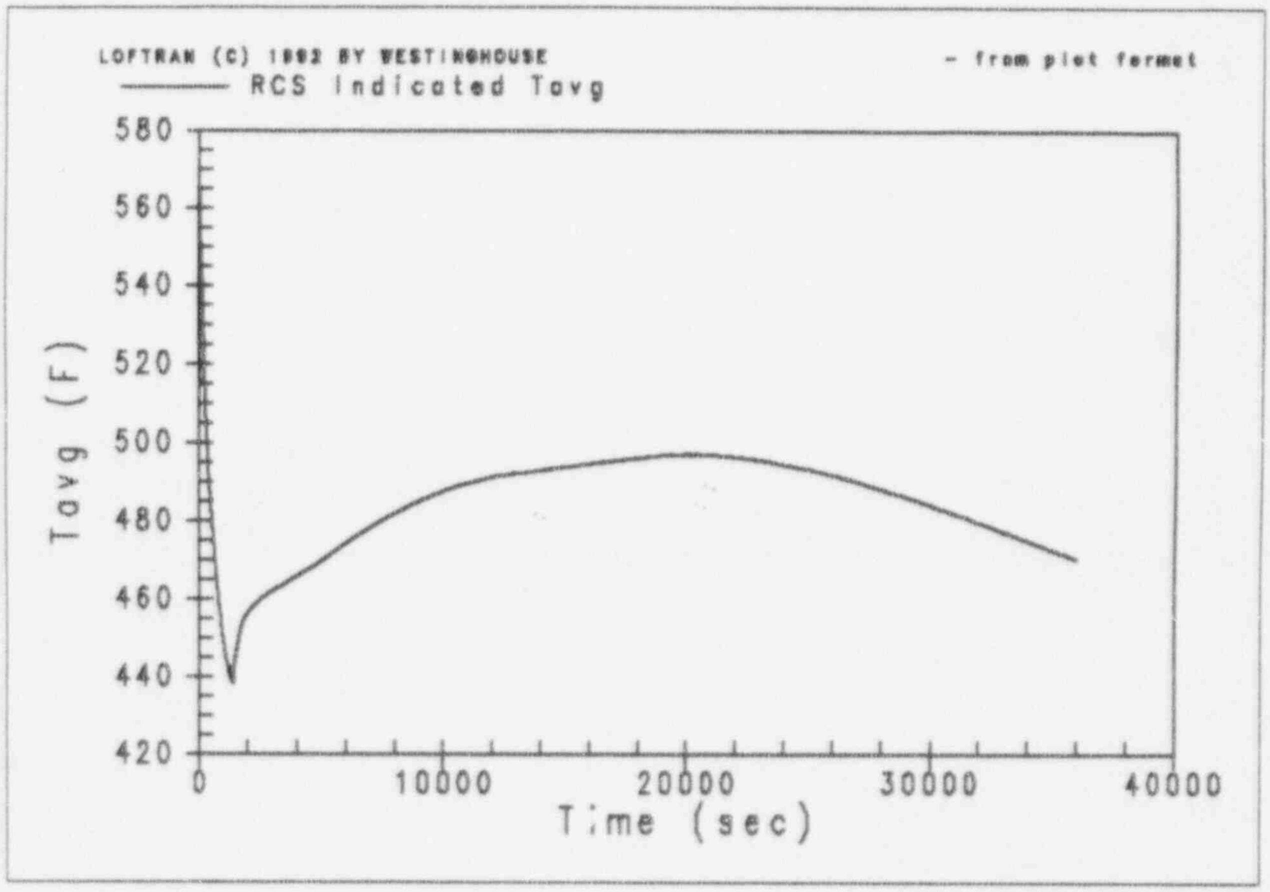


Figure 3.1.3-5
Inadvertent Operation of the PRHR System

RCS Pressure

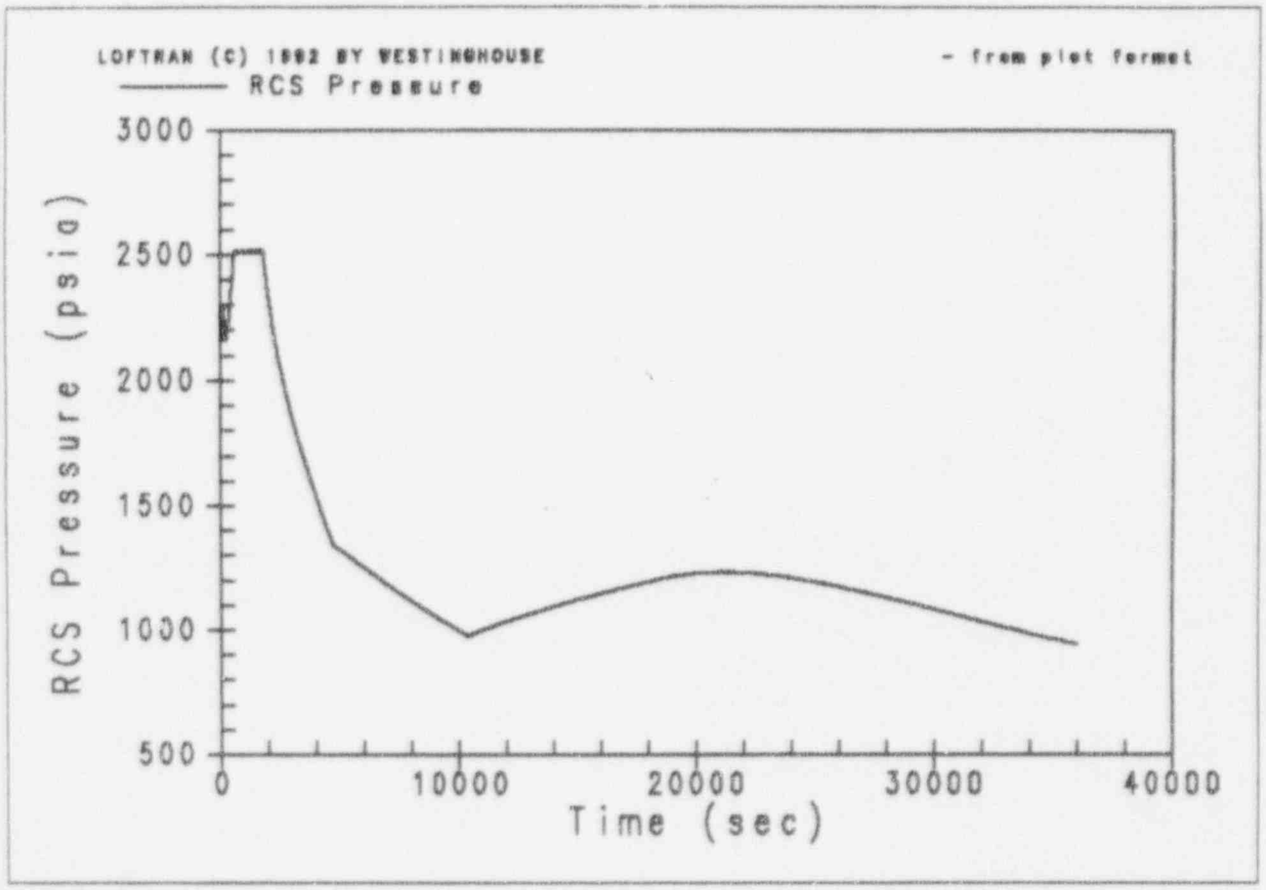


Figure 3.1.3-6
Inadvertent Operation of the PRHR System

Pressurizer Water Volume

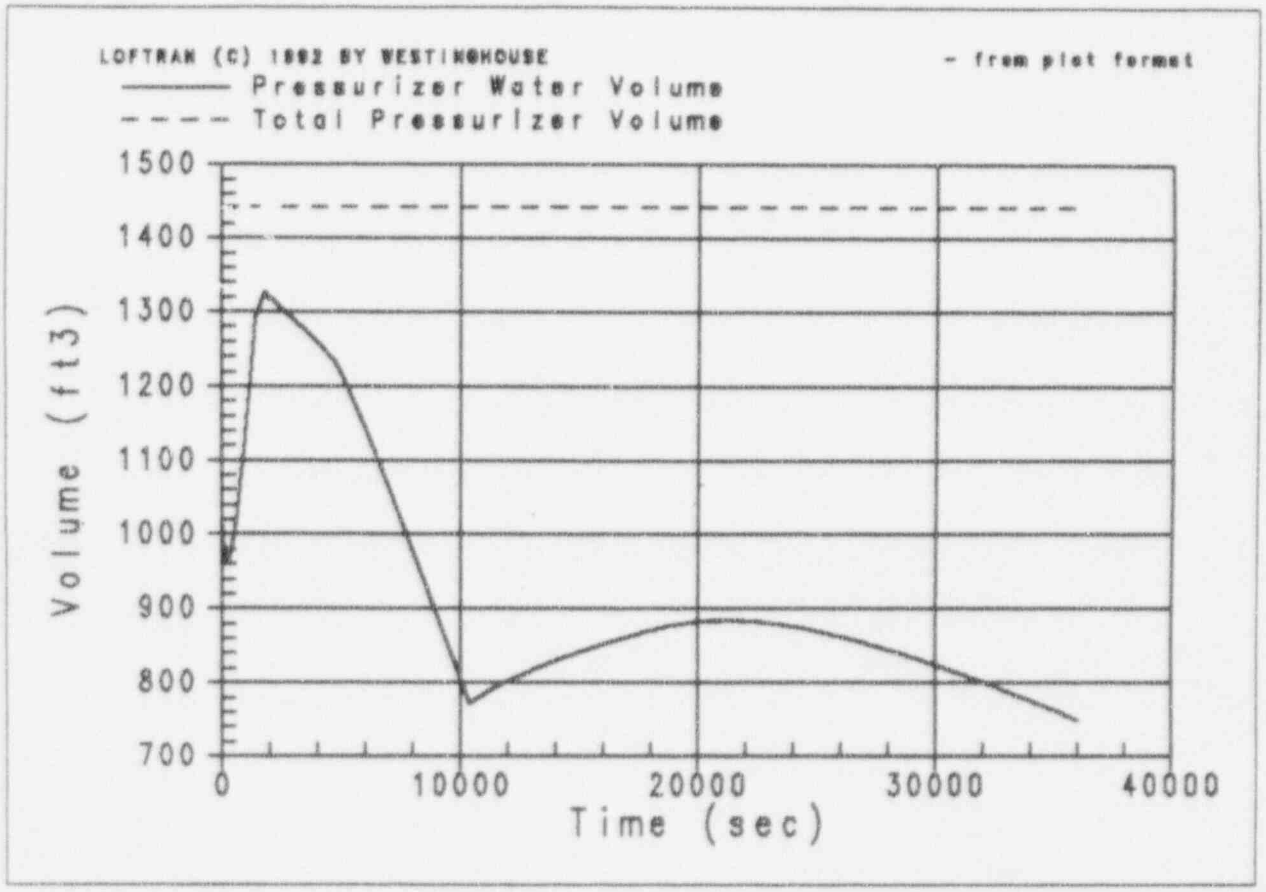
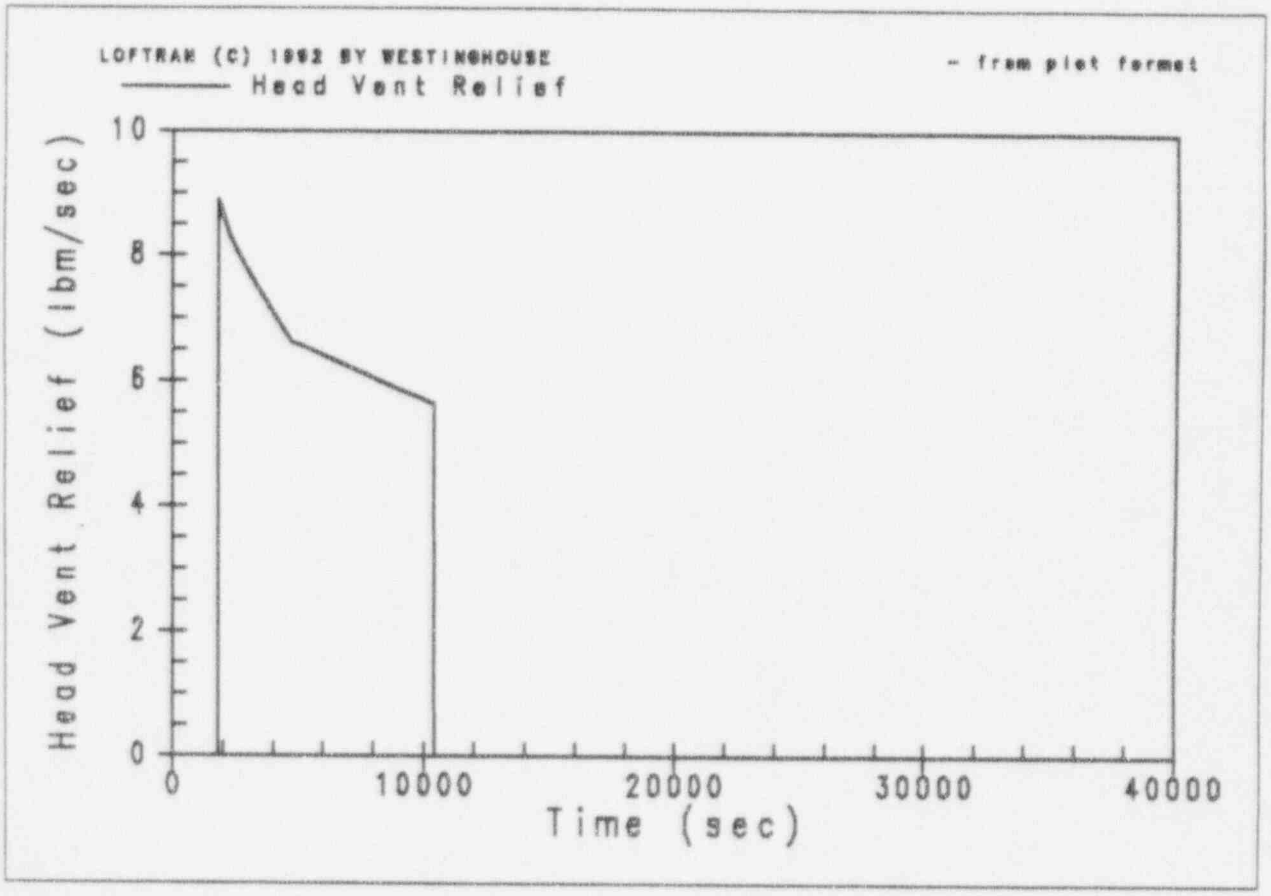


Figure 3.1.3-7
Inadvertent Operation of the PRHR System

Head Vent Flow Rate



## 3.2 Loss of Coolant Accidents

### 3.2.1 Introduction

The AP600 SSAR LOCA analysis is a spectrum of postulated break sizes ranging from a one-inch equivalent diameter break to double-ended hot leg (DEHLG) and cold leg (DECLG) guillotine breaks. The DECLG cases exhibit the limiting calculated peak cladding temperature (PCT) values. In these large break LOCA cases, minimal CMT injection occurs before PCT occurs; the calculated large break LOCA ECCS performance is minimally affected by the design change to eliminate the pressurizer/core makeup tank pressure balance line.

Two of the SSAR small break LOCA cases were reanalyzed for the February 15, 1994 Design Change Report (Reference 5.3) to determine the impact of changes to passive core cooling systems design. LOCA analyses of the postulated double-ended direct vessel injection line (DEDVI) break and inadvertent ADS actuation event demonstrated the beneficial nature of the February 15, 1994 design changes. The inadvertent ADS case, presented in the February report, is negligibly impacted by the removal of the pressurizer/CMT balance line because ADS actuation establishes the pressurizer as the low pressure point in the system very early in the event and the check valve in the now-deleted line closes before any flow of significance passes. The rapid draining of the broken loop CMT leads to an early ADS actuation during the DEDVI break, closing the check valve before pressurizer to CMT flow is a major factor in the transient. These two cases were not reanalyzed for this design change report.

Two small break LOCA cases from the SSAR spectrum, expected to be impacted by the removal of the pressurizer balance line, have been analyzed modeling this design change. For a double-ended (cold leg) pressure balance line rupture, the deletion of the pressurizer CMT balance line removes a steam vent path from the pressurizer to the break location. This event was analyzed and the results presented in this report. The deletion of the pressurizer balance line has eliminated a source of steam to the CMTs which assisted in the heating and subsequent draining of liquid in the tanks to achieve ADS actuation. Since the one -inch cold leg break is the SSAR case with the longest duration of CMT flow from the pressurizer, it is analyzed to evaluate the effects of the design change on ADS actuation and the achievement of IRWST injection.

The NOTRUMP computer code (References 5.4 and 5.5), which was used in the SSAR small break LOCA analysis, was utilized in this analysis. Only safety related systems were modeled. The NOTRUMP AP600 input model used in the SSAR analyses to comply with the standard Westinghouse Small Break LOCA Evaluation Model methodology (Reference 5.5) was used. However, for better representation of the AP600, the following changes were made to the SSAR model:

1) The double-link horizontal stratified flow links between the reactor coolant pump and cold leg fluid nodes are replaced with single links. The purpose of applying double links was to properly consider the possible spillover of liquid from the cold legs into the standard plant loop seal piping. Since AP600 reactor coolant pumps do not possess loop seals it is more appropriate to use a single link model.

2) The double-link horizontal stratified flow links are no longer used for the surge line connections. Rather, single links are utilized because they more appropriately model the surge line flow path.

3) AP600 design changes identified in the February 15, 1994 design change report (Reference 5.3) were incorporated into the model.

4) A multi-node PRHR representation of the heat exchanger (eight fluid nodes) is used. PRHR HX actuation occurs on a Safeguards ("S") signal. Standard condensation heat transfer correlations are applied when primary side steam condenses in the PRHR.

The timer-based actuation of ADS stages two and three means that first stage ADS area is not crucial for the depressurization of the RCS to accumulator actuation pressure in the cases analyzed; the larger second and third stages provide much greater flow capability in short order after the ADS signal. Therefore, the single active failure assumed herein is the failure of one of the four fourth-stage ADS valves to open.

### 3.2.2 Double-ended Pressure Balance Line Break Results

This case models the double-ended rupture of one of the two cold leg pressure balance lines at an elevation just above its entry location into the cold leg. The broken loop core makeup tank is not modeled because it has no means of pressure equalization and is unable to deliver flow. This line break evaluates the ability of the plant to recover from a moderately large break with only one of the two core makeup tanks operational. A discussion of the results follows; refer to Table 3.2-1 for a sequence of events summary table.

The break is assumed to open instantaneously at 0.0 seconds. The subcooled discharge from the broken pressure balance line (Figure 3.2-1) causes a rapid RCS depressurization (Figure 3.2-2), and a reactor trip signal is generated at 6.4 seconds. The "S" signal is generated at 7.9 seconds and following a 1.2 second delay, the isolation valves on the CMT tank outlet and cold leg balance lines begin to open. The "S" signal also causes closure of the main feedwater isolation valves after a five second delay and trips the reactor coolant pumps after a 16.2 second delay. The opening of the PRHR isolation valve on an "S" signal starts the flow through the heat exchanger.

At about 27 seconds the mixture level drops in the upper plenum to the hot leg elevation (Figure 3.2-3). The elevation of the top of the core is 18.8 feet. The upper parts of the RCS start to drain (Figures 3.2-4 and 3.2-5), and a mixture level forms in the downcomer at about 130 seconds (Figure 3.2-6), falls below the elevation of the cold legs, returns to within the cold leg perimeter, then falls again. With no balance line to pass steam from the pressurizer, the fluid at the top of the intact loop CMT does not saturate and form a level until 230 seconds after the inception of the break (Figure 3.2-7). The first stage ADS setpoint is not reached until more than 700 seconds into the transient, and after an appropriate delay, the first stage paths open. The ensuing steam discharge from the top of the pressurizer (Figure 3.2-8) increases the RCS depressurization rate.

Depressurization due to the large break flow enables the accumulator to begin to inject at 200 seconds (Figure 3.2-9). After 200 seconds, accumulator injection into the downcomer causes the downcomer mixture level to rise. Accumulator injection (together with intact loop CMT flow) replenishes the reactor coolant system mass inventory both before and after ADS initiation. After first stage ADS actuation, timers initiate the second and third stages according to the design for the ADS. After the accumulator empties, stable but decreasing injection continues from the intact loop CMT as the RCS pressure declines slowly (Figure 3.2-10). IRWST injection begins well before the intact loop core makeup tank empties at 1931 seconds transient time. Stable injection from the IRWST occurs at a rate of about 180 lb/s after the CMT has emptied. This flow is greater than the break and ADS flows, resulting in a slow rise in RCS inventory (Figure 3.2-11) once the IRWST provides the only injection. The minimum RCS mass inventory of 104,000 lbs. occurs when accumulator injection has just begun, at around 200 seconds.

### 3.2.3 One-Inch cold leg break Results

A break of one-inch equivalent diameter is modeled in one of the Loop 1 (pressurizer loop) cold legs. This is the same location analyzed in the SSAR. Only safety-related systems are assumed to operate in this analysis. The second and third stage ADS valves actuate based on the design time delays. At the 20 percent mixture level in the core makeup tank, the fourth stage ADS valves, which are on the hot legs, receive signals to open. Three of the four fourth stage ADS paths are assumed to open; one of the fourth stage paths fails to open as the assumed single active failure. The one-inch break scenario analyzed is the same as in the SSAR; the sequence of events for the transient is given in Table 3.2-2.

The break initially depressurizes the RCS rather slowly. The reactor trip, reactor coolant pump trip and safeguards "S" signals are generated via the pressurizer low pressure signals with appropriate delays. The reduction in core power due to reactor trip causes the primary pressure to fall more rapidly (Figure 3.2-12) until it plateaus near the steam generator safety valve set pressure. The upper plenum liquid level drops to the hot leg elevation

(Figure 3.2-13) within the first 1000 seconds. Although the "S" signal opens the valves isolating the CMTs and injection of cold water begins (Figure 3.2-14) at 121 seconds, the mixture level in the CMTs remains constant until about 1800 seconds, when the tanks begin to drain (Figure 3.2-15).

