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REVIEW OF TRAC CALCULATIONS FOR CALVERT CLIFFS PTS STUDY

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ABSTRACT

Six selected transient calculations out of thirteen performed by LANL using the TRAC-PF1 code for the USNRC PTS study of the Calvert Cliffs Nuclear Power Plant have been reviewed in depth at BNL. Simple hand calculations based on the mass and energy balances have been performed to predict the temperature and pressure of the reactor system, and the results have been compared with those of TRAC. Comparison was also made between the TRAC and RETRAN calculations for two of these transients, which were performed by ENSA. In general, the results calculated by TRAC appear to be reasonable based on the comparison with RETRAN and hand calculations.

EXECUTIVE SUMMARY

Brookhaven National Laboratory was requested by the USNRC to review the thermalhydraulic calculations performed by Los Alamos National Laboratory (LANL) and Idaho National Engineering Laboratory (INEL) as a part of an NRC program to study the Pressurized Thermal Shock safety issue. The thermal-hydraulic calculations for this study were performed at LANL and INEL using the latest versions of the TRAC-PWR and RELAP5 codes, respectively. This report presents the results of the BNL review of the selected transients calculated by LANL using the TRAC-PF1 code for the Calvert Cliffs Nuclear Power Plant.

LANL performed TRAC calculations for thirteen transients. TRAC input decks and steady-state results for these calculations were reviewed at BNL and a quick preliminary review of all thirteen calculations was also performed. No major discrepancies were found in the input deck or the steady-state calculations.

BNL selected six transient calculations out of thirteen performed by LANL for further in-depth review. In order to provide a quantitative review of these calculations, a simple method was developed at BNL to predict the primary system temperature on the basis of the overall energy balance. In this approach, the whole reactor system, including the secondary sides of the steam generators and the metal structures, is lumped into a single volume and represented by a single average temperature. It was shown that the primary temperatures calculated by TRAC were indeed in close agreement with those obtained by simple hand calculations for most transients. Since the primary and secondary pressures were more difficult to predict by simple analysis due to significant nonequilibrium effects involving condensation and evaporation, two limiting pressures based on adiabatic and equilibrium assumptions were calculated and compared with the TRAC-calculated pressure. The actual pressure is somewhere between these two extremes. It was found that the TRAC pressure was usually closer to the adiabatic than to the equilibrium pressure. The same approach was used to extrapolate the calculations and to predict the ultimate state of the system.

In general, the temperatures and pressures of the primary system calculated by TRAC have been found to be quite reasonable. The secondary pressures calculated by TRAC indicate that the TRAC code may have some difficulty with the condensation model and further work is needed to assess the code calculation of the U-tube steam generator pressure when the cold auxiliary feedwater is introduced into the steam generator. However, this uncertainty is expected to have no significant effect on the transient calculations.

ACKNOWLEDGMENT

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ABBREVIATIONS

ADV	Atmospheric Dump Valve
AFAS	Auxiliary Feedwater Actuation Signal
AFW	Auxiliary Feedwater
BG&E	Baltimore Gas and Electric Company
BNL	Brookhaven National Laboratory
HFP	Hot Full Power
HPI	High Pressure Injection
HZP	Hot Zero Power
LANL	Los Alamos National Laboratory
LOCA	Loss of Coolant Accident
MFRV	Main Feedwater Regulating Valve
MFW	Main Feedwater
MSIV	Main Steam Line Isolation Valve
ORNL	Oak Ridge National Laboratory
PORV	Power Operated Relief Valve
PTS	Pressurized Thermal Shock
SG	Steam Generator
SGIS	Steam Generator Isolation Signal
SIAS	Safety Injection Actuation Signal
TBV	Turbine Bypass Valve
TSV	Turbine Stop Valve
USNRC	U.S. Nuclear Regulatory Commission

1. INTRODUCTION

Rapid cooling of the reactor pressure vessel during a transient or accident accompanied by high coolant pressure is referred to as pressurized thermal shock (PTS). In late 1981 the U. S. Nuclear Regulatory Commission (NRC) designated PTS as an unresolved safety issue and developed a task action plan (TAP A-49) to resolve the issue.

The safety issue exists because rapid cooling at the reactor vessel wall inner surface produces thermal stresses within the wall. As long as the fracture toughness of the reactor vessel is high, overcooling transients will not cause vessel failure. However, NRC staff analyses (SECY-82-465) showed that certain older plants with copper impurities in vessel weldments may become sensitive to PTS in a few years as the nil-ductility transition temperature of the weld material gradually increases. The purpose of the thermal-hydraulic analyses presented in this report is to better understand the behavior of a plant during various kinds of postulated severe overcooling transients with multiple failures of equipment and without operator corrective action. The understanding gained from these detailed calculations will be used to interpolate coolant temperature and pressure responses in the downcomer for other postulated transients using a simplified mass-and-energy balance approach. For each of these postulated transients, Oak Ridge National Laboratory (ORNL) will then calculate the reactor vessel temperature distribution and stresses during the transient and the conditional probability of vessel failure if the transient should occur. ORNL will publish a report that integrates these results to estimate the likelihood of PTS driving a crack through the reactor vessel wall and to identify important event sequences, operator and control actions, and uncertainties.

This series of analyses is intended to provide information to help the NRC staff confirm the bases for the screening criteria in the proposed PTS rule (proposed 10CFR 50.61) and determine the content required for licensees' plant-specific safety analysis reports and the acceptance criteria for corrective measures.

The Nuclear Regulatory Commission (NRC) has selected three plants representing PWRs supplied by three vendors in the United States for detailed PTS study. These are: Oconee-1 (Babcock and Wilcox), Calvert Cliffs (Combustion Engineering), and H. B. Robinson (Westinghouse Electric). Oak Ridge National Laboratory, which is the lead contractor for the entire PTS study has identified several groups of transients with multiple equipment failure and with no corrective operator action which could lead to severe overcooling in these plants. The thermal-hydraulic calculations for these transients were performed at the Los Alamos National Laboratory (LANL) and the Idaho National Engineering Laboratory (INEL) using the latest versions of the TRAC-PWR and RELAP5 codes, respectively. The Oconee-1 transients were divided between LANL and INEL, with some transients common to both. The Calvert Cliffs and Robinson transients were assigned to LANL and INEL, respectively.

Brookhaven National Laboratory (BNL) was requested by the NRC to review and compare the plant input decks developed at LANL and INEL, and to review the calculation results. This report presents the results of the BNL review of the selected Calvert Cliffs calculations performed at LANL.

LANL performed TRAC calculations of thirteen transients, as shown in Table 1.1 [1].* Four of these, Transient Nos. 1, 2, 10, and 11, were steam line break accidents initiated from the hot zero power (HZP) condition. The remainder were various transients initiated from the hot full power (HFP) condition. TRAC input decks and steady-state results for these calculations were reviewed at BNL, and comments were transmitted to NRC, LANL, and ORNL study members in January 1984. Also, a quick preliminary review of all thirteen calculations was performed at BNL and a letter report was sent to the study members in February 1984. For the sake of completeness, copies of these communications are presented in Appendices A and C, respectively. Also included in Appendix B is the LANL response to the BNL review of the input decks and the steady state calculations. Six of the thirteen transients have been selected for detailed review at BNL: Transients 1 and 11 for the HZP condition, and Transients 3, 6, 7A, and 9 for the HFP conditions. The reasons for their selection are as follows:

1. All four HZP transients are steam line break accidents. Two are 1-ft^2 steam line breaks and the other two are full double-ended guillotine steam line breaks. Transients 1 and 11, representing one each from the two different break sizes, have been selected for this detailed review. The same transients were also calculated using the RETRAN code by ENSA for BG&E. Thus, a comparison between the TRAC and RETRAN calculations can also be made.

2. Basically, three different categories of transients were initiated from the HFP condition: (a) steam line break or valve failure (Transients 3, 4, and 4A), (b) small-break LOCA (Transients 7 and 7A), and (c) steam generator overfeed (Transients 6, 8, and 9). Transient 5 is a combination of primary and secondary failures (PORV and ADV stuck-open).

Transient 3 has been selected to represent the steam line break/valve failure transients. The break size of this transient (1 ft^2) is the same as that of Transient 1 of the HZP case, and this allows comparison of the same transients initiated at two extreme power levels. Transient 7A has been selected as representative of the small break LOCA transients, since Transient 7 involved artificial and thus unrealistic flow blockage of the primary loop. Transients 6 and 9 have been selected for the steam generator overfeed cases, representing the AFW and MFW overfeed, respectively.

In order to provide a quantitative review of the above TRAC calculations, a simple method has been developed to predict the primary system temperature based on the mass and energy balances. In this approach, the whole reactor system, including the secondary sides of the steam generators and the metal structures (unless otherwise mentioned), is lumped into a single volume and the energy balance is applied to that volume. However, separate mass balance

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*It should be noted that the transient calculations described in Table 1.1 were purely hypothetical and not necessarily probable. The transients were chosen to give as much insight as possible in a minimum set of calculations to the effect of certain operator and equipment failures, even when the probability of the combination of these failures was extremely low.

equations are used for the primary system and the secondary side of each SG. Details of this method can be found in Section 2 of Appendix D (Simple Approach). This approach assumes that the temperature differences between the cold and hot legs of the primary loops and between the primary and secondary sides of SGs are relatively small. It will be shown in this report that the primary temperatures calculated by TRAC were indeed in close agreement with those obtained by simple hand calculations for most transients.

The primary and secondary pressures have been more difficult to analyze with this simple approach, especially when the cold water is entering into the pressurizer or the secondary sides of the SGs. Due to the significant nonequilibrium effect, the pressure prediction depends largely on the condensation or evaporation rate, which is difficult to estimate by simple analysis. Many factors affect the condensation and evaporation rates, such as temperature of the liquid and vapor, mass flow rate, mixing of the incoming water with the bulk water, and the mode of heat transfer between the liquid, vapor and wall. Therefore, in some transient calculations, attempts have been made to compare the pressurizer water levels obtained by the TRAC and BNL simple calculations instead of the pressures. It has been observed that the trend of the pressurizer pressure calculated by TRAC closely approximates the trend of the water level in the pressurizer in many transients. Whenever possible and applicable, calculation for the pressurizer pressure has been based on the adiabatic and/or equilibrium assumptions (Section 4 of Appendix D, Pressurizer Model). The adiabatic approach assumes no mass and energy transfer between the liquid and vapor phases (no condensation or evaporation). The pressure thus calculated is expected to be the lower bound of the actual pressure when the pressurizer is being emptied and the upper bound when the pressurizer is being filled. On the other hand, the equilibrium approach assumes that the phases are in complete equilibrium, and it is expected to provide the upper bound pressure when emptying and the lower bound when filling. The actual pressure is expected to be somewhere between these two extreme pressures. It has been found that the pressure calculated by TRAC is usually closer to the adiabatic than to the equilibrium pressure.

A similar nonequilibrium effect has also been observed in the secondary side pressure of SG calculated by TRAC, especially when the SG is being filled with the cold auxiliary feedwater (AFW). In several transients, the secondary pressure remains high while the temperature declines. This indicates high nonequilibrium effect. It appears that further code assessment work is needed to verify the code calculation of the U-tube steam generator pressure when the cold auxiliary feedwater is introduced into it. However, this uncertainty is not expected to affect the transient calculations significantly.

A similar approach may be used for the extrapolation of the calculations if necessary. In fact, attempts have been made, whenever possible, to predict the ultimate state of the system beyond the calculated time.

Abbreviations such as TRAC temperature or BNL pressure are frequently used in the following discussion for convenience. They mean the temperature calculated by the TRAC code or the pressure obtained by the simple hand calculations by BNL staff, respectively.

Table 1.1 Calvert Cliffs PTS Transients

Transient No.	Descriptive Title	Initial Plant State	Initiating Event	Equipment Failures on Demand	Operator Actions
1.	1-ft^2 steam line break at standby	Hot 0% Power	1.0-ft^2 hole in steam line A	None	None
2.	Full double-ended guillotine steam line break	Hot 0% Power	Full steam line break	Auxiliary Feedwater (AFW) is not isolated	None
3.	1-ft^2 steam line break at full power	100% Power	1.0-ft^2 hole in steam line	None	None
4.	Turbine-trip with turbine-bypass valve (TBV) stuck open	100% Power	Turbine trip	TBV sticks wide open	None
4a.	Turbine trip with one TBV and one MSIV stuck open	100% Power	Turbine trip	TBV & MSIV stuck open	
5.	Primary power-operated & atmospheric-dump valve (ADV) stuck open	100% Power	PORV transfers to wide open	1 ADV opens on demand and sticks open	None
6.	AFW overfeed after AFW response failure	100%	MFW system trips	AFW delay for 20 min.	AFW valves opened fully at 20 min.
7.	Small break loss-of-coolant accident with blocked natural circulation	100% Power	An 0.02-ft^2 hole appears in the hot leg	None	None

Table 1.1 (cont)

Transient No.	Descriptive Title	Plant State	Initiating Event	Failures on Demand	Operation Actions
7a.	Small break LOCA with no artificial flow blockage	100% Power	An 0.02-ft^2 hole in the hot leg	None	None
8.	Main feedwater overfeed	100% Power	Turbine trip	2 MFRVs stick open	None
9.	Main feedwater overfeed to one SG	100% Power	Turbine trip	1 MFRV sticks open	None
10.	1-ft^2 steam line break with 2 RCPs left operating	Hot 0% Power	1.0 ft^2 hole in steam line	None	None
11.	Full double-ended guillotine steam line break	Hot 0% Power	Full steam line break	MSIVs fail to close	AFW turned off at 8 min.

2. TRANSIENT 1: 1-FT^2 STEAM LINE BREAK IN HZP CONDITION

This transient was initiated by a 1-ft^2 break at the main steam line during the HZP operation. No other equipment failure or operator action was assumed. The transient scenario as specified by ORNL is shown in Table 2.1. The initial steady state for the HZP calculated by TRAC is shown in Table 2.2

Figure 2.1 shows the downcomer liquid temperature calculated by TRAC with the system average temperature obtained by BNL hand calculation, as discussed in the previous section. Two BNL-calculated temperatures are shown in the figure. One is calculated with the assumption that heat transfer between the wall of the reactor (and other structures) and liquid is instantaneous and, thus, the metal temperature changes with the liquid temperature. The other calculation assumes that the heat transfer is so slow that the metal temperature does not change. The real temperature should be between these two extremes. The TRAC downcomer temperature initially agrees well with the temperature calculated without the metal mass accounted for, and then it eventually approaches that calculated with the metal mass accounted for, as expected. This indicates that the metal takes a considerably longer time to cool. The liquid temperatures calculated by TRAC at the various locations are shown in Figure 2.2, along with the BNL system average temperatures, with and without the metal heat transfer during the initial 1500 seconds. The figure shows that the downcomer temperature may be representative of the system average temperature and, again, both TRAC and BNL calculations agree very well.

Figure 2.3 shows the system pressures as calculated by TRAC and the BNL staff. The BNL pressure is calculated on the assumption of adiabatic compression during the filling stage. As discussed in the preceding section, the adiabatic assumption yields the highest rate of pressure increase during compression. The actual pressure is expected to be lower than this, as is the case in this calculation. The figure also shows, for comparison, the water level in the pressurizer as calculated by BNL. As expected, the pressure and the BNL water level behave similarly. However, the TRAC pressurizer level decreases while the TRAC pressure increases between 170 and 550 seconds, as shown in Figure 2.4. This appears to be contradictory.

Figure 2.5 shows the TRAC pressure of the secondary sides of both steam generators. The saturation pressures corresponding to the BNL average temperature and the TRAC intact steam generator temperature are also shown in the figure. These would be the expected pressures of the steam generators if the equilibrium condition prevails. The broken steam generator pressure stays at the atmospheric pressure as it becomes empty, as expected. However, the intact steam generator pressure remains much higher than the saturation pressure and also shows several sharp turns. A similar steam generator pressure response is observed in several other transients when the steam generator is being filled with cold AFW. This is apparently related to the severe non-equilibrium effect caused by the TRAC condensation model. It appears that the TRAC condensation model underpredicts the condensation rate and, thus, overestimates the non-equilibrium effect. However, this is not expected to alter the course of the rest of the transient significantly, since the SG pressure is not involved in the control of the system after the initial 100 seconds in this transient.

The TRAC calculation was terminated at 7200 seconds. After 7200 seconds, the system temperature is expected to continue to decrease until it eventually reaches 357°K, where the decay heat balances with the cooling by the charging and the AFW.

There is a corresponding RETRAN calculation performed by ENSA for BG&E available for this transient for the initial 1000 seconds. Figure 2.6 shows good agreement between the downcomer temperature calculated by RETRAN and those obtained by TRAC and BNL calculations. Figure 2.7 shows that the RETRAN pressure is virtually identical to the TRAC pressure, while the BNL pressure based on the adiabatic assumption is higher than these, as expected. Figure 2.8 compares the pressurizer water level for all three calculations. The results from the BNL and RETRAN calculations agree closely, while the TRAC level shows a somewhat contradictory trend between 170 and 550 seconds, as mentioned earlier. Figure 2.9 shows the pressure in the steam generators from both RETRAN and TRAC calculations. The saturation pressure corresponding to the system average temperature calculated by BNL is also shown in the figure. The BNL saturation pressure matches the broken SG pressures for both TRAC and RETRAN calculations very closely. However, the intact SG pressure for TRAC increases while the RETRAN pressure continues to decrease. As discussed earlier, further work is needed to clarify this uncertainty.

In summary, both TRAC and RETRAN codes present reasonable results except for the TRAC intact SG pressure, which may have an insignificant effect on the final results.

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

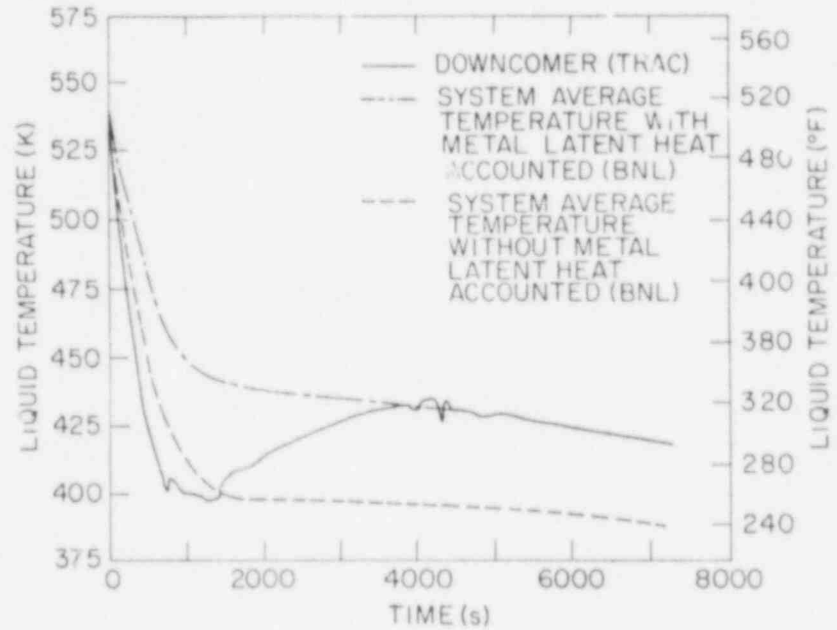

Figure 2.1 Transient 1: Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions

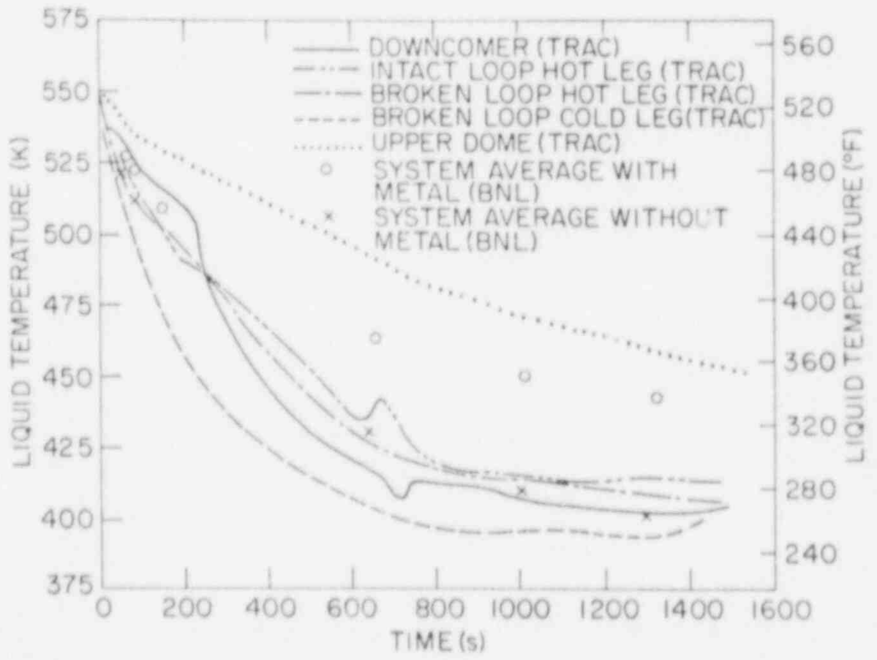

Figure 2.2 Transient 1: Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

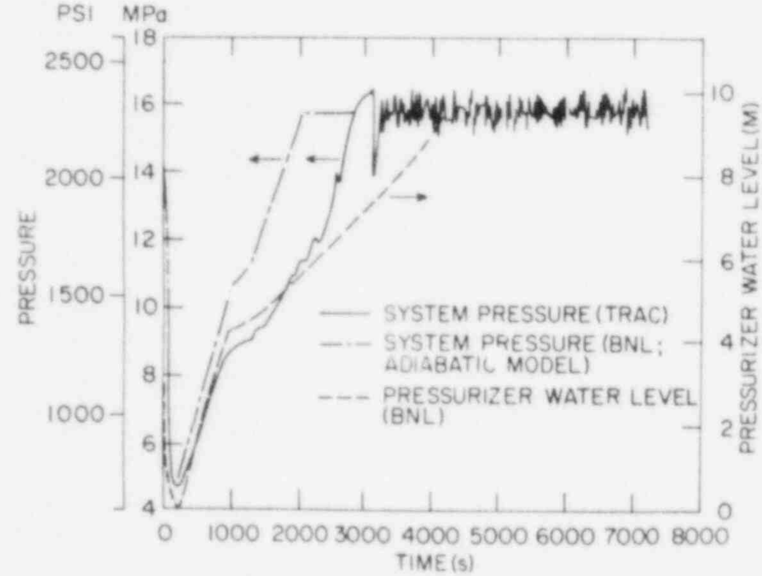

Figure 2.3 Transient 1: System Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

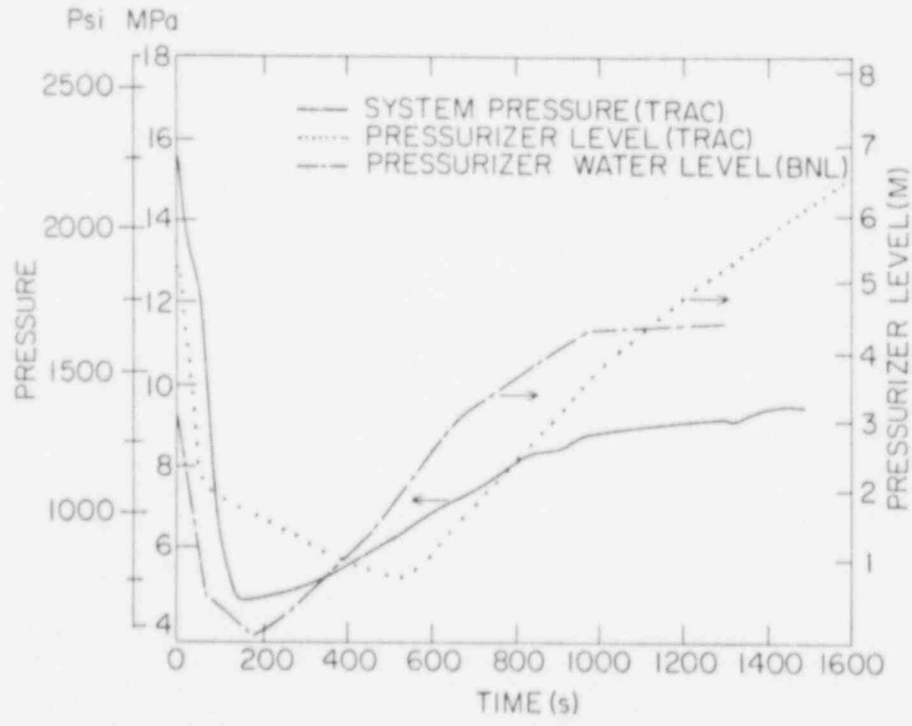

Figure 2.4 Transient 1: System Pressure and Pressurizer Level

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

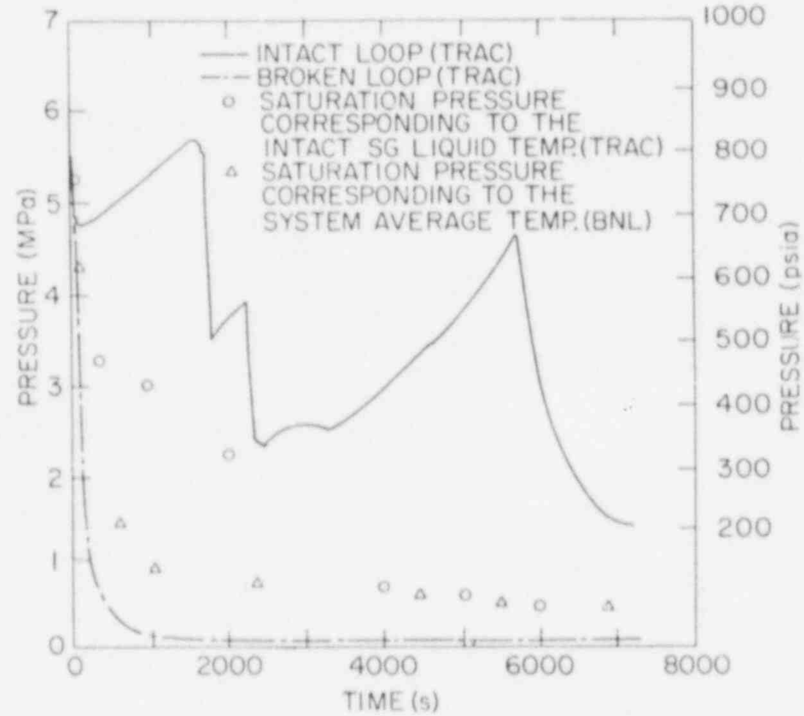

Figure 2.5 Transient 1: Steam Generator Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