Actuation of the PRHR on an "S" signal (Reference 5.3) has a major impact on this postulated event. As Figure 3.2-12 indicates, the early PRHR actuation depressurizes the RCS below the steam generator safety valve setpoint. The PRHR becomes the heat sink for the primary system, while the steam generator secondaries are heat sources. Depressurization related to PRHR operation becomes even more pronounced once the Loop 1 steam generator drains (Figure 3.2-16). At this time steam is able to pass through the steam generator to condense on the PRHR effluent in the outlet plenum. Thus, after 1500 seconds the PRHR not only removes heat directly into the IRWST but also via condensation in the steam generator plenum. The action of the PRHR, together with core makeup tank and (later) accumulator injection, maintains the downcomer full of subcooled liquid until after ADS actuation (Figure 3.2-17). Figure 3.2-18 presents the liquid flow entering the steam generator outlet plenum from the PRHR. Some further condensation occurs when steam from the intact Loop 2 cold legs mixes with subcooled downcomer liquid once that steam generator drains. Relative to the corresponding SSAR case, the accumulators actuate about 2000 seconds earlier as a consequence of the earlier PRHR actuation causing the primary pressure to fall more rapidly (Figure 3.2-12). The accumulator mixture level transient is presented in Figure 3.2-19.

The mass discharge through the break is also affected by the early PRHR operation. Figure 3.2-20 presents the break flow; it remains almost solely liquid throughout the entire transient, as was true in the SSAR case. The break mass flow remains high even though the pressure is much lower than in the SSAR because the break enthalpy is relatively low due to the break location in the PRHR loop cold leg. Even though the pressurizer vapor space has been eliminated as a source of steam to heat the core makeup tanks, and even though CMT injection flow is diminished by accumulator flow, first stage ADS actuation occurs earlier in this case than in the SSAR analysis; the much lower RCS pressure condition which results from PRHR operation leads to voiding in the CMT and then its level falling steadily.

The levels in the CMTs eventually reach the fourth stage ADS setpoint, and those vent paths open in the hot legs and begin discharging fluid. The single active failure assumed is that one of the four fourth stage ADS paths fails to open, minimizing the capability to depressurize the RCS to achieve IRWST injection. The liquid and vapor flow rates through the fourth stage ADS paths are presented in Figures 3.2-21 and 3.2-22. These paths initially discharge a two-phase mixture. After they begin to discharge only steam at about 4200 seconds, the RCS pressure quickly falls enough to allow gravity drain from the IRWST to begin. The calculation was stopped with the IRWST delivery exceeding the ADS and break flows (which are removing the decay heat) such that the RCS mass inventory is slowly rising. Figure 3.2-23 presents the RCS mass inventory behavior during the one-inch cold break transient.

The minimum RCS mass inventory in this revised AP600 design case is 107,000 lbs mass occuring just after the inception of IRWST injection. The ADS system of the AP600 capably depressurizes the RCS to the IRWST delivery pressure, and it does so before the core makeup tanks empty completely of liquid. The ADS vent area is sufficient to depressurize the RCS even assuming the failure of one fourth stage ADS valve to open and utilizing Appendix K decay heat, which conservatively over estimates the core steam generation rate. Even under these limiting conditions, IRWST injection is obtained readily, and the core remains covered such that no cladding heatup occurs.

### 3.2.4 Conclusions

Two small break LOCA cases from the AP600 SSAR have been reanalyzed with NOTRUMP to investigate the subject design change. No uncovering of the core is predicted for the double-ended pressure balance line break case. The one-inch cold leg break case evaluated depressurizes the primary system more rapidly than does the SSAR case, due to the action of the PRHR following its actuation on an "S" signal. The increased capacity of the ADS fourth stage valves implemented in the February 1994 design change allows IRWST injection to be achieved more readily than in the SSAR one-inch break case. Overall, these cases demonstrate that the elimination of the CMT/pressurizer pressure balance line is acceptable for postulated small break LOCA events.

Table 3.2-1
Double Ended Balance Line Break
Sequence of Events

| Event | Time |
|---|---|
| Break open | 0.0 seconds |
| Reactor trip signal | 6.4 seconds |
| "S" signal | 7.9 seconds |
| Reactor coolant pumps start to coast down | 24.1 seconds |
| ADS stage 1 flow starts | 736 seconds |
| Accumulator injection starts | 200 seconds |
| ADS stage 2 flow starts | 806 seconds |
| ADS stage 3 flow starts | 926 seconds |
| Accumulator injection ends | 914 seconds |
| ADS stage 4 flow starts | 1555 seconds |
| IRWST injection starts | 1740 seconds |

Table 3.2-2
One-Inch Cold Leg Break
Sequence of Events

| Event | Time |
|---|---|
| Break Opens | 0.0 seconds |
| Reactor trip signal | 116.9 seconds |
| "S"signal | 120.2 seconds |
| Reactor coolant pumps start to coast down | 136.4 seconds |
| Accumulator injection starts | 1820 seconds |
| ADS Stage 1 flow starts | 3083 seconds |
| ADS stage 2 flow starts | 3153 seconds |
| Accumulator empty | 3536 seconds |
| ADS stage 3 flow starts | 3273 seconds |
| ADS stage 4 flow starts | 3968 seconds |
| Core make up tank empty | 4400 seconds |
| IRWST injection starts | 4296 seconds |