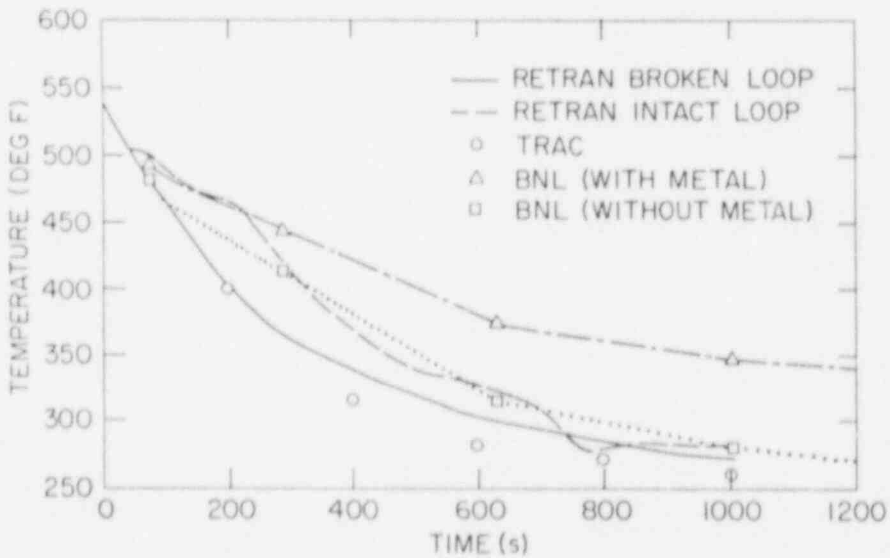

Figure 2.6 Transient 1: Liquid Temperature in the Downcomer

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

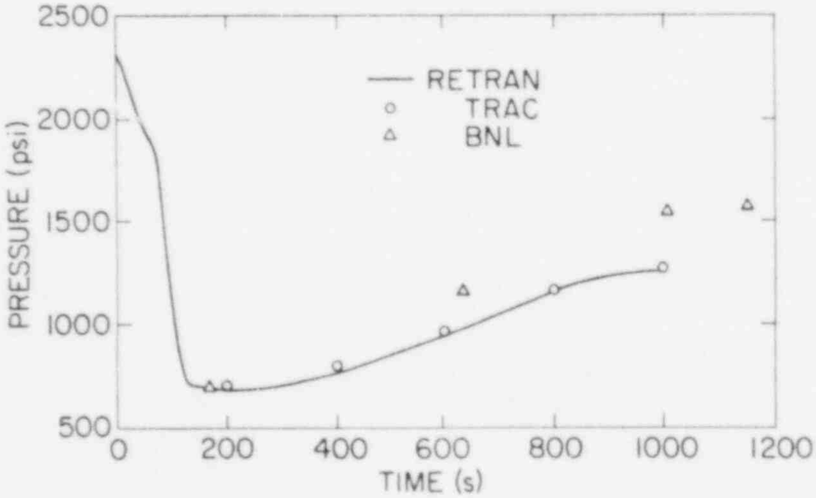

Figure 2.7 Transient 1: Pressure in the Vessel Downcomer

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

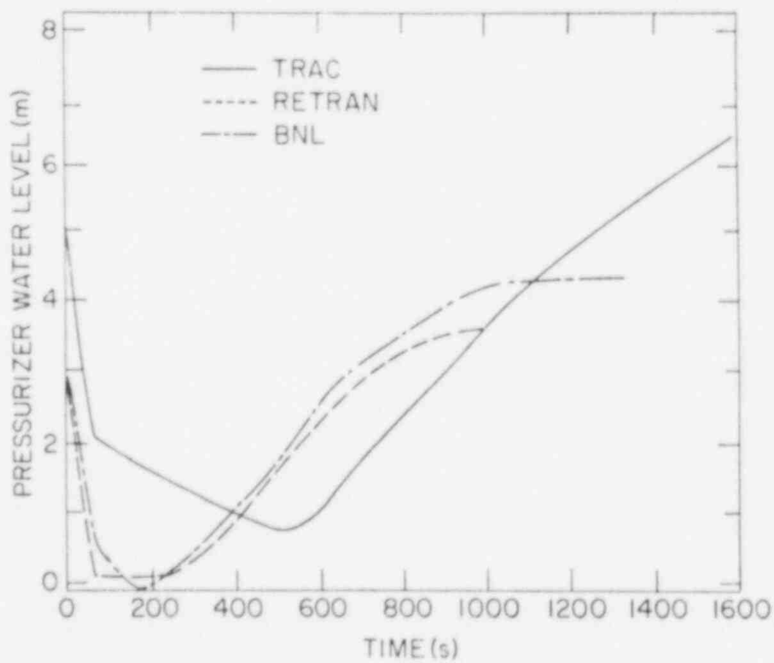

Figure 2.8 Transient 1: Pressurizer Water Level

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

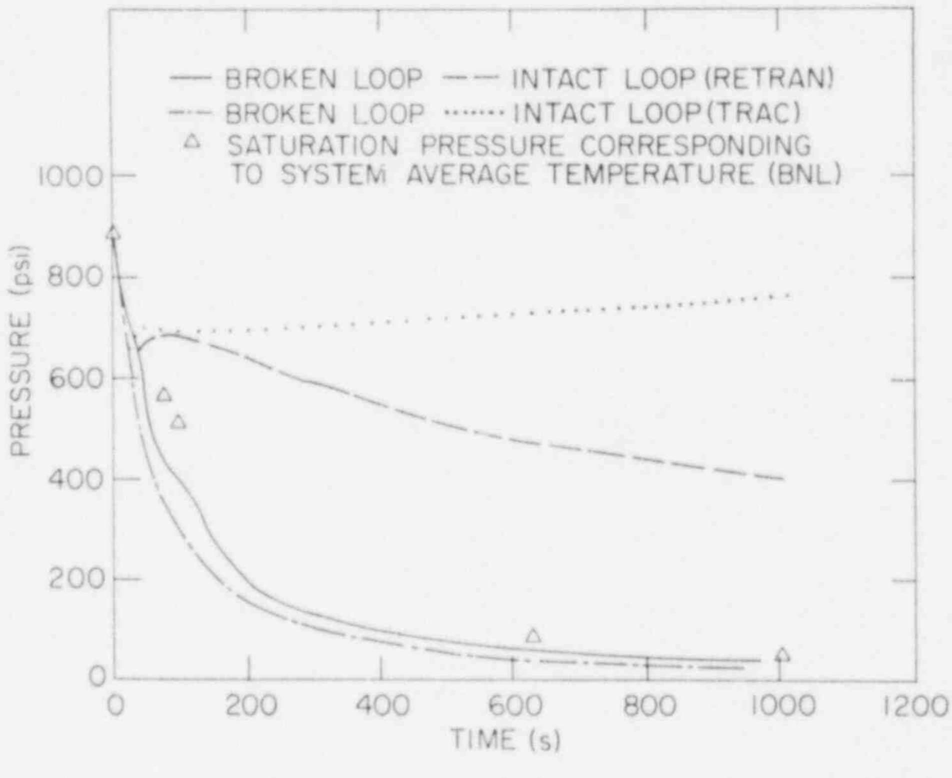

Figure 2.9 Transient 1: Pressure in the Steam Generators

TABLE 2.1 SCENARIO DESCRIPTION

TRANSIENT NO. 1

Plant Initial State - Just prior to transient initiator

General Description: Hot standby, 0% Power after 100 hr of shutdown
System Status
- Turbine: Not latched
- Turbine Bypass Valves (TBV): Automatic control
- Atmospheric Dump Valves (ADVs): Automatic control
- Charging System: Automatic control
- Pressurizer: Automatic control
- Engineering Safety Features: Automatic control
- Power Operated Relief Valves (PORVs): Automatic control
- Reactor Control: Manual
- Main Feedwater: In bypass mode, manual control to provide zero level in SGs; 1 condensate pump, 1 booster pump, 1 MFWP operating on steam supplied by unit 2.
- Aux Feedwater: Automatic control
- Main Stream Isolation Valves (MSIVs): Open, automatic control
- Main Feedwater Isolation Valves (MFIVs): Open, automatic control

Transient Initiator - A 1.0-ft^2 hole appears in steam line A outside containment upstream of the MSIV and downstream of the flow restrictor.

Equipment Failures which occur during the accident transient if the equipment is demanded.

None

Operator actions/inactions

a. Operator will turn off all RCPs 30 seconds after SIAS based on low pressurizer pressure.
b. Operator fails to turn off charging pumps prior to full repressurization.
c. Operator fails to control repressurization.
d. Operator fails to maintain level in intact SG.
e. Operator fails to respond to high SG alarm at 30".
f. Operator fails to respond to high SG alarm at 50".

TABLE 2.2
Comparison Between TRAC and Design/Plant at Hot Zero Power Conditions

		Design/Plant Data	TRAC Predictions
PRIMARY SIDE			
	Power 100 hr after shutdown		
	Decay Heat	-	9.38 MW
	Pump Power	-	17.38 MW
	Pressure	15.52 MPa (2250 psia)	15.52 MPa (2250 psia)
	Mass Flow	19300 kg/s (42,549 lb/s)	19700 kg/s (43,431 lb/s)
	Average Temperature	550.9°K (532°F)	551.8°K (533.6°F)
	Pressurizer Level	3.68 m (144.0 in)	3.68 m (144.0 in)
SECONDARY SIDE			
	Feedwater flow per SG	10.1 kg/s (22.3 lb/s)	11.8 kg/s (26.0 lb/s)
	SG Dome Pressure		
	SG 11 (TRAC component 22)	6.20 MPa (900 psia)	6.17 MPa (895.5 psia)
	SG 12	6.20 MPa (900 psia)	6.17 MPa (895.5 psia)
	Feedwater Temperature	299.8°F (80.0°F)	299.8°F (80.0°F)
	TBV % Open	-	5.0
	SG Liquid Mass	102,058 kg (225,000 lb)	102,058 kg (225,000 lb)

3. TRANSIENT 11: FULL DOUBLE-ENDED GUILLOTINE STEAM LINE BREAK WITH MSIV FAILURE TO CLOSE DURING HZP OPERATION

This transient is initiated by a full double-ended guillotine break in a steam line during the HZP operation. In addition, it is assumed that both MSIVs fail to close on SGIS and that the operator turns off the AFW system at eight minutes after the beginning of the transient. Transient scenario as specified by ORNL is shown in Table 3.1.

The major differences between this transient and Transient 1 are the additional failure of the MSIVs to close and the operator action to turn off the AFW. The break size is not considered to be a major difference, since the location of the break is downstream of the flow restrictor which is located at the exit of the SG.

Figure 3.1 shows the TRAC downcomer temperature and the BNL system average temperature. They match very closely. The reactor rapidly cools down and depressurizes due to blowdown of both SGs. The system temperature converges to the saturation temperature corresponding to the atmospheric pressure (373°K or 100°C) as the SGs dry out and depressurize to the atmospheric pressure. The blowdown continues and the system remains at this temperature until both SGs are finally empty. We estimate this time to be approximately 7800 seconds based on the energy and mass balance. Once SGs dry out, the temperature will slowly rise, since charging flow is not sufficient to balance the decay heat. It will eventually reach the steady-state temperature where the decay heat balances with cooling due to charging. We estimate this temperature to be approximately 545°K.

A substantial amount of water is entrained through the break in the beginning of the transient. This entrainment slows the rate of the temperature and pressure decreases. This may mean that the initial cooling could be somewhat faster or slower depending on the adequacy of the TRAC entrainment model. The entrainment will also affect the timing of the dryout of the steam generators. However, the effect of entrainment on the final outcome of this transient is not expected to be significant.

Figure 3.2 shows the TRAC primary pressure and the pressurizer water level from the TRAC and BNL calculations. They all show a consistent trend. As expected, the secondary side pressure of both SGs decreases approximately along the saturation pressure corresponding to the BNL system average temperature, as shown on Figure 3.3.

A corresponding RETRAN calculation performed by ENSA and BG&E is also available for the first 600 seconds of this transient. Figure 3.4 compares the downcomer temperature of the RETRAN, TRAC and BNL calculations. They all agree very well. Figure 3.5 shows significant deviation between the pressurizer pressures calculated by the TRAC and RETRAN calculations. The RETRAN pressure continues to decrease while the TRAC pressure increases after 200 seconds. This indicates that the RETRAN pressurizer model is closer to equilibrium than that of TRAC. Figure 3.6 shows that the RETRAN SG pressure matches that of a TRAC as well as the saturation pressure corresponding to the BNL average system temperature, as expected.

In summary, the calculated results of this transient by both codes appear to be very reasonable.

TABLE 3.1 SCENARIO DESCRIPTION

TRANSIENT NO. 11

Plant Initial State - Just prior to transient initiator

General Description: Hot standby, 0% Power after 100 hr of shutdown
System Status
- Turbine: Not latched
- Turbine Bypass Valves (TBV): Automatic control
- Atmospheric Dump Valves (ADVs): Automatic control
- Charging System: Automatic control
- Pressurizer: Automatic control
- Engineering Safety Features: Automatic control
- Power Operated Relief Valves (PORVs): Automatic control
- Reactor Control: Manual
- Main Feedwater: In bypass mode, manual control to provide zero level in SGs; 1 condensate pump, 1 booster pump, 1 MFWP operating on steam supplied by unit 2.
- Aux Feedwater: Automatic control
- Main Stream Isolation Valves (MSIVs): Open, automatic control
- Main Feedwater Isolation Valves (MFIVs): Open, automatic control

Transient Initiator - A full double-ended guillotine pipe break in steam line A upstream of the MSIV and downstream of the flow restrictor.

Equipment Failures which occur during the accident transient if the equipment is demanded.

Both MSIVs fail to close.

Operator actions/inactions

a. Operator will turn off all RCPs 30 seconds after SIAS based on low pressurizer pressure.
b. Operator fails to turn off charging pumps prior to full repressurization.
c. Operator fails to control repressurization.
d. Operator fails to maintain level in intact SG.
e. Operator fails to respond to high SG alarm at 30".
f. Operator fails to respond to high SG alarm at 50"...
g. Operator turns off the AFW at 8 minutes.
h. Operator fails to manually close the stuck-open MSIVs.

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

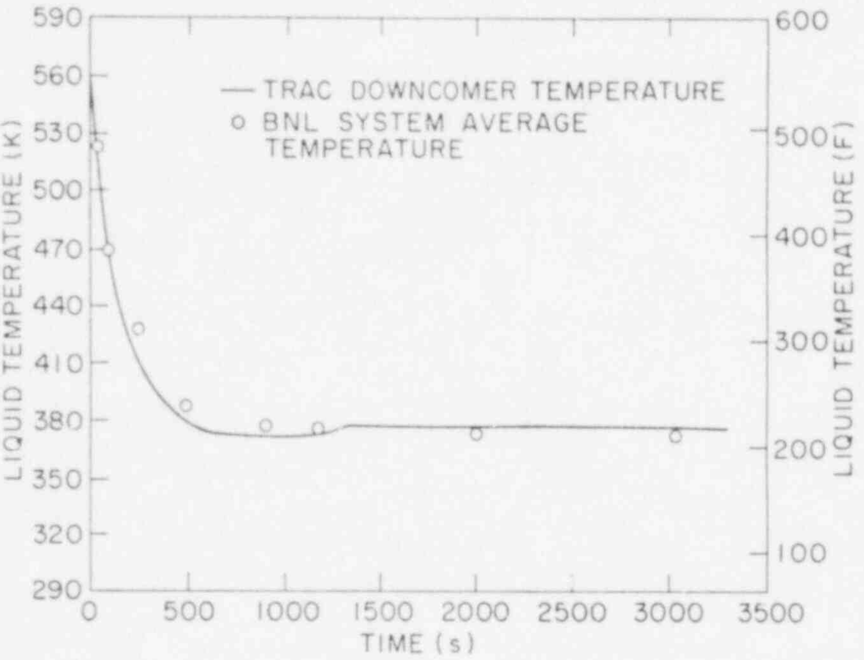

Figure 3.1 Transient 11: Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

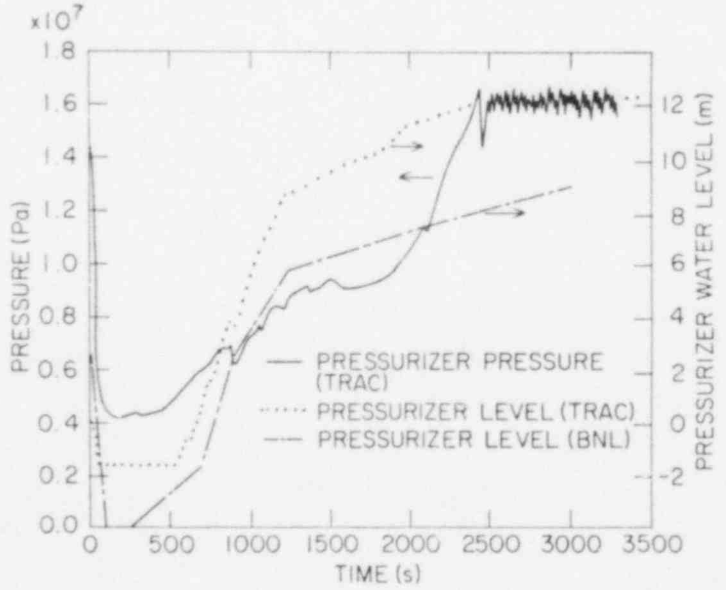

Figure 3.2 Transient 11: Pressurizer Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

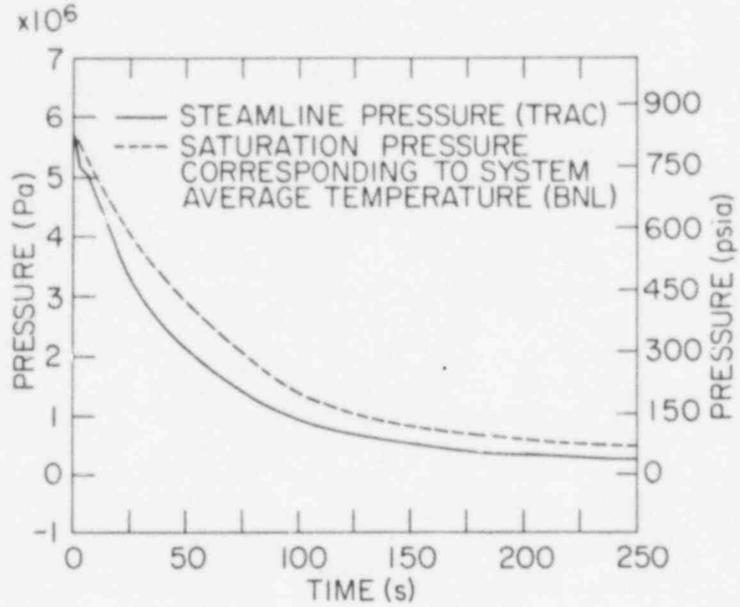

Figure 3.3 Transient 11: Steam Line Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

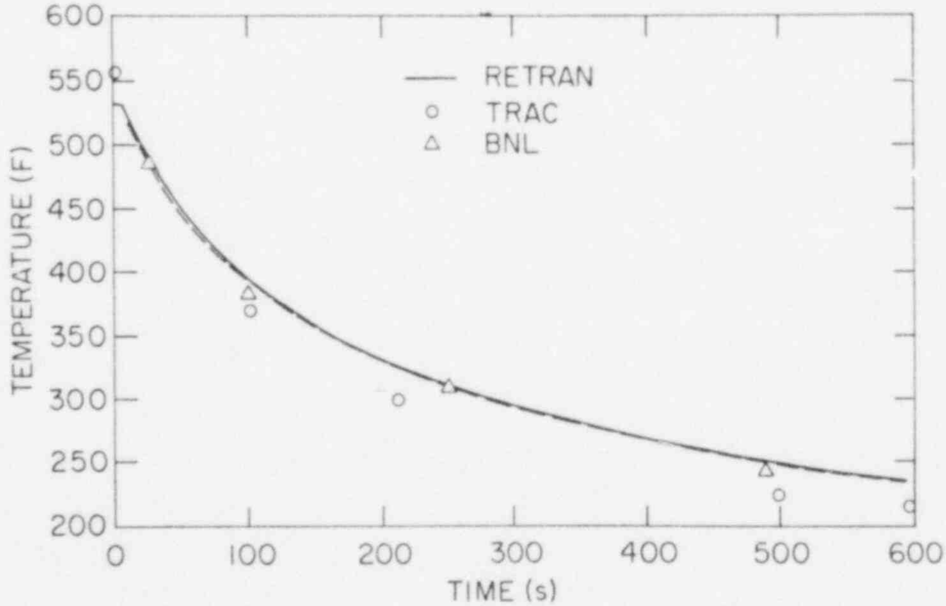

Figure 3.4 Transient 11: Temperature in the Vessel Downcomer

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

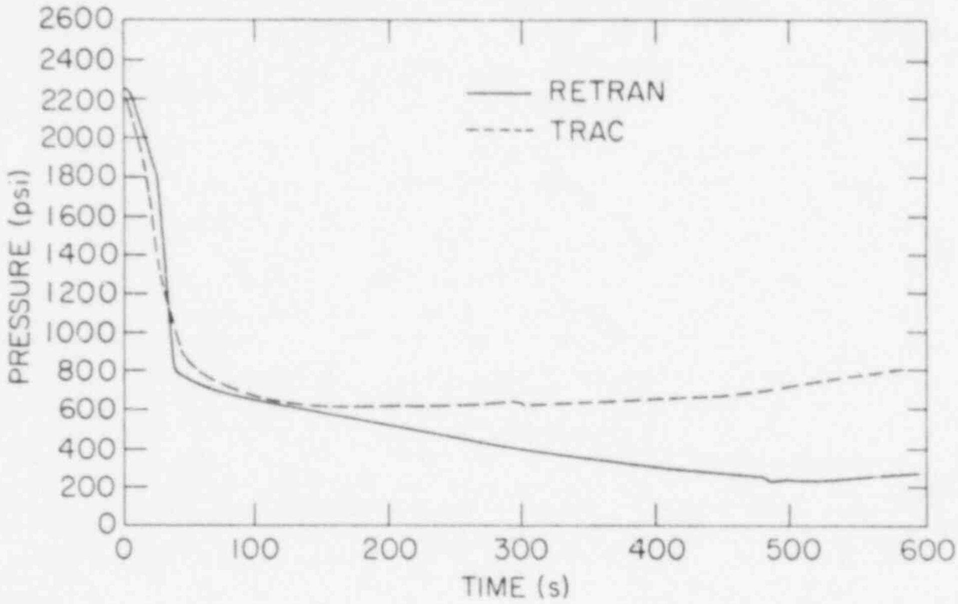

Figure 3.5 Transient 11: Pressurizer Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

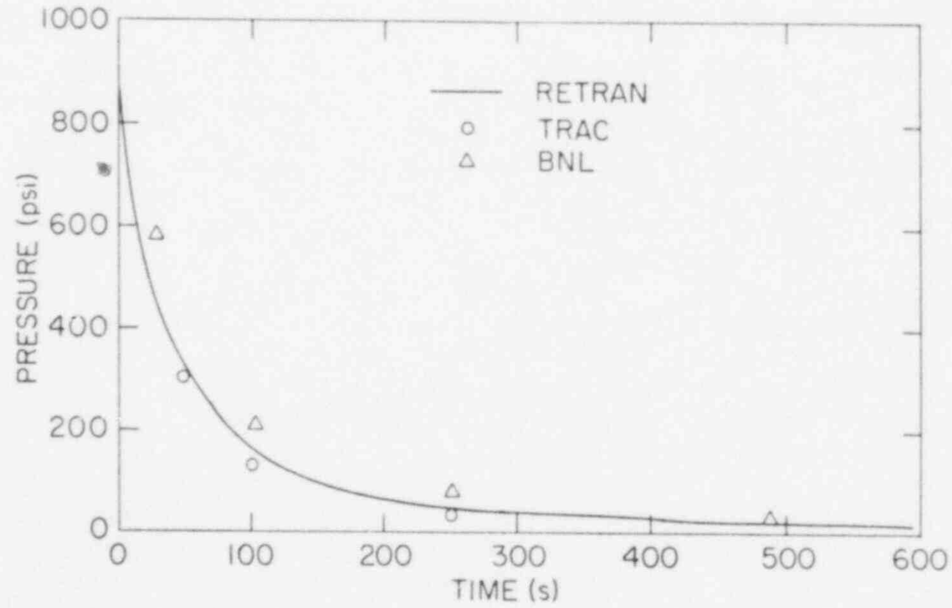

Figure 3.6 Transient 11: Pressure in the Steam Generators

4. TRANSIENT 3: HFP 1-FT^2 STEAM LINE BREAK IN HFP CONDITION

Transient 3, which is initiated by a 1-ft^2 break at the main steam line, is similar to Transient 1 except that it started during the HFP operation. In general, the course of the transient is also similar to that of Transient 1. Table 4.1 shows the transient scenario as specified by ORNL. The initial steady state for HFP operation is presented in Table 4.2.

Figure 4.1 compares the total steam flow from the steam generators including break flow for both transients. The steam flow rate is higher for Transient 3 due to the higher initial energy level (higher average temperature) and higher decay heat production for the HFP condition. However, the initial water inventory is less for Transient 3. These combined effects cause the broken SG to become empty much faster than for Transient 1. Figure 4.2 shows the TRAC downcomer temperature and the BNL system average temperature. As in Transient 1, the BNL average temperature is initially higher than the TRAC temperature due to the delayed cooling of metal walls, but they eventually converge. As expected, the minimum temperature is much higher in Transient 3 than in Transient 1 owing to higher initial temperature, higher decay heat, and less initial water inventory in the SGs. Once the SG dries out, the temperature starts to slowly increase, since the decay heat production is still higher than the cooling by HPI and AFW. The temperature is expected to continue to increase at an estimated rate of 1.5°C for every 1000 seconds until it reaches approximately 535°K around 6000 seconds, and then start to decrease slowly owing to decreased decay heat production. Figure 4.3 shows the TRAC and BNL primary pressures and BNL pressurizer water level. The TRAC pressure agrees very closely with the BNL pressure which represents the highest rate of pressure rise due to the adiabatic compression assumption. The pressure in this transient is expected to be closer to adiabatic conditions than in Transient 1, since the temperature of the water surging into the pressurizer is higher and is increasing.

Figure 4.4 shows the TRAC pressure in the SG secondary sides and the saturation pressure corresponding to the BNL average temperature. As expected, the broken SG pressure stays at the atmospheric pressure as it becomes empty. The intact steam generator pressure also agrees well with the saturation pressure, contrary to Transient 1, where a severe nonequilibrium effect is exhibited in the intact steam generator. The intact SG is estimated to be completely full at about 550 seconds.

In summary, the TRAC calculation of this transient appears to be reasonable.

TABLE 4.1 SCENARIO DESCRIPTION

TRANSIENT NO. 3

Plant Initial State - Just prior to transient initiator

General Description: 100% Power steady state
System Status
- Turbine: Automatic control
- Turbine Bypass Valves (TBV): Automatic control
- Atmospheric Dump Valves (ADVs): Automatic control
- Charging System: Automatic control
- Pressurizer: Automatic control
- Engineering Safety Features: Automatic control
- Power Operated Relief Valves (PORVs): Automatic control
- Reactor Control: Automatic
- Main Feedwater: Automatic
- Aux Feedwater: Automatic control
- Main Stream Isolation Valves (MSIVs): Open, automatic control
- Main Feedwater Isolation Valves (MFIVs): Open, automatic control

Transient Initiator - A 1.0-ft^2 hole appears in steam line A outside containment upstream of the MSIV and downstream of the flow restrictor.

Equipment Failures which occur during the accident transient if the equipment is demanded.

None

Operator actions/inactions

a. Operator will turn off all RCPs 30 seconds after SIAS based on low pressurizer pressure.
b. Operator fails to turn off charging pumps prior to full repressurization.
c. Operator fails to control repressurization.
d. Operator fails to maintain level in intact SG.
e. Operator fails to respond to high SG alarm at 30".
f. Operator fails to respond to high SG alarm at 50"...

TABLE 4.2

Comparison Between TRAC and Design/Plant at Full Power Conditions.