FIGURE 3.2-1
BREAK LIQUID FLOW, DE BALANCE LINE BREAK

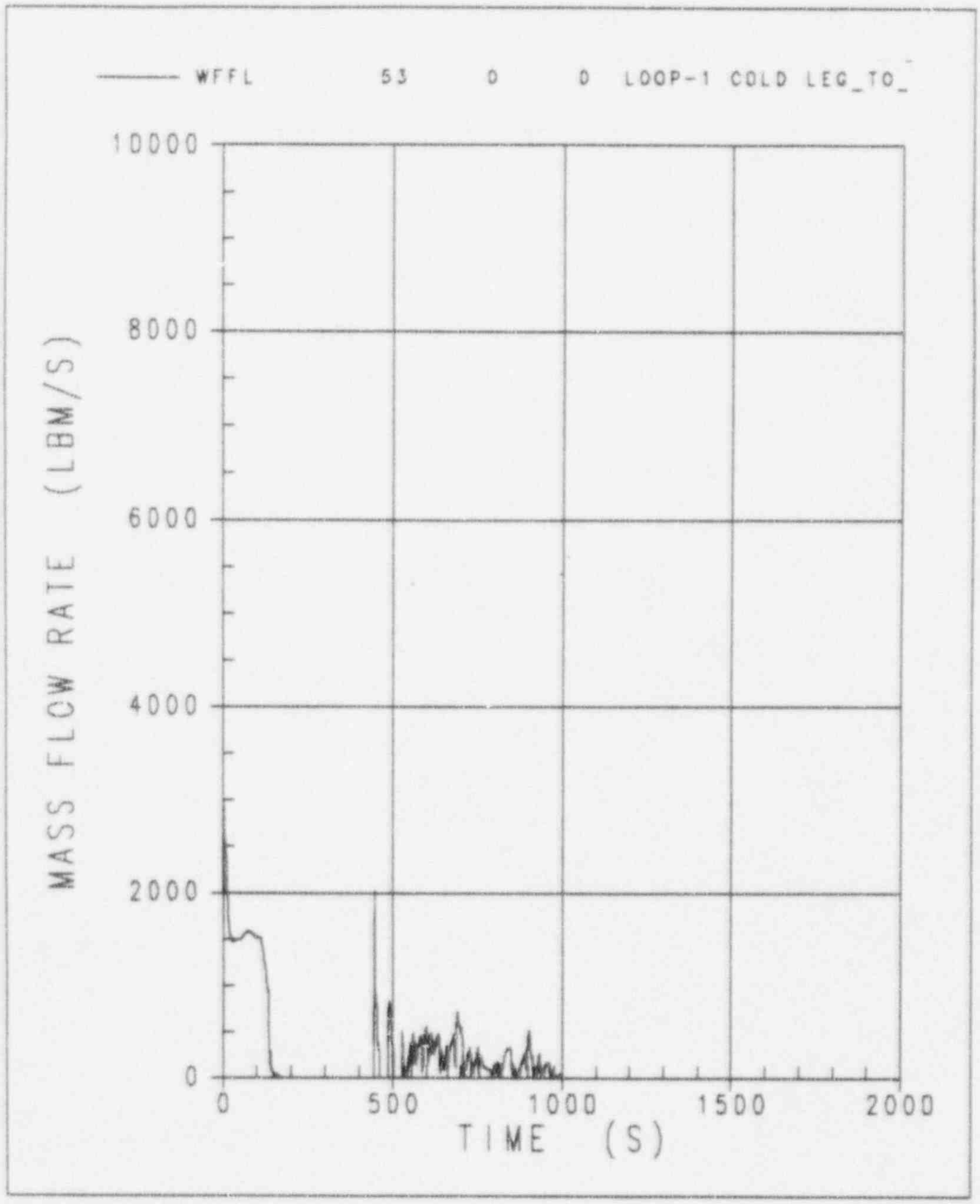


FIGURE 3.2-2
DOWNCOMER PRESSURE, DE BALANCE LINE BREAK

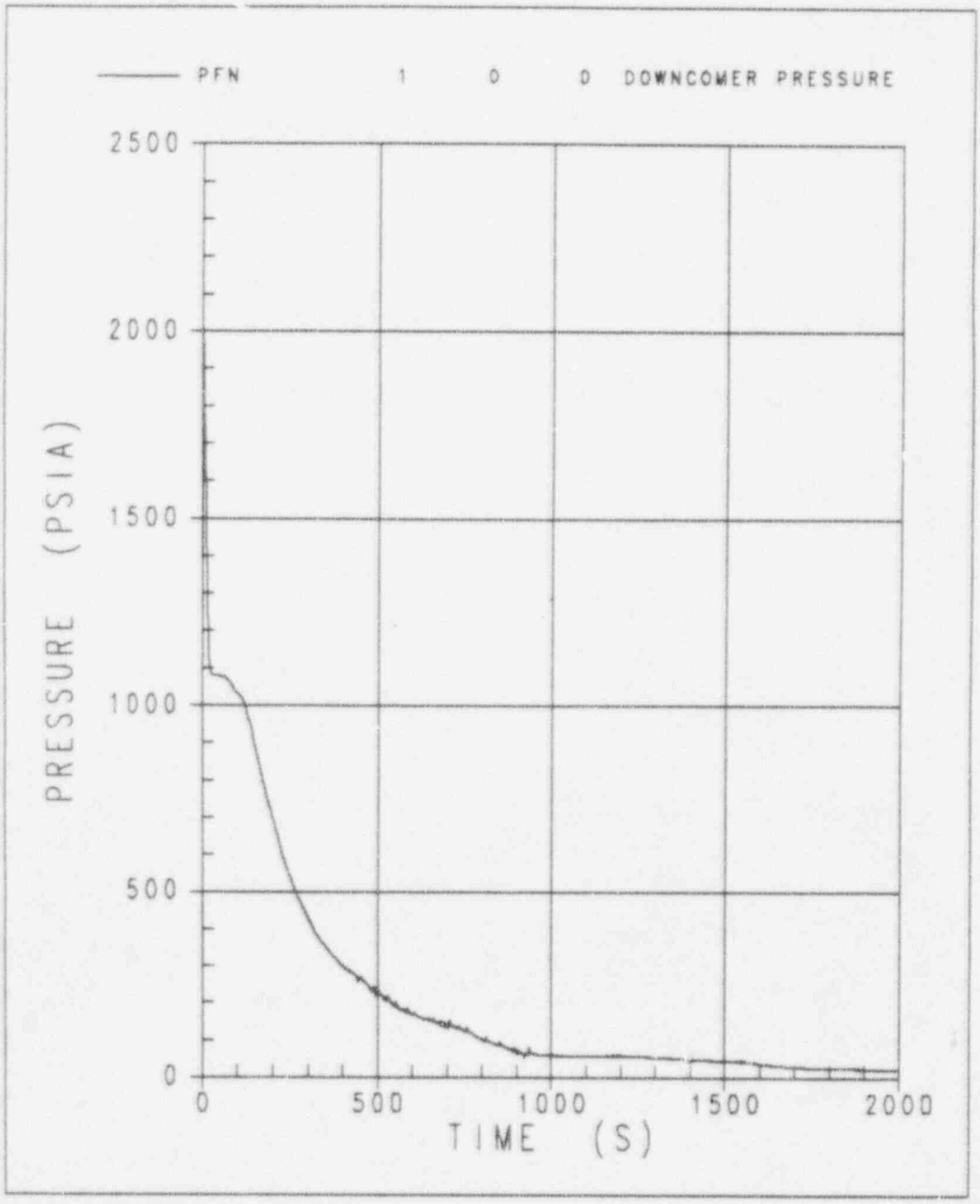


FIGURE 3.2-3
INNER VESSEL MIXTURE LEVEL, DE BALANCE LINE BREAK

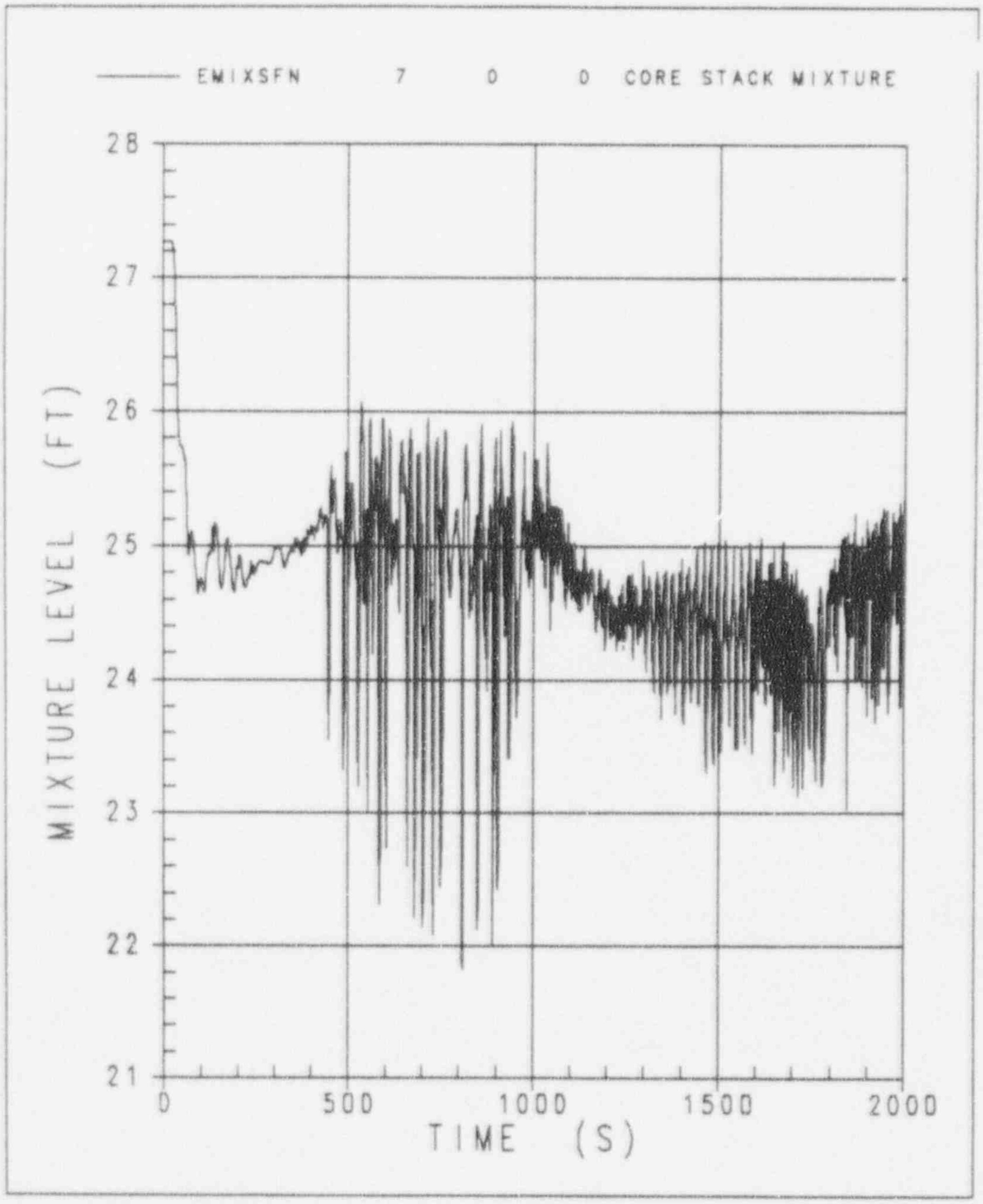


FIGURE 3.2-4
UPPER HEAD MIXTURE LEVEL, DE BALANCE LINE BREAK

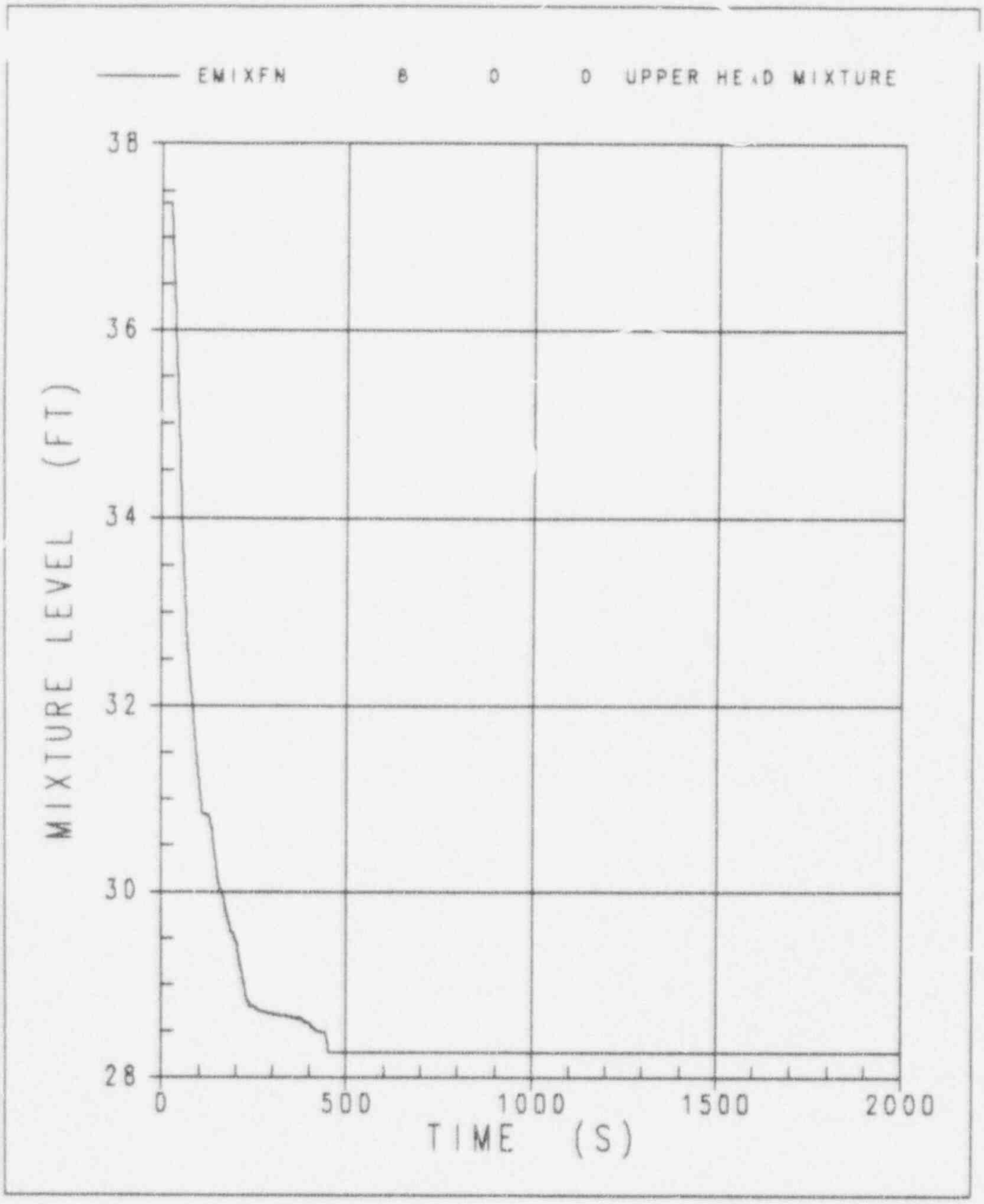


FIGURE 3.2-5
LOOP 1 STEAM GENERATOR MIXTURE LEVEL, DE BALANCE LINE BREAK

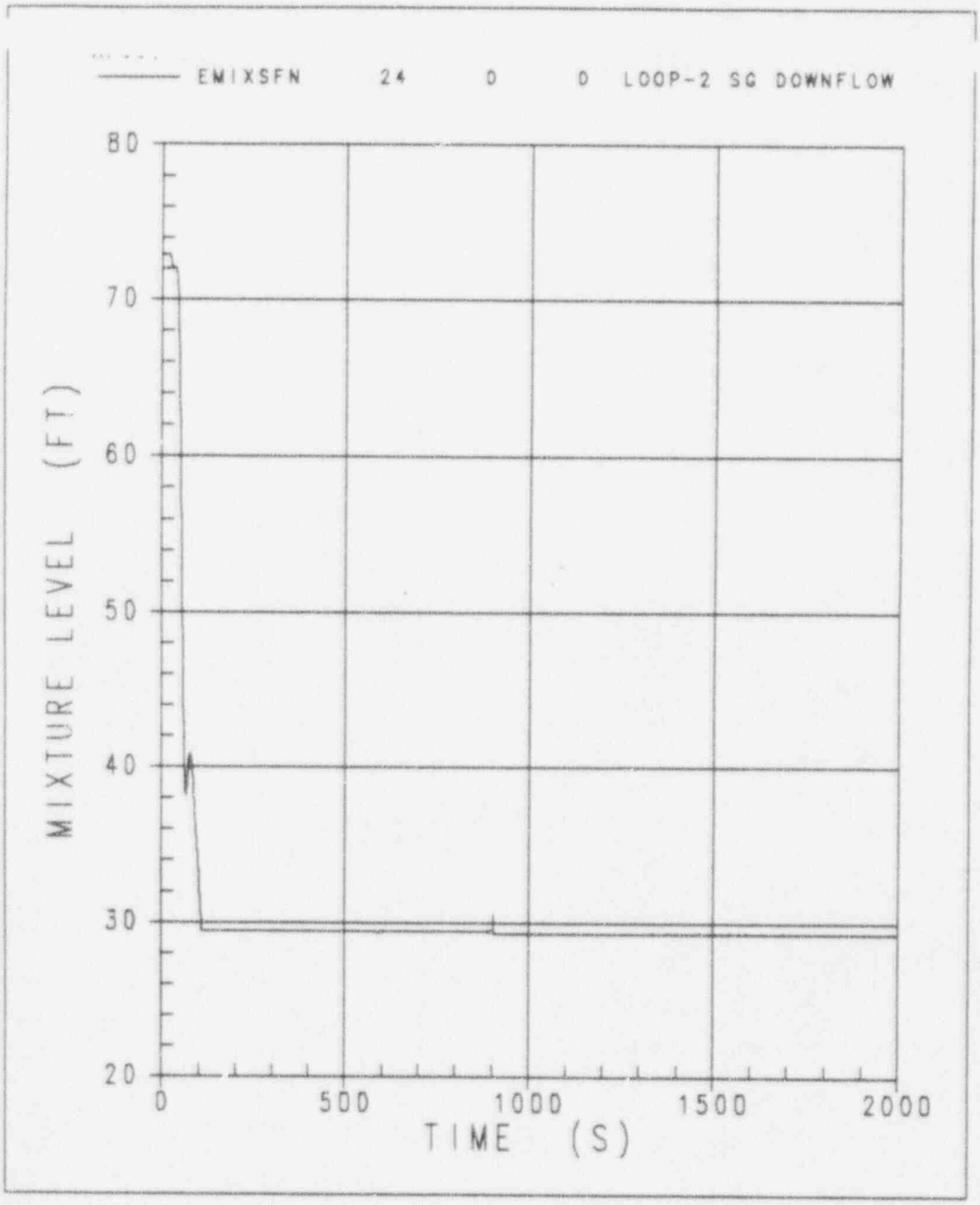


FIGURE 3.2-6
DOWNCOMER MIXTURE LEVEL, DE BALANCE LINE BREAK

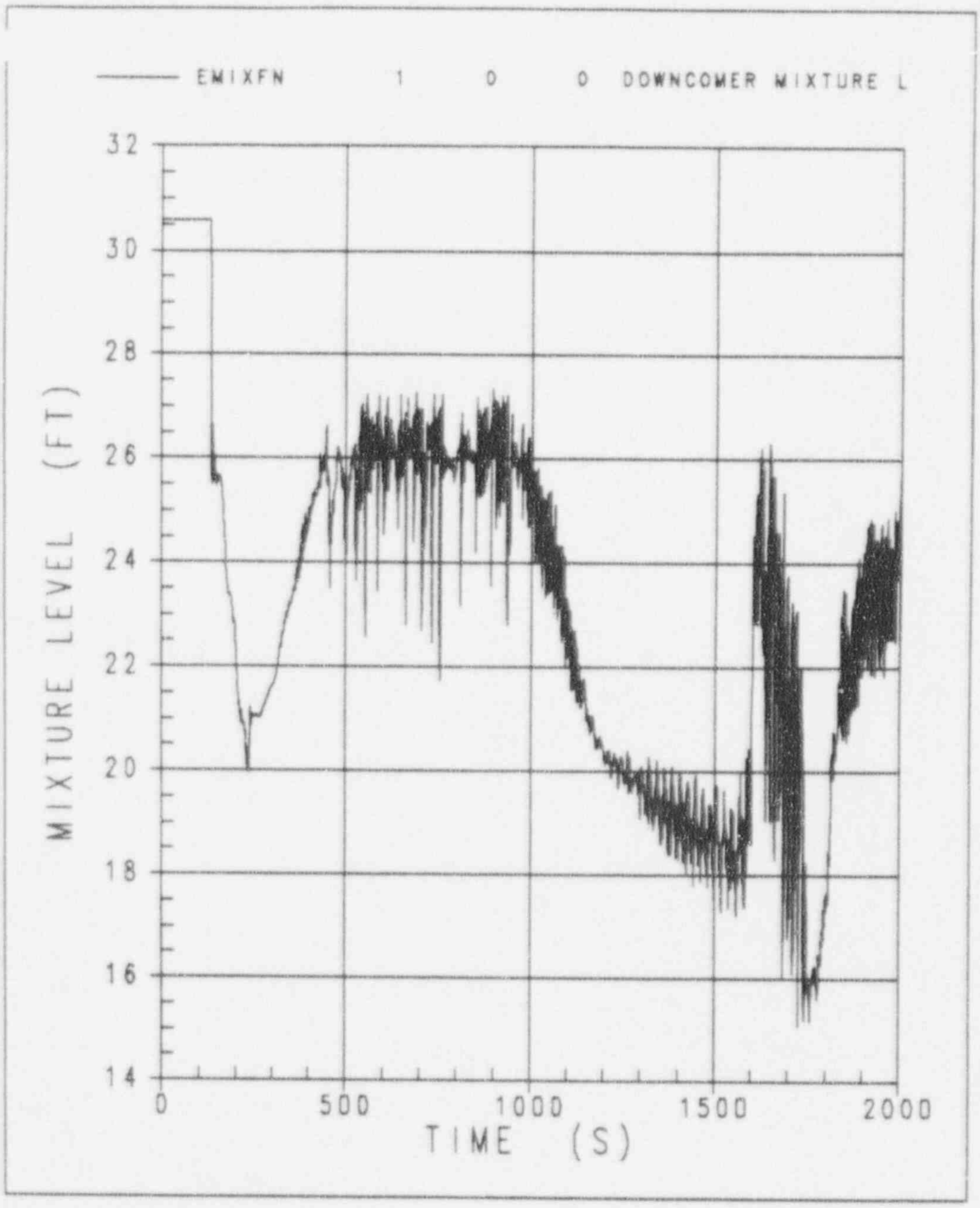


FIGURE 3.2-7