	Design/Plant Data	TRAC Predictions
PRIMARY SIDE		
Core power	2694 MW	2700 MW
Vessel flow	25.27 m^3/s (401,121 gpm)	25.28 m^3/s (401,324 gpm)
ΔP_{vessel}	-	0.28 MPa (40.65 psid)
ΔP_{sg}	0.19 MPa (28.15 psid)	0.24 MPa (34.60 psid)
ΔP_{loop}	0.54 MPa (78.73 psid)	0.538 MPa (76.28 psid)
T_{hot}	585.7°K (594.6°F)	585.6°K (595.1°F)
T_{cold}	559.3°K (547.0°F)	559.6°K (547.6°F)
ΔT_{vessel}	26.4°K (47.6°F)	26.4°K (47.5°F)
SECONDARY SIDE		
Feedwater flow per SG	749 kg/s (5.95 Mlb/hr)	737 kg/s (5.85 Mlb/hr)
SG Dome Pressure		
SG 11	5.90 MPa (856 psia)	5.90 MPa (852.9 psia)
SG 12	5.86 MPa (850 psia)	5.89 MPa (853.7 psia)
MFW Pump Discharge Pressure		
MFW 11	7.8 MPa (1130.7 psia)	7.67 MPa (1112.6 psia)
MFW 12	7.63 MPa (1106.7 psia)	7.57 MPa (1097.4 psia)

Table 4.2 (cont)

	Design/Plant Data	TRAC Predictions
Feedwater Temperature	494.8°K (431.0°F)	496.2°K (433.5°F)
MFRV % open	~90	88.9
SG liquid mass	62,350 kg (137,458 lb)	64,600 kg (142,419 lb)

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

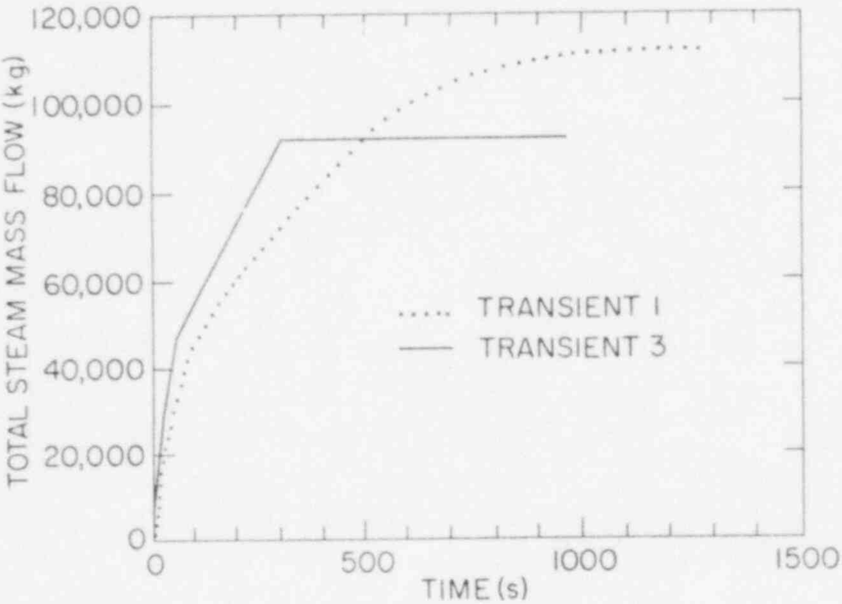

Figure 4.1 Transient 3: Total Integrated Steam Flow From Steam Generators

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

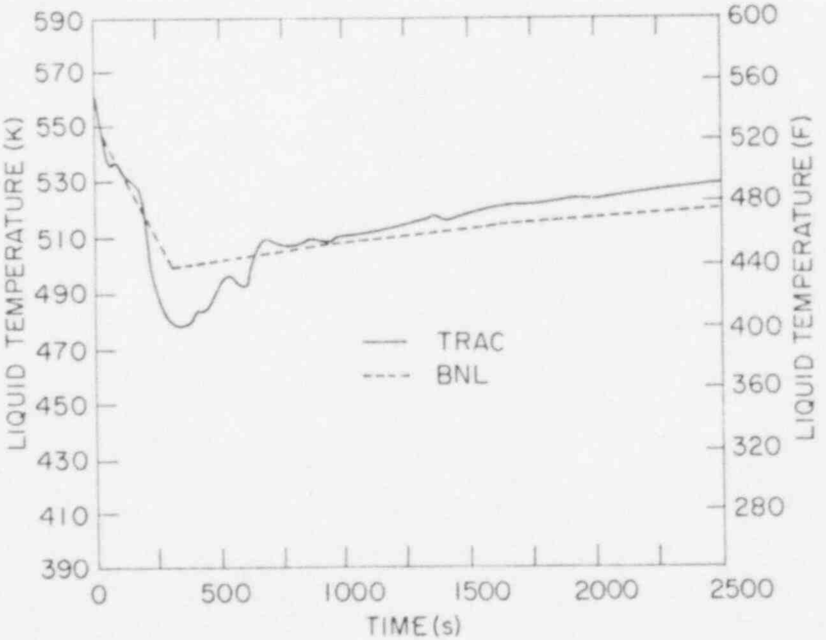

Figure 4.2 Transient 3: Downcomer Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

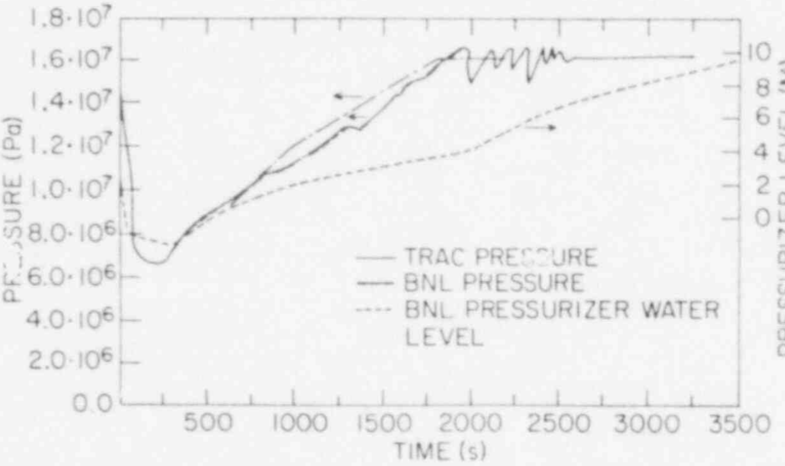

Figure 4.3 Transient 3: Downcomer Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

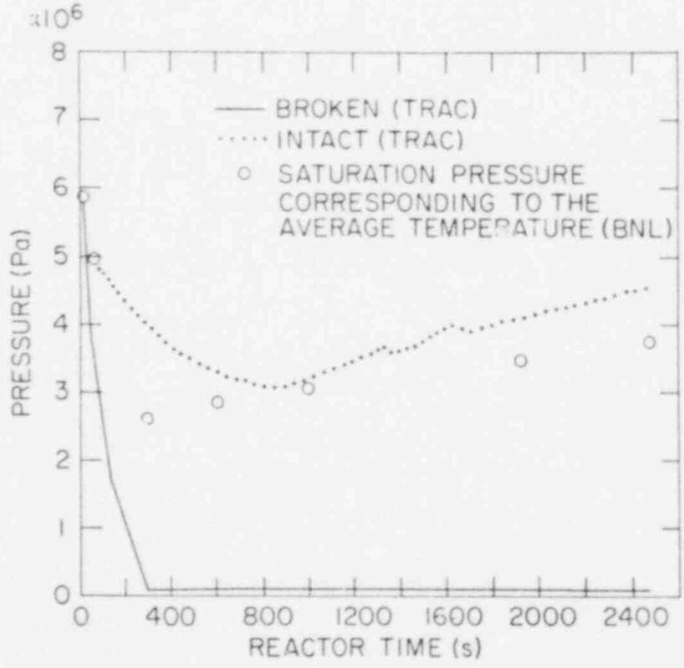

Figure 4.4 Transient 3: Pressure in the Steam Generators

5. TRANSIENT 6: AFW OVERFEED FROM HFP

This transient is initiated by the loss of MFW due to MFW pump trip. Additionally, the AFW does not start on AFAS until AFW pumps to both steam generators are started by the operator at 20 minutes into the transient. The transient scenario is shown in Table 5.1

Upon loss of the MFW, the SG level starts decreasing, and the reactor and turbine are tripped on low SG level. The ADVs and TBVs also open at the same time. The average primary temperature and pressure start decreasing rapidly. However, since the ADVs and TBVs are programmed to open and close on the primary temperature of 552°K, the primary temperature is maintained at this set point until both SGs are empty. Figure 5.1 shows that both TRAC and BNL calculations maintain this temperature until about 800 seconds. Figure 5.2 shows the total steam flow through the ADVs and TBVs necessary to maintain this condition during this period for both TRAC and BNL calculations. It shows good agreement. This also holds the secondary temperature at this temperature (or slightly below 550°K) and the SG pressure at the saturation pressure (60 bar) corresponding to this temperature (Figure 5.4). In the meantime, the primary pressure slowly starts increasing due to the pressurizer heaters (Figure 5.3). Once both SGs dry out, there is no cooling of the primary system. The primary temperature starts increasing due to the decay heat, and the primary pressure increases faster until it reaches the PORV set point. The secondary pressure starts decreasing since the ADV/TBVs are still open due to high primary temperature. This decreasing pressure causes the SGIS to isolate the TBVs. However, since the ADVs still remain open, the secondary pressure continues to decrease. The results obtained by both the TRAC and BNL calculations generally match the expected trend as described above up to this point (1200 seconds).

In the TRAC calculation, the opening of ADV was programmed to depend on the primary temperature only. However, there was a question if it should also depend on the secondary pressure. If ADVs are programmed this way, the secondary side pressure would be kept at the set pressure of the ADVs (probably 60 bar) and the secondary side temperature at the corresponding saturation temperature (552°K). This, in turn, would keep the average primary temperature near this temperature, which would be equivalent to controlling the primary temperature. The only time the secondary side behavior deviates from this course significantly would be when the secondary side water level is very low and, therefore, the steam generator as a heat sink is lost anyway. Therefore, even this change of programming on the control of the ADVs would not make any significant difference for the rest of the transient.

At 1200 seconds after of the transient began, the operator activates the AFW pumps to both SGs. The specified AFW flow rate for this transient is much higher than the normal AFW flow rate (about 5 times). Figure 5.1 compares the TRAC downcomer temperature with the BNL system average temperatures calculated by use of two different AFW flow rates. BNL 1 represents the result obtained by use of the same AFW flow rate as in the TRAC calculation, and BNL 2 represents the expected result if normal AFW flow rate is used. For either case, initiation of AFW causes rapid cooling of the primary system. The BNL 1 temperature matches the TRAC temperature very closely. The BNL 2 temperature decreases much more slowly, as expected. Figure 5.3 shows the TRAC primary pressure and the BNL pressurizer water level by using both AFW flow rates.

The BNL 2 level is shown to remain much higher than that of the BNL 1. This may indicate that the primary pressure may never reach the SIAS set point (121 bar) and/or the HPI pump shutoff head (88.7 bar)or it may take a much longer time. This would further slow down the temperature drop and also lessen the rate of pressure increase by injecting less HPI/charging water into the primary system

Figure 5.4 shows that the SG pressure for both the TRAC and BNL 1 calculations rapidly decreases due to the temperature drop following the AFW initiation. It also indicates that the SGs are completely filled at about 3000 seconds for both calculations. On the other hand, the BNL 2 results show that the secondary side pressure stays high and then starts to decrease slowly. The SGs are estimated to be full at about 9500 seconds according to the BNL 2 calculation. For both the BNL 1 and BNL 2 calculations, the temperature is expected to continue to decrease beyond 6000 seconds, until it eventually reaches the steady-state temperature, where the decay heat balances with cooling due to charging and AFW flow, if the AFW flow persists. We estimate this temperature to be 300°K and 380°K for the BNL 1 and BNL 2 cases, respectively. However, the feedwater supply system may run out of water long before that time, especially for the higher AFW flow case (BNL 1).

The TRAC calculation shows severe asymmetric pressure and pressure oscillation between the two steam generators (Figure 5.4) when the AFW is introduced. This appears to be due to condensation caused by introduction of a large amount of cold AFW. However, this phenomenon may not affect the primary pressure and temperature significantly, since the overall cooling may depend on the total amount of AFW rather than its distribution. Also, this phenomenon is not expected to happen for the normal AFW flow rate case.

In summary, the TRAC calculated results appear to be acceptable, given the high AFW flow rate.

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* This transient was recalculated by LANL using the normal AFW flow rate, which corresponds to the BNL2 case. Figure 5.5 compares the temperatures calculated by TRAC and BNL simple method for both AFW flow rates. They agree very closely for each case.

TABLE 5.1 SCENARIO DESCRIPTION

TRANSIENT NO. 6

Plant Initial State - Just prior to transient initiator

General Description: 100% Power steady state
System Status
- Turbine: Automatic control
- Turbine Bypass Valves (TBV): Automatic control
- Atmospheric Dump Valves (ADVs): Automatic control
- Charging System: Automatic control
- Pressurizer: Automatic control
- Engineering Safety Features: Automatic control
- Power Operated Relief Valves (PORVs): Automatic control
- Reactor Control: Automatic
- Main Feedwater: Automatic
- Aux Feedwater: Automatic control
- Main Stream Isolation Valves (MSIVs): Open, automatic control
- Main Feedwater Isolation Valves (MFIVs): Open, automatic control

Transient Initiator - Both Main Feedwater pumps trip simultaneously.

Equipment Failures which occur during the accident transient if the equipment is demanded.

Aux Feedwater pumps fail to start.

Operator actions/inactions

a. Operator will turn off all RCPs 30 seconds after SIAS based on low pressurizer pressure.
b. Operator fails to turn off charging pumps prior to full repressurization.
c. Operator fails to control repressurization.
d. Operator fails to maintain level in intact SG.
e. Operator fails to respond to high SG alarm at 30".
f. Operator fails to respond to high SG alarm at 50"...
g. Operator initiates actions to correct Aux flow problem and overrides Aux flow control to provide max flow at 20 minutes. Aux flow control valves turned wide open, and all AFW pumps started.

Note: Terminate computer run if and when auxiliary feed tanks are empty.

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

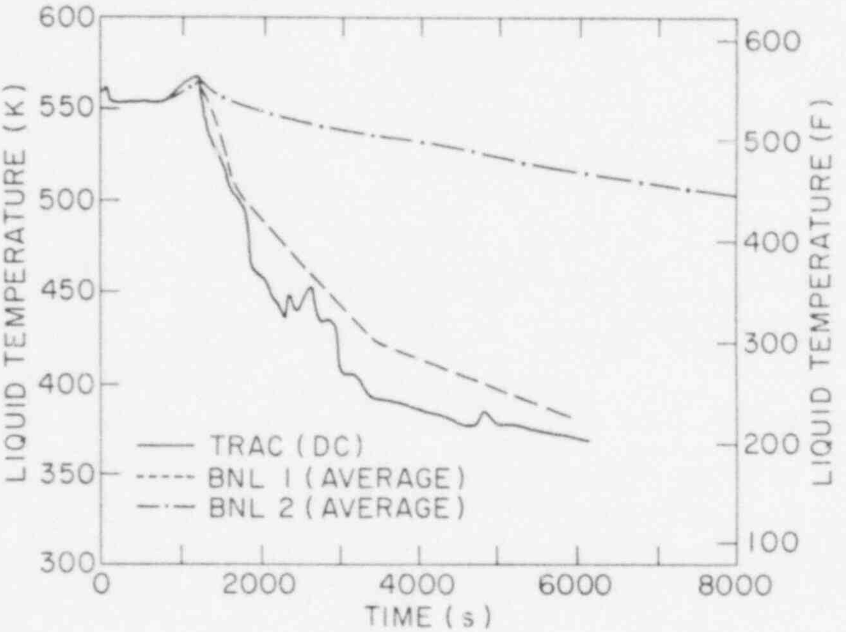

Figure 5.1 Transient 6: Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

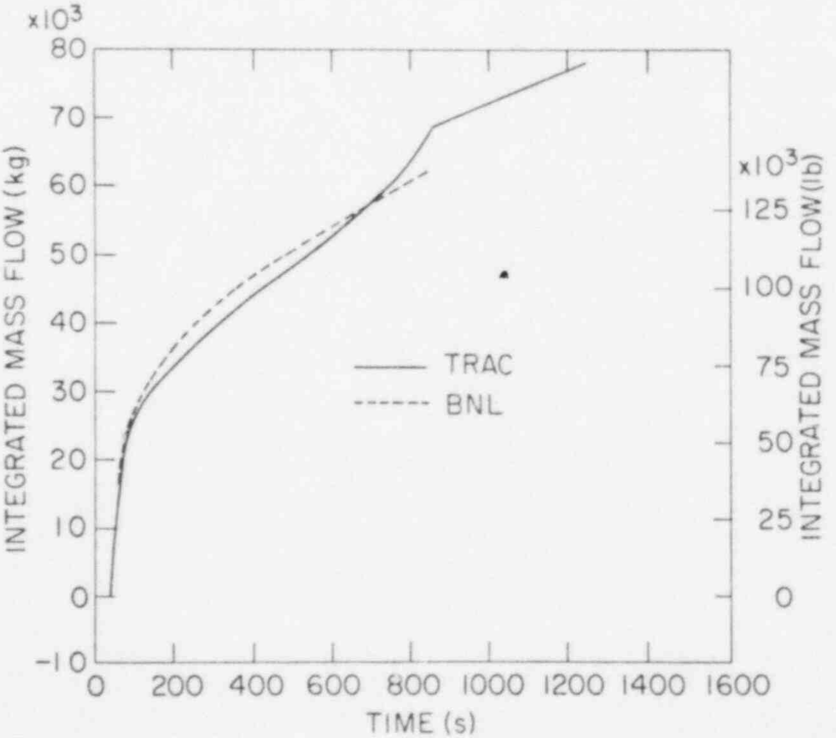

Figure 5.2 Transient 6: Total Steam Flow From Steam Generators

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

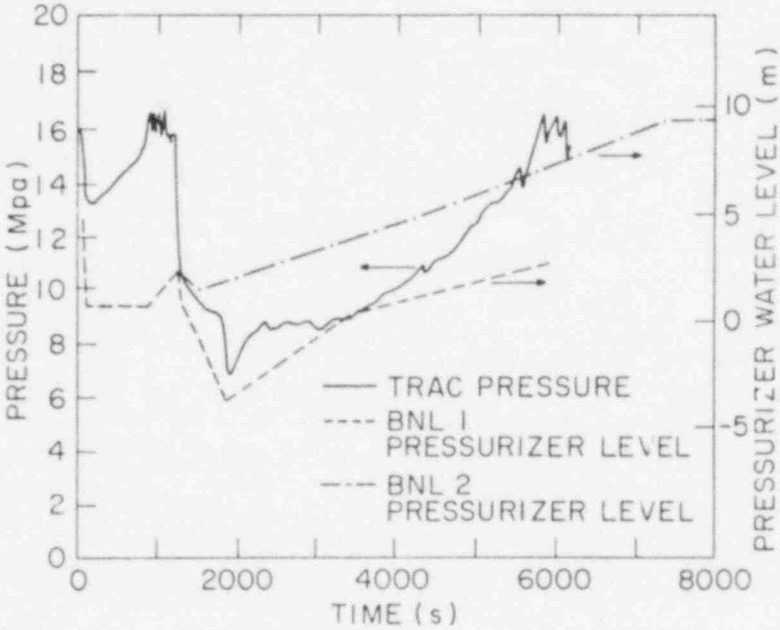

Figure 5.3 Transient 6: Primary Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

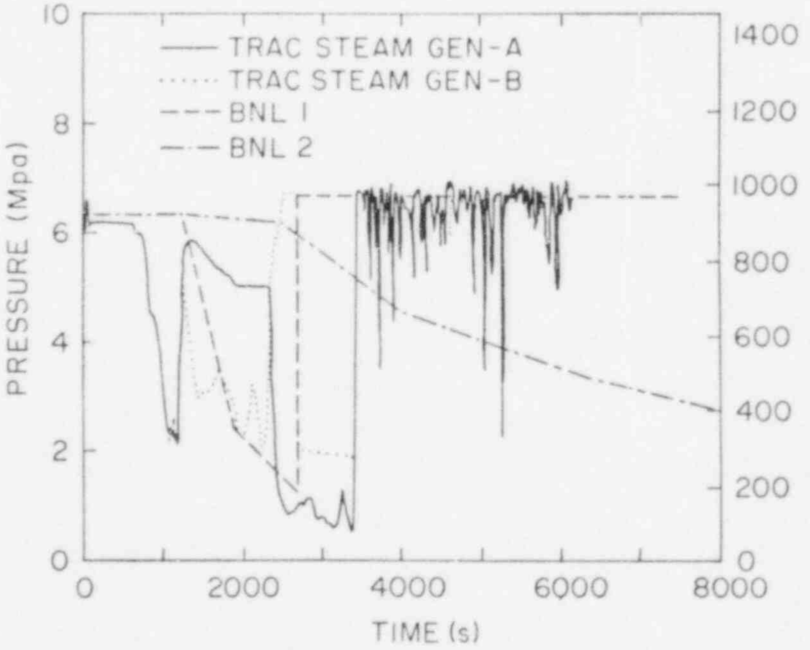

Figure 5.4 Transient 6: Secondary Pressures

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

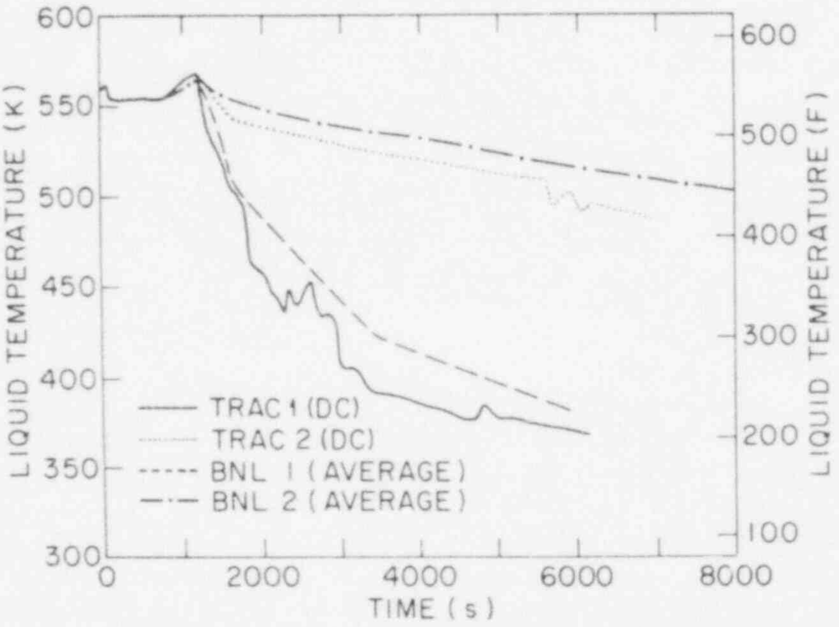

Figure 5.5 Transient 6: Comparison of the Liquid Temperature Calculated by TRAC Code and BNL Method Using Two Different Auxiliary Feedwater Flow Rates

6. TRANSIENT 7A: SMALL BREAK LOCA IN A HOT LEG

This transient is initiated by a small break (0.02 ft^2) in a hot leg during HFP operation. The transient scenario is presented in Table 6.1.

Figure 6.1 shows the temperatures at various locations calculated by TRAC and the BNL system average temperature. The BNL temperature agrees reasonably well with the average of the hot and cold leg temperatures. Figure 6.2 shows the TRAC primary pressure and the saturation pressure corresponding to the BNL system average temperature. The figure indicates that the primary pressure is very close to the saturation pressure, as expected for LOCA, but still the primary system is generally subcooled.

At the initiation of the break, the primary pressure starts decreasing rapidly (Figure 6.2). At 2100 psia (144.8 bar), the low primary pressure trips the reactor and turbine. ADVs and TBV open at the same time. The primary pressure continues to decrease due to continued loss of mass through break, triggering the SIAS at 1740 psia (121 bar) and reactor coolant pump trip at 30 seconds after that. Introduction of HPI makes up some of the water lost through the break and reduces the rate of depressurization.

The water lost through the break is mostly in the liquid form and, therefore, does not contribute significantly to the energy loss from, or cooling of, the system. (This would be a major difference between this transient and a similar small break LOCA transient due to failure of the PORV to close. The primary temperature would decrease faster in the PORV LOCA transient.) Cooling in this transient is achieved mainly by the opening of the ADV/TBVs and the release of some steam from the SGs. Opening these valves initially causes a sharp drop of the primary temperature. However, since the ADV/TBVs are controlled to open or close at the average primary temperature of 552°K, the average primary temperature is maintained at 552°K once it reaches this temperature (Figure 6.1). Figure 6.3 shows the total steam flow necessary to maintain this condition during this period for both TRAC and BNL calculations, which shows very good agreement. This state continues until either the AFW starts due to low SG level (which does not appear to happen in this transient) or the continued cooling by the HPI finally exceeds the decay heat. This brings the primary temperature down below 552°K and closes the ADV/TBVs. The primary temperature continues to fall due to cooling by HPI/charging. Since the break flow is slightly higher than the HPI, the system pressure also continues to decline slowly until the break flow finally balances with the HPI flow and then levels off. In the TRAC calculation, the TBVs are closed a little earlier than expected because of SGIS at 502 seconds, which is caused by high containment pressure. (Information on how the containment pressure was calculated was not available.) However, this does not make any significant difference since the ADVs remain open until the primary temperature falls below 552°K. The secondary temperature also slowly decreases at the same rate as the primary temperature starts to decrease. The TRAC calculation shows that secondary pressure stays constant for a long time (Figure 6.4), while it is expected to decline corresponding to the saturation pressure of the declining primary temperature. Also, one of the SGs started to empty and asymmetric pressure starts to develop at about 5000 seconds, while there appears to be no particular event to cause this. The cause of this anomaly appears to be the inadequate condensation model of the TRAC code.

During the presentation of this transient calculation by LANL on December 13, 1983, there was some discussion concerning the stagnation of the primary loops due to voiding at the steam generator U-tubes. Subsequently, LANL issued a report [2] contending that voiding at the U-tube did not happen because 1) the primary system remained subcooled during the entire transient due to the nonequilibrium effect built into the TRAC code and, thus, the reverse heat transfer from the SG was not sufficient enough to cause boiling of primary fluid at the U-tubes; 2) the liquid level in the upper plenum did not decrease below the hot leg penetration level. BNL generally agrees with these arguments. As discussed earlier, Figure 6.2 shows that the primary pressure remains above the saturation pressure during the entire transient. This is partly due to the non-equilibrium effect, as mentioned by LANL, and partly to the fluid in the upper dome remaining hotter so that its saturation pressure is higher than the rest of the primary system. Figure 6.5 shows the vapor space volume in the primary system during the transient calculated by BNL. It confirms that the upper dome is never completely empty in this particular transient.

In summary, it appears that the sequence of events of the calculations generally follows the expected trend, and the TRAC-calculated results are reasonable except for the SG secondary side pressure.

TABLE 6.1 SCENARIO DESCRIPTION

TRANSIENT NO. 7A

Plant Initial State - Just prior to transient initiator

General Description: 100% Power steady state
System Status
- Turbine: Automatic control
- Turbine Bypass Valves (TBV): Automatic control
- Atmospheric Dump Valves (ADVs): Operating/Automatic control
- Charging System: Automatic control
- Pressurizer: Automatic control
- Engineering Safety Features: Automatic control
- Power Operated Relief Valves (PORVs): Automatic control
- Reactor Control: Automatic
- Main Feedwater: Automatic control
- Aux Feedwater: Automatic control
- Main Stream Isolation Valves (MSIVs): Open, automatic control
- Main Feedwater Isolation Valves (MFIVs): Open, automatic control

Transient Initiator - A 0.02 ft^2 hole appears in the hot leg of loop A.

Equipment Failures which occur during the accident transient if the equipment is demanded.

None

Operator actions/inactions

a. Operator will turn off all RCPs 30 seconds after SIAS based on low pressurizer pressure.
b. Operator fails to turn off charging pumps prior to full repressurization.
c. Operator fails to control repressurization.
d. Operator fails to maintain level in intact SG.
e. Operator fails to respond to high SG alarm at 30".
f. Operator fails to respond to high SG alarm at 50"...