INTACT CMT MIXTURE LEVEL, DE BALANCE LINE BREAK

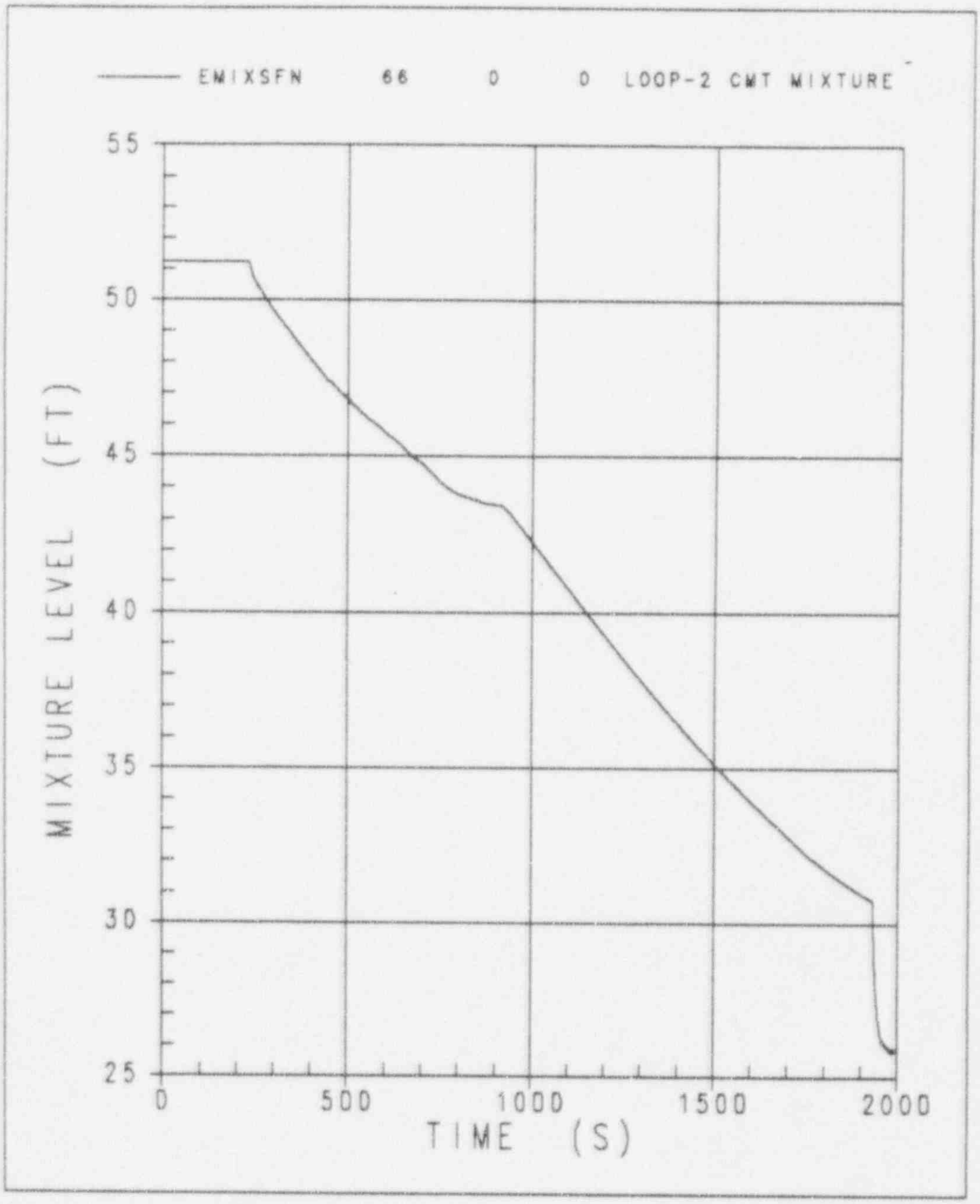


FIGURE 3.2-8
ADS STAGES 1-3 STEAM FLOW RATE, DE BALANCE LINE BREAK

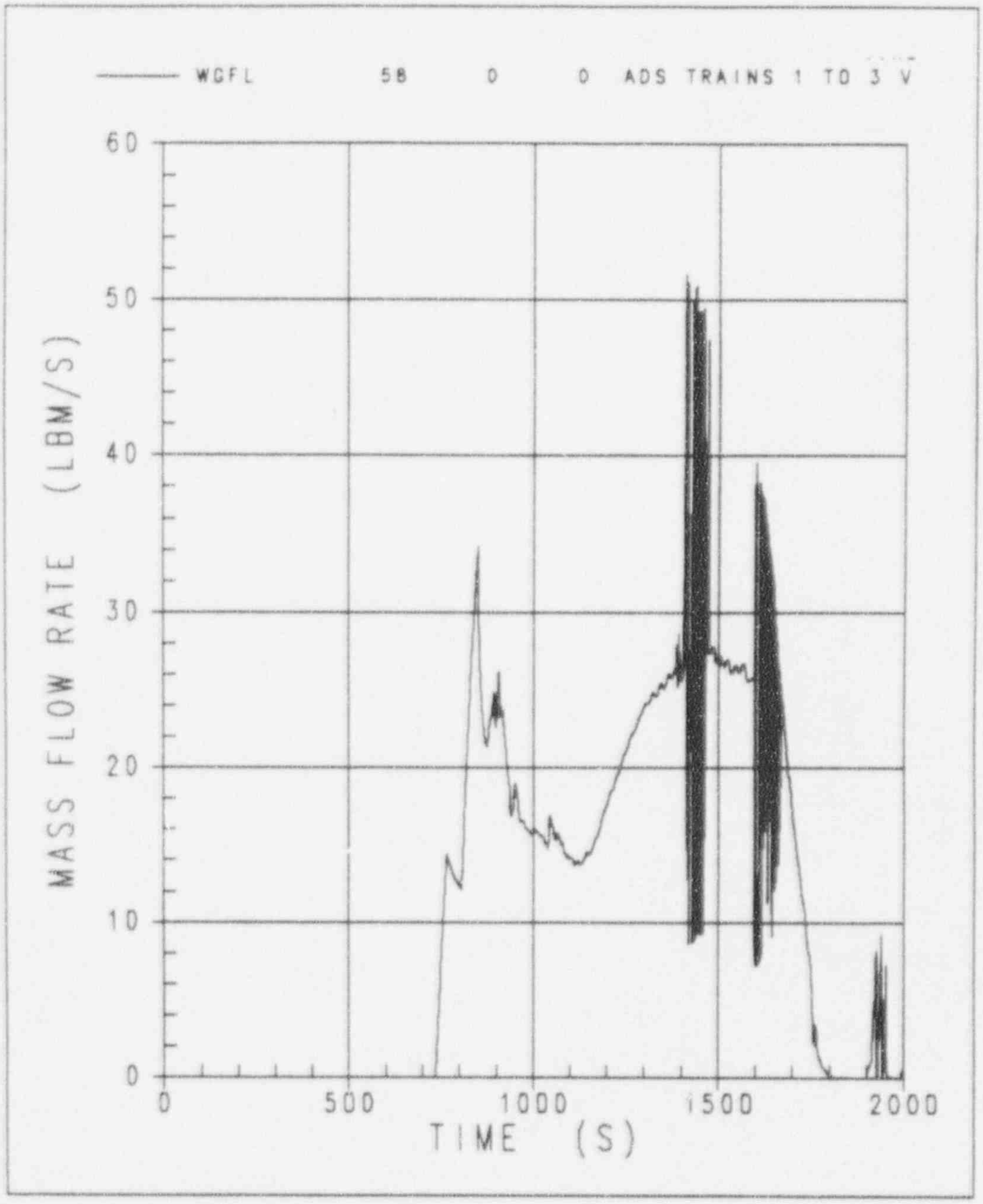


FIGURE 3.2-9
ACCUMULATOR FLOW RATE, DE BALANCE LINE BREAK

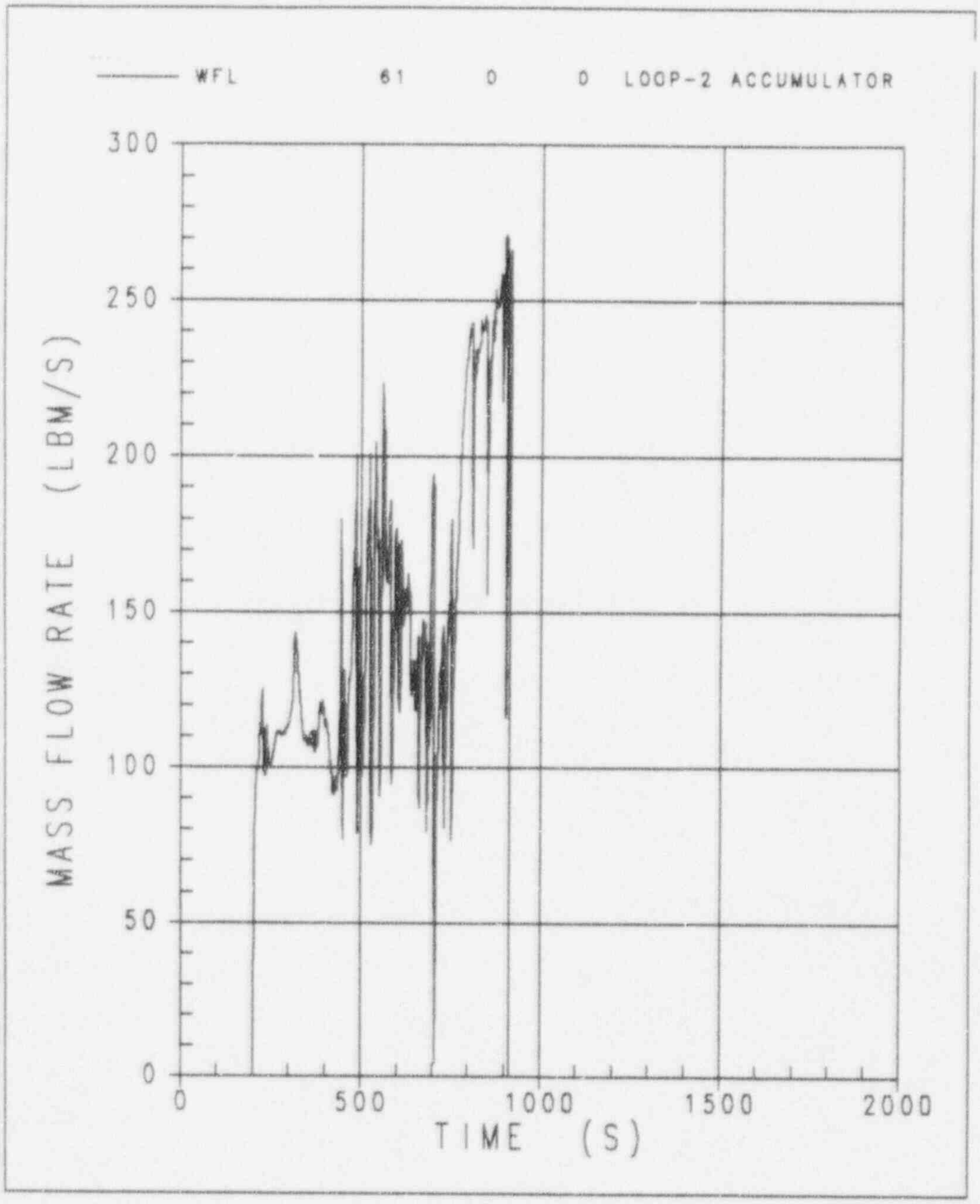


FIGURE 3.2-10
INTACT LOOP CMT INJECTED FLOW, DE BALANCE LINE BREAK

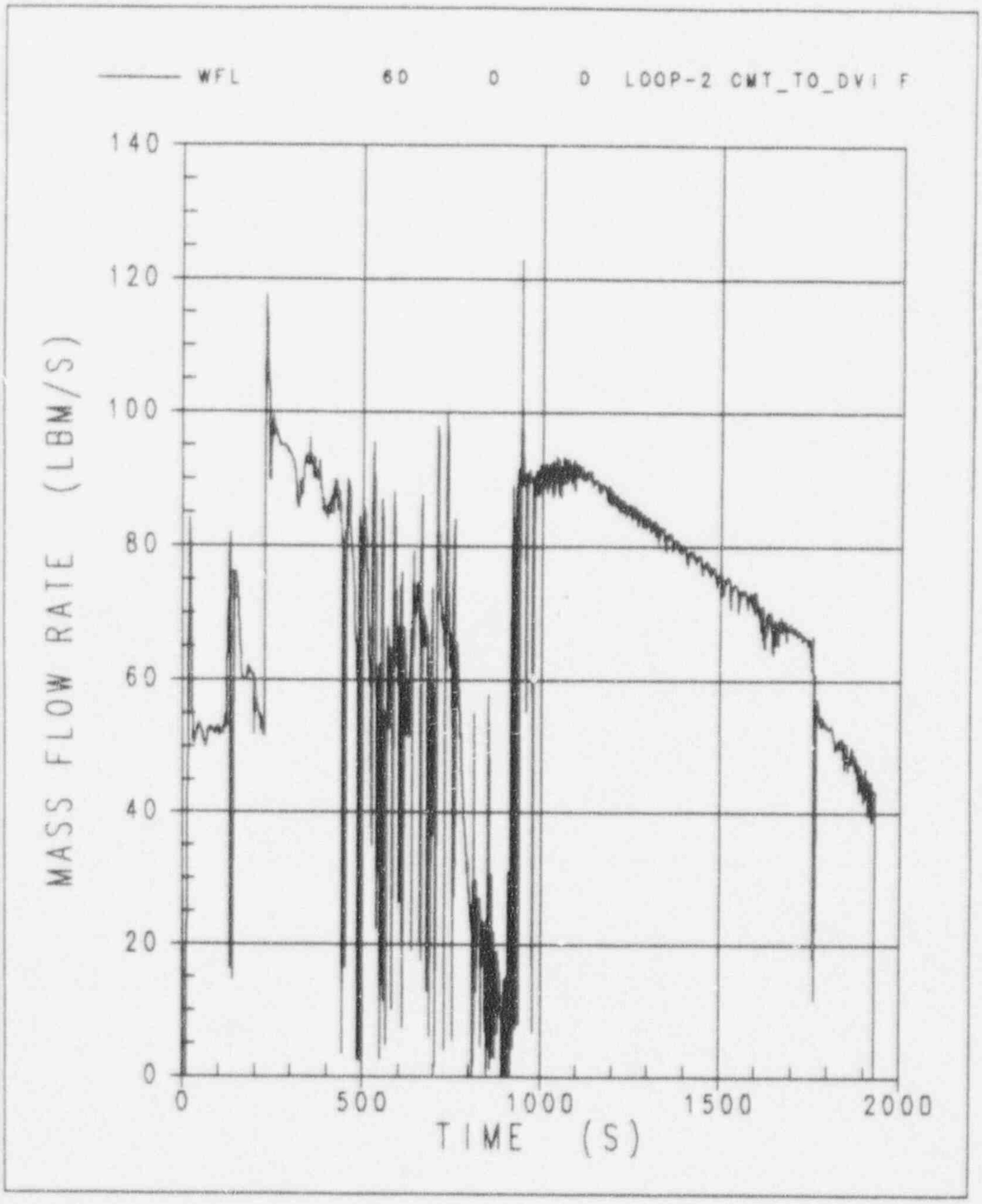


FIGURE 3.2-11
PRIMARY MASS INVENTORY, DE BALANCE LINE BREAK

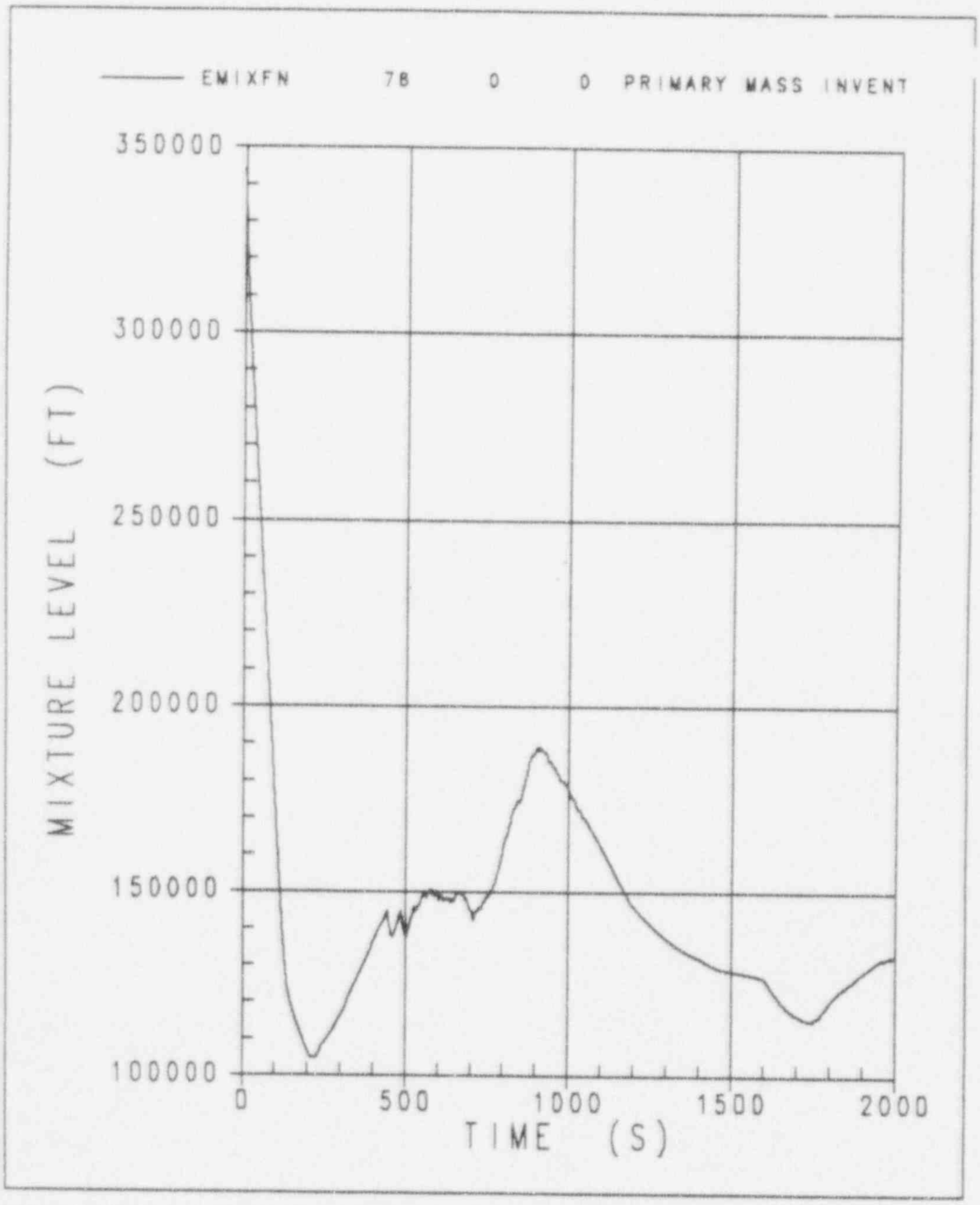


FIGURE 3.2-12
DOWNCOMER PRESSURE, ONE INCH COLD LEG BREAK

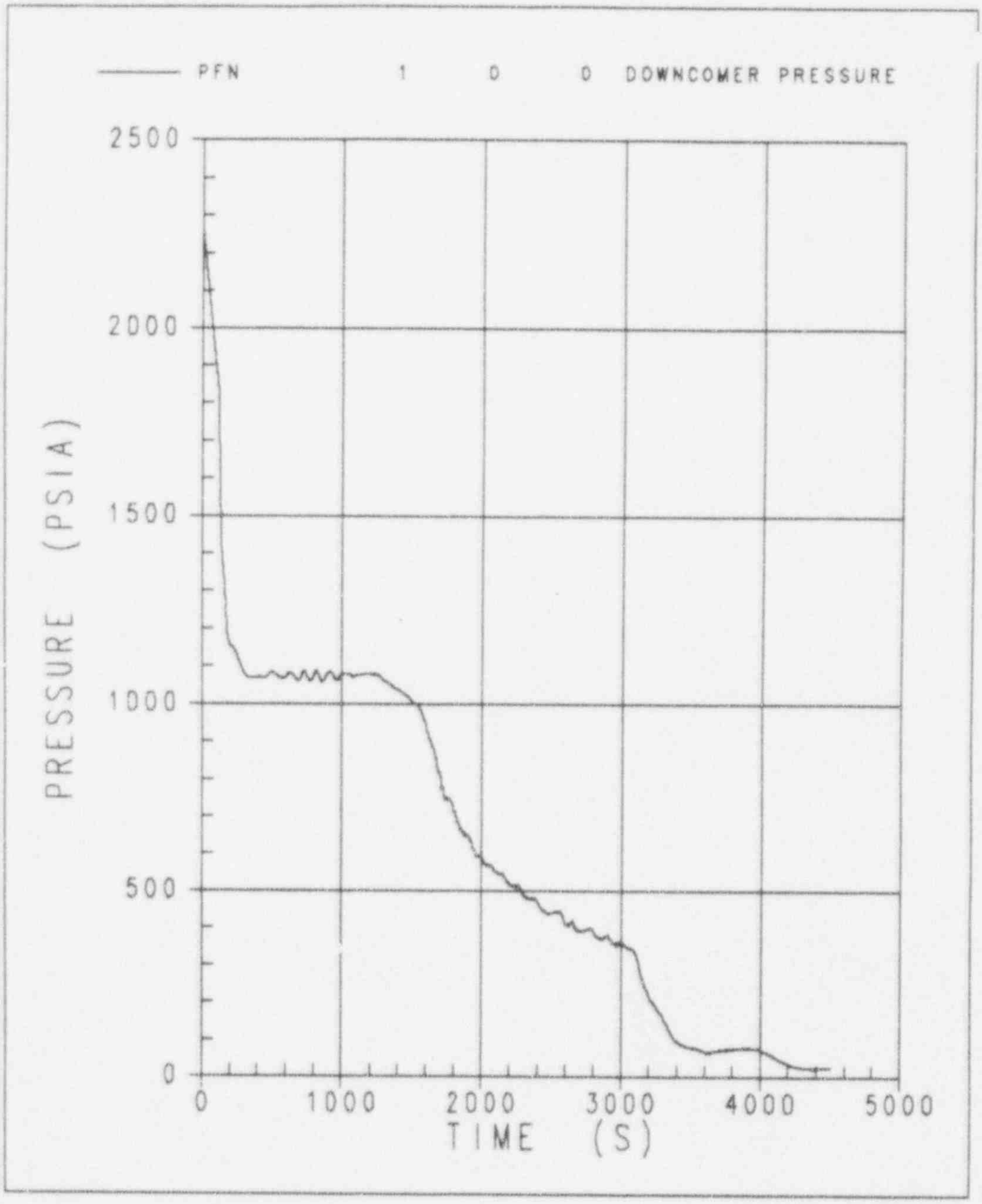


FIGURE 3.2-13