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

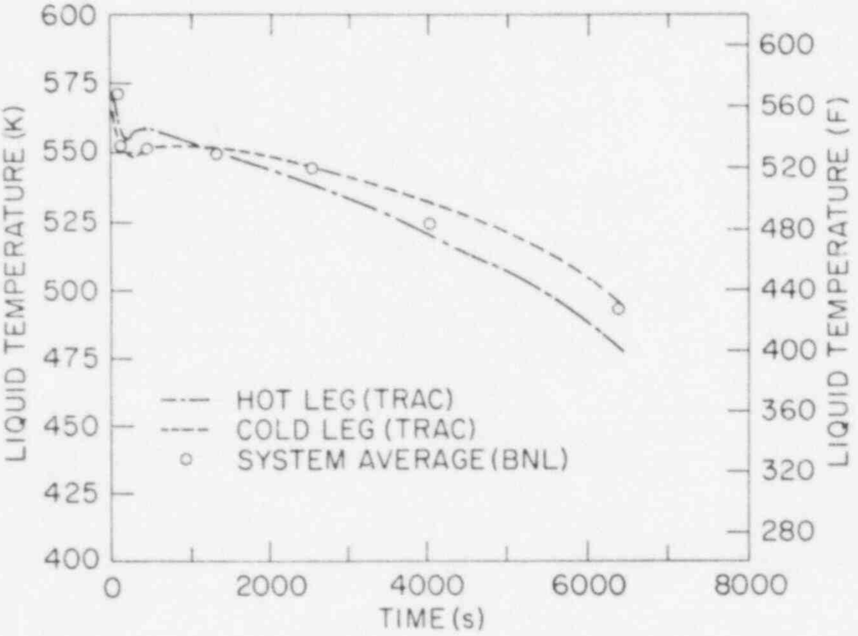

Figure 6.1 Transient 7A: Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

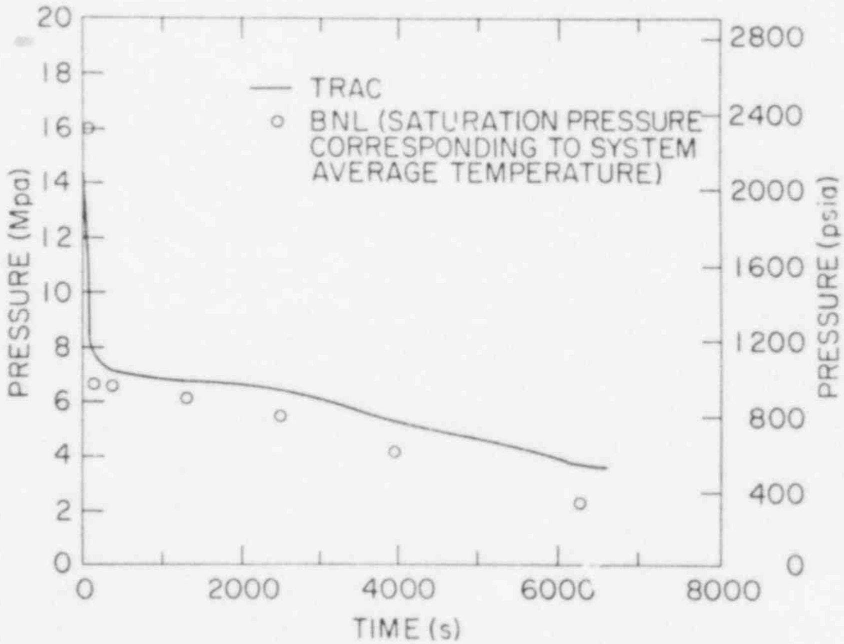

Figure 6.2 Transient 7A: Primary Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

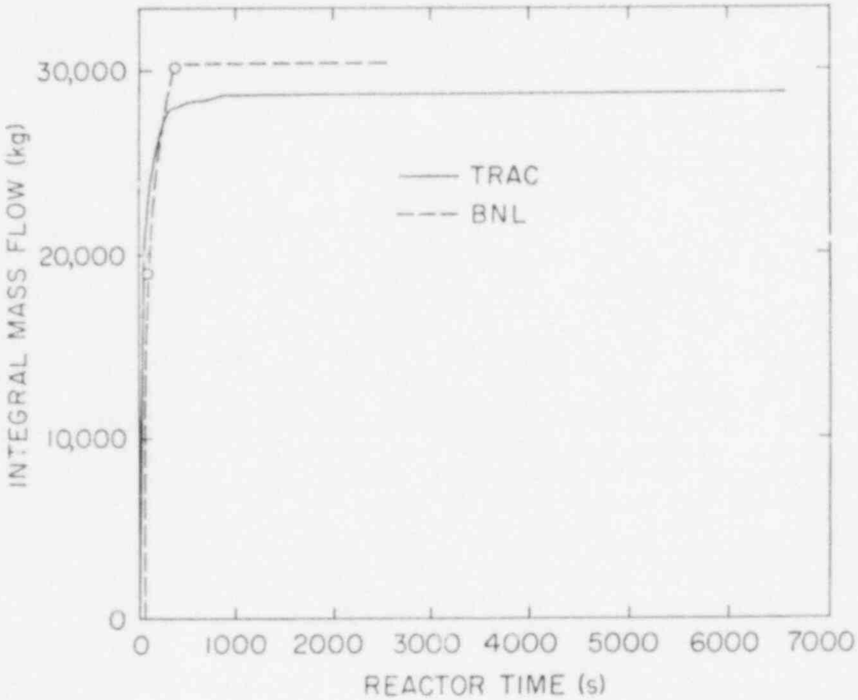

Figure 6.3 Transient 7A: Total Steam Discharge

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

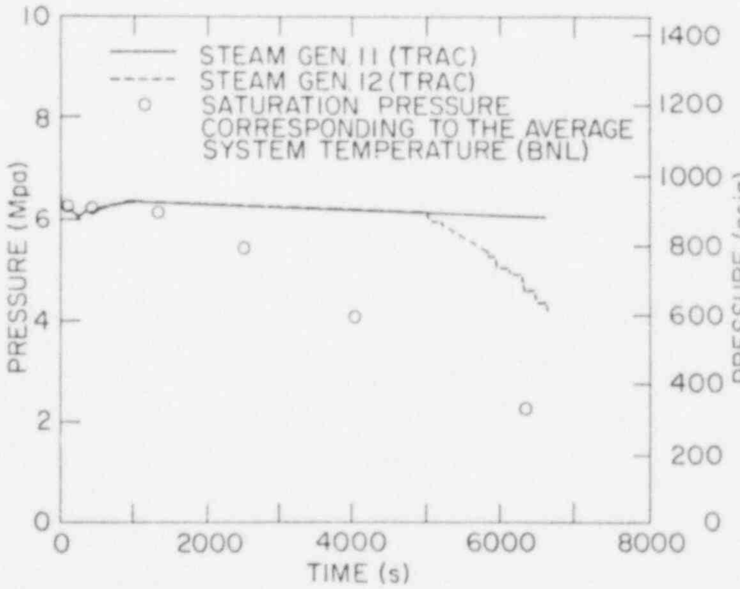

Figure 6.4 Transient 7A: Secondary Pressures

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

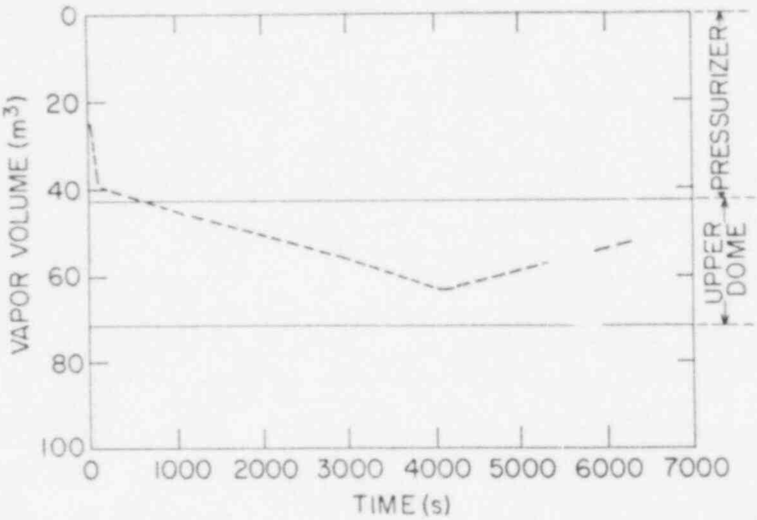

Figure 6.5 Transient 7A: Vapor Space Volume

7. TRANSIENT 9: MFW OVERFEED TO ONE STEAM GENERATOR

This transient is initiated when a MFRV fails to close when the turbine trips during the HFP operation. This allows full feedwater flow to the affected SG until the MFW pumps are finally tripped due to low condenser/hot well inventory. The transient scenario as specified by ORNL is shown in Table 7.1.

Figure 7.1 shows the liquid temperature at various locations calculated by TRAC as well as the BNL system average temperature. During the initial 300 seconds while the MFW continues, the primary liquid temperature declines sharply. A large temperature difference between the hot and cold legs also persists due to the continued cooling by MFW. The affected SG completely fills at about 130 seconds and the excess feedwater is released through the TBV/ADVs. The HPI begins at about 250 seconds and contributes to further cooling. At about 300 seconds when the MFW finally stops due to low condenser/hot well inventory, the primary temperature starts climbing rapidly, since the decay heat far exceeds cooling by the HPI, which is the only cooling mechanism for the entire system at the moment. When the primary temperature finally reaches 552°K, the TBV/ADVs open and start releasing steam. BNL estimates this time to be about 4200 seconds based on the energy balance. Opening of the TBV/ADVs maintains the primary temperature at 552°K. During this period, the SG continues to lose steam and the AFW starts due to low liquid inventory. Once the AFW starts, the system temperature is estimated to drop at the rate of about 7°C for every 1000 seconds until it levels off at about 380°K.

As shown in Figure 7.2, the secondary temperature generally follows a similar trend to that of the primary temperature. The intact SG temperature generally remains much higher than other parts of the system during the initial 1000 seconds. This may indicate some stagnation of the intact loop.

The behavior of the primary pressure is similar to that of the primary temperature, as shown in Figure 7.3. The system pressure and pressurizer water level calculated by BNL are also shown in the figure for comparison. As discussed in the introduction, the BNL pressure is obtained on the basis of the adiabatic assumption, which is the maximum pressure attainable during compression. The TRAC pressure is lower than this, as expected.

Figure 7.4 shows the TRAC pressure in the secondary sides of the SGs. The pressure of the affected SG remains near TBV set point (61.1 bar) since it is completely full at 130 seconds. However, the intact SG pressure is also shown to stay above 60 bars even during the initial 300 seconds when the temperature declines steeply. This appears to indicate a severe nonequilibrium effect, which is observed in several other transients. The actual pressure is expected to be somewhere between this pressure and the saturation pressure corresponding to its liquid temperature. Both steam generator pressures start to decline at 4800 seconds when AFW is initiated, as they should.

In summary, the results calculated by TRAC for this transient appear to be reasonable except for some parts of the intact SG pressure.

TABLE 7.1 SCENARIO DESCRIPTION

TRANSIENT NO. 9

Plant Initial State - Just prior to transient initiator

General Description: 100% Power steady state
System Status
- Turbine: Automatic control
- Turbine Bypass Valves (TBV): Automatic control
- Atmospheric Dump Valves (ADVs): Automatic control
- Charging System: Automatic control
- Pressurizer: Automatic control
- Engineering Safety Features: Automatic control
- Power Operated Relief Valves (PORVs): Automatic control
- Reactor Control: Automatic
- Main Feedwater: Automatic
- Aux Feedwater: Automatic control
- Main Stream Isolation Valves (MSIVs): Open, automatic control
- Main Feedwater Isolation Valves (MFIVs): Open, automatic control

Transient Initiator - Turbine trip.

Equipment Failures which occur during the accident transient if the equipment is demanded.

Main feedwater to SGA fails to run back (remains at 100% power characteristics).

Operator actions/inactions

a. Operator will turn off all RCPs 30 seconds after SIAS based on low pressurizer pressure.
b. Operator fails to turn off charging pumps prior to full repressurization.
c. Operator fails to control repressurization.
d. Operator fails to maintain level in intact SG.
e. Operator fails to respond to high SG alarm at 30".
f. Operator fails to respond to high SG alarm at 50"...

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

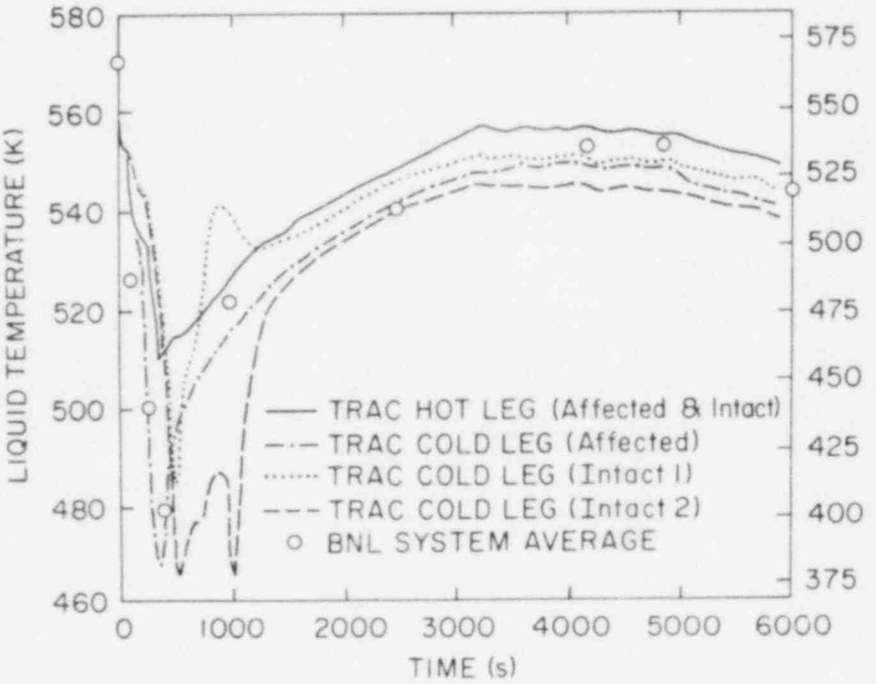

Figure 7.1 Transient 9: Liquid Temperature

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

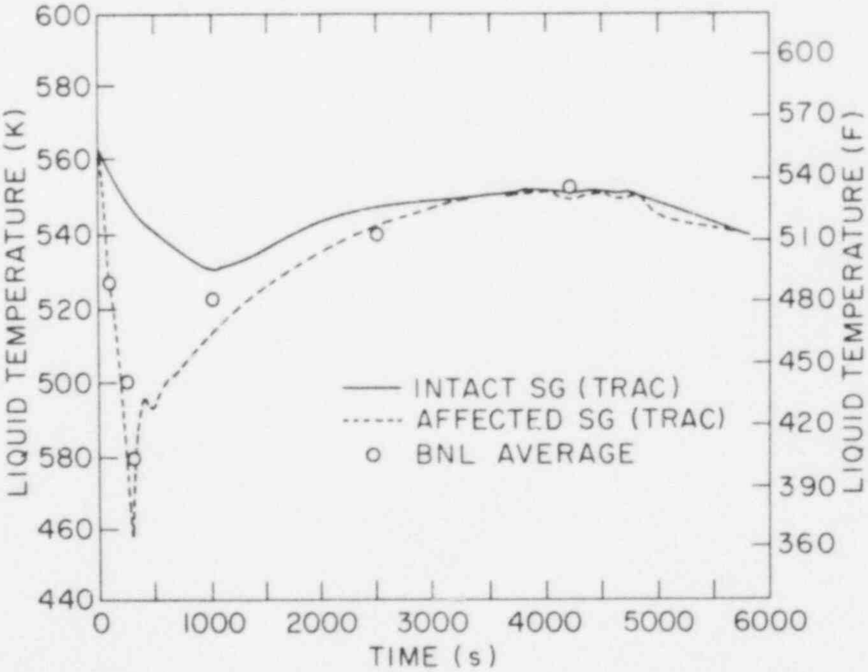

Figure 7.2 Transient 9: SG Liquid Temperatures

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

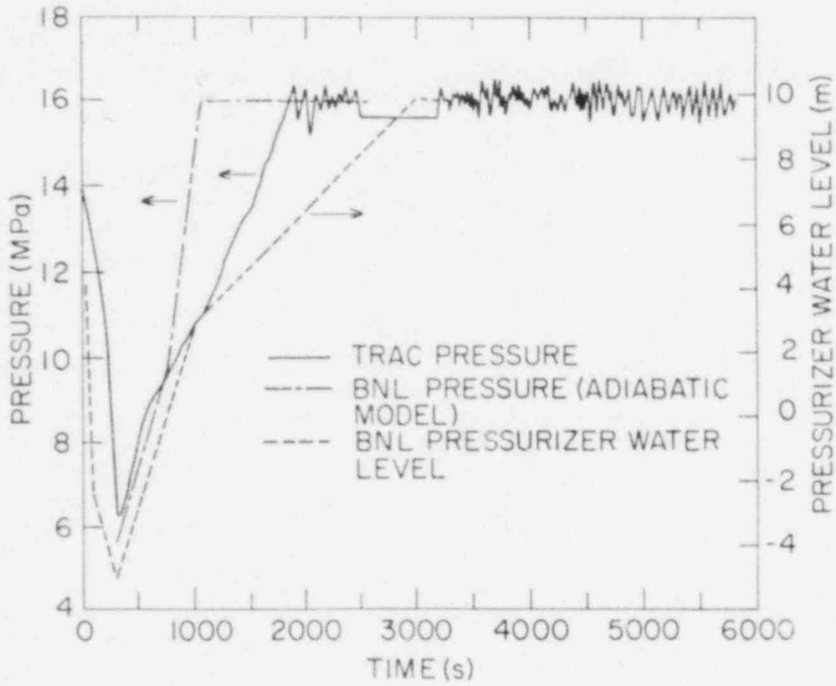

Figure 7.3 Transient 9: System Pressure

CAUTION: The scenario simulated contains significant conservatisms in operator actions and equipment failures. For details, see the scenario descriptions.

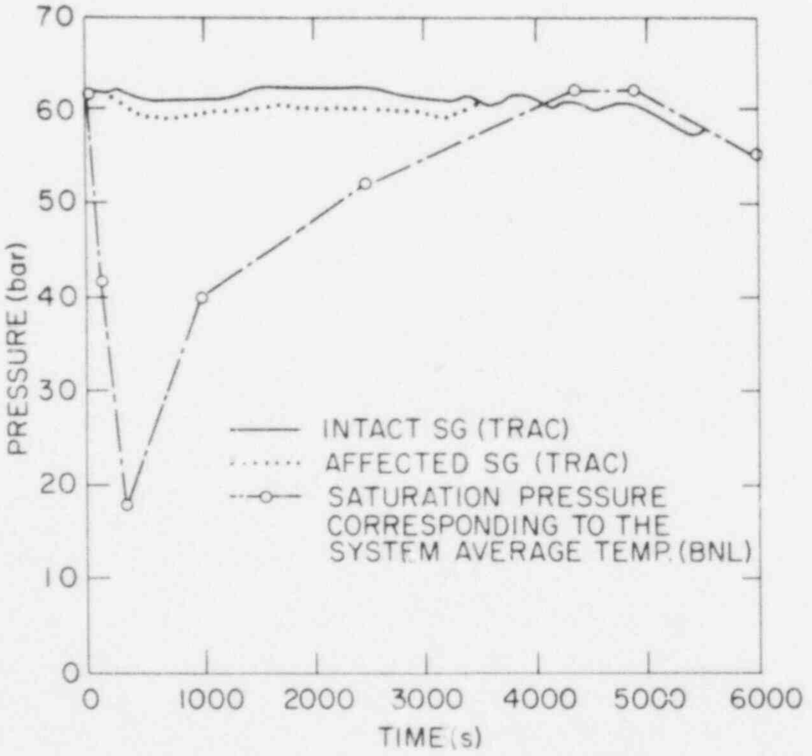

Figure 7.4 Transient 9: Steam Generator Secondary Side Pressure

8. SUMMARY AND CONCLUSIONS

Several selected transient calculations performed by LANL using the TRAC-PF1 code for the USNRC PTS study of the Calvert Cliffs Nuclear Power Plant have been reviewed at BNL. Six of the thirteen calculations consisting of two HZP and four HFP transients have been selected for the in-depth review. Simple hand calculations, based on the mass and energy balances of the entire reactor system, have been performed to predict the temperature and pressure of the reactor system, and the results have been compared with those obtained by TRAC.

In general, the temperatures and pressures of the primary system calculated by TRAC have been very reasonable. The secondary pressures calculated by TRAC appear to indicate that the TRAC code has some difficulty with the condensation model and further work is needed to assess the code calculation of the U-tube steam generator pressure when the cold auxiliary feedwater is introduced to the steam generator. However, it is not expected that this uncertainty would affect the transient calculations significantly.

REFERENCES

1. J. E. Koenig et al., "TRAC Analyses of Potential Overcooling Transients at Calvert Cliffs - 1 for PTS Risk Assessment," Los Alamos National Laboratory, December 1983.

2. G. D. Spriggs and R. Smith," Review of TRAC Results for small Break LOCA," Communication with J. N. Reyes, Jr., NRC, Los Alamos National Laboratory, February 1, 1984.

APPENDIX A

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: January 12, 1984

TO: Pradip Saha

FROM: J. Jo

SUBJECT: BNL REVIEW OF PTS INPUT AND STEADY-STATE CALCULATIONS PERFORMED BY LANL FOR CALVERT CLIFFS NUCLEAR PLANT

This is an interim report on the progress of the review of PTS input decks and steady state calculations performed by Los Alamos National Laboratory (LANL) for the Calvert Cliffs nuclear plant which is owned by Baltimore Gas & Electric Co. (BG&E).

As you know, we were not involved in the initial stage of the PTS study on the Calvert Cliffs plant when the geometric and plant operation data were collected from Combustion Engineering and BG&E. Most of the information used for this review was based on the handouts obtained from LANL at the two meetings I attended for the study group (one at LANL on June 27, 1983 and the other at BG&E on September 20, 1983) and the Calvert Cliffs FSAR. Therefore, as was in the Oconee review, the main emphasis was placed on a general review of the input deck and steady state output rather than confirmation of specific numbers used in the input deck. Since LANL developed two separate input decks, one for Hot Zero Power (HZP) and the other for Hot Full Power (HFP) conditions, these two decks were compared for consistency. The versions of input listings reviewed here were those obtained from LANL at the September review meeting. It is my understanding that some of these input, especially that for HFP, have been modified since then.

The TRAC codes used for LANL calculations were some intermediate versions of the TRAC-PF1/MOD1 code. It appeared that different versions of the code were used for the HZP and HFP inputs. BNL recently obtained a draft copy of the TRAC-PF1/MOD1 manual. However, the input listings were not consistent with some sections of the manual.

Most of the findings listed here were communicated to Ms. J. Koenig of LANL over the telephone on November 10, 1983. Specific details of the review and its findings are summarized as follows:

A. Review of Input

1. Connections of the components were checked to ensure that they were consistent with noding diagram including the number of nodes. Several minor discrepancies were found, but they were insignificant.

2. Symmetry of the loops was checked. Several minor non-symmetry were found but they were either real differences in the plant or insignificant.

3. Safety injection tanks and low pressure injection systems were not modeled. It appeared that these components were judged not to be needed for the specified transients.

4. Total volume of the primary side agreed very closely with that given in the FSAR. Individual pipe diameters and volumes including core, primary side of steam generator and pressurizer matched those given in the FSAR. In the secondary side of the steam generator, several differences in volume were found between the HZP and HFP inputs.

   a. The steam dome volume of HFP deck = 20.33 m^3

      HZP deck = 45.40 m^3

   These differences were already identified by the LANL staff at the September meeting and the steam dome volume of the HFP input deck was corrected.

   b. The downcomer volume of HFP deck = 28.52 m^3

      HZP deck = 39.2 m^3

   This difference appears to be significant. Wrong downcomer volume would result in wrong water mass or in the wrong water level if the water mass was matched. Either of these differences may have some effect on the course of the overcooling transient.

   c. There were significant differences in the hydraulic diameters of the tube region and the heat transfer area between the primary and the secondary sides of the two input decks.

	HFP	HZP
Hydraulic Diameter	0.073 m	0.005 m
Heat Transfer Area	9088/10353 m^2	7338/8361 m^2
(Inner Wall/Outer Wall)		

It appears that the hydraulic diameter was adjusted in the HZP deck while the heat transfer area was increased in the HFP input to match the heat transfer. I do not know if this adjustment is required to match the plant condition, or which is the better way to obtain proper heat transfer if necessary. This would indicate deficiency of the code and should be explained.

5. Different friction factor options were used for different components and sometimes even in the different cells of the same component. Also, no frictions were used in many places. These appear to be questionable and may affect the natural circulation flow rate which is important in the PTS study.

6. Friction factors of very large magnitude (10^{21} and 10^{10}) were used at the exit of the steam generator to the steamline and auxiliary feedwater line, respectively, in the HZP input. However, I did not notice a very high pressure drop across these junctions in the steady state output which was expected from the high friction factors used.

7. The single phase homologous curve option was used (not fully degraded two-phase homologous) for the Reactor Coolant Pump (RCP) modeling. This may cause slightly faster coastdown of the pump if some vapor exists when it is tripped. But this effect is considered to be very minor.

8. In the pressurizer heater model, a certain amount of heat was taken out of the pressurizer when the heater was off. This was explained to me as a heat loss from the pressurizer to the atmosphere. However, since this heat loss would be balanced with addition of heat by the heater no net heat should be removed from the pressurizer during the steady state.

9. Most of the trips and controllers were incorporated correctly as specified in the LANL handouts except:

   a. Extensive time smoothing was used in the estimation of the steamline pressure which was used for Turbine Bypass Valve (TBV) control in the HZP input. This may reduce the sensitivity of those controls.

   b. The following equation was used to calculate the pressurizer level:

$$L = \frac{\Delta p - 9445}{4792.72} \text{ m} ,$$

where Δp was the pressure difference across the pressurizer. I could not find how the number 4792.72 was obtained here. (If it is ρg, it should be 5987.8 since $\rho = 611\ kg/m^3$, $g = 9.8 m/sec^2$.)

c. Auxiliary feedwater actuation signal (AFAS) logic was different between the HZP and HFP input decks. Auxiliary feedwater (AFW) to both steam generators was actuated by the same trip so that the AFW would be delivered to both steam generators once it was tripped for the HZP input deck, while AFW would be delivered only to the steam generator with higher pressure on asymmetric steam generator detection for the HFP deck as it should be.

d. The atmospheric dump valve (ADV) was programmed to remain closed for the HZP case. However, this may be needed to be opened later when the secondary side pressure increases.

B. Steady State

1. Generally very good steady state was obtained for the HFP case.

2. Acceptable steady state was obtained for the HZP case. The secondary side energy balance was off by 10%. However, for a very low power case, this may not be important (it takes an extremely long computer time to obtain good steady state for a low power case).

3. The liquid volume in the pressurizer was less than in the FSAR for the HFP case:

FSAR	800 ft^3
HFP	678 ft^3

However, this may be due to operational differences from the FSAR.

4. The liquid in the pressurizer of the HFP case was highly subcooled. I do not believe this is real and could cause a delay of pressure rise even if the heater was activated.

5. For both cases, i.e., HFP and HZP, the void fraction suddenly decreased just above the tube region of the secondary side (separator region). This does not appear to be real but may not be important because no heat transfer was involved in this region.

6. There was very little recirculation from the heated tube region to the downcomer (about 10%). This is contrary to the expectation. (I understand the recirculation ratio is very high for low power operation.) The main feedwater was heated mainly by the wall heat transfer in the downcomer for the tube region, not by mixing with the recirculation flow. This needs to be checked. However, this may not have any significant effect on the transient.

In summary, the input decks and the steady states were acceptable. However, some of the items mentioned above, particularly Items 4.b, 4.c, 6 and 9 of the input review and Items 4 and 5 of the steady state review, should be further addressed or explained by the LANL staff.

APPENDIX B

APPENDIX B: LANL Response to the BNL Review of the Calvert Cliffs Input Decks and Steady State Calculations

Input deck:

A1. Refer to 4b - The correct downcomer volume is 39.2 m^3. This was the volume used in the full power input deck as well as the hot zero power input deck. In the full power deck, however, some of the downcomer volume was placed in a TRAC component above the one that was labeled as the downcomer.

A2. Refer to 4c - In order to match steady state conditions with TRAC, it is necessary to adjust the heat transfer area or the hydraulic diameters. Here, two different analysts took separate approaches. Adjusting the heat-transfer area is probably preferable because it will not affect the pressure drops.

A3. Refer to 5 - Some erroneous friction factors were found and corrected for later calculations. Transient 1 and 2 were thought to have unrealistic flow oscillations (although small) when the loops should have been almost stagnant.

A4. Refer to 6 - These high friction factors are flags to invoke the phase-separation option at that cell face.

A5. Refer to 8 - Heat loss from the pressurizer would occur when the heaters had tripped on low level.

A6. Refer to 9b - The equation that we finally used was:

$$\text{Level} = \frac{\Delta P - 9517}{4949}$$

This equation gave the correct level indication at steady state.

A7. Refer to 9c - The AFW logic was the same for all transients. In earlier decks, however, the AFW flow was zeroed out in a restart deck on an asymmetric-SG-pressure signal instead of being automatically zeroed out.

Steady State:

A8. Refer to 4 - For the particular steady state that you studied, this was an error. Calculations initiated from this steady state were rerun if the PTS-review group thought it was necessary.

A9. Refer to 6 - An exact steady state was not obtained for the hot-zero power case. However, it was thought to be adequate for the purpose of initiating a transient.

APPENDIX C

A PRELIMINARY REVIEW OF TRAC CALCULATIONS

FOR CALVERT CLIFFS PTS STUDY*

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January 1984

* Prepared under the auspices of the U. S. Nuclear Regulatory Commission.

A Preliminary Review of TRAC Calculations

For Calvert Cliffs PTS Study

This report documents the preliminary BNL comments on the TRAC calculations performed by LANL for the USNRC PTS study of Calvert Cliffs nuclear plant. A quick review of all the TRAC calculations was performed at BNL based on the LANL draft report [1] and the handouts obtained at the two Calvert Cliffs PTS study group meetings (September 20, 1983 at Baltimore Gas and Electric Co. and December 13, 1983 at Los Alamos National Laboratory). A more detailed review of a few selected transients will follow.

LANL performed TRAC calculations of 13 transients as shown in Table 1 (reproduced from the LANL draft report [1]). Four of these, i.e., Transient Nos. 1, 2, 10 and 11 are the hot zero power (HZP) steam line break accidents and the rest of them are various transients for the hot full power (HFP) condition. For the sake of convenience, the order of transients discussed below has been changed from Table 1. The HZP transients will be first discussed, followed by the HFP transients.

1. HZP Steamline Break Accidents

1.1 Transient 1: 1-ft^2 Steamline Break

This transient was initiated by a 1-ft^2 break at the main steam line during the HZP operation. There was a misstatement in Table 4.1 (Sequence of Events of Transient 1) of the LANL draft report that the minimum pressure was reached at 700 seconds. Figure 1 (Figure 4.2 of the LANL report) shows that the minimum pressure was reached at about 170 seconds. Figure 2 showed the pressurizer level was decreasing while the pressure of the primary system was increasing between 170 seconds and 550 seconds. This appeared to be contradictory.

The downcomer liquid temperature (Figure 3) increased substantially from 400°K to 425°K between 1300 seconds and 3000 seconds. However, the decay heat did not appear to be large enough to sustain this temperature rise. A simple calculation based on the energy balance indicated that the temperature should level off during this period. Part of this temperature rise may be due to the gradual mixing of the hotter ι r head liquid with the bulk of the liquid in the system. This point will be further checked in the detailed review.

The steam line pressure of the intact loop (Figure 4) showed a sharp reversal when the intact steam generator was isolated at 20 seconds and continued to increase. This appeared to be contradictory since the primary side temperature of the intact loop continued to decrease during this period.

The steam line pressure of the intact steam generator showed a sudden drop at about 1600 seconds. However, there was not any particular event to cause this drop at this time. This may have been caused by some sudden condensation computed by the TRAC code which may not be realistic. (Similar behavior was observed in many other transients.)

In summary, the TRAC calculation of this transient was acceptable. However, the cause of the temperature rise between 1300 and 3000 seconds and the intact steam generator pressure need further investigation.

1.2 Transient 10: 1-ft^2 Steam Line Break with Two RCPs Left Running

This was a similar transient as Transient 1 except that two of the four RCPs were left running when the RCP trips were on. The sequence of events should have been the same as Transient 1 until the pump tripped. However, there were some differences in the timing of the events. There appeared to be substantially more feedwater delivered into each steam generator in the beginning of the transient than Transient 1. This may be partly responsible for the above discrepancy. There was no charging flow in this transient after the HPI was terminated at 950 seconds (Figure 5) while charging continued in all other transients. The downcomer liquid temperature (Figure 6) at the end of the transient calculation (at 5300 seconds) was about 30°K higher than that of Transient 1 at the same time (425°K for the Transient 1 and decreasing; 455°K for Transient 10 and stabilized). This difference can be accounted for by the extra energy added by the pumps and appeared to be in the right range. There was no HPI/charging after 950 seconds; yet the rate of pressurization was about the same as Transient 1 where the charging continued. Absence of charging should lessen the pressurization rate.

In summary, the major difference between this transient and Transient 1 would be the extra energy added by the pumps, which resulted in the higher downcomer liquid temperature. The calculated results, with the exception of the primary pressure, appeared to be reasonable. The pressure increased faster than Transient 1 despite no charging. This point needs further clarification from the LANL staff.

1.3 Transient 2: Full Double-Ended Guillotine Steam Line Break

This transient was initiated by a full double-ended guillotine break in a steam line. Additionally, the Auxiliary Feedwater (AFW) to the broken steam generator was not manually isolated.

Although the size of the break of this transient was very different from that of Transient 1, the total break flow and the pressure history of the secondary side of both steam generators were not that different from Transient 1. This was expected since the location of the break was after the flow restrictor and, in any case, the amount of integrated mass loss was eventually equal to the initial liquid mass in the broken steam generator. Based on the overall energy balance, the major difference between this transient and Transient 1 would be the failure of the operator to isolate the AFW rather than the break size. This additional AFW to the broken steam generator would act as a continuous heat sink and eventually bring the entire system to the saturation temperature of the broken steam generator, i.e., 100°C (373°K), which the calculation did (Figure 7).

This condition would continue until the broken steam generator was completely filled with water. Then the entire system temperature would slowly decrease again toward about 350°K (the expected steady state liquid temperature to balance the decay heat with HPI/AFW flow) if the AFW to the broken steam generator persisted. We estimate this time to be approximately 12000 seconds.

In summary, the TRAC calculation of this transient appeared to be very reasonable.

1.4 Transient 11: Full Double-Ended Guillotine Steam Line Break with Failure of MSIV to Close

This transient should be the same as Transient 2 except that both MSIVs failed to close on the Steam Generator Isolation Signal (SGIS) so that both SGs continued to blowdown. However, the timing of SGIS was different between these two transients. Also the timing of the Auxiliary Feedwater Actuation Signal (AFAS) was very different. These differences should be clarified by the LANL staff. However, these details in the beginning of the transient would not affect the course of the transient significantly.

This appears to be a relatively simple transient to analyze. The system would rapidly cool down due to the blowdown of both SGs until the system reached the saturation temperature corresponding to the atmospheric pressure (i.e., 373°K or 100°C). The system would remain at this temperature until both SGs were finally empty. The calculation confirmed this trend (Figure 8). Based on the TRAC calculated break flow and assuming that the break flow was all vapor, the system should reach 100°C at about 90 seconds. However, considerably longer time was taken to reach this temperature for the TRAC calculation. This may indicate that a substantial amount of liquid was entrained through the break. This entrainment would also explain the slower depressurization rate than expected from the simple energy balance.

The secondary side pressure of the SGs decreased approximately along the saturation pressure of the system temperature (Figure 9). The system reached the PORV set point earlier than Transient 2 despite similar temperature behavior. This may be due to the longer HPI period. Both steam generators were expected to be empty at 7800 seconds based on the liquid mass in the SGs at 3000 seconds.

In summary, the TRAC calculated results of this transient appeared to be very reasonable.

2. HFP Transients

2.1 Transient 3: 1-ft^2 Steam Line Break

Transient 3, which was 1.0 ft^2 steam line break from full power, was similar to Transient 1 except it started from HFP. This transient calculation was repeated because there was an error in the steady state temperature in the pressurizer, which might have caused faster depressurization than expected. This could result in longer periods of safety injection and eventually lower system temperature. Comparison between the original and corrected calculations confirmed this. The primary temperature of the corrected run started to deviate from that of the original run at about 300 seconds, consistent with the HPI flow rate which showed a substantial difference between the two runs after 300 seconds. The broken steam generator dried out substantially earlier in the corrected calculation than in the original calculation. This appeared somewhat puzzling since the timing of the SGIS was about the same between both runs. The magnitudes of the primary temperature drop before, and rise after the SG dry-out were in the right range for both runs based on the total break flow and decay power by ANS curve (ANS decay power curve was used throughout this review of the HFP transients. Information on actual power generated was not available at the time of review; the power was calculated by the point kinetics with the reactivity table in all TRAC HFP calculations). The broken steam generator dried out earlier (less initial water mass) and the primary pressure reached at the PORV set point earlier than the HZP case (Transient 1) as expected. The calculated results with the corrected steady state pressurizer temperature appeared to be reasonable.

2.2 Transient 4: Turbine Trip with TBV Stuck Open

Transient 4 was not reviewed here since there was an error in the input which caused a significant difference in timing for the major events such as

the SIAS. The initial portion of this calculation (0 - 570 seconds, up to SGIS) would be the same as that of Transient 4A as discussed below.

2.3 Transient 4A: Turbine Trip With One TBV and One MSIV Stuck Open

This transient is basically similar to Transient 3. The major difference was the rate of mass loss at the break. The rate of mass loss through the break (i.e., stuck-open valves) was much smaller in this transient and, accordingly, this was a much milder transient. The rate of temperature drop (Figure 10) was lower, the minimum temperature was higher and the pressure (Figure 11) changed much slower than Transient 3. The temperature change matched approximately those obtained by simple hand calculations based on the mass and energy balances. The primary system pressure leveled off at 600 seconds and started increasing at 1000 seconds while the primary system temperature continued to decrease. There was no HPI or charging flow during this period. This appears to be contradictory and needs further explanation. The timing of the broken steam generator dryout was within the expected range. The pressure of the intact steam generator changed approximately along the saturation pressure of the calculated temperature, which was expected.

In summary, the calculated results appear to be reasonable except for some portion of the primary pressure response.

2.4 Transient 7: Small Break LOCA With Artifically Blocked Natural Circulation

Transient 7 was not reviewed since this calculation involved artificial and unrealistic blockage of the primary loop.

2.5 Transient 7A: Small Break LOCA

This transient was initiated by a small break (0.02 ft^2) in a hot leg. Figures 12 and 13 show the calculated primary temperature and pressure, respectively. At the initiation of the break, the primary pressure would start

decreasing sharply. At some point (2100 psia), the low primary pressure would trip the reactor and turbine. ADVs and TBV would open at the same time. The primary pressure would continue decreasing due to continued loss of mass through break, triggering the HPI and pump trip at 1275 psia. Introduction of HPI would reduce the rate of depressurization and pressure would increase much slowly. Meantime, opening and closing of ADVs and TBVs would maintain the average primary and secondary temperature at 552°K (set temperature of the ADVs and TBVs) or near it. This state would continue until either the AFW started due to low SG level (which did not appear to happen in the calculation) or the continued cooling by HPI eventually brought down the primary temperature below 552°K. This would close the ADVs/TBVs. The primary temperature would continue to fall due to the cooling by HPI. Since the break flow was slightly higher than the HPI, the system pressure would continue to drop slowly until the break flow finally balanced with the HPI flow. The secondary pressure and temperature would also slowly decrease along the primary temperature and its saturation pressure. In the calculation, the TBVs were closed because of SGIS, which was caused by high containment pressure. (Information was not available on how the containment pressure was calculated.) This closed the TBVs a little earlier than expected. However, this may not have made any significant difference since the ADVs were still open. The calculation showed a constant secondary pressure (Figure 14) maintained for a long time after the ADVs were closed despite the declining primary temperature, and some asymmetric pressure between the two SGs at around 5000 seconds (Figure 14). Also, one of the SGs started to empty or boil while there appeared to be no event to cause this.

In summary, the sequence of events of the calculations generally appeared to follow the expected trend except the SG pressure. There was insufficient information in the handout to check the timing of the events or the magnitude of the temperature and pressure change.

2.6 Transient 5: Primary PORV and Secondary ADV Stuck Open

The transient was similar to Transient 7A until one of the ADVs failed to close. Also, it appeared that the flow through the PORV was smaller than the break flow of Transient 7A. After the reactor trip, the stuck-open ADV, instead of maintaining the primary temperature by opening and closing, allowed the continuation of steam generator blowdown. This caused the primary temperature and pressure to continue to decrease (Figures 15 and 16). The HPI increased as the system pressure decreased and, at some point (around 70 bar), the HPI flow matched the PORV flow. This stabilized the pressure. If this condition persisted, the primary temperature would eventually drop near the HPI water temperature. Again, there was not enough information available such as PORV and ADV flow rate, in the handout to check the magnitude of the temperature drop or timing of the events.

2.7 Transient 6: AFW Overfeed

This transient was initiated by the loss of MFW due to MFW pump trip. Additionally, the AFW did not start on AFAS until 20 minutes into the transient when AFW pumps were started to both steam generators by the operator.

Upon the loss of the MFW, the SG level would start decreasing, and reactor and turbine would be tripped on low SG level. The ADVs and TBVs would also open at this time. The average primary temperature and pressure would start decreasing rapidly. However, since the ADVs and TBVs were programmed to open

and close on the primary temperature, this would maintain the primary temperature at the set point, i.e., 552°K. This also would hold the secondary temperature at this temperature (or slightly lower ~550°K) and the SG pressure at the saturation pressure (~60 bar) corresponding to this temperature. Meantime, the primary pressure would slowly start increasing due to the pressurizer heaters. This state would continue until both SGs became empty or nearly empty. At this point, there would be no cooling of the primary system. The primary temperature would start increasing due to the decay heat and the primary pressure would increase faster until it reached the PORV set point. The secondary pressure would start decreasing since the ADV/TBVs were still open due to high primary temperature while SGs became empty. This decreasing pressure would cause the SGIS which would isolate the TBVs. However, since the ADVs would still remain open, the secondary pressure would continue decreasing. The calculated results generally matched the expected trend as described above (Figures 17 and 18).

As programmed in the calculation, the opening of ADV depended on the primary temperature only. However, there was a question if it should also depend on the secondary pressure. If ADVs were programmed this way, it would have kept the secondary side pressure at the set pressure of the ADVs (probably 60 bar) and its temperature at the saturation temperature (552°K) of this pressure. This, in turn, would have kept the average primary temperature near this temperature. This would be equivalent to controlling the primary temperature. The only time when the secondary side behavior deviated from this course significantly would have been when the secondary side water level was very low and, therefore, the steam generator as a heat sink was lost anyway. Therefore, this change of programming on the control of the ADVs may not have made any significant difference for the rest of the transient.

At 20 minutes after the beginning of the transient, the operator activated the AFW pumps to both SGs. This caused rapid cooling and depressurization of the primary system. Low primary pressure activated the SIAS. Meantime, the low primary temperature caused the ADVs to close. The secondary pressure started to increase and the secondary temperature rapidly increased to the primary temperature. The primary pressure and temperature continued decreasing until HPI flow began. The pressure started increasing while the temperature continued its downward trend. At this point, the calculation showed severe asymmetric pressure and temperature between the two steam generators (Figure 19). This was explained by the LANL staff as instability caused by condensation which is not considered realistic. However, this may not affect the primary pressure and temperature significantly, since the overall cooling may depend on the total amount of AFW rather than its distribution.

In summary, the calculated results appeared to be reasonable except for the asymmetric SG behavior after the AFW was introduced.

2.8 <u>Transient 8: MFW Overfeed to Both SGs</u>

This transient was not reviewed, since not enough information was available in the handout.

It appears that the temperature drop before, and rise after the MFW was tripped off, were of correct magnitude.

2.9 <u>Transient 9: MFW Overfeed to One SG</u>

This transient was initiated when a Main Feedwater Regulating Valve (MFRV) failed to close when the turbine tripped. This allowed full feedwater flow to the affected SG until the MFW pumps were tripped. This was a relatively difficult transient to analyze. Considerable heat transfer continued in the affected steam generator and, consequently, there was a large temperature

difference between the primary and second sides of the system, and the cold and hot legs of the primary loops for a substantially long period of time (until the MFW pump tripped at 300 seconds).

Initial steep drop of temperature and pressure (Figures 20 and 21) of the system due to the loss of the steam in both SGs through the TBVs and ADVs were within the expected range. The continued drop of system pressure and temperature due to continued MFW to the affected SG and the sharp increase of the temperature and pressure after the MFW was discontinued at 300 seconds, were also as expected. The timing of the affected SG fill-up (about 130 second) also matched that of the simple hand calculation based on the MFW flow rate and the initial SG water inventory. However, the continued high pressure of the intact SG until 300 seconds despite decreasing temperature was not expected (Figure 22). There was high mass flow in the steam line of the affected SG between 200 and 300 seconds. However, neither the primary temperature nor the secondary pressure appeared to be high enough to open TBV/ADVs during this period.

There was a sharp leveling of the system temperature at around 3200 seconds, yet it appeared that no major event occurred at this time. This leveling of temperature appeared to be a little too sudden. Decrease of the temperature around 4800 seconds was expected since AFW started at this time. However, the cause of the AFAS at this time was not clear because there was no major mass loss from the steam generator, and the temperature remained high. As mentioned earlier, this was a difficult transient to assess. There are still several points which need further investigation.

3. Plan for the Detailed Review

Among the thirteen transient calculations performed by LANL, six transients have been selected for the detailed review. They are Transient Nos. 1 and 11 for the HZP transients and 3, 6, 7a and 9 for the HFP transients.

All four HZP transients are steam line break accidents. Two of them were 1-ft^2 steam line break and the other two are full double-ended guillotine steam line breaks. Transients 1 and 11, representing two different break sizes, are selected for further review. There are also corresponding RETRAN calculations done by ENSA for BG&E available for these two transients. Results of the TRAC and RETRAN calculations will be compared for these two transients.

There are basically three different categories of HFP transients. These are: (a) steam line break/valve failure (Transients 3, 4 and 4a), (b) small break LOCA (Transients 7 and 7a) and (c) runaway-feedwater (Transients 6, 8 and 9) transients. Transient 5 was a combination of primary and secondary failures (PORV and ADVs stuck-open).

Transient 3 has been selected to represent the steam line break/valve failure transient. The break size of this transient (1-ft^2) is the same as that of Transient 1 of the HZP case and this will allow comparison of these two transients initiated at two extreme power levels.

Transient 7a is selected for the small break LOCA transient, since Transient 7 involved artificial and thus unrealistic blockage of the primary loop.

Transients 6 and 9 are selected for the runaway feedwater cases, representing the AFW and MFW overfeed, respectively.

It should be noted from Table 1 that the transients selected for detailed review (Transient Nos. 1, 3, 6, 7a, 9 and 11) do include most of the more severe overcooling transients calculated by LANL for the NRC Calvert Cliffs PTS study.

REFERENCES

1. J. G. Koenig, et al., "TRAC Analyses of Potential Overcooling Transients at Calvert Cliffs-1 for PTS Risk Assessment," Los Alamos National Laboratory, December 1983.

TABLE 1 CALVERT CLIFFS PTS TRANSIENTS

Transient No.	Descriptive Title	Initial Plant State	Initiating Event	Equipment Failures on Demand	Operation Actions	Minimum T(K)	Minimum P(MPa)	Repressurization
1.	1-ft^2 steam line break at standby	Hot 0% Power	1.0-ft^2 hole in steam line A	None	None	395	4.8	Yes
2.	Full double-ended guillotine steam line break	Hot 0% Power	Full steam line break	Auxiliary feedwater (AFW) is not isolated	None	377	3.7	Yes
3.	1-ft^2 steam line break at full power	100% Power	1.0-ft^2 hole in steam line	None	None	468	6.0	Yes
4.	Turbine-trip with turbine-bypass valve (TBV) stuck open	100% Power	Turbine trip	TBV sticks wide open	None	530	10.8	Yes
4a.	Turbine trip with one TBV and one MSIV stuck open	100% Power	Turbine trip	TBV & MSIV stick open		500	11.4	Yes
5.	Primary power-operated and atmospheric-dump valve (ADV) stuck open	100% Power	PORV transfers to wide open	1 ADV opens on demand and sticks open	None	407	6.0	No
6.	AFW overfeed after AFW response failure	100% Power	MFW system trips off	AFW delay for 20 min.	AFW valves opened fully at 20 min.	375	6.5	Yes
7.	Small break loss-of-coolant accident with blocked natural circulation	100% Power	An 0.02- ft^2 hole appears in the hot leg	None	None	342	2.6	No
7a.	Small break LOCA with no artificial flow blockage	100% Power	"	None	None	440	3.8	No
8.	Main feedwater overfeed	100% Power	Turbine trip	2 MFRVs stick open	None	480	7.0	Yes
9.	Main feedwater overfeed to one SG	100% Power	Turbine trip	1 MFRV sticks open	None	490	6.4	Yes
10.	1 ft^2 steam line break with 2 RCPs left operating	Hot 0% Power	1.0 ft^2 hole in steam line	None	None	446	3.9	Yes
11.	Full double-ended guillotine steam line break	Hot 0% Power	Full steam line break	MSIVs fail to close	AFW turned off at 8 min.	376	4.5	Yes