INNER VESSEL MIXTURE LEVEL, ONE INCH COLD LEG BREAK

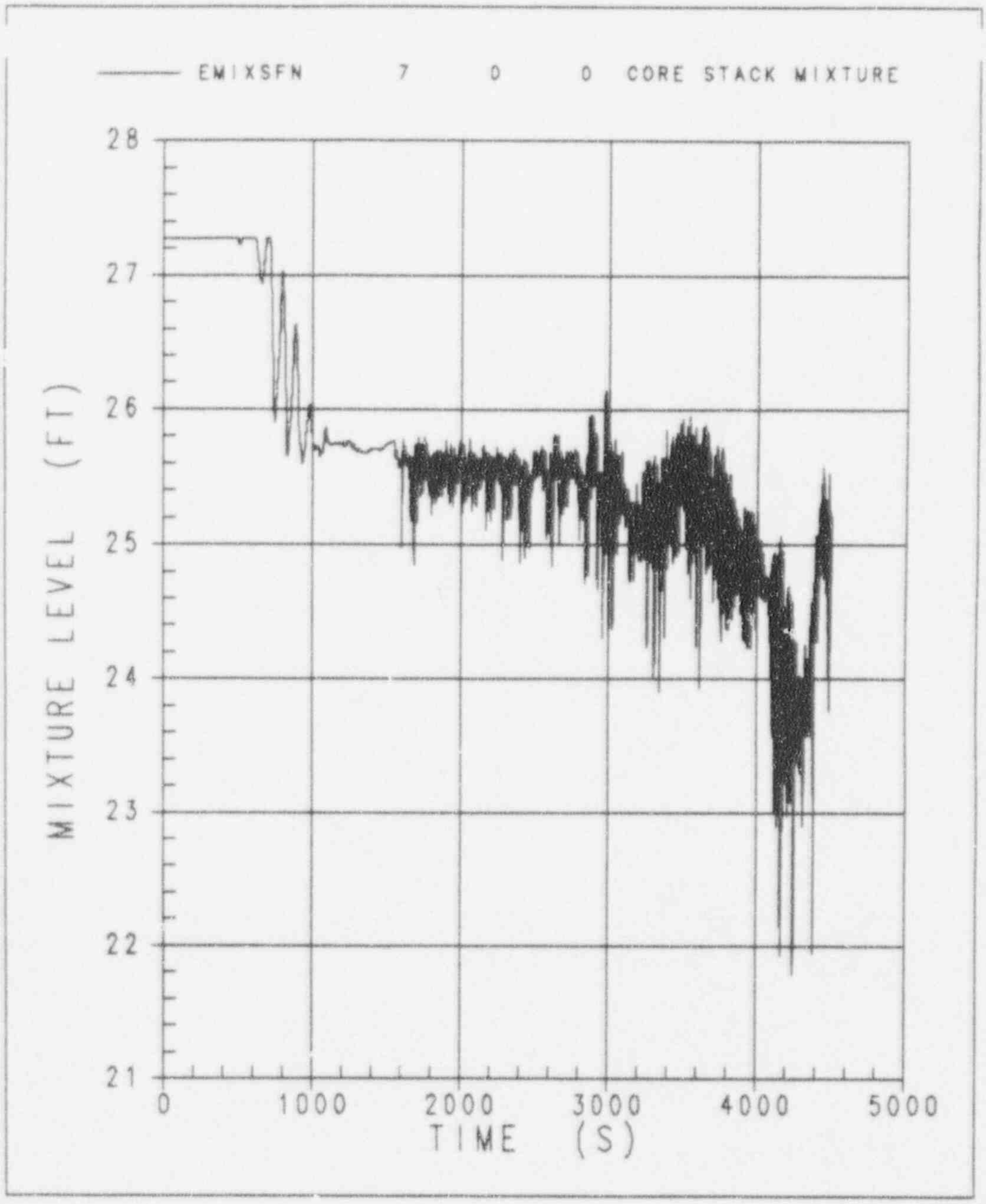


FIGURE 3.2-14
SINGLE CMT INJECTION RATE, ONE INCH COLD LEG BREAK

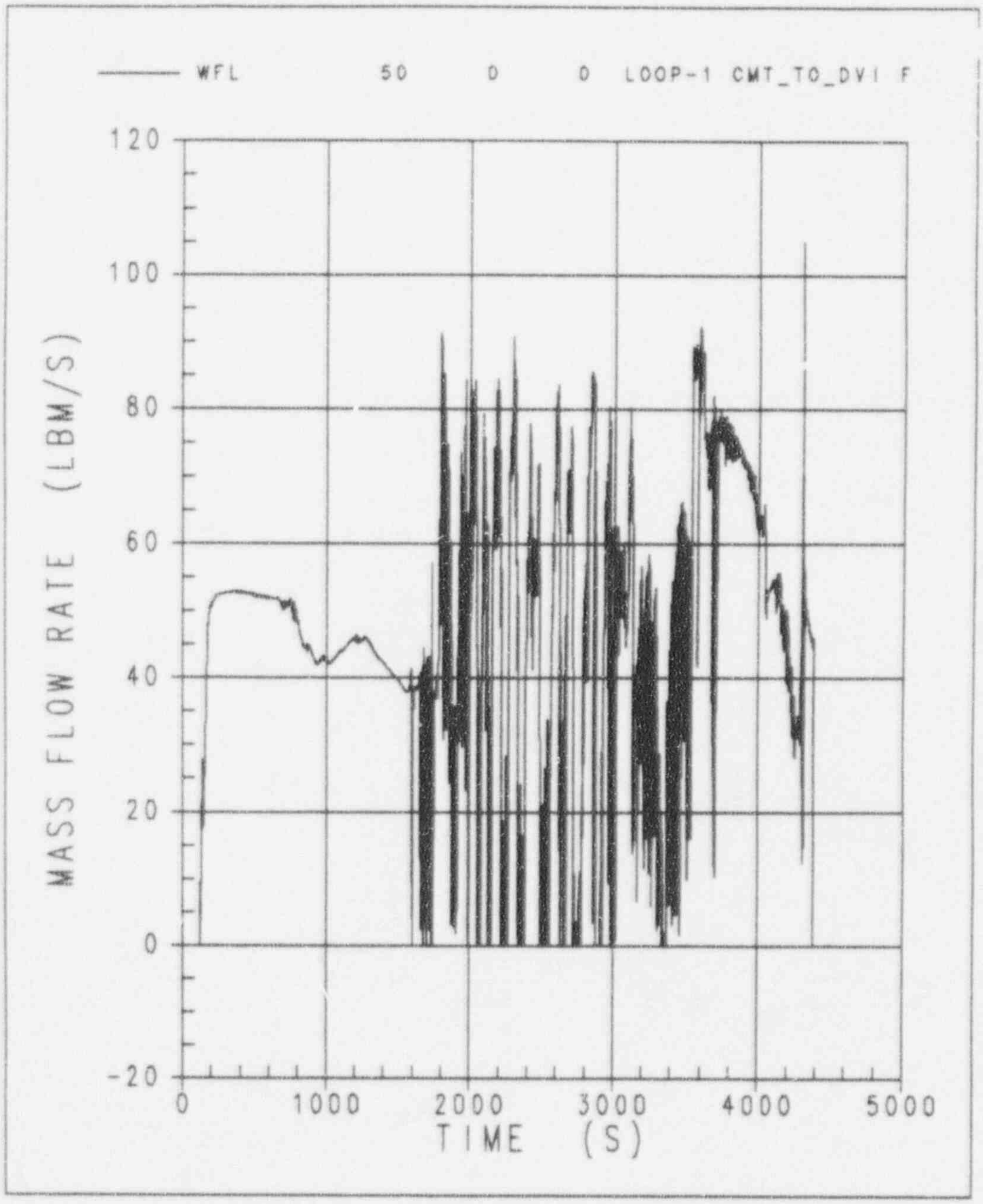


FIGURE 3.2-15
CMT MIXTURE LEVEL, ONE INCH COLD LEG BREAK

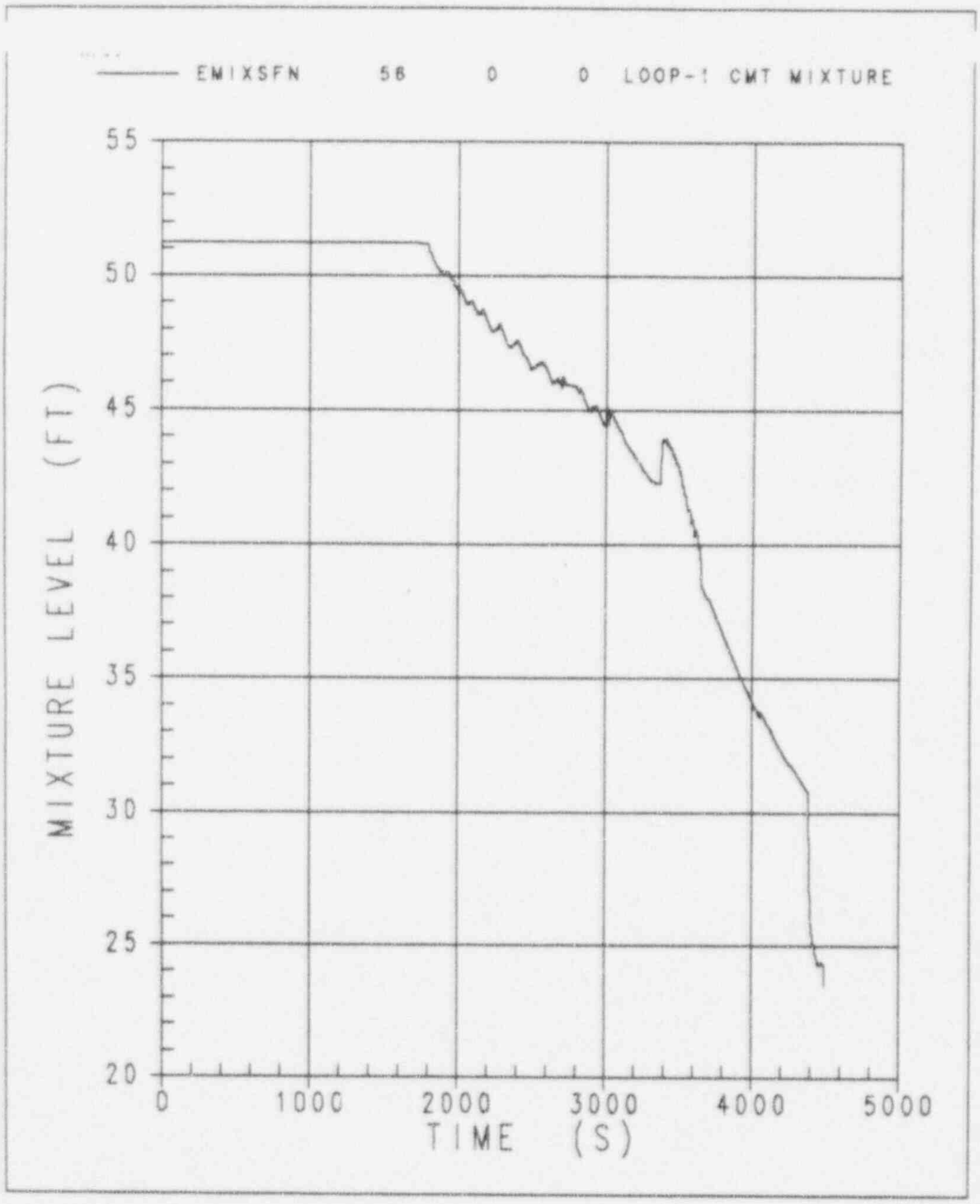


FIGURE 3.2-16
LOOP 1 STEAM GENERATOR MIXTURE LEVEL, ONE INCH COLD LEG BREAK

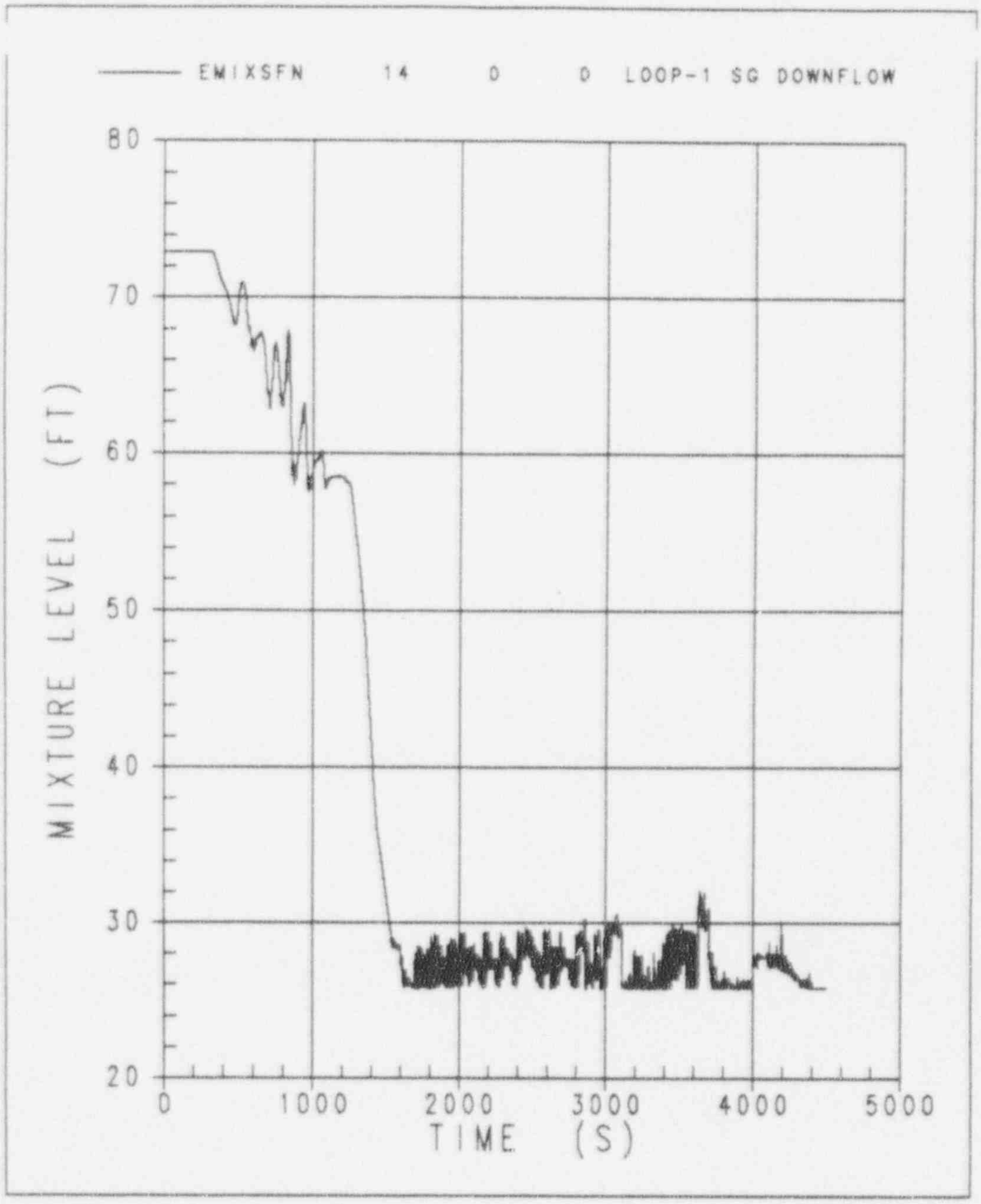


FIGURE 3.2-17
DOWNCOMER MIXTURE LEVEL, ONE INCH COLD LEG BREAK

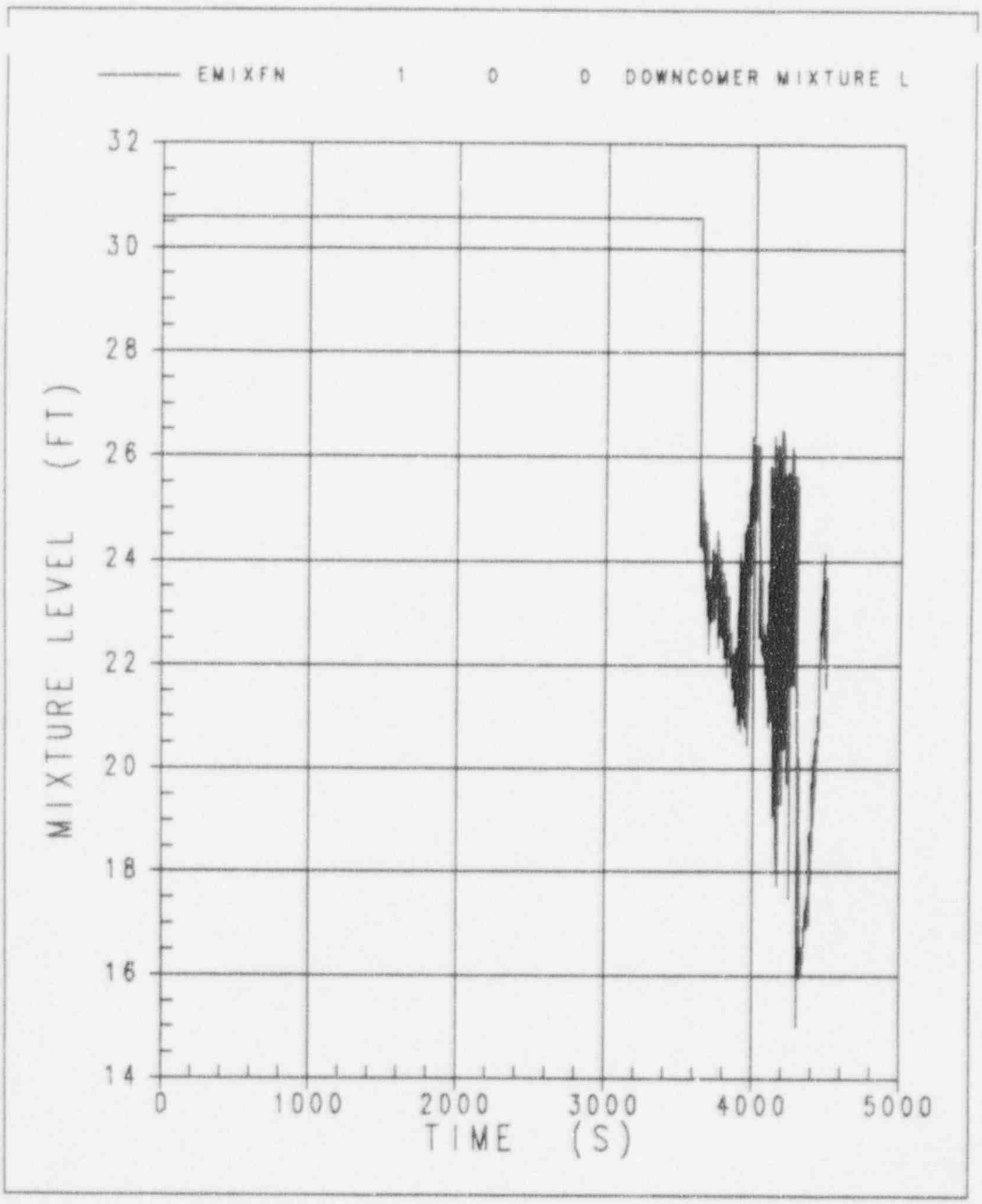





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FIGURE 3.2-18
PRHR TO STEAM GENERATOR PLENUM FLOW, ONE INCH COLD LEG BREAK