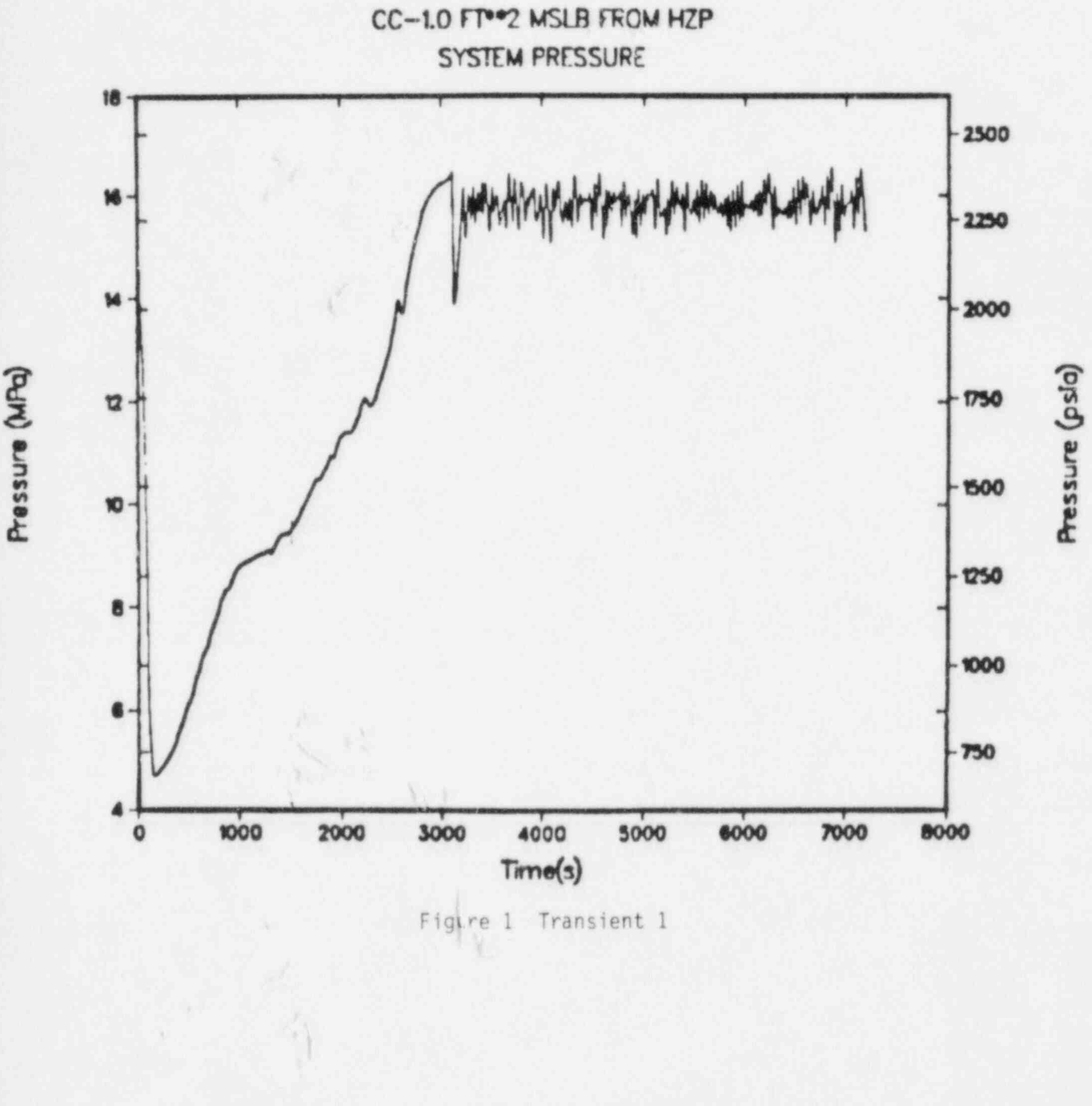

Figure 1 Transient 1

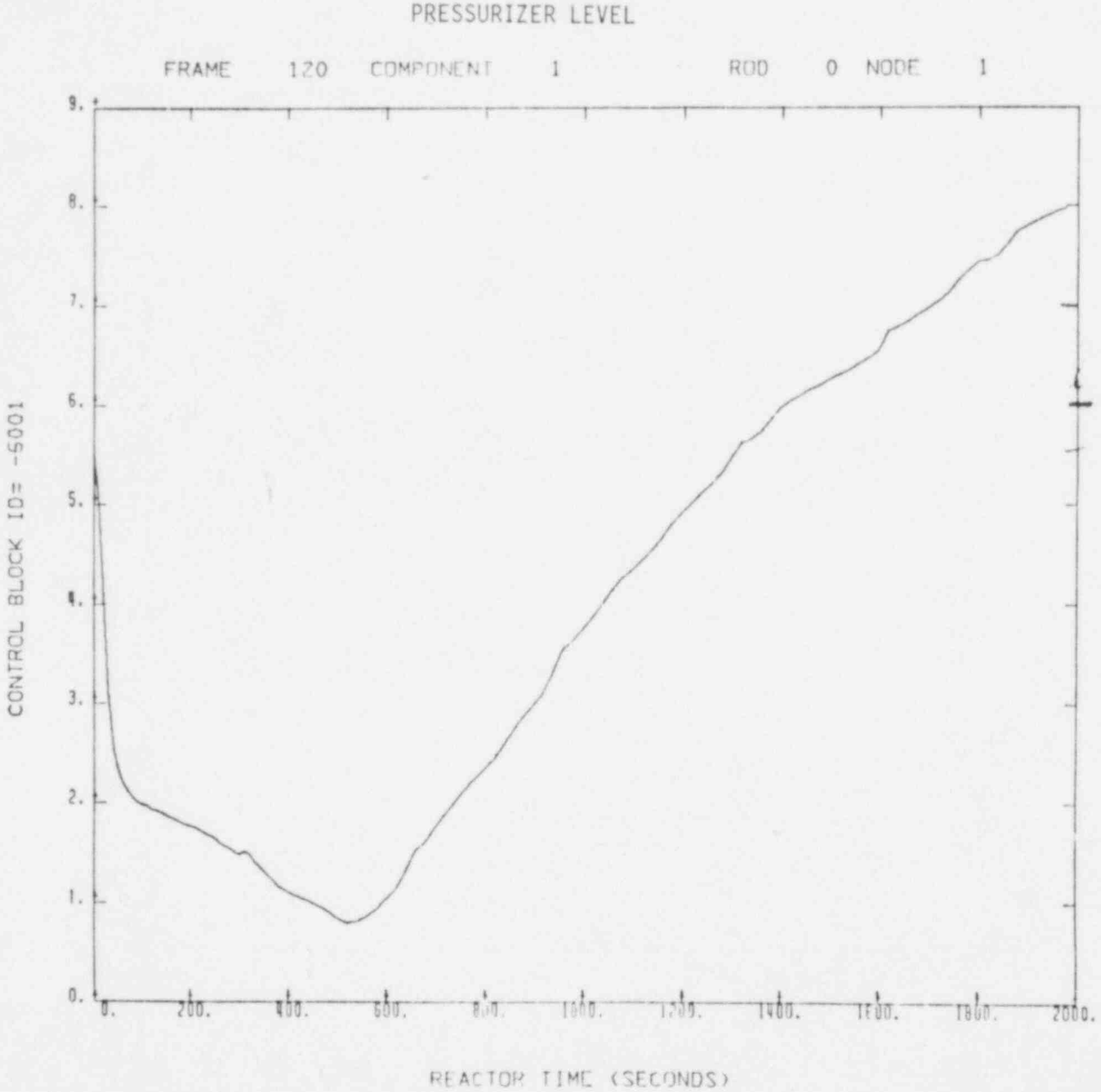

Figure 2 Transient 1

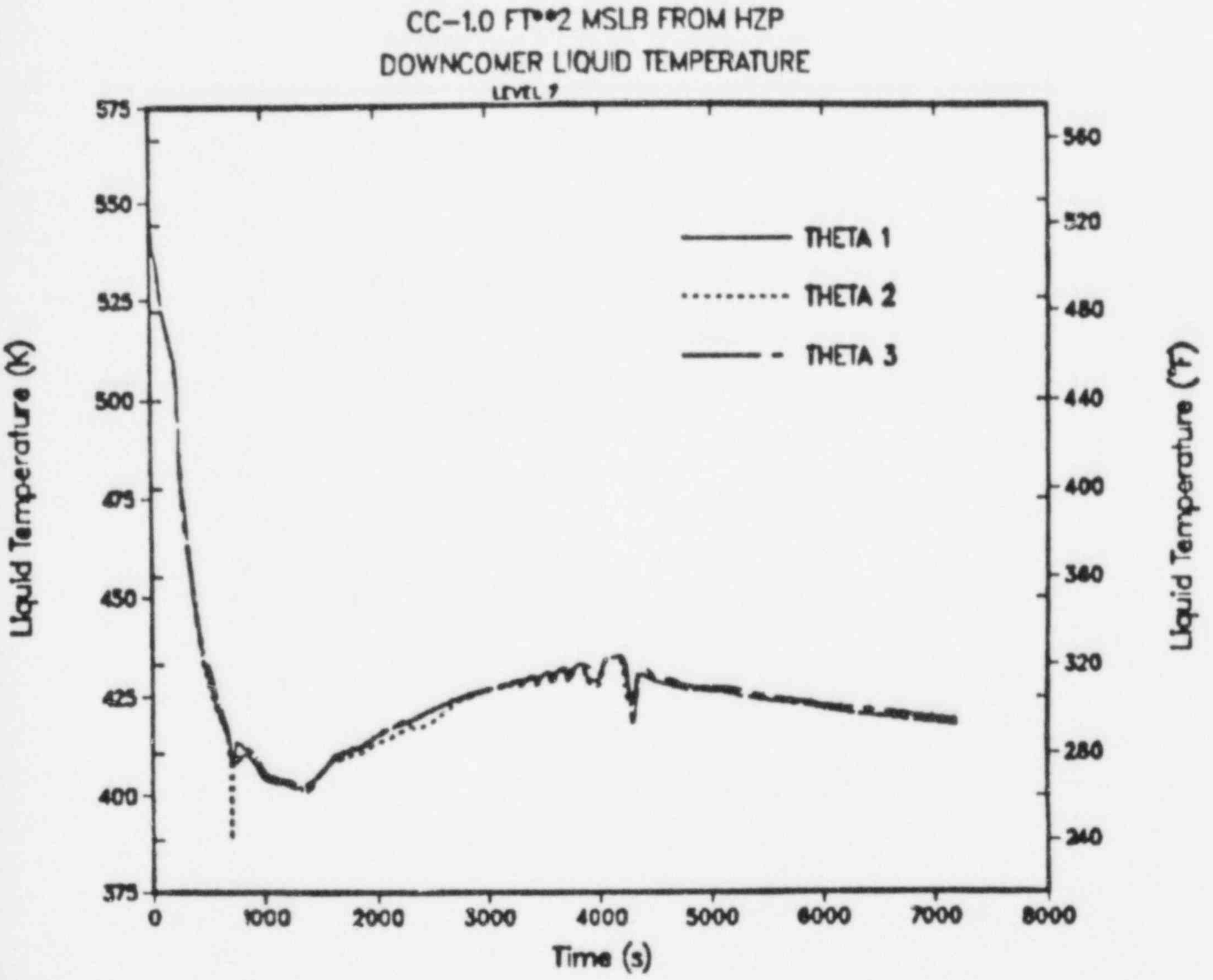

Figure 3 Transient 1

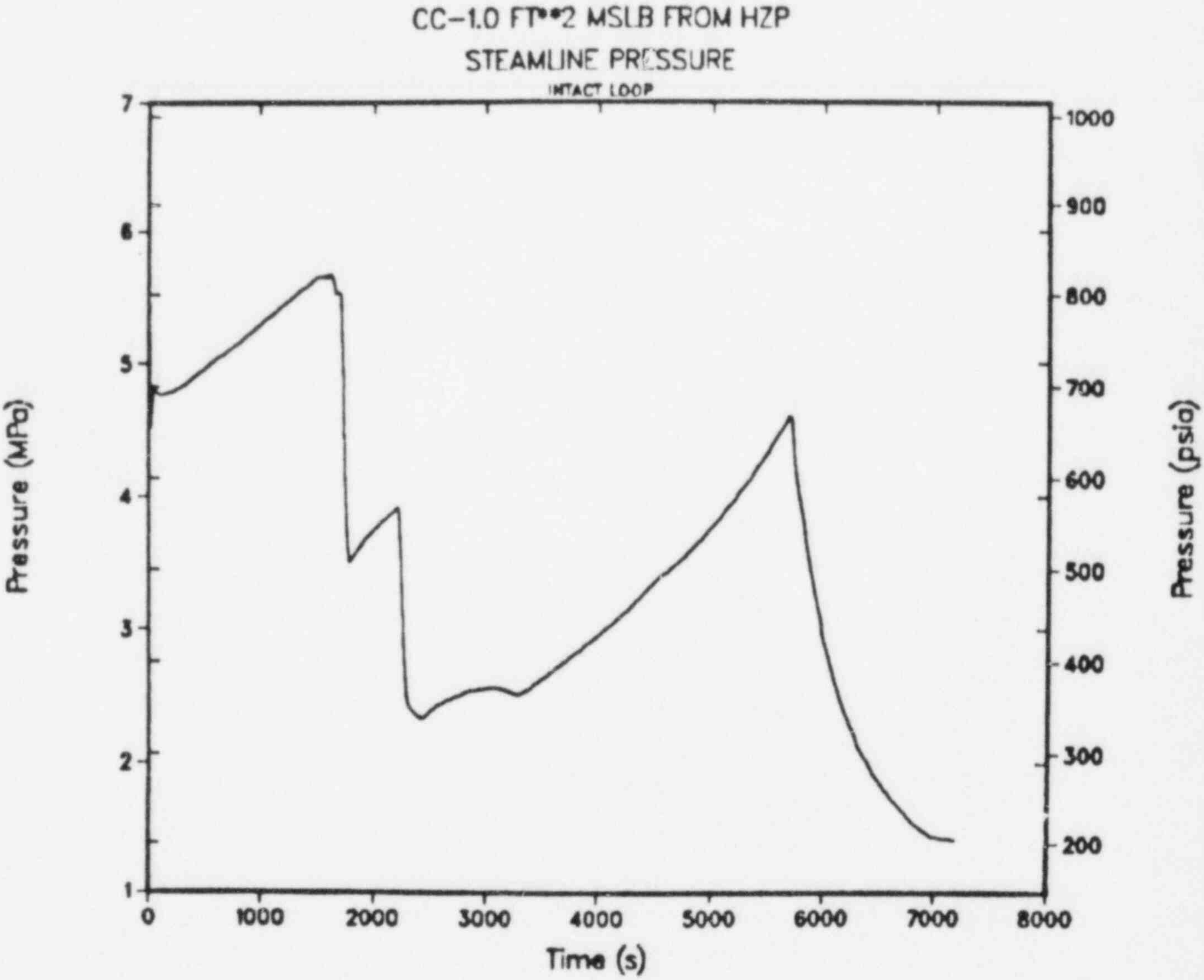

Figure 4 Transient 1

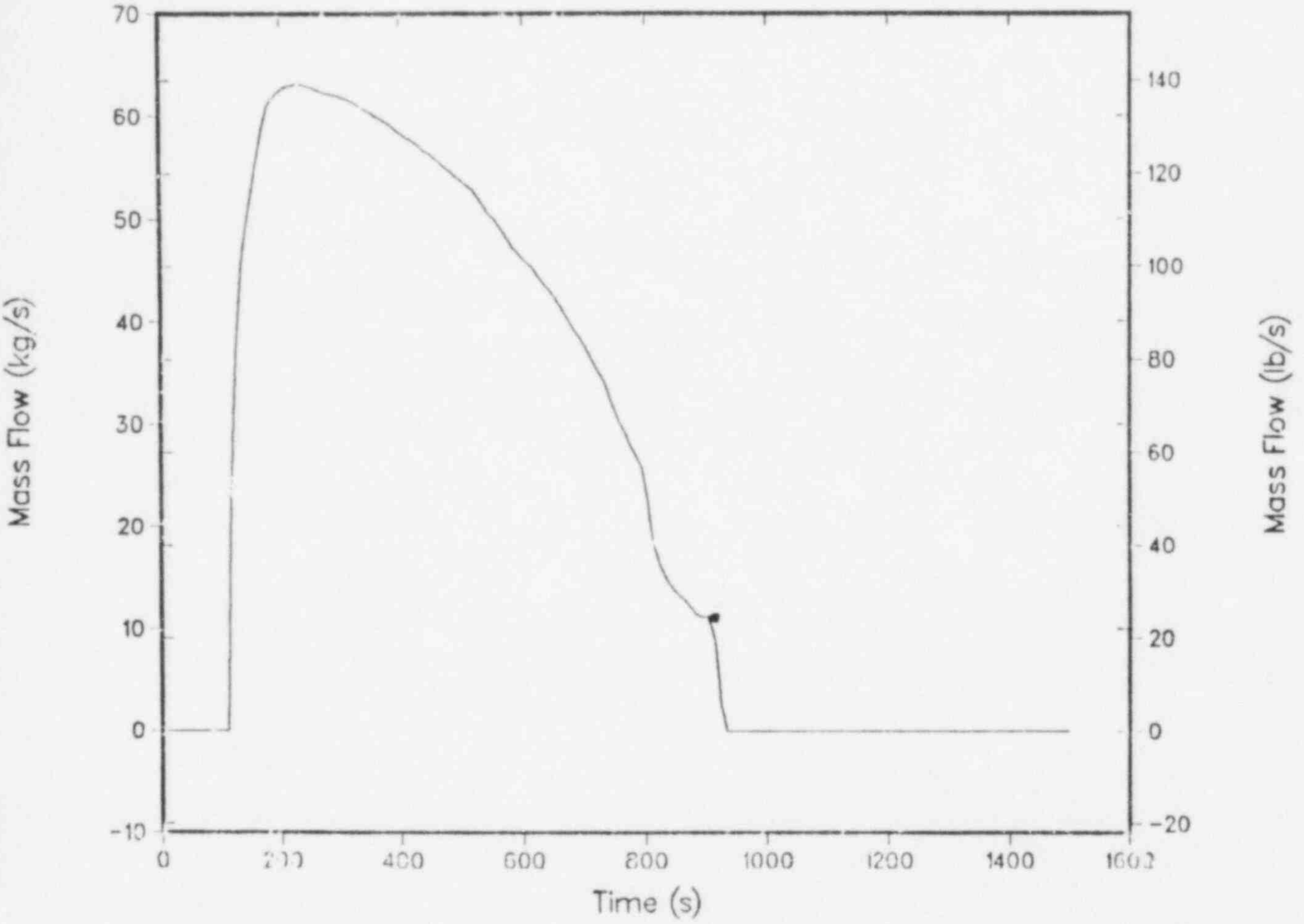

Figure 5 Transient 10: Total HPI Flow

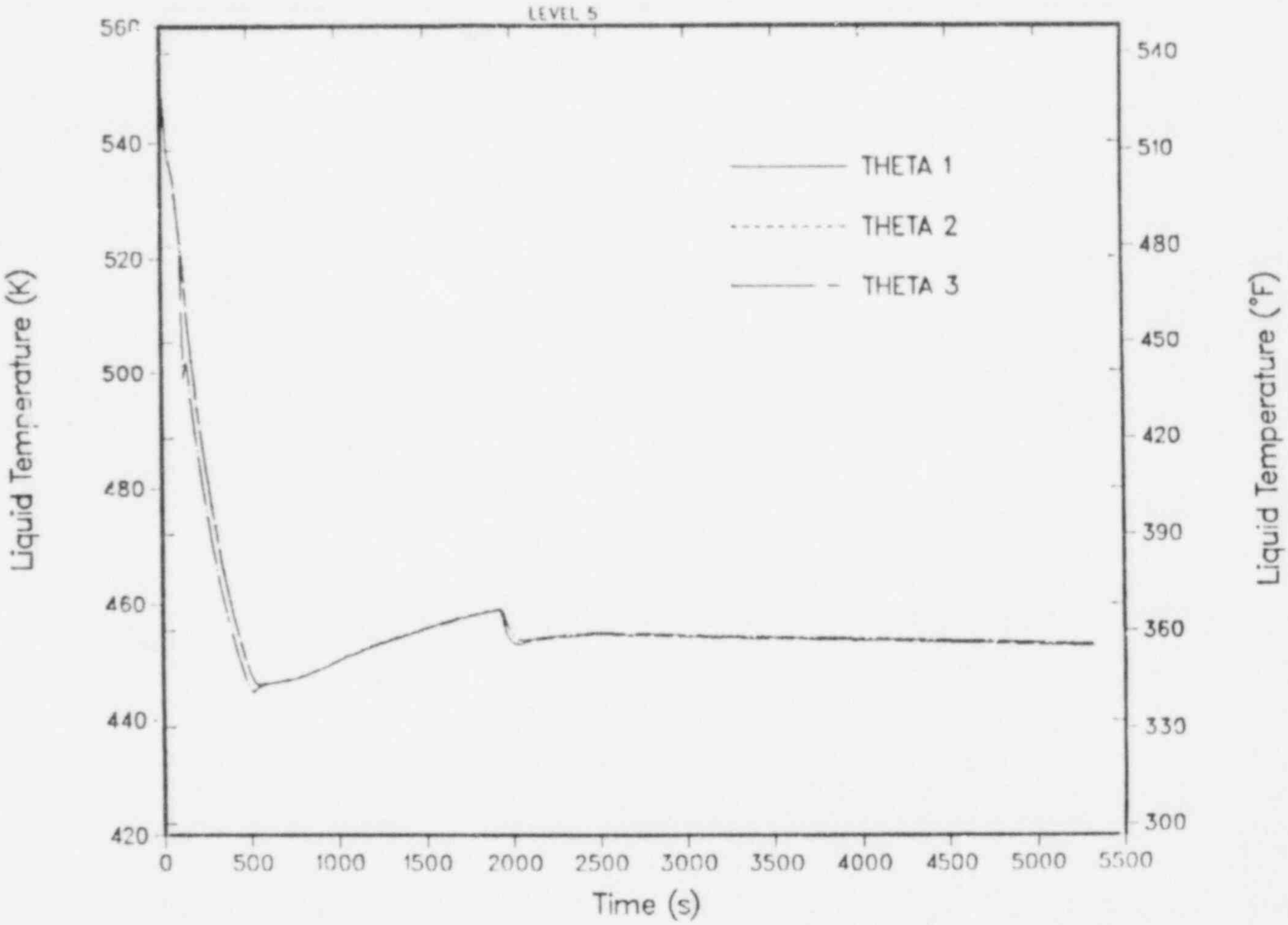

Figure 6 Transient 10: Downcomer Liquid Temperature

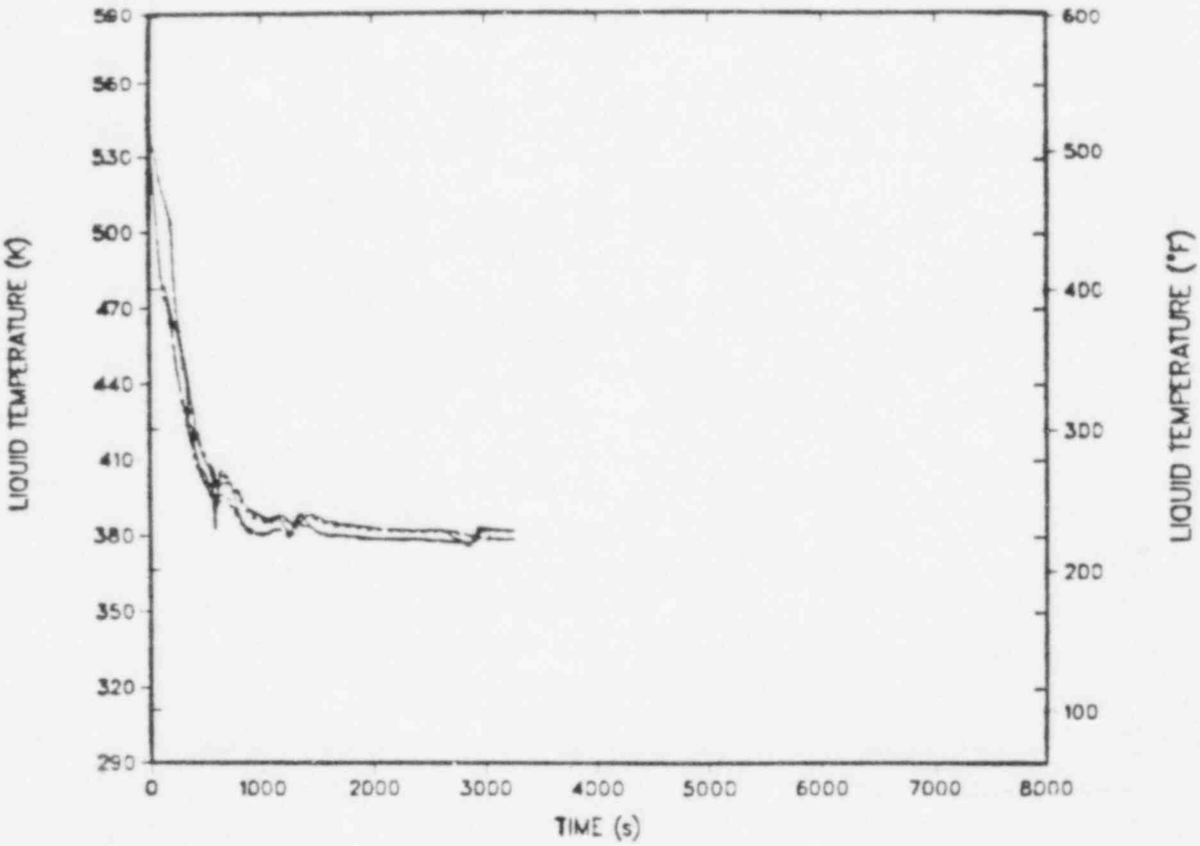

Figure 7 Downcomer Liquid Temperature During Transient 2

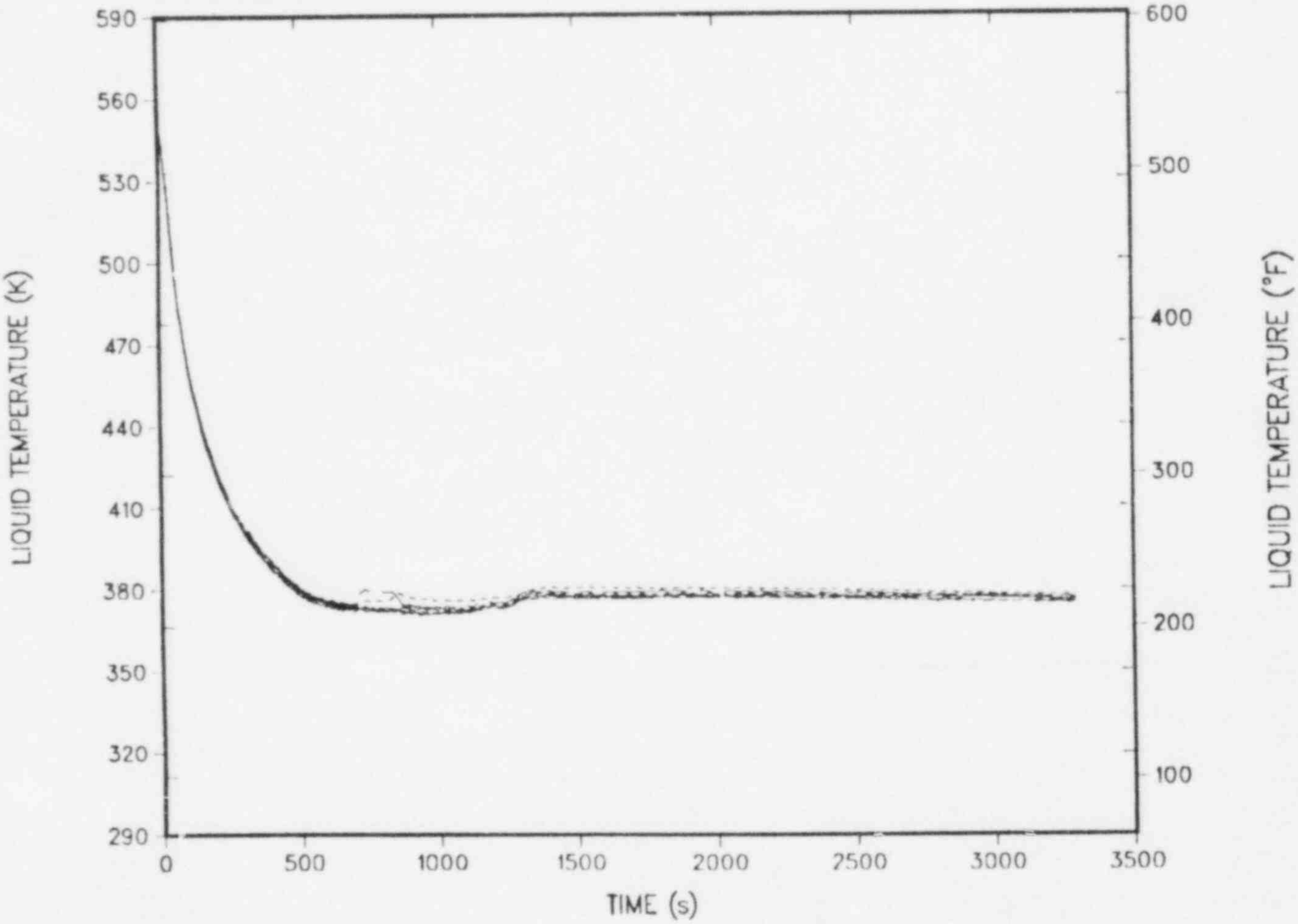

Figure 8 Transient 11: Full Steam Line Break with Stuck Open MSIVS
Downcomer Liquid Temperature

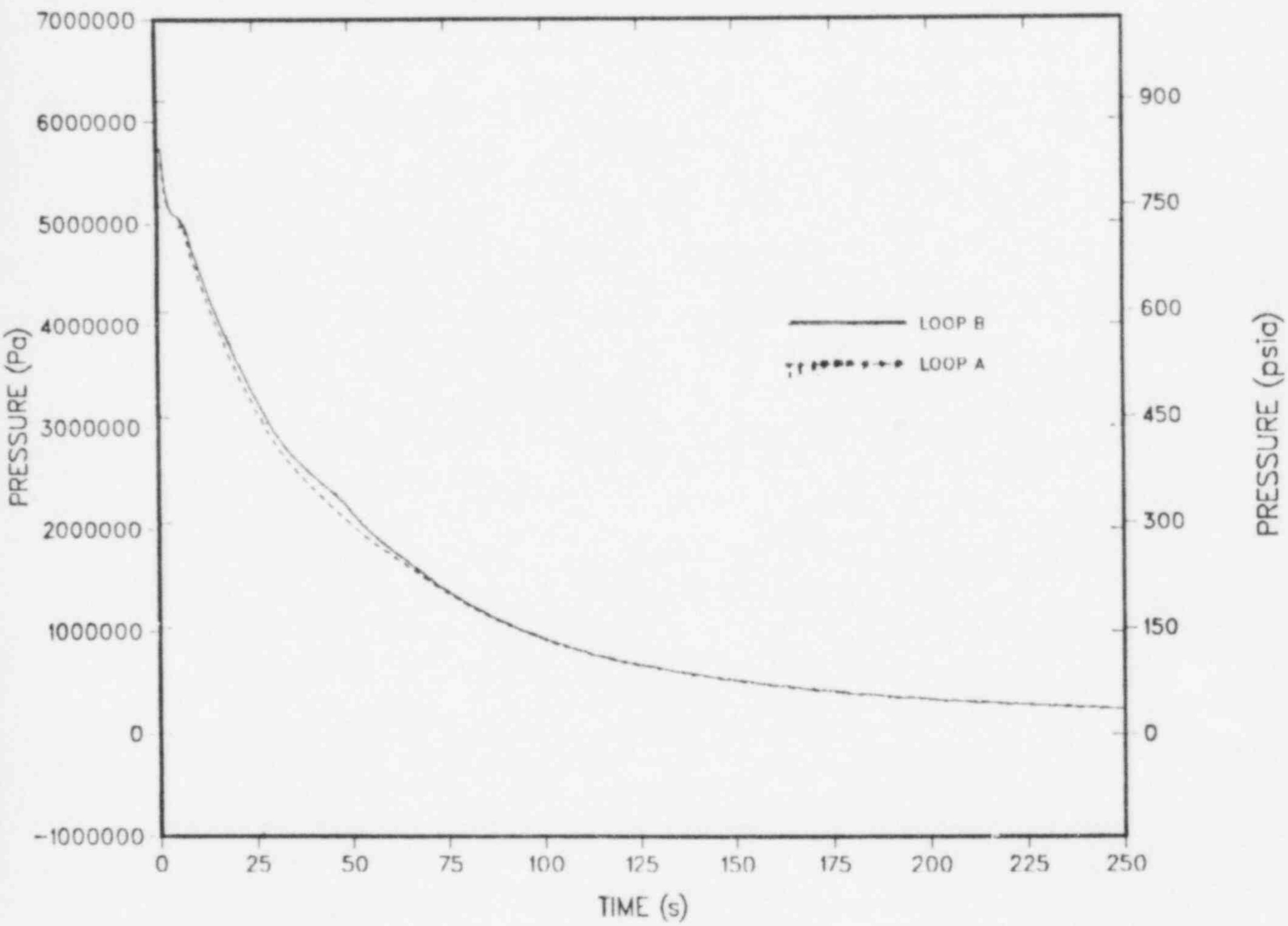

Figure 9 Transient 11: Full Steam Line Break with Stuck Open MSIVS
Steamline Pressure