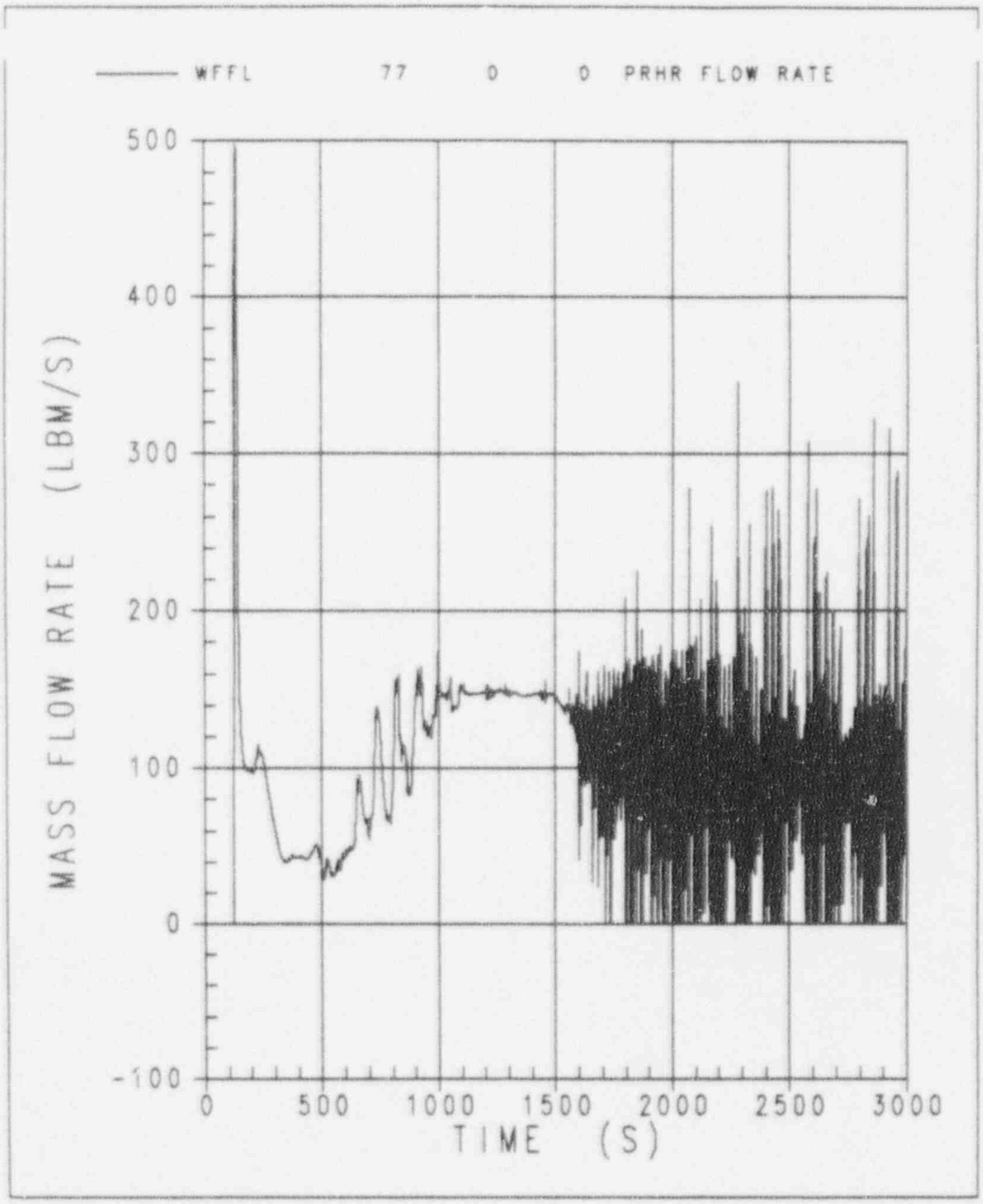


FIGURE 3.2-19
ACCUMULATOR MIXTURE LEVEL, ONE INCH COLD LEG BREAK

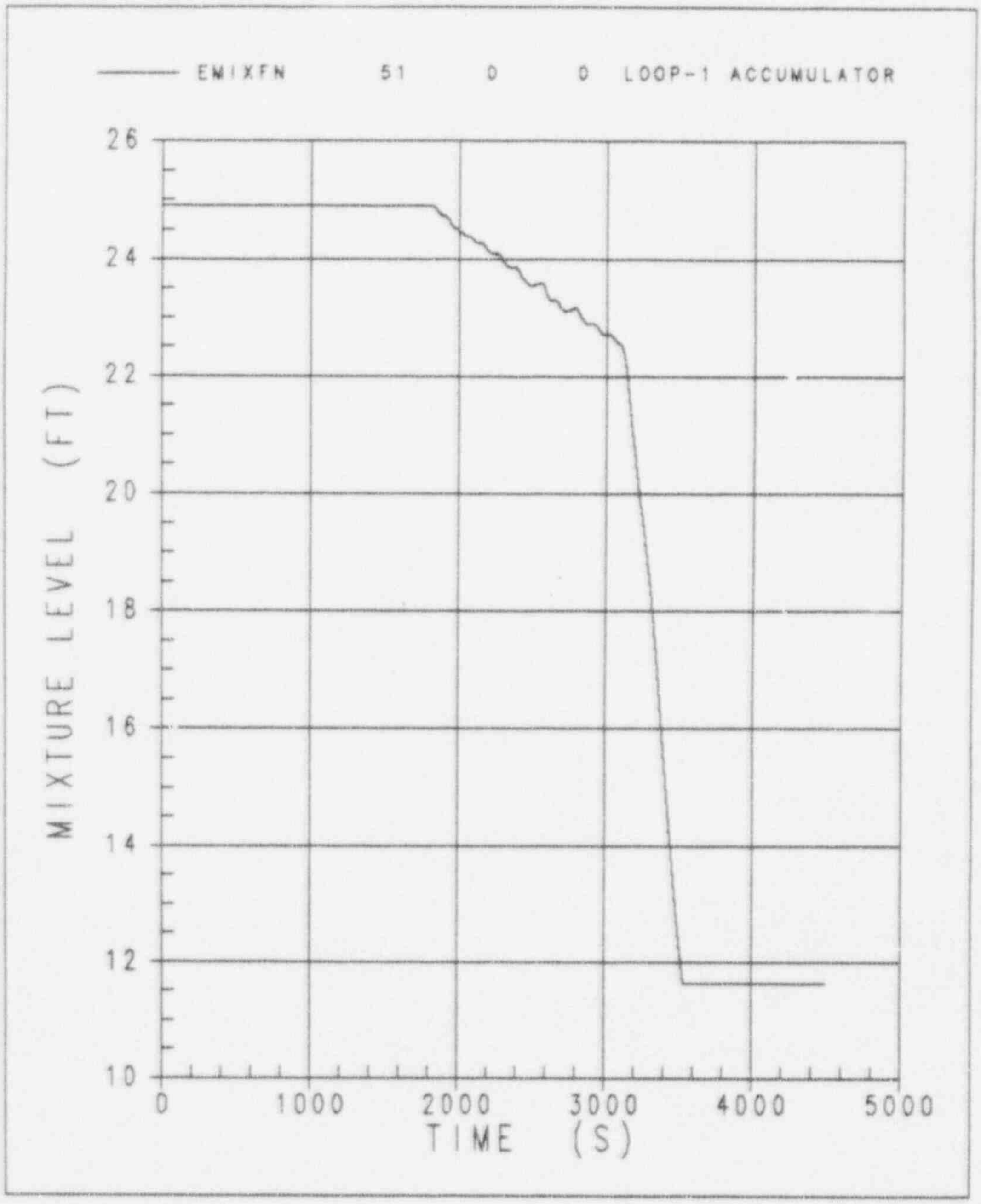


FIGURE 3.2-20
BREAK MASS FLOW RATE, ONE INCH COLD LEG BREAK

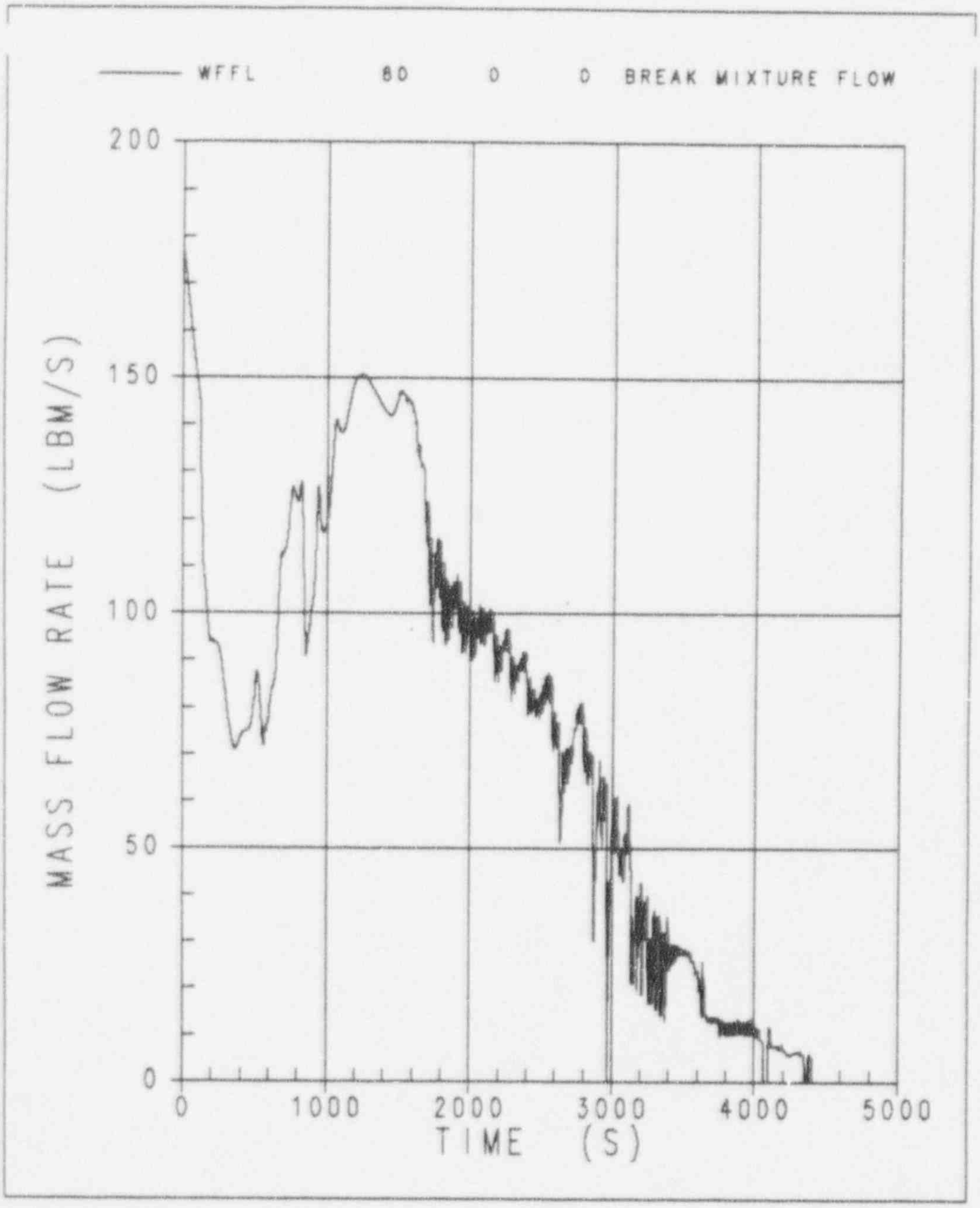


FIGURE 3.2-21
ADS TRAIN 4 LIQUID FLOW RATE, ONE INCH COLD LEG BREAK CASE

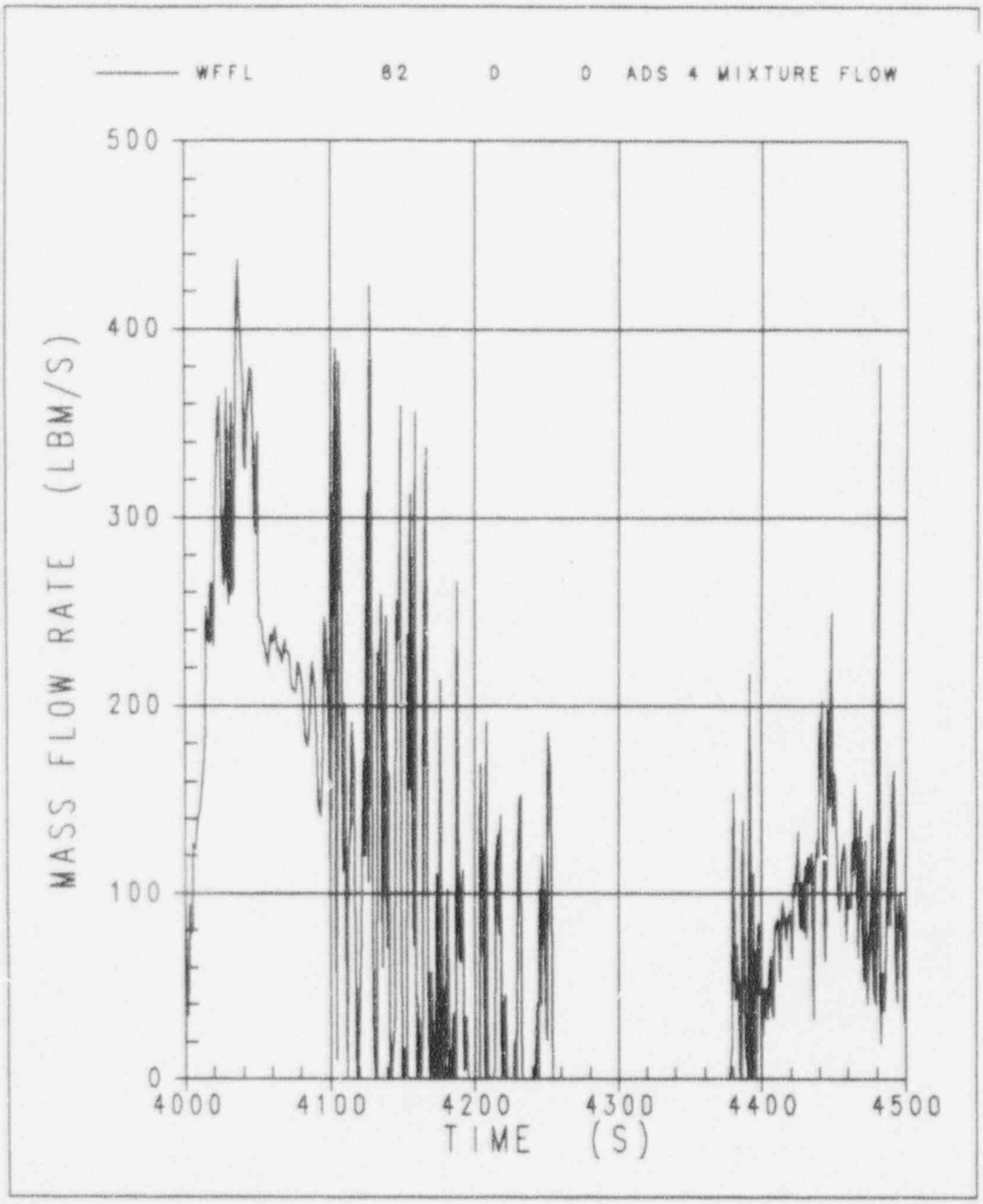


FIGURE 3.2-22
ADS TRAIN 4 VAPOR FLOW RATE, ONE INCH COLD LEG BREAK

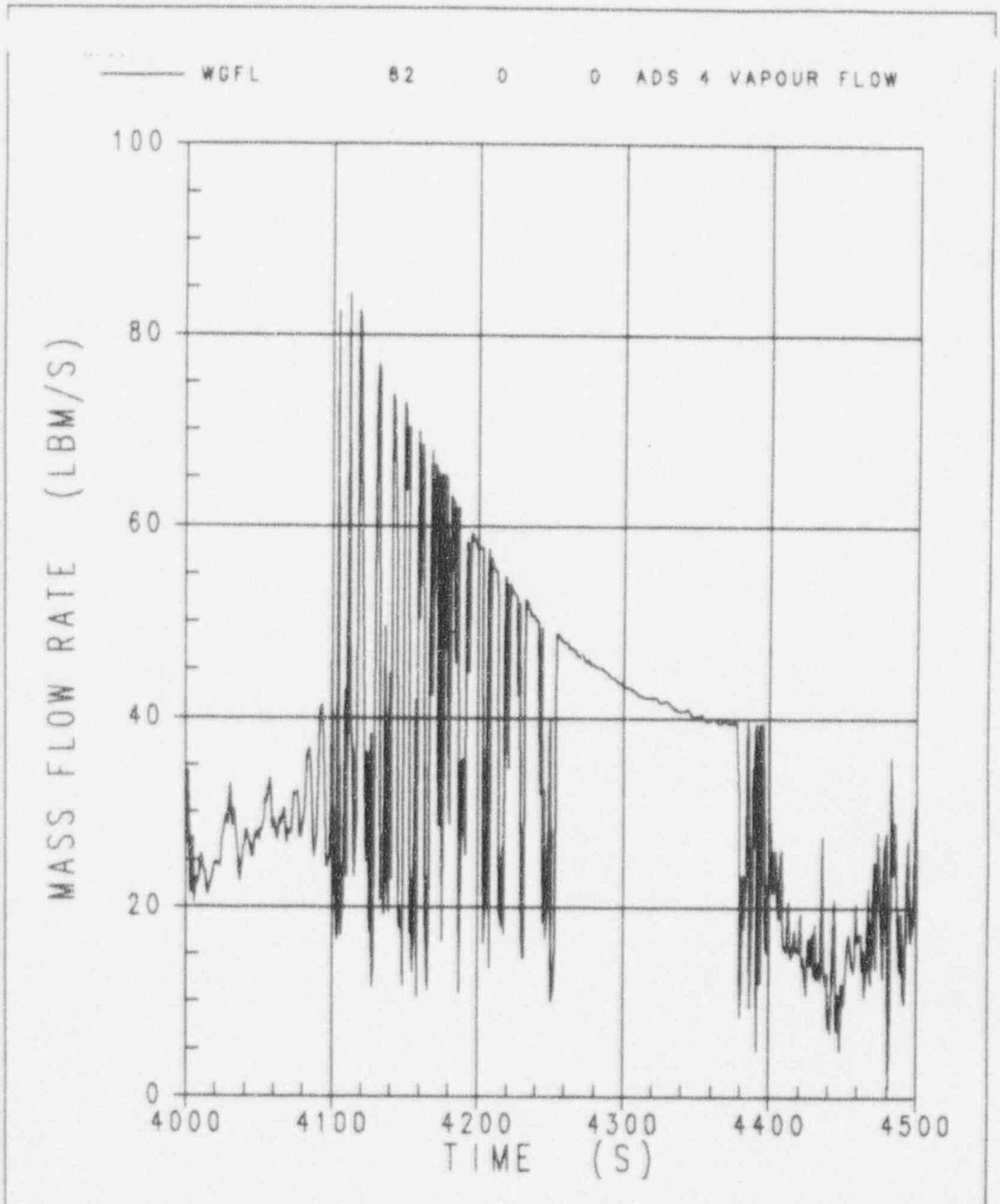
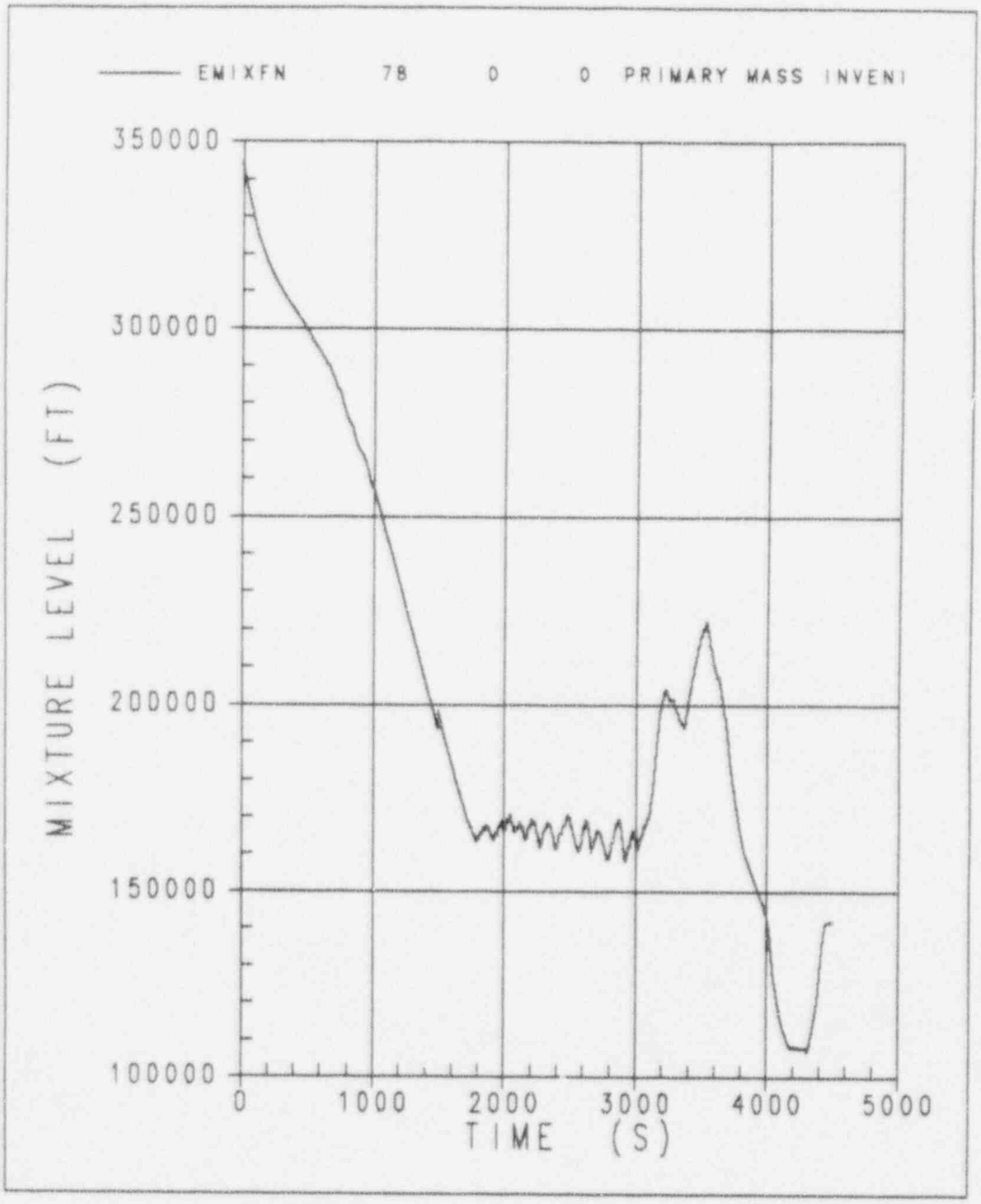


FIGURE 3.2-23
PRIMARY MASS INVENTORY, ONE INCH COLD LEG BREAK



# 4.0 SPES-2 Test Results

## 4.1 Introduction

Three small break LOCA tests which were performed in SPES-2, were evaluated to determine the effect, if any, of the elimination of the pressurizer to CMT balance lines.

Test S00203 was a simulated 2 inch cold leg break with operation of the passive safety systems. The Chemical and Volume Control System (CVCS), Normal Residual Heat Removal (NRHR), and Startup Feedwater System (SFW) were not operated during the event. Test S00203 was performed with the pressurizer to CMT balance lines modeled in the system.

Test S00303 was identical to S00203, with the exception that the pressurizer to CMT balance lines were removed from the system. Comparing these two tests should identify any effect of the line removal for a simulated 2 inch LOCA event.

Test S00401 was also a cold leg break but with a simulated 1-inch cold leg break. The pressurizer to CMT balance lines were removed in this test.

## 4.2 Comparison of 2 inch break with (S00203) and without (S00303) Pressurizer to CMT balance lines

### 4.2.1 Overall System Response

The two tests were nearly identical, with only a few distinguishing observations. From the initiation of the transient until ADS 1 occurs (at approximately 900 seconds), the pressure in the primary system was slightly higher for S00203 than for S00303. After ADS 1 and throughout the rest of the transient, the pressures were almost identical for the event. This higher pressure for S00203 was related to a higher temperature in the outlet plenum and hot leg (by about 6 °F) at the start of the transient lasting until ADS stage 1, which provides a higher saturation pressure in the upper plenum. The effect of the higher saturation pressure was seen in the pressurizer level, which for S00203 partially recovered between 200 and 700 seconds, while for S00303 stayed drained until ADS stage 1.

The temperatures at the top of the CMTs were affected by the CMT to pressurizer balance lines. With the pressurizer to CMT balance line (test S00203), the water temperature at the top of the CMTs increased more during the natural circulation mode of operation than without the balance line. The balance lines appeared to be supplying steam to the subcooled liquid in the CMTs. However, as long as the liquid in the CMTs was subcooled, the steam from the pressurizer was condensed, and no free surface (break of syphon) occured to initiate the CMT draining mode until the cold leg voided.

The system level events, such as ADS stages 1, 2, 3 and 4, and the transition from CMT natural circulation to injection mode occurred at almost identical times into the transient for the two tests.

### 4.2.2 Power Channel (PC) Benchmarks

Power channel benchmarking of events includes evaluation of the fluid levels in the PC upper head, the PC upper plenum, and the heater rod bundle (core).

For the 2" CL LOCA with pressurizer to CMT balance line (S00203), the level in the upper head decreased steadily from the initiation of the event, and by 900 seconds the upper head was drained and never reflooded during the transient.

The upper plenum above the hot leg drained rapidly after the initiation of the transient (approximately 112 seconds). The level recovered temporarily at the end of the accumulator injection, and permanently when the IRWST injection suppressed the boiling in the core (approximately 2300 seconds).

The level in the upper plenum did not drop below the hot leg level during the event, but due to significant boiling in the core (resulting in a high void fraction of the fluid), the collapsed level indicated a drop below the hot leg. The core was covered throughout this event by the fluid level in the upper plenum.

The level in the heater bundle (core) showed that boiling was occurring during the event, resulting in a high vapor void fraction of the fluid in the core (collapsed level of 11 to 12 feet vs. actual level of 17.4 feet, indicating a vapor void fraction of 30 to 40 percent). The boiling was temporarily suppressed by the injection from the accumulators which actually subcooled the fluid in the upper plenum, and by the injection from the IRWST later in the transient.

The transient responses in the PC fluid levels for S00303 were essentially identical to S00203.

The comparison between S00203 and S00303 indicates no detectable differences in the response to the 2 inch break, with and without the PRZ to CMT balance lines in the system.

## 4.3 Comparison between the 2 inch break tests (S00X03) and the 1 inch break test (S00401).

### 4.3.1 Overall System Response

The S00401 transient developed much slower than S00X03, and ADS stage 1 did not occur until approximately 4600 seconds into the event (compared to 900 seconds for S00303). The CMTs operated in the natural circulation mode for approximately 2500 seconds, before injection mode was initiated. The accumulator injection started with a very low flow at 2500 seconds, but the high flow injection did not occur until ADS stage 1 at 4600 seconds.

### 4.3.2 Power Channel Benchmarks

The 1 inch break drained the upper head slowly (3000 seconds), which stayed drained for the duration of the event.

The upper plenum above the hot leg drained during the first 500 seconds, and stayed essentially drained until the IRWST injection flow suppressed the boiling in the core (6500 seconds). The level then partially recovered for the duration of the event. The upper plenum level was flooded to the hot leg elevation for most of the event, but a vapor void fraction due to core boiling can be seen in the collapsed level. The accumulator injection suppresses the core boiling. During a subsequent period of active boiling (5500 to 6000 seconds), the level in the upper plenum dropped below the hot leg, however, the core was fully covered throughout the event.

The heater bundle (core) level showed boiling during the first 4500 seconds of the S00401 event, however, the vapor void fraction in the core was significantly less than for the 2 inch break (approximately 20 percent vs. 30 to 40 percent). After the accumulator injection a period of active boiling occurred (5500 to 6000 seconds), which resulted in a vapor void fraction of 42 percent in the core. This boiling was eventually suppressed when the IRWST injection started.