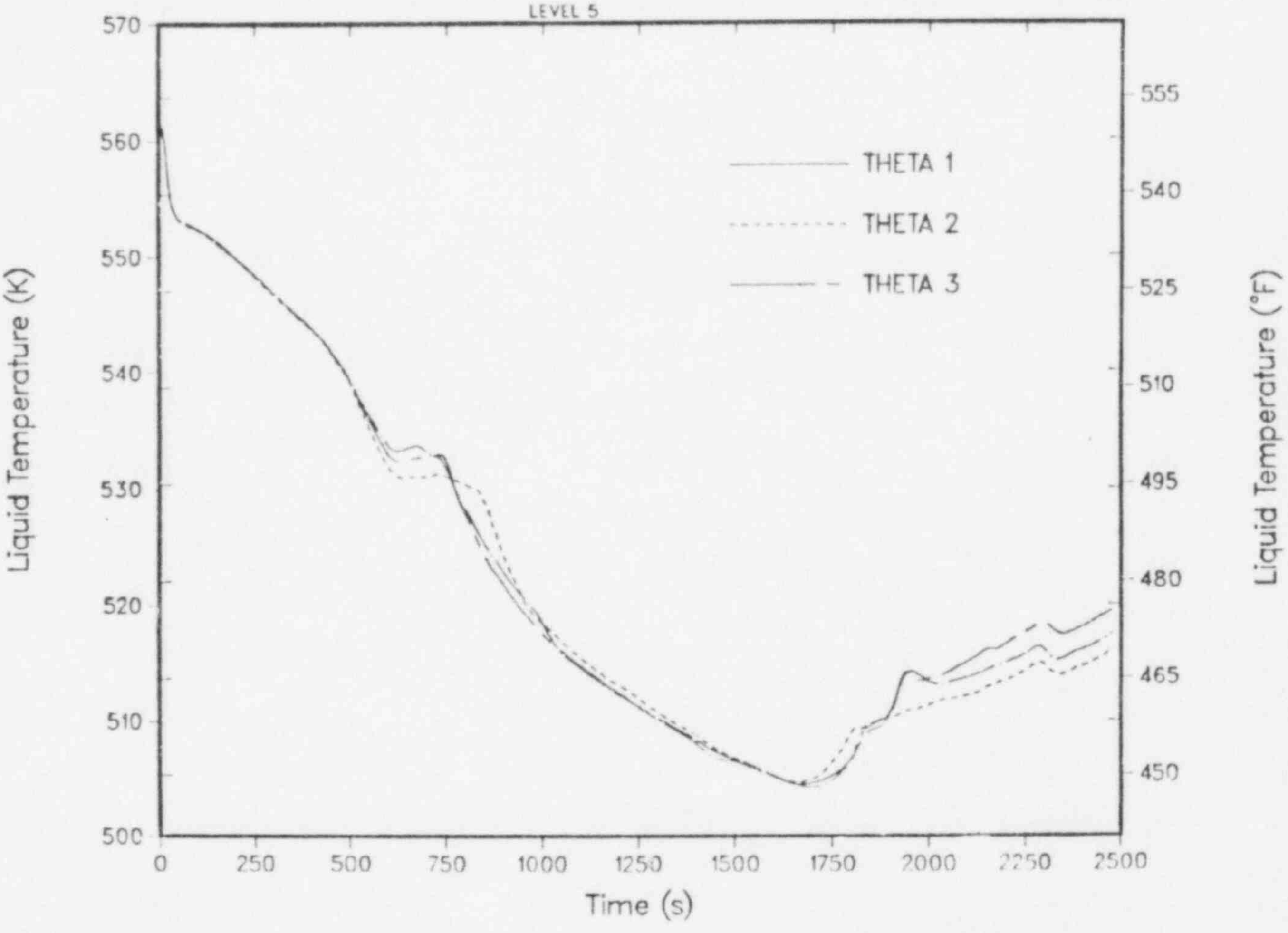

Figure 10 Transient 4A: Downcomer Liquid Temperature

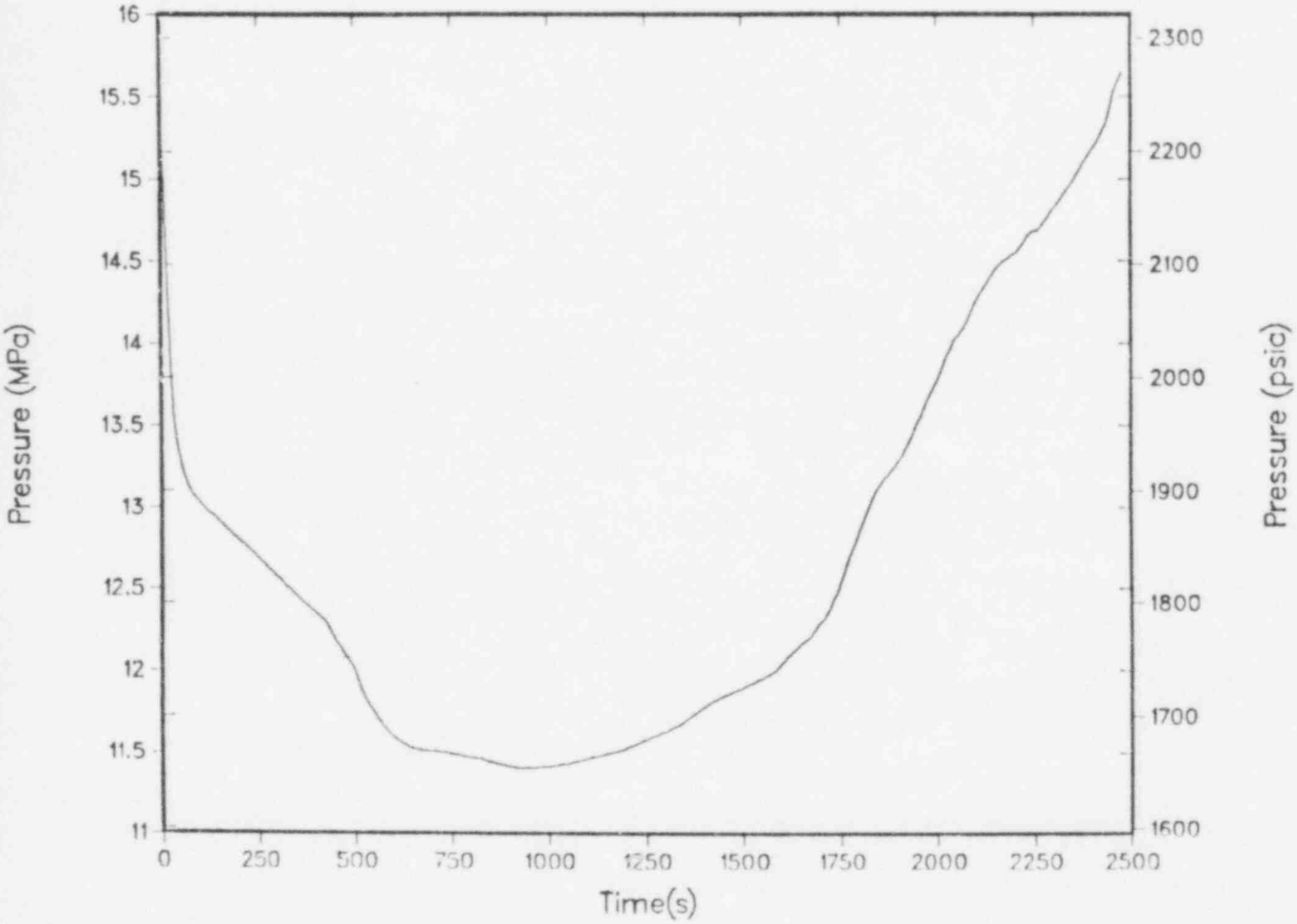

Figure 11 Transient 4A: System Pressure

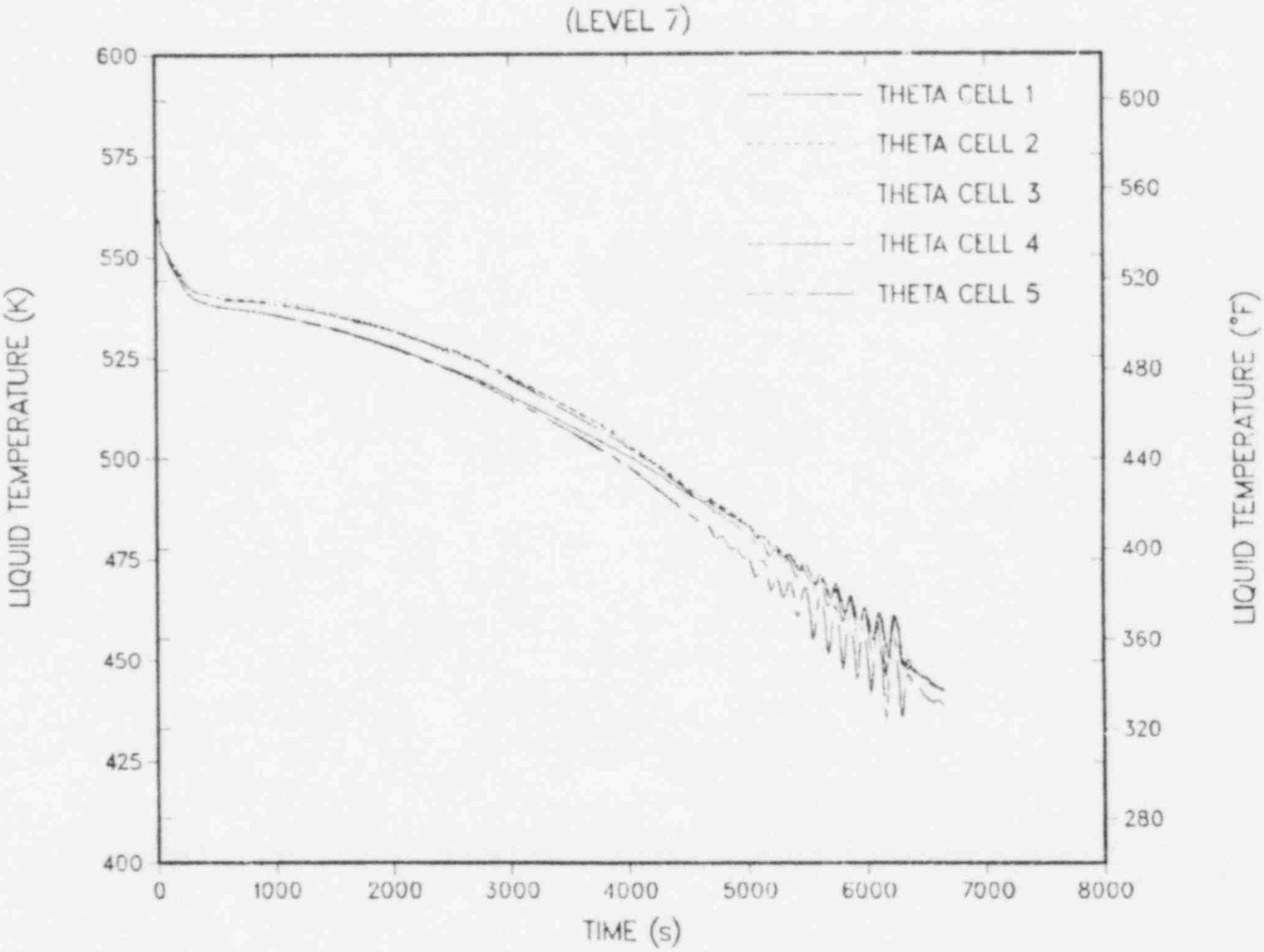

Figure 12 Calvert Cliffs Unit 1 - PTS Transient 7A:
Reactor Vessel Downcomer

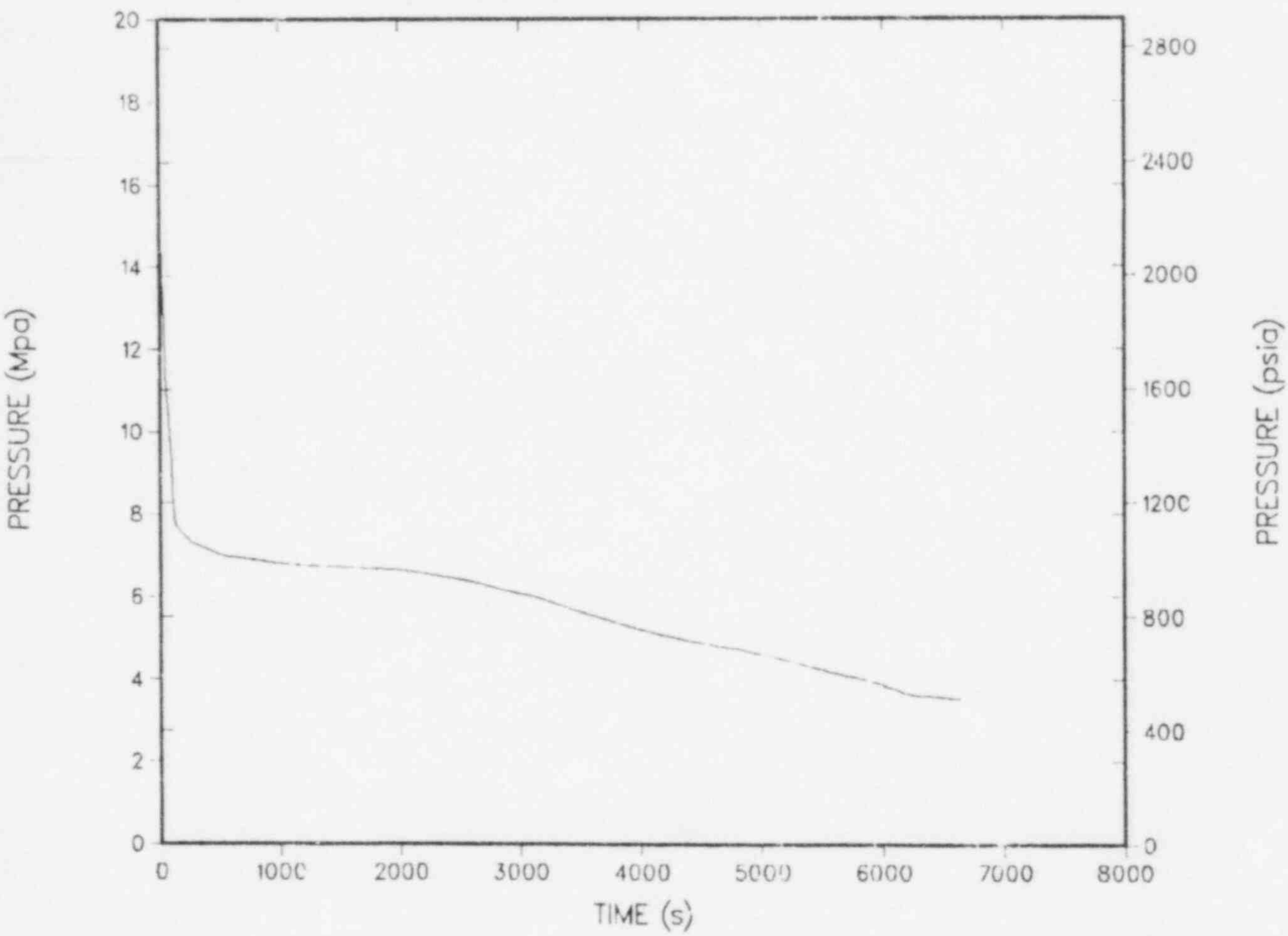

Figure 13 Calvert Cliffs Unit 1 - PTS Transient 7A:
Primary Pressure

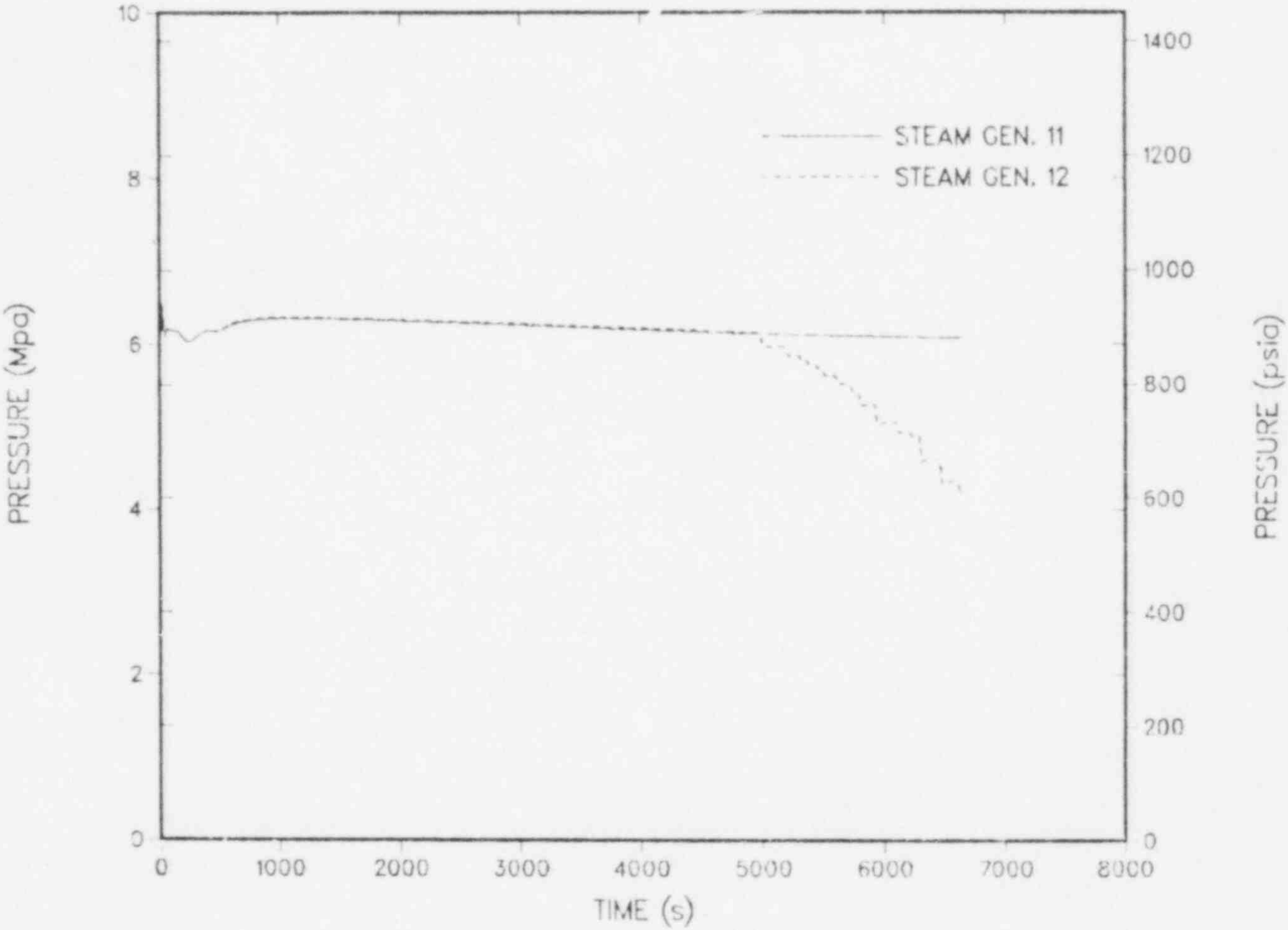

Figure 14 Calvert Cliffs Unit 1 - PTS Transient 7A: Secondary Pressures

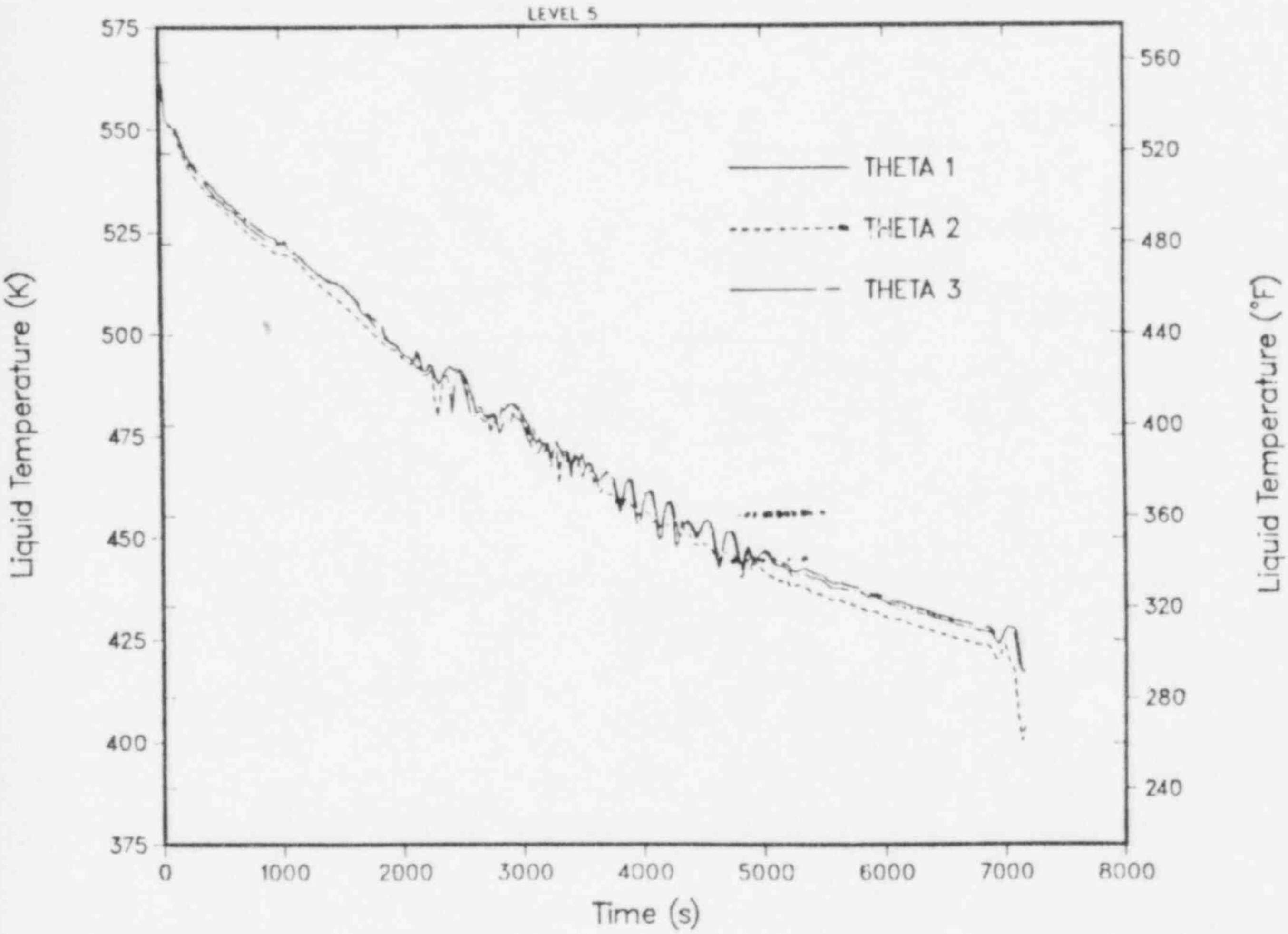

Figure 15 Transient 5: Downcomer Liquid Temperature

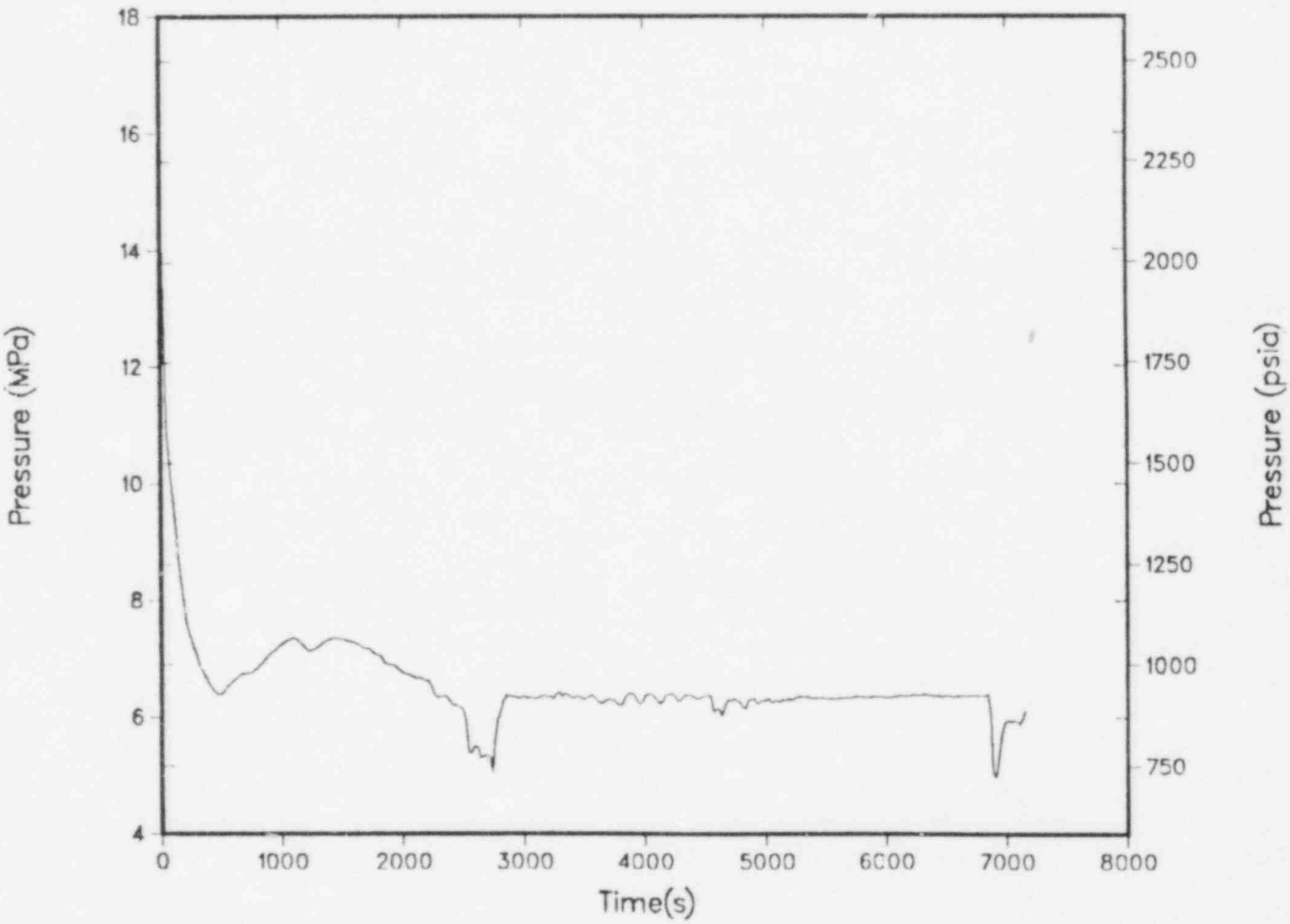

Figure 16 Transient 5: System Pressure

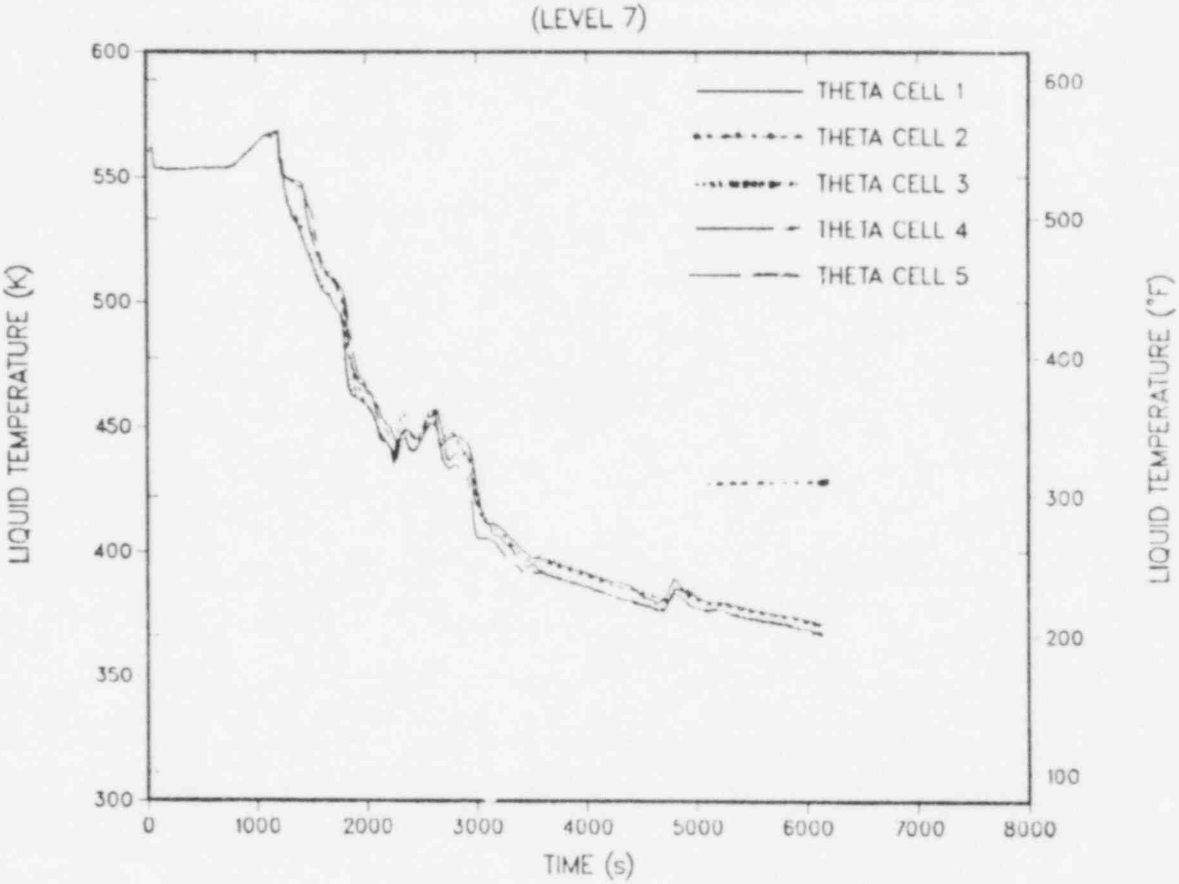

Figure 17 Calvert Cliffs Unit 1 - PTS Transient 6:
Reactor Vessel Downcomer

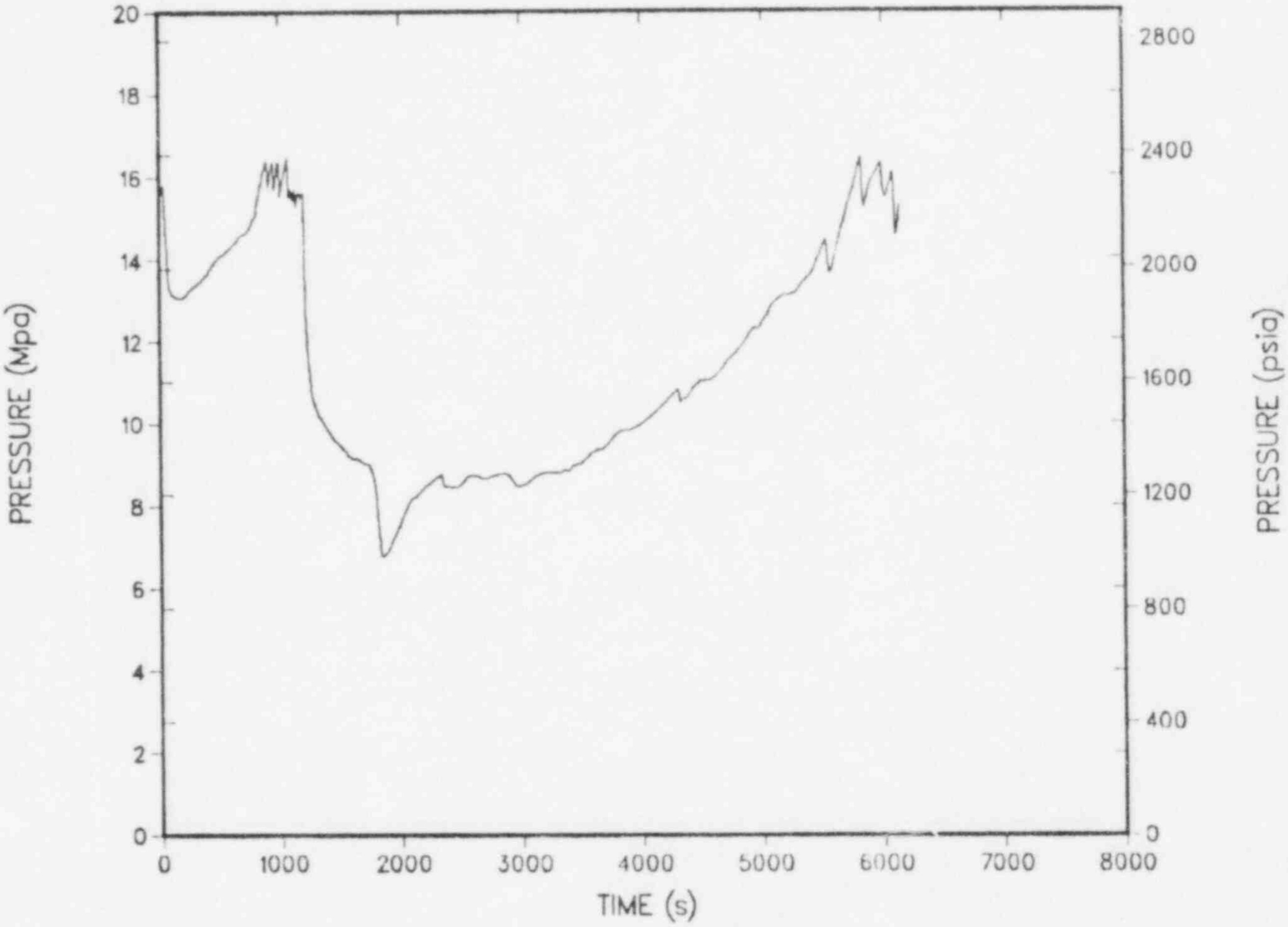

Figure 18 Calvert Cliffs Unit 1 - PTS Transient 6: Primary Pressure

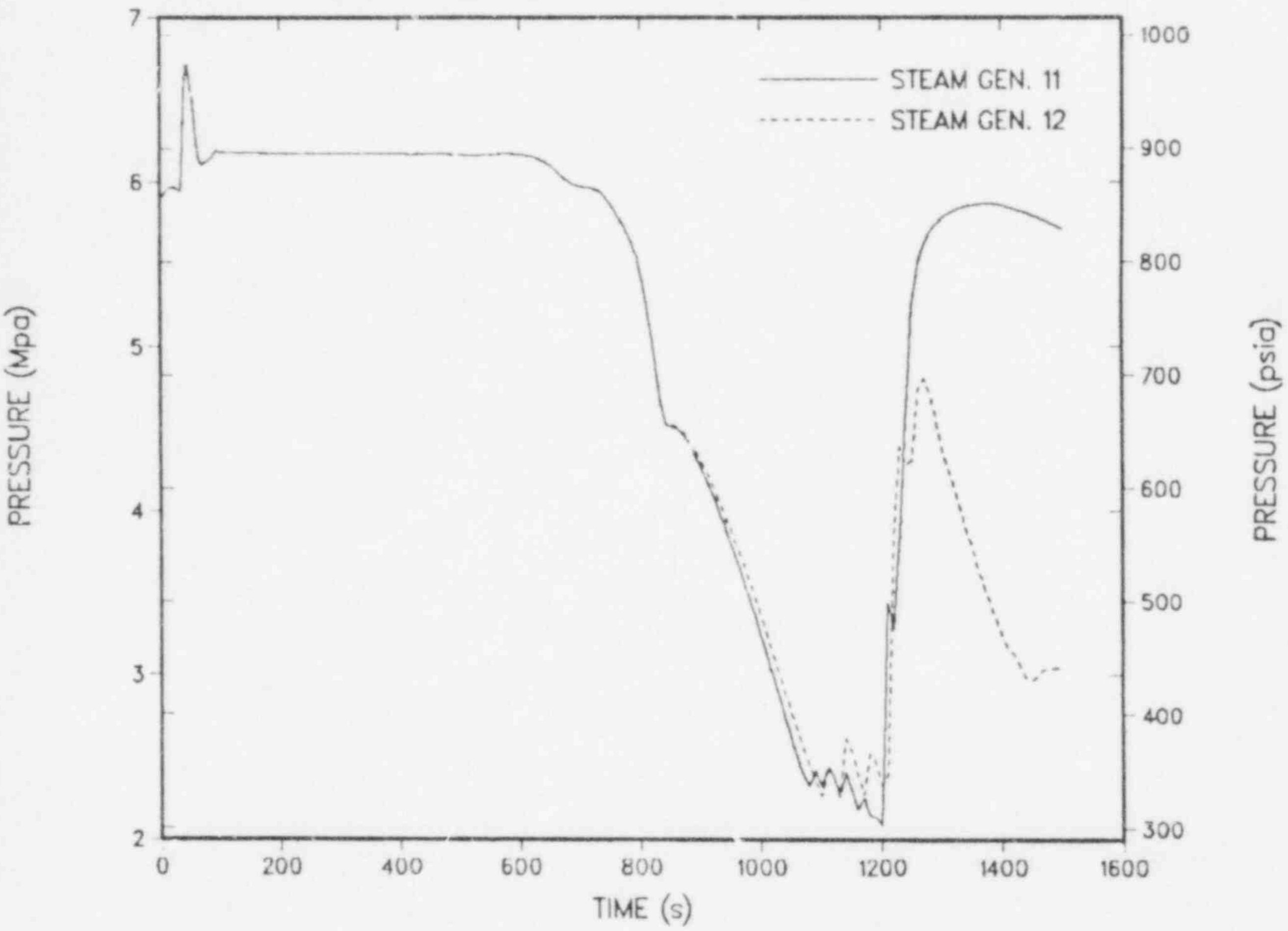

Figure 19 Calvert Cliffs Unit 1 - PTS Transient 6: Secondary Pressures

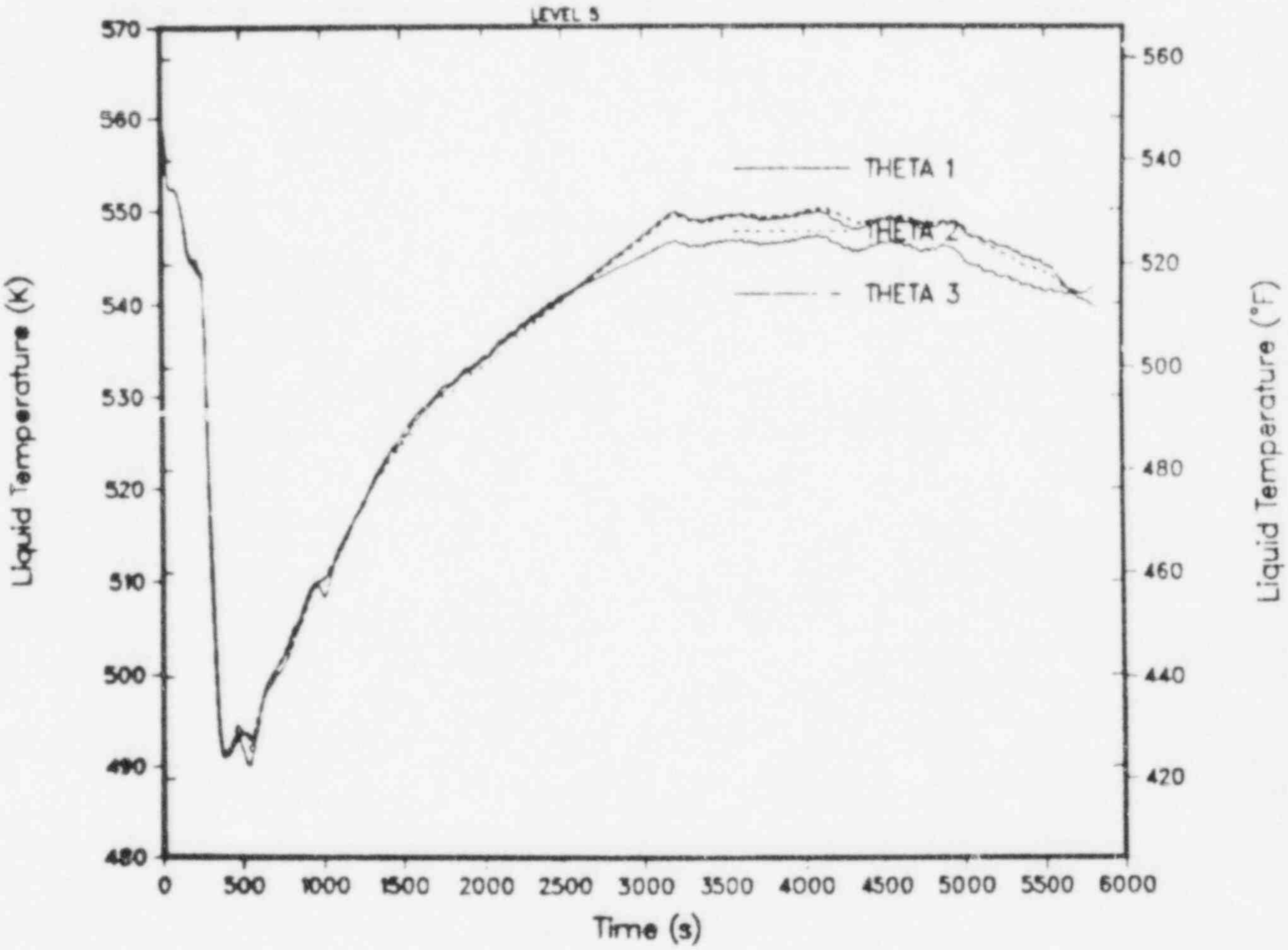

Figure 20 Transient 9: Downcomer Liquid Temperature

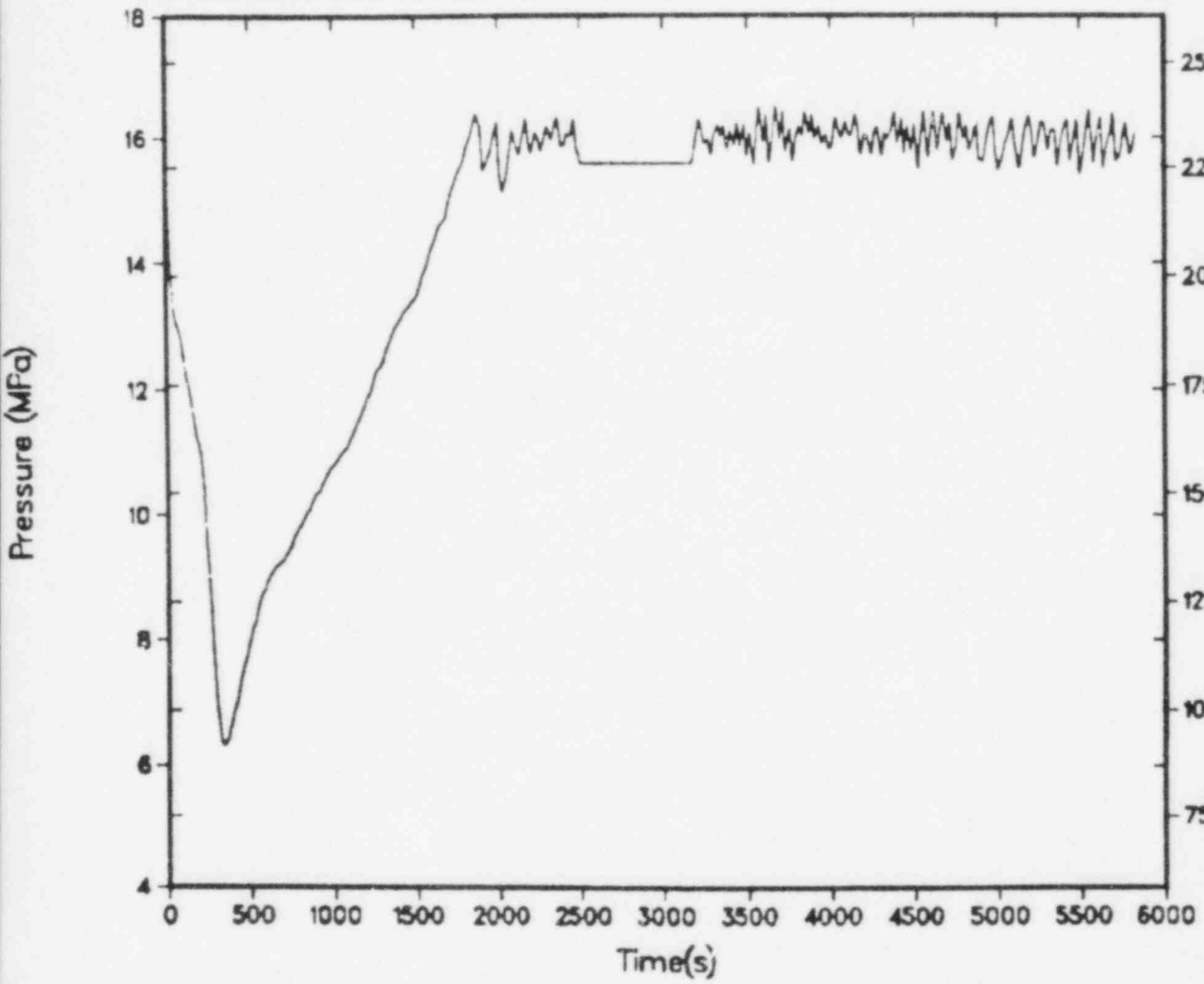

Figure 21 Transient 9: System Pressure

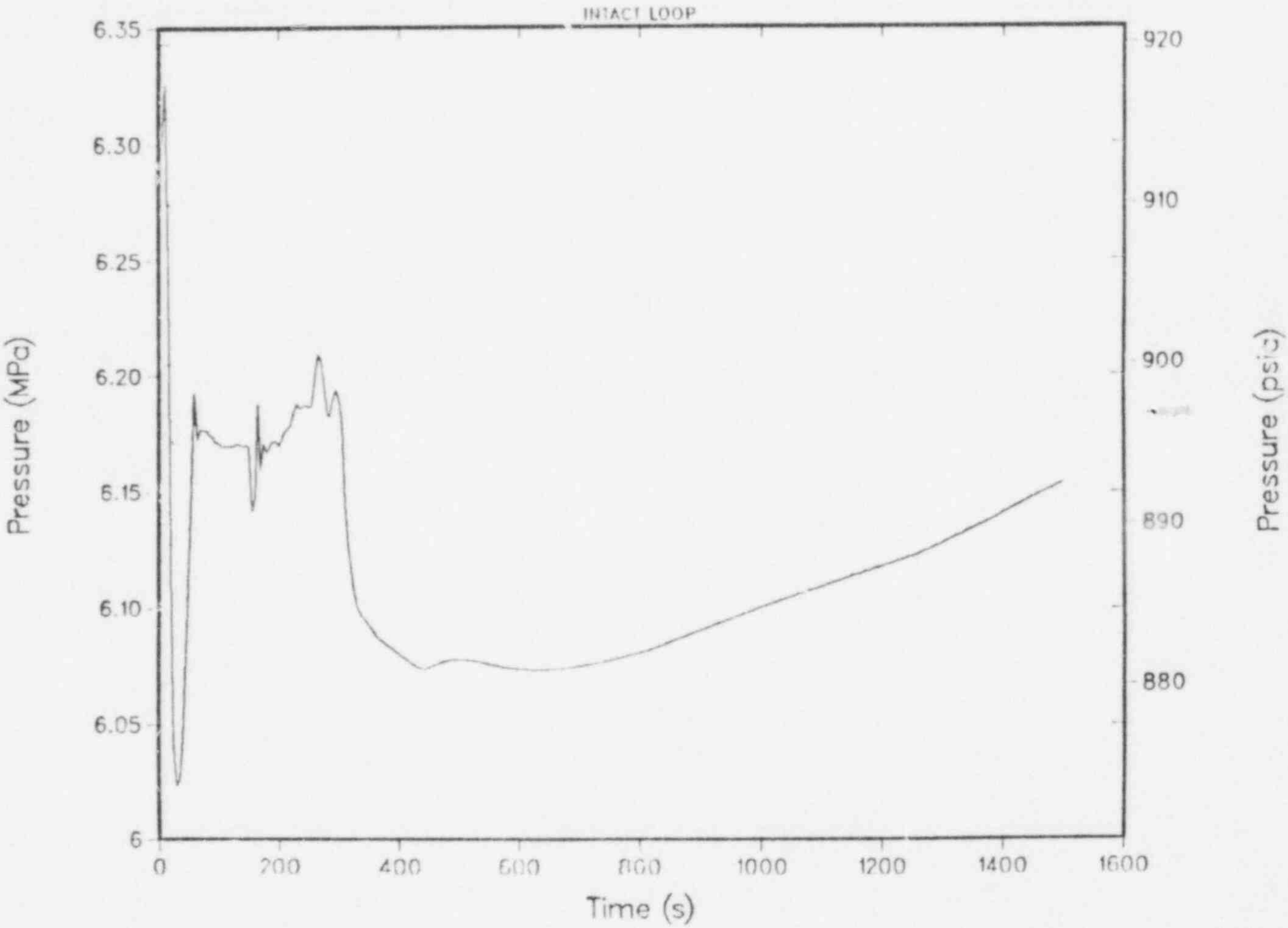

Figure 22 Transient 9: Steamline Pressure

APPENDIX D

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: January 12, 1984

TO: P. Saha

FROM: U. S. Rohatgi and J. Jo

SUBJECT: Extrapolation of Existing PTS Calculations With or Without Changes in Boundary Conditions

NRC has requested LANL and INEL to compute primary side response to various hypothetical accident scenerios using the advanced codes such as RELAP5 and TRAC-PF1. However, there are many probable event sequences and only a few of them could be considered for detail calculations. These calculations will provide downcomer liquid temperatures and wall heat transfer coefficients which will be used in stress analysis code. However, the other possible transients will not be calculated by advanced codes, but the downcomer fluid temperature, wall heat transfer coefficient and primary pressure will be estimated using the results of other transients with similar features and simplified balance equations. This memorandum describes some approaches to systematically extrapolate the calculation from any time in the transient.

1. Multi Volume Approach:

In this approach primary and secondary sides are modeled as separate volumes with heat transfer in the steam generator. The heat transfer calculation in the steam generator takes into account the liquid level.

Primary Side

Mass balance:

$$\frac{dM_p}{dt} = W_{HPI} + W_c - W_{BR} \tag{1}$$

Energy balance:

$$\frac{d}{dt}\left(M_p h_p + M_m h_p\right) = Q_d + Q_p + Q_{mis} + W_{HPI} h_{HPI} + W_c h_c - W_{BR} h_{BR} - \sum^{n} Q_{SGI} \tag{2}$$

where the M_p, M_m, h_p are primary side total mass, system metal equivalent fluid mass and average enthalpy, and W_{HPI}, W_c, W_{BR}, Q_d, Q_p, Q_{mis} and Q_{SGi} are HPI, charging and break mass flow rates, decay heat, pump power, energy input through spray, and heat transfer to secondary side of the steam generator, respectively.

Secondary side

Each steam generator will have the following set of balance equations:

Mass balance:

$$\frac{d}{dt} M_{si} = W_{fwi} - W_{sti} \tag{3}$$

Energy balance:

$$\frac{d}{dt}(M_{si}\, h_{si}) = W_{fwi}h_{fwi} - W_{sti}h_{gi} + Q_{SGi} \tag{4}$$

Here, M_s, h_s are secondary side total mass and average enthalpy, and W_{fw}, h_{fw}, and W_{st}, are feed water flow rate, feed water enthalpy and steam flow rate, respectively.

$$M_{si} = AL_i\rho_{\ell i} + A\,(L_t - L_i)\,\rho_{gi} \tag{5}$$

$$M_{si}h_{si} = AL_i\rho_i h_{\ell i} + A(L_t - L_i)\rho_{gi}h_{gi} \tag{6}$$

$$Q_{SGi} = P(L_iH_{\ell i} + (L_t - L_i)H_{gi})(T_p - T_{si}) \tag{7}$$

$$T_p = T_p\,(h_p) \tag{8}$$

$$h_{gi} = h_g\,(T_{si}) \tag{9}$$

$$h_{\ell i} = h_\ell\,(T_{si}) \tag{10}$$

$$\rho_{\ell i} = \rho_\ell\,(T_{si}) \tag{11}$$

$$\rho_{gi} = \rho_g\,(T_{si}) \tag{12}$$

Here A, L_i, L_t, P, T_p, T_{si}, $H_{\ell i}$ and H_{gi} are flow area, liquid level, total height, perimeter, primary side temperature, secondary side temperature, liquid and vapor region heat transfer coefficients, respectively. In general there are two steam generators and one may be blowing down. The three volumes in this situation are; primary side and two secondary side for two steam generators. So there are twenty-one variables; M_p, h_p, T_p for the primary side and M_s, h_s, h_ℓ, h_g, Q_{SG}, L, T_s, ρ_ℓ, ρ_g for each steam generator. There are also twenty-one equations, i.e., (1), (2) and (8), and two sets consisting of Equations (3) to (7) and (9) to (12).

This system of equations can be further simplified,

$$Q_{SGi} = H_{oi}\,(T_p - T_{si})L_i \tag{13}$$

where

$$H_{oi} = \frac{Q_{SG,i,o}}{L_{i,o}(T_p - T_{si})_o}$$

Here H_o, Q_{SGO}, L_o and $(T_p - T_{si})$ are heat transfer coefficient, steam generator heat transer rate, liquid level and temperature difference in steam generator at the time from where the extrapolation will begin. It has been assumed that most of the heat transfer will be in the liquid phase and the net heat transfer will be proportional to the liquid level. In this model, H_o represents an average heat transfer coefficient and assumed to be constant during the time period of the extrapolation. This approach implies that as the steam generator secondary side fills up the heat transfer will improve. The other important variable is the break flow rate and it will be estimated from the primary pressure which will be computed separately from the pressurizer analysis.

2. Simple Approach

Previous approach will require detailed analysis of each steam generator and in many instances, that is not required either for extrapolation or checking the detail calculations. This simple approach will apply to situations where the heat transfer between the primary and secondary side is small and variation in fluid temperature throughout the system is small. The system, consisting of primary side and all the secondary sides can be modeled as single volume. In computing system energy the contribution due to secondary side steam energy can be neglected. The metal part of the system stores a significant amount of energy and it is accounted for by estimating equivalent liquid mass and adding it to the system fluid mass. The balance equations are:

$$\frac{d}{dt}(M_p) = W_{HPI} + W_c - W_{BR} \tag{14}$$

$$\frac{d}{dt}(M_{si}) = W_{fwi} - W_{sti} \tag{15}$$