Figure 4-1 SPES-2 Test S00203; Pressurizer/CMT Pressure vs. Time

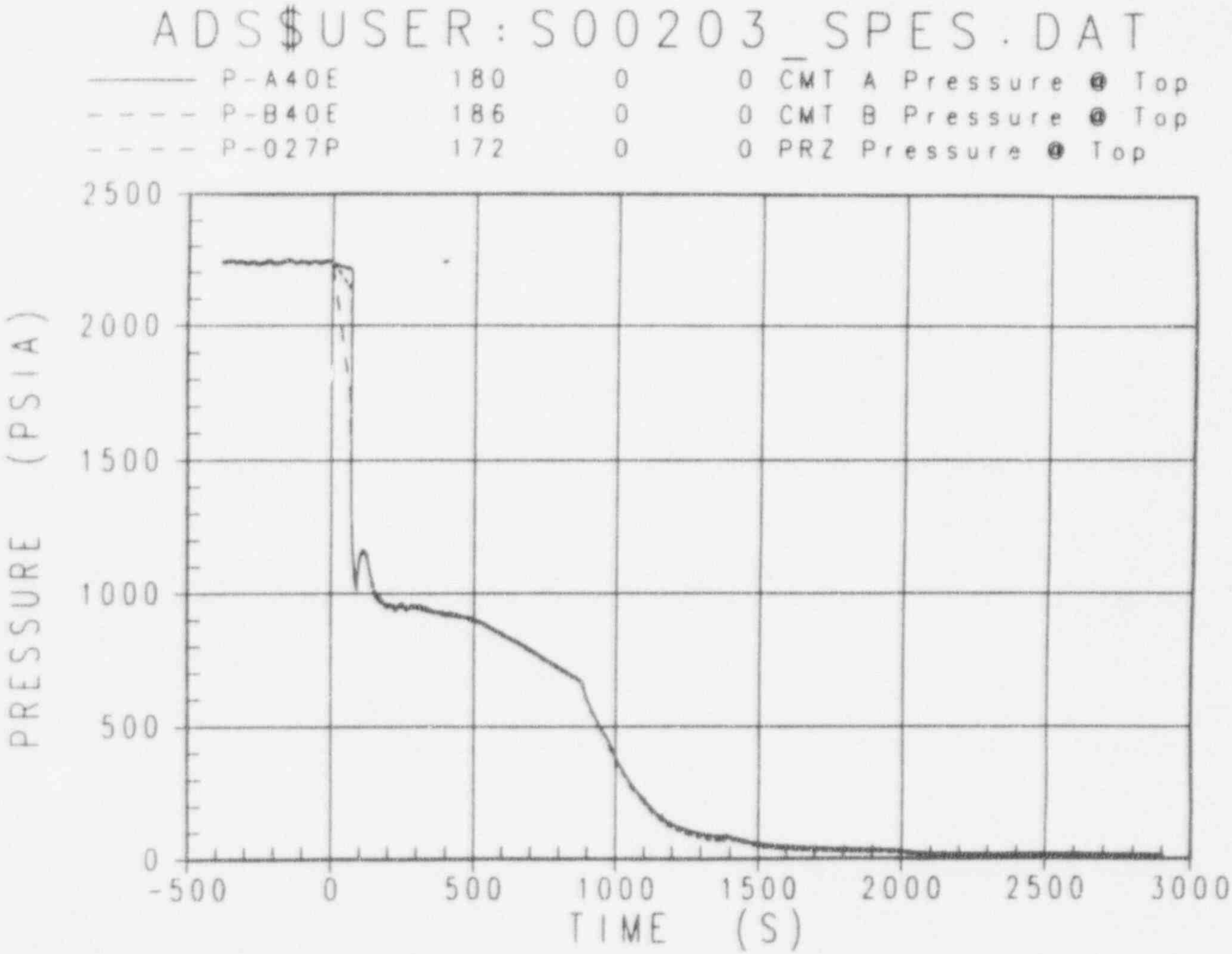


Figure 4-2 SPES-2 Test S00303; Pressurizer/CMT Pressure vs. Time

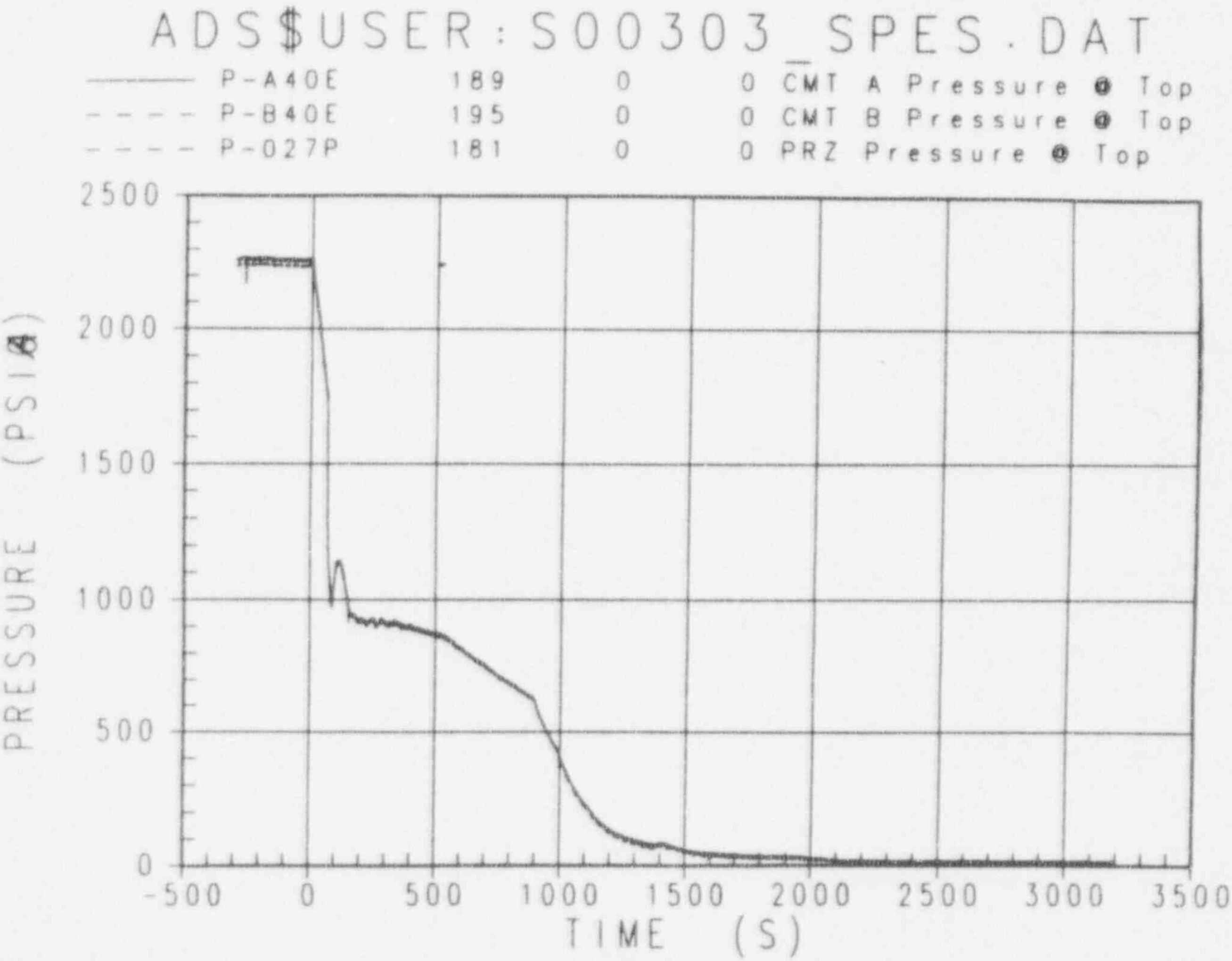


Figure 4-3 SPES-2 Test S00401; Pressurizer/CMT Pressure vs. Time

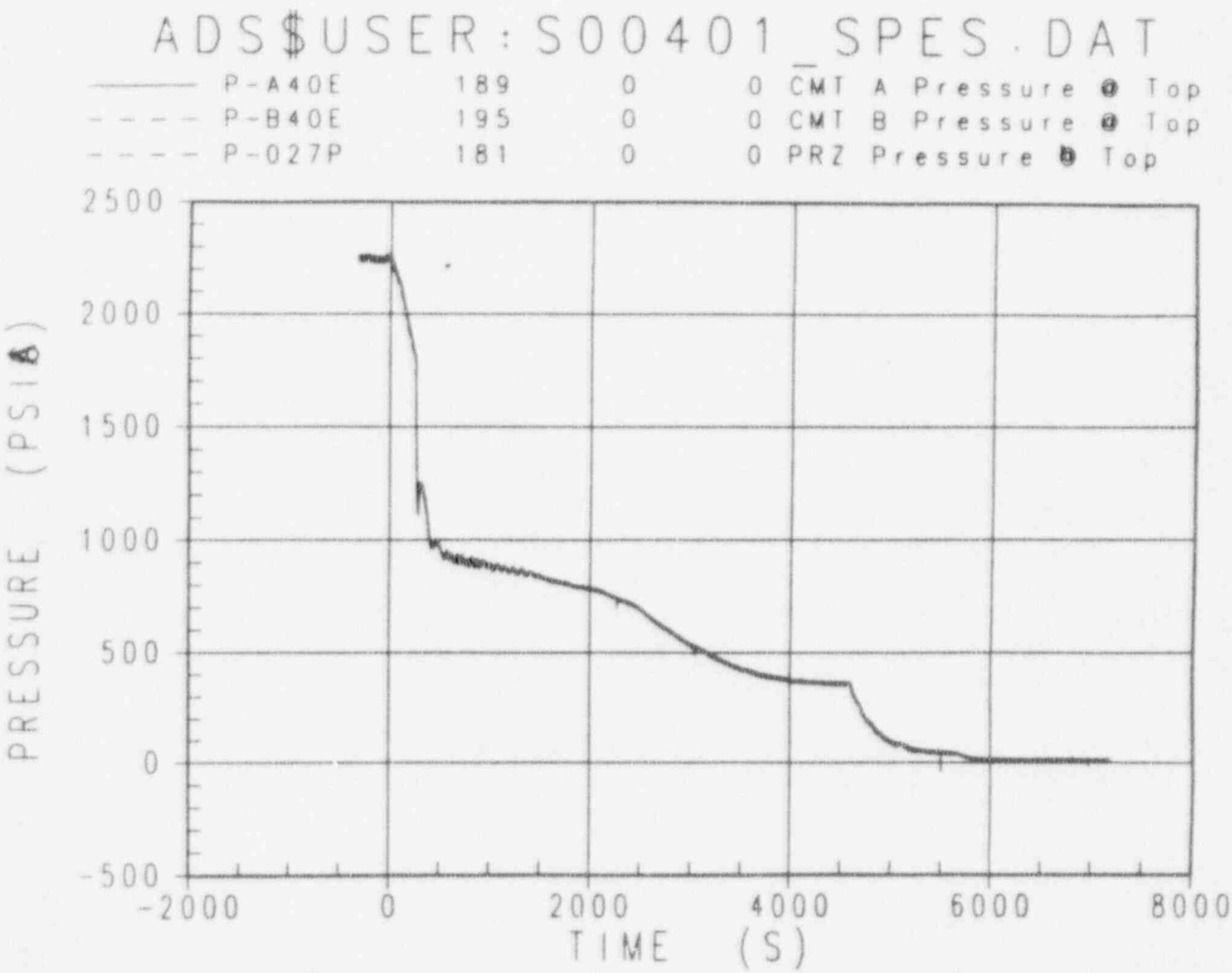


Figure 4-4 SPES-2 Test S00203; Upper Head Pressure vs. Time

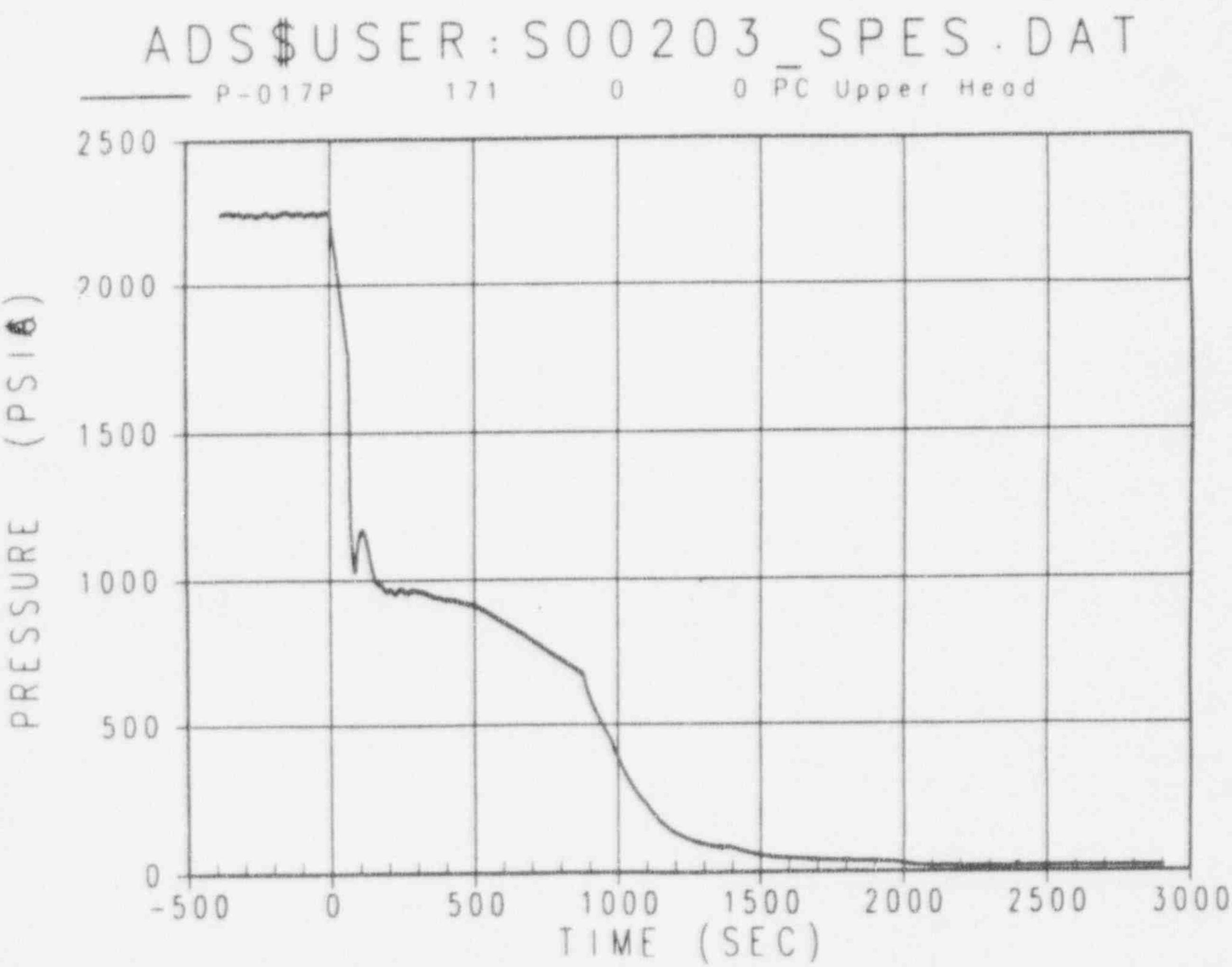


Figure 4-5 SPES-2 Test S00303; Upper Head Pressure vs. Time

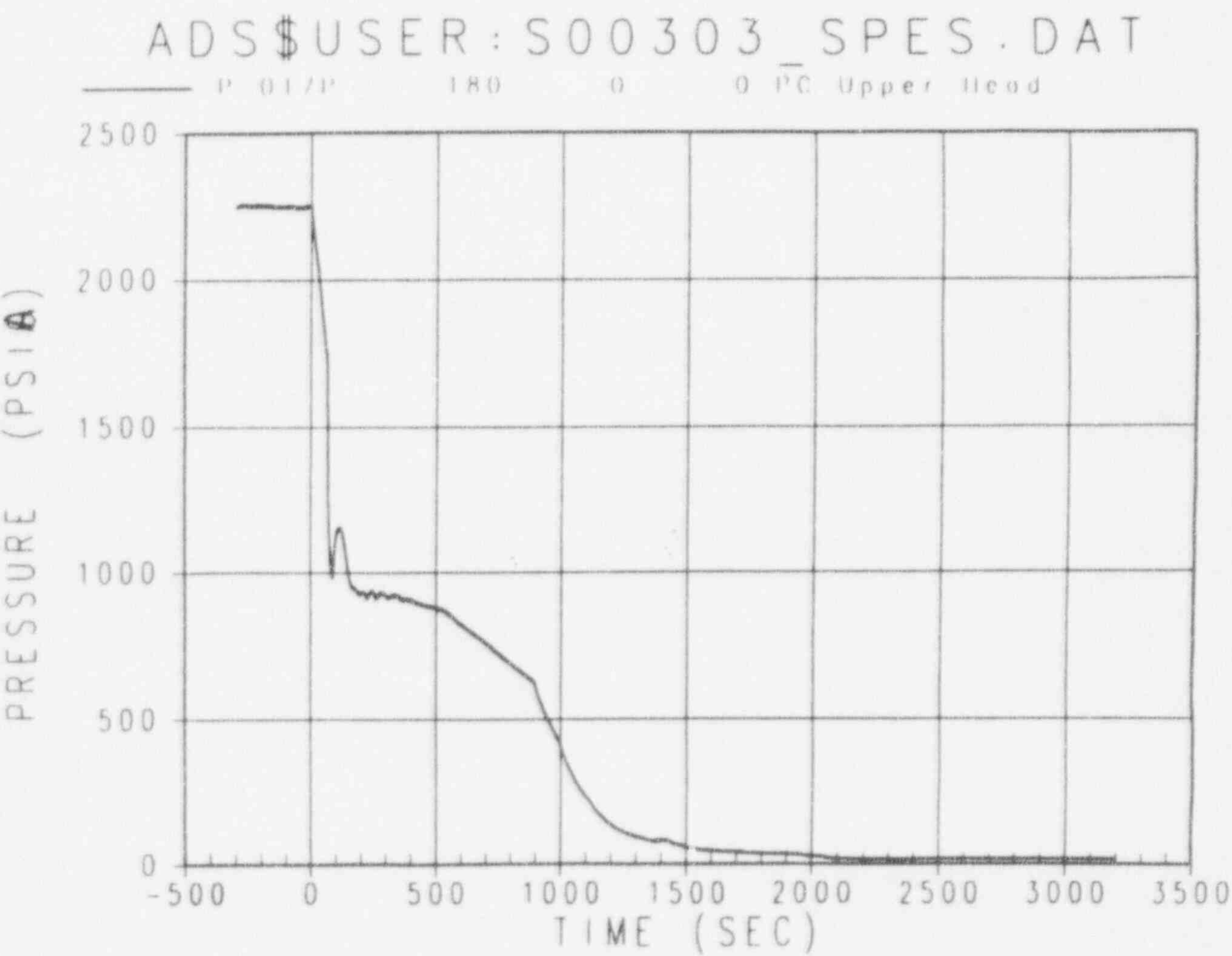


Figure 4-6 SPES-2 Test S00203; CMT B Temperature vs. Time

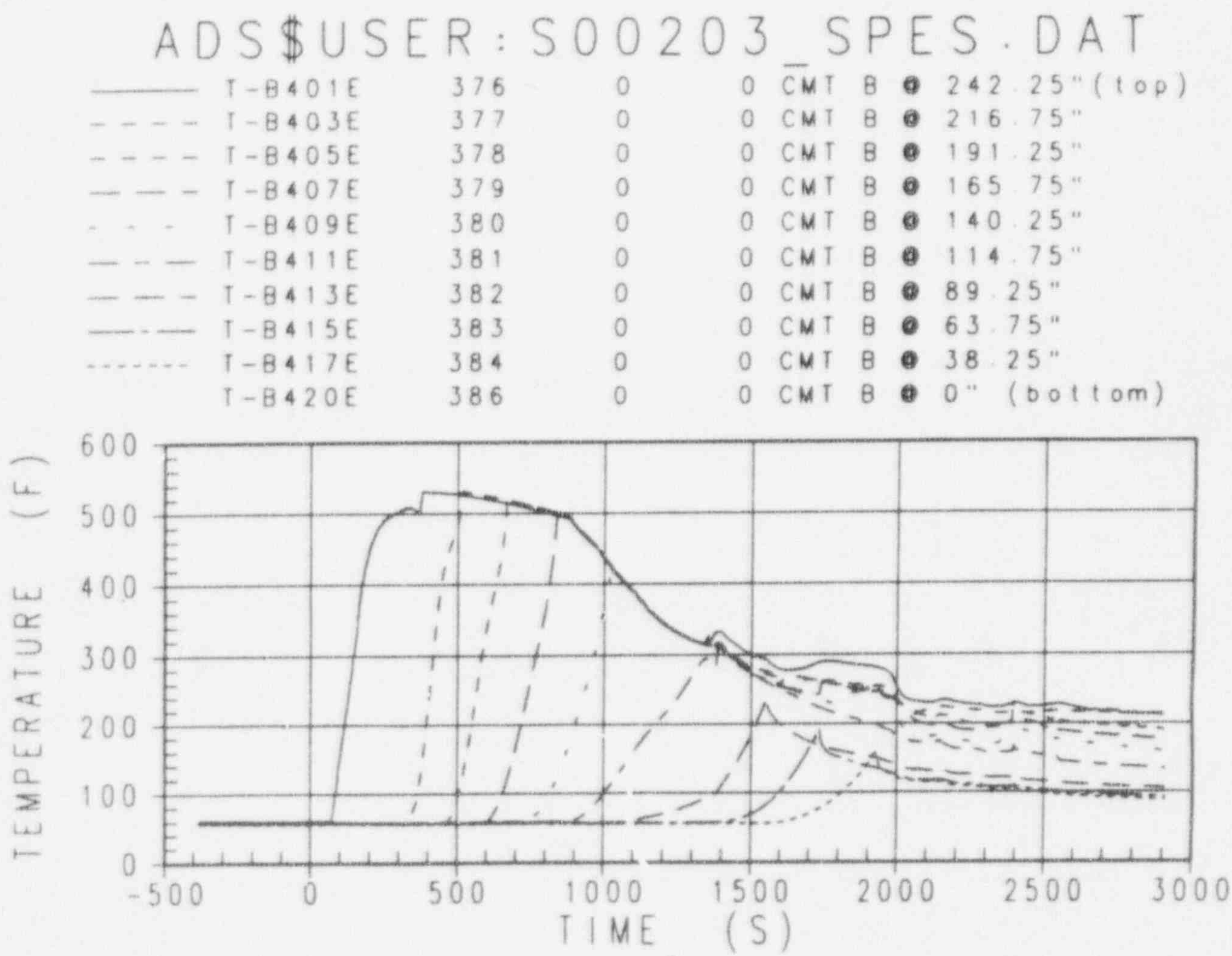


Figure 4-7 SPES-2 Test S00203; CMT A Temperature vs. Time

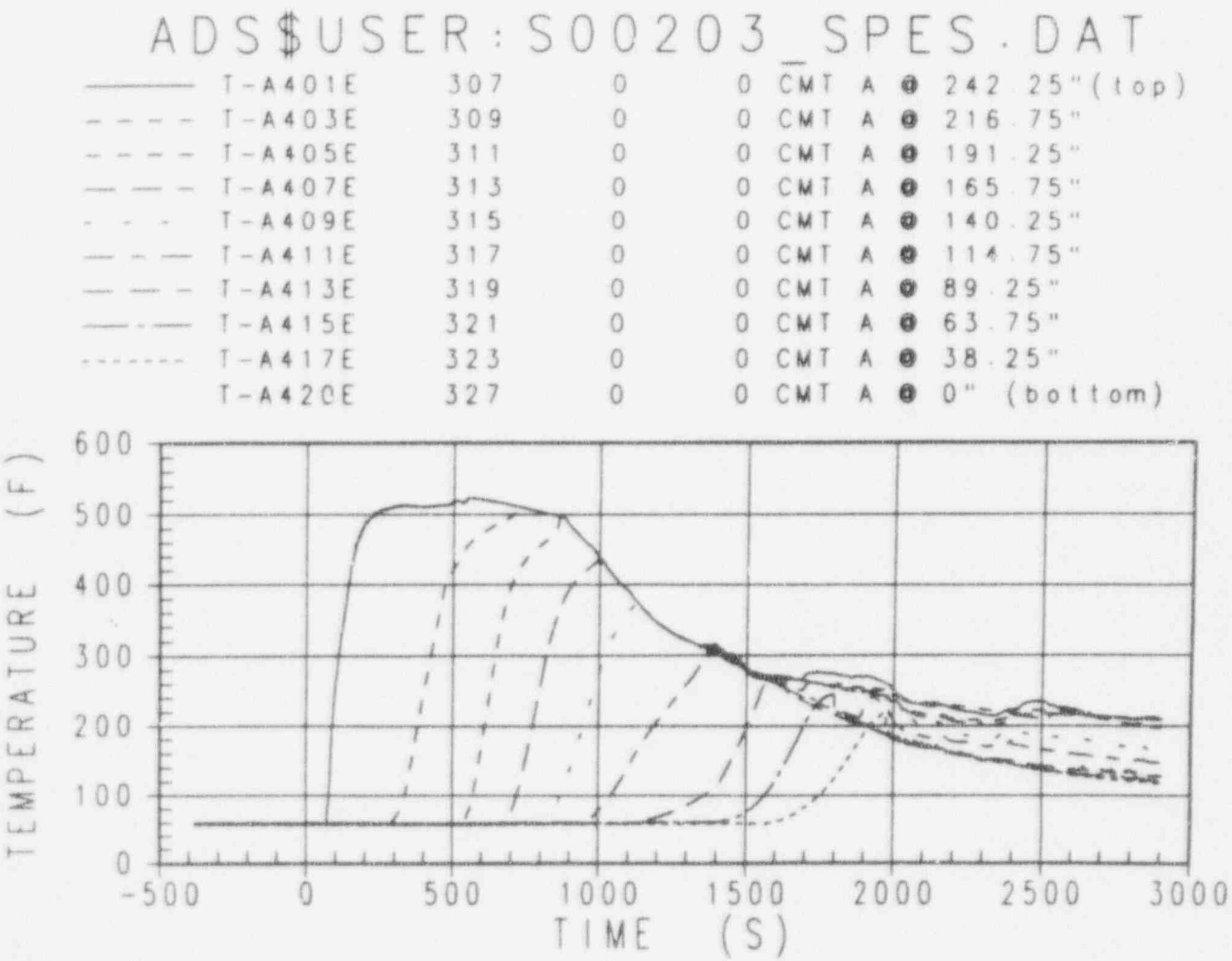


**Figure 4-8 SPES-2 Test S00303; CMT B Temperature vs. Time**

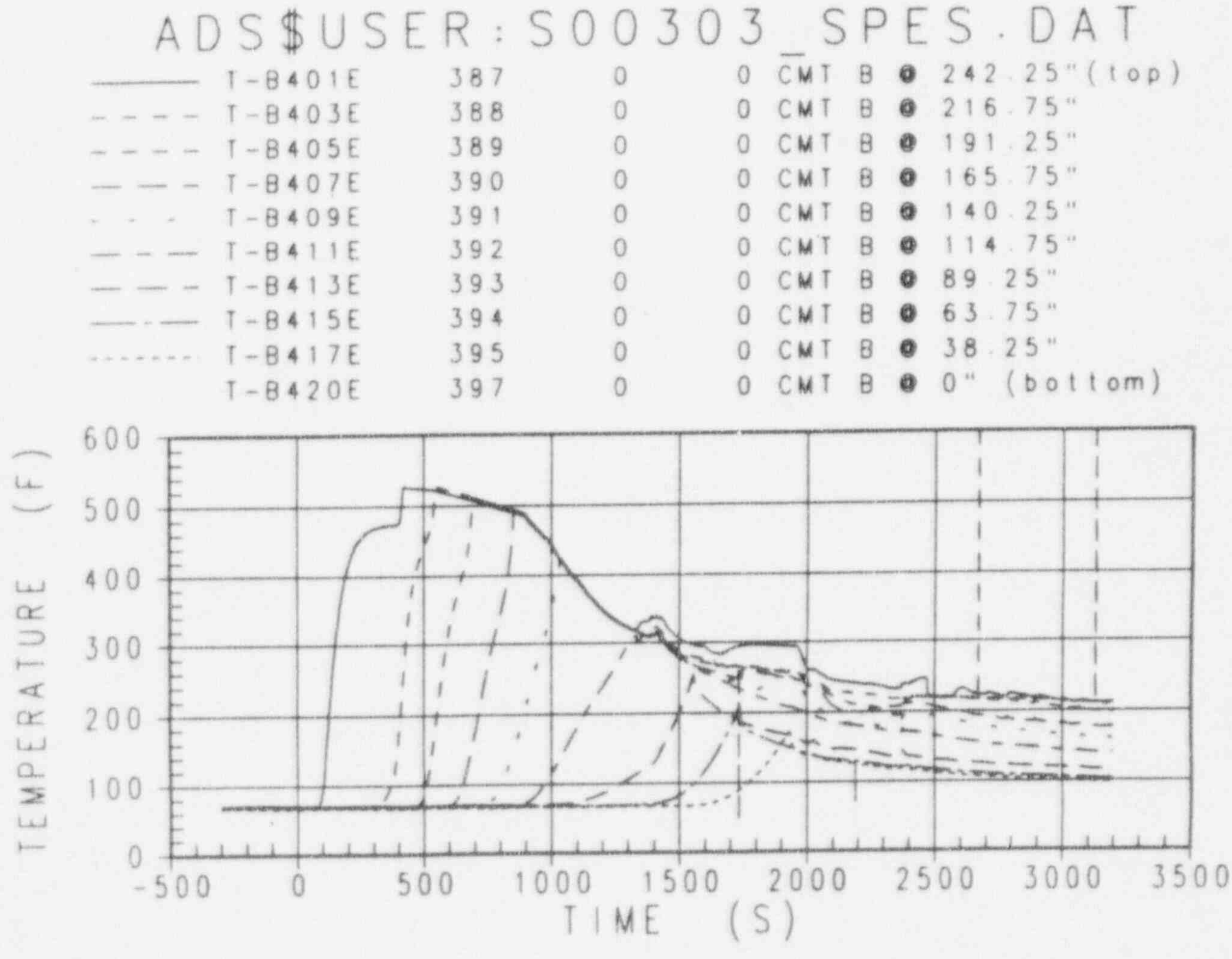


Figure 4-9 SPES-2 Test S00303; CMT A Temperature vs. Time

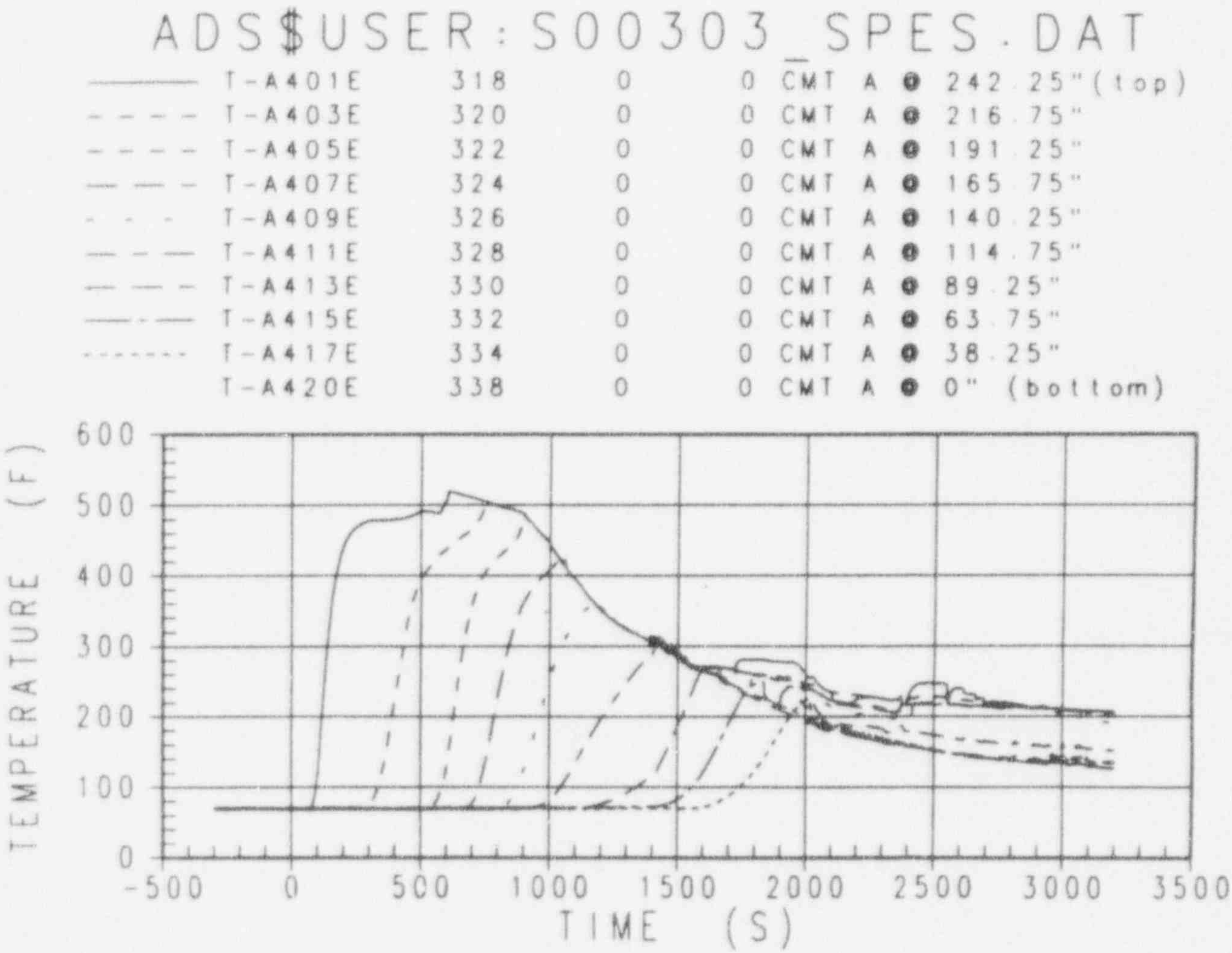


**Figure 4-10 SPES-2 Test S00203; RCS Liquid Levels vs. Time**

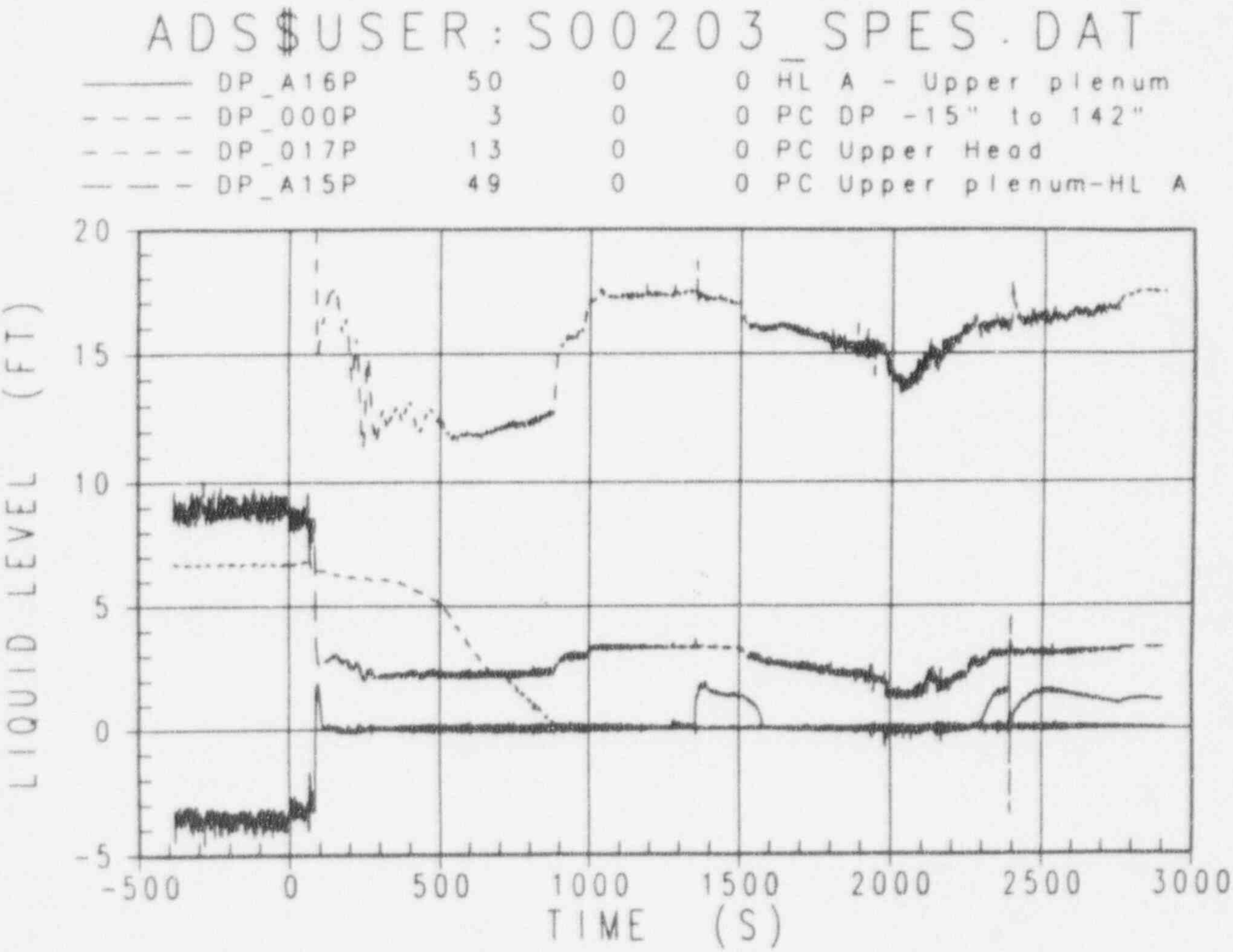


**Figure 4-11 SPES-2 Test S00303; RCS Liquid Levels vs. Time**

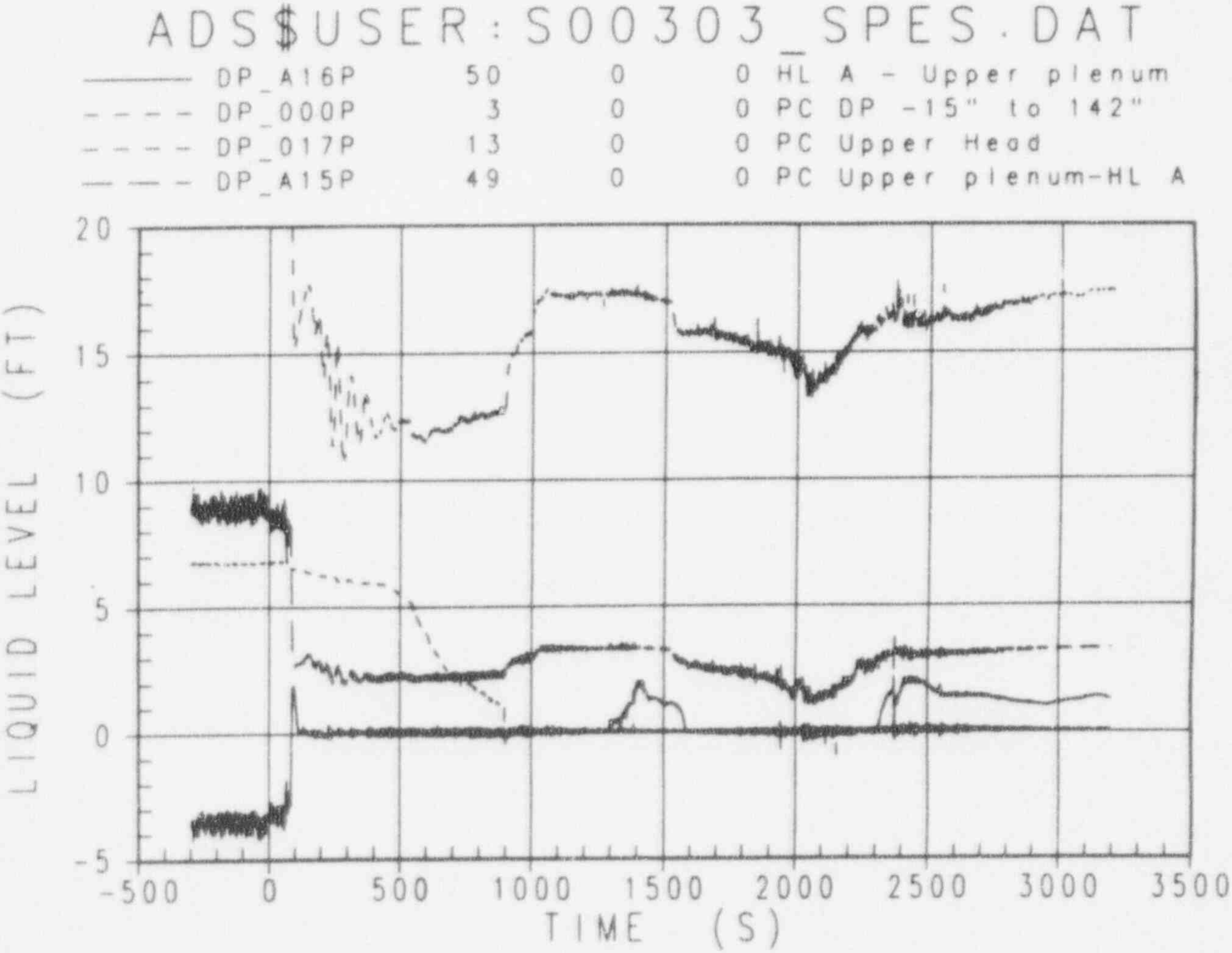


Figure 4-12 SPES-2 Test S00401; RCS Liquid Levels vs. Time