$$\begin{aligned}\frac{d}{dt}((M_p+M_m+\Sigma M_{si})h) = {} & Q_d+Q_p+Q_{mis}+W_{HPI}h_{HPI} \\ & + W_c h_c - W_{BR}h_{BR} + \Sigma W_{fwi}h_{fwi} \\ & - \Sigma W_{sti}h_{sti}\end{aligned} \tag{16}$$

where h is the average fluid enthalpy for the system. The other variables are the same as described in the previous approach. For the system with two steam generators, there are 4 equations in four unknowns which are, M_p, M_{s1}, M_{s2} and h.

3. Boundary Conditions

Both approaches described so far require high pressure injection (HPI), charging and feed water conditions. These are generally known as they are input to the system and in some instances are function of the pressure of the volume in which they are introduced. The flow through the breaks and valves are also functions of the conditions such as pressure and void fraction of the volume in which they are located. This will require modeling pressurizer and steam generator secondary side separately to estimate the pressures. The steam generator secondary side model has been described in this formulation. The secondry side pressure is assumed to be saturation pressure corresponding to its temperature. In the cases where saturation pressure exceeds the TBV pressure setting the valve will open and steam will be released. This steam flow will also depend upon the secondary side pressure.

4. Pressurizer Model

This component controls the pressure in the primary side through sprays and heaters. However, during the transient there is flow through the surge line which will affect the pressurizer pressure. The model described here will predict primary side pressure for cases where the primary side has no vapor except in the pressurizer. The surge line flow will depend upon the contraction or expansion of the liquid in the remaining primary side. The balance equations are as follows:

$$\frac{d}{dt} M_L = W_{sr} + W_{sp} - \Gamma \tag{17}$$

$$\frac{d}{dt} M_v = -W_{BR} + \Gamma \tag{18}$$

$$\frac{d}{dt} (M_L h_L) = Q_h + W_{sr} h_{sr} + W_{sp} h_{sp} - \Gamma h_v \tag{19}$$

$$\frac{d}{dt} (M_v h_v) = - W_{BR} h_v + \Gamma h_v \tag{20}$$

$$W_{BR} = f(P) \tag{21}$$

$$V_t = \frac{M_\ell}{\rho_\ell} + \frac{M_v}{\rho_v} = \text{pressurizer volume} \tag{22}$$

$$\rho_v = \rho_v (P, h_v) \tag{23}$$

$$h_{sr} = h_L \text{ or } h_p \text{, depending upon surge line flow direction.} \tag{24}$$

The unknowns of the model are M_L, h_L, M_v, h_v, W_{BR}, Γ, W_{sr}, h_{sr}, p and ρ_v, which are liquid inventory and enthalpy, vapor inventory and enthalpy, break flow, vapor generation rate, surge line flow and enthalpy, pressure and vapor density. However, there are only eight equations for ten unknowns and two more equations are needed. The primary side liquid has much larger volume compared to the liquid volume in the pressurizer and small expansion or contraction of primary loop liquid will have significant change in the liquid inventory of the pressurizer.

$$W_{sr} = V_p \, d\rho_\ell/dt \tag{25}$$

$$\rho_\ell = \rho_\ell \, (P, T_p)$$

Here V_p, ρ_ℓ, and T_p are primary side liquid volume, liquid density and temperature. This still leaves this formulation short of one equation which will come from assumption on the processes of vapor generation.

In the first limiting case it can be assumed that there is no vapor generation and it is a frozen case, which implies that liquid could become superheated and vapor could become subcooled depending upon the direction of surge line flow. In this case

$$\Gamma = 0 \tag{26}$$

This completes the formulation. However, it can be further simplified if the vapor expansion or contraction can be represented by some polytropic processes

$$P/\rho k = \text{constant} \tag{27}$$

This simplication will replace Equations (20) and (23) by Equation (27) and also vapor enthalpy h_v will not be needed. The variable k is 1.0 for isothermal process and is 1.33 for isentropic process.

The second limiting case is where the liquid and vapor are both saturated and any addition of mass or energy will change the pressure along the saturation conditions. The system of equations is as follows:

$$\frac{dM}{dt}L = W_{sr} + W_{sp} - \Gamma \tag{28}$$

$$\frac{dM}{dt}v = - W_{BR} + \Gamma \tag{29}$$

$$\Gamma = \frac{Q_h + W_{sr}(h_{sr} - h_f) + W_{sp}(h_{sp} - h_f) - M_L \frac{dh_f}{dp} \frac{dp}{dt}}{h_{fg}} \quad (30)$$

$$W_{BR} = W_{BR(P)} \quad (31)$$

$$\rho_f = \rho_{f(P)} \quad (32)$$

$$\rho_g = \rho_{g(P)} \quad (33)$$

$$h_f = h_f(P) \quad (34)$$

$$h_{fg} = h_{fg}(P) \quad (35)$$

$$V_t = \frac{M_L}{\rho_f} + \frac{M_v}{\rho_g} = \text{pressurizer volume} \quad (36)$$

$h_{sr} = h_f$ or h_p, depending upon the direction of flow. (37)

$$W_{sr} = V_p \frac{d\rho_f}{dt} \quad (38)$$

So there are eleven equations and eleven unknowns which are, M_L, M_v, Γ, W_{BR}, ρ_f, ρ_g, h_f, h_{fg}, h_{sr}, W_{sr} and P.

These two cases will provide limiting pressure histories for the primary side. In case of flow into the pressurizer, the frozen case will predict higher pressure than the equilibrium case, while for flow out of the pressurizer the frozen case will predict lower pressure as flashing of pressurizer liquid in equilibrium case will try to maintain the pressure. Equations (26) and (38) restrict this model to transients which have intact primary side with only vapor region in the pressurizer.

5. Solution Procedure

All the differential equations are linear and so simple Euler types of integration can be used. Most of the equations are essentially equation of state and can be replaced by steam table. As most of the changes during PTS transients occur over the long term, these equations can be finite differenced. This will make it possible to use hand calculations to estimate temperature and pressure history on the primary side.

af

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R. J. Cerbone

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Six selected transient calculations out of thirteen performed by LANL using the TRAC-PF1 code for the USNRC PTS study of the Calvert Cliffs Nuclear Power Plant have been reviewed in depth at BNL. Simple hand calculations based on the mass and energy balances have been performed to predict the temperature and pressure of the reactor system, and the results have been compared with those of TRAC. Comparison was also made between the TRAC and RETRAN calculations for two of these transients, which were performed by ENSA. In general, the results calculated by TRAC appear to be reasonable based on the comparison with RETRAN and hand calculations.

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