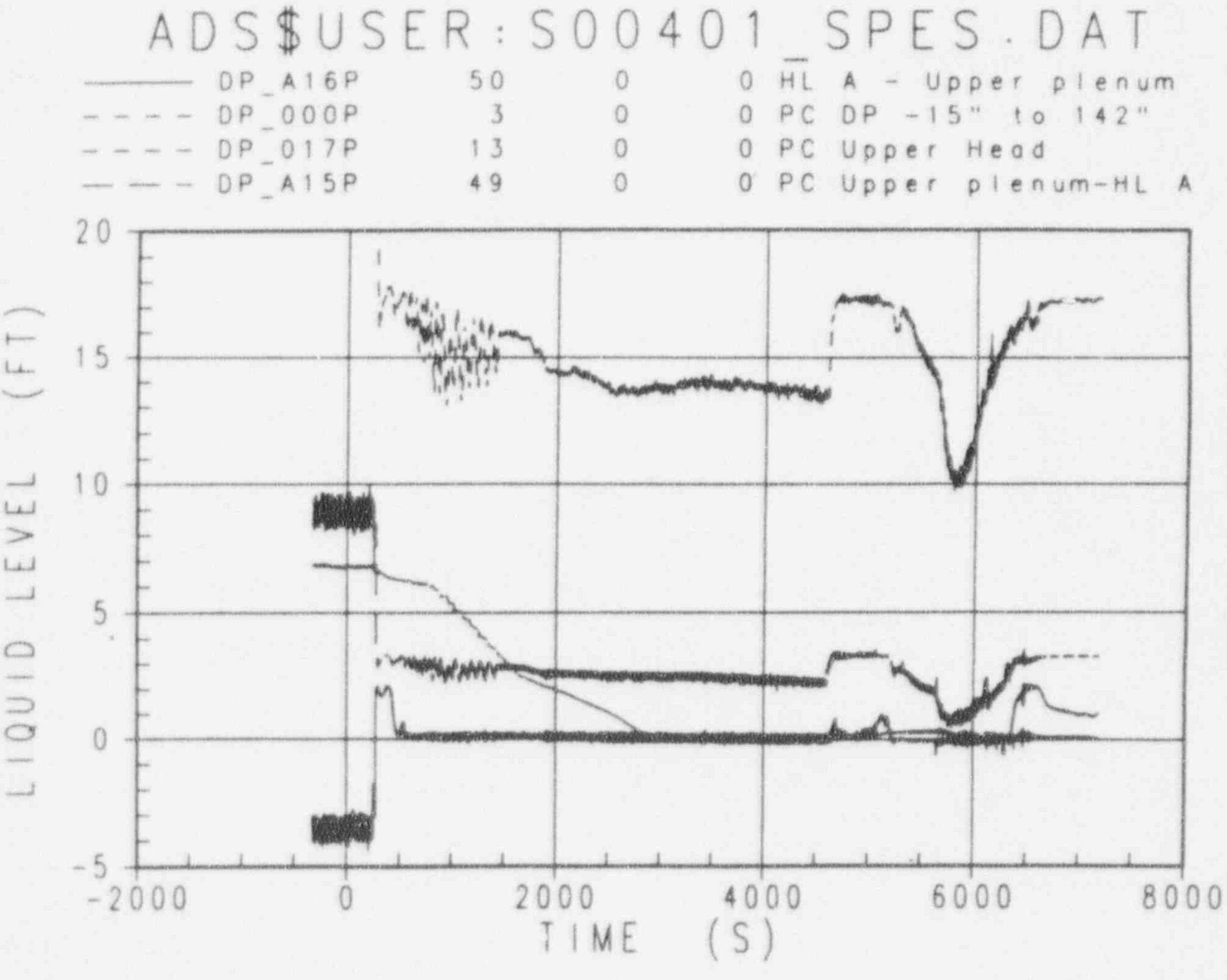


Figure 4-13 SPES-2 Test S00303; Integrated Mass Flows vs. Time

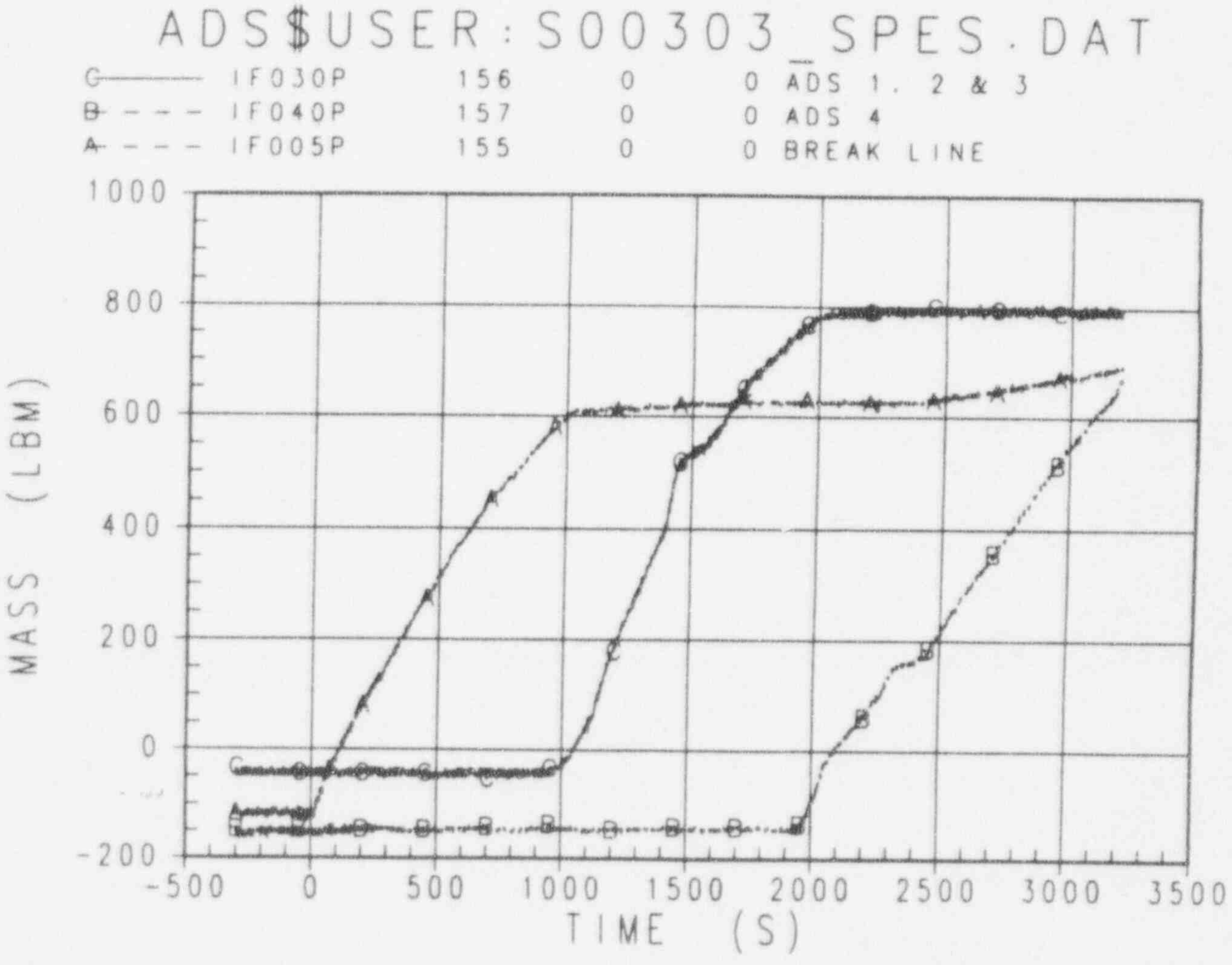
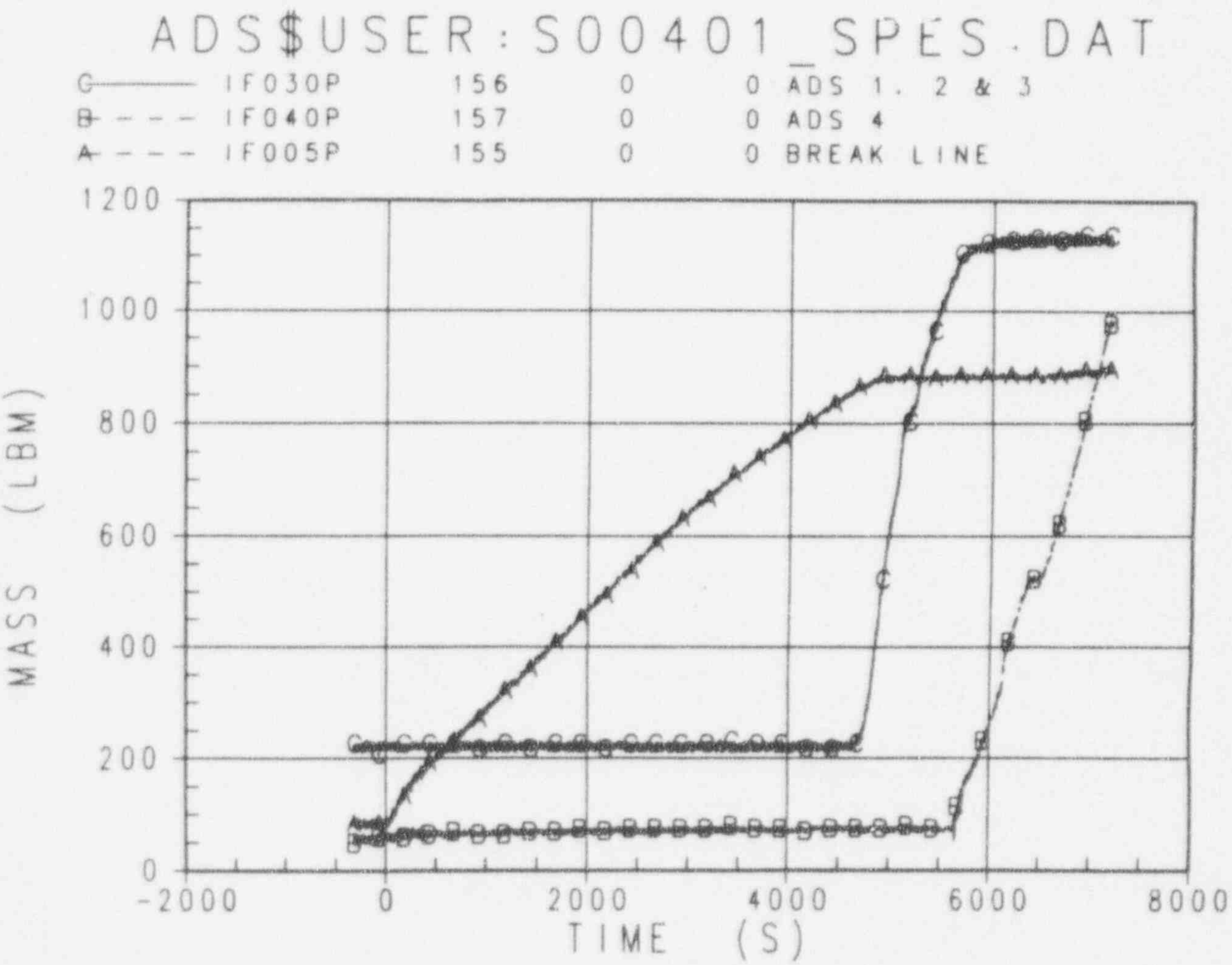


**Figure 4-14 SPES-2 Test S00401; Integrated Mass Flows vs. Time**



## 5.0 References


5.1 Document No. GWGL021, "Westinghouse AP600 Standard Safety Analysis Report", Revision 1, 1/13/94.

5.2 Document No. GWGL022, "Westinghouse AP600 Probabilistic Risk Assessment", Revision 0, 6/26/92.

5.3 AP600 Design Change Description Report, Enclosure to Westinghouse Letter NTD-NRC-94-4064, February 15, 1994.

5.4 Meyer, P.E., "NOTRUMP - A Nodal Transient Small Break and General Network Code," WCAP-10079-P-A, (Proprietary) and WCAP-10080-A (Nonproprietary), August 1985.

5.5 Lee, N., Rupprecht, S.D., Schwartz, W.R., and Tauche, W.D., "Westinghouse Small Break ECCS Evaluation Model Using the NOTRUMP Code," WCAP-10054-P-A (Proprietary) and WCAP-10081-A (Nonproprietary), August 1985.

APPENDIX A-1

MARKUP OF AP600 SSAR SECTION 6.3 -

PASSIVE CORE COOLING SYSTEMS

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## APPENDIX A-2

## MARKUP OF AP600 PXS AND RCS P&ID

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