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ASSESSMENT OF SELECTED TRAC AND RELAP5 CALCULATIONS FOR OCONEE-1 PRESSURIZED THERMAL SHOCK STUDY

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EXECUTIVE SUMMARY

Several Oconee-1 overcooling transients were computed by LANL using TRAC-PF1 and by INEL using RELAP5/MOD1.5. These calculations and the input decks were reviewed by BNL. Three of these transients were selected for detailed review as they either had the potential of challenging the integrity of the pressure vessel or highlighting the effect of the code differences. The three transients selected were: (1) main Steam Line Break (MSLB), (2) All Turbine Bypass Valves Stuck Open, and (3) 1-Inch Small Break LOCA.

Comparison of the computations of the MSLB transient indicated that the difference in the minimum downcomer fluid temperature predictions was due to the modeling of the control system that regulated the MFW and EFW pumps, to the multi-dimensional effects resulting in different temperature histories for the hot legs, and to the modeling of the upper head as through-flow or dead-end volume. Both calculations had some weaknesses and a method has been described to predict the best-estimate downcomer fluid temperature using INEL's early temperature prediction and RCP restart time and azimuthal temperature distribution from LANL's calculation.

The second transient compared was initiated by the failure of all four TBVs at the full open position after a turbine trip. This transient is like a small break in the steamline. Here the initial conditions (full power for TRAC and hot standby for RELAP5) and additional failures were different. The codes predicted the transients reasonably well. However, the important reasons for the differences in the calculations were the controller failure to throttle EFW based on the secondary side level and the failure of the operator to close the TBVs at 600 seconds in the TRAC calculation.

The third transient compared was the Small Break (2-inch) LOCA in a hot leg. The ICS was assumed to work as designed. Both TRAC and RELAP5 computed a continuous drop in the primary side pressure during the transient. This made the transient less critical for PTS. However, comparison of the two calculations indicated that there were many differences. The codes modeled the reactor trip differently. RELAP5 correctly based it on the low primary side pressure while TRAC assumed it to occur at 0.5 seconds. Furthermore, after the loss of natural circulation due to candy cane voiding, TRAC computed flow oscillations in the cold legs while RELAP5 predicted a stable circular flow between the cold legs connected to the common steam generators. The loop oscillations in the TRAC calculation warmed up the cold leg and the downcomer fluids. However, it is not clear if these oscillations are real. Moreover, the TRAC calculation was not carried out far enough in time to determine the minimum downcomer fluid temperature with confidence. The RELAP5 calculation, on the other hand, is more complete and looks reasonable.

Both codes were reasonably successful in modeling these transients. The major differences in their results were due to the differences in modeling the plant, control systems, and event sequences, and to the one-dimensional modeling of reactor vessel thermal hydraulics by RELAP5.

ABSTRACT

Several Oconee-1 overcooling transients that were computed by LANL and INEL using the latest versions of TRAC-PF1 and RELAPS/MOD1.5 codes have been reviewed by BNL. Three of these transients were selected for detailed review as they either had the potential of challenging the integrity of the pressure vessel or highlighted the effect of code differences. These are (1) Main Steam Line Break (MSLB), (2) All Turbine Bypass Valves Stuck Open, and (3) 2-Inch Small Break LOCA.

Both codes were reasonably successful in modeling these transients. Howver, there were differences in the code results even though the specified scenarios were exactly the same for two transients (MSLB and Small Break LOCA). This report compares the code results and explains the possible reasons for these differences. Recommendations have been made regarding which result seems more reasonable for a specific transient.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of Mrs. Ann Fort in typing this report and preparing the figures. They are also grateful to Don Fletcher of INEL and B. Bassett and J. Ireland of LANL for providing information and clarifications about their calculations.

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1. INTRODUCTION

Rapid cooling of the reactor pressure vessel during a transient or accident accompanied by high pressure has the potential of producing severe thermal stresses in the vessel wall and challenging the vessel integrity. This phenomenon is called overcooling or Pressurized Thermal Shock (PTS). As long as the fracture toughness of the reactor vessel remains high, overcooling transients will not cause vessel failure. However, the Nuclear Regulatory Commission (NRC) staff analysis (SECY-85-465) showed that certain older plants with copper impurities in the vessel weldments may become sensitive to PTS in a few years as the nil ductility transition temperature of the weld material gradually increases.

In late 1981, the NRC designated PTS as an unresolved safety issue and developed a Task Action Plan (TAP-49) to resolve the issue. The NRC has selected three plants representing PWRs supplied by three vendors in the United States for detailed PTS study: Oconee-1 (Babcock and Wilcox), Calvert Cliffs (Combustion Engineering), and H. B. Robinson (Westinghouse Electric). Oak Ridge National Laboratory (ORNL) is the lead contractor for the entire PTS study, and they have 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 to be calculated at the Los Alamos National Laboratory (LANL) and the Idaho National Engineering Laboratory (INEL) using the latest versions of 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. Emphasis would be placed on explaining the differences between the common calculations performed at these two laboratories, and on recommending which result seemed more reasonable for a specific transient. For transients computed at only one laboratory, a review focusing on the reasonableness of the results will be performed. This report presents the results of the BNL review of the selected Oconee-1 calculations performed at LANL and INEL.

In the first part of the task, the BNL staff reviewed and compared the plant input decks for Oconee-1 as prepared by LANL and INEL. There were some differences between these decks in the reactor vessel and heat structure descriptions. BNL also reviewed the models for control systems as developed by Science Application, Inc. (SAI) for RELAP5 and by LANL for TRAC-PF1. The comments based on these reviews were transmitted to the NRC and the Oconee-1 PTS study participants through several letters and presentations during August to October 1982. For the sake of completeness, a copy of these communications is presented in Appendix A of this report.

Calculations for twelve Oconee-1 transients specified by ORNL were divided between LANL and INEL (Fletcher, et al 1984 and Basset, et al 1983). Some of them -- transients such as the Main Steamline Break (MSLB), 2-Inch Hot Leg

Small Break Loss-of-Coolant Accident (SBLOCA), and the actual Turbine Trip transient at Oconee-3 - - were common to both the laboratories. The TRAC and RELAP5 results for these transients were compared at BNL. It was also observed that the MSLB and the Turbine Bypass Valves (TBVs) stuck open transients were relatively severe transients. Therefore, all four TBVs stuck open transients were also investigated.

The Oconee-3 turbine trip transient was the first calculation performed by both LANL and INEL. The review of this transient indicated several differences between the TRAC and RELAP5 code calculations and the data. However, after this calculation, the codes were modified and the conclusions from this transient are no longer relevant to the other transients. Moreover, the plant data are proprietary to Duke Power Company. Therefore, this transient will not be discussed here.

This report will, therefore, discuss the results of the following three transients in details:

1. Main Steamline Break (MSLB).
2. Failure of all (4) Turbine Bypass Valves (TBVs) at full open position.
3. Small Break (2-Inch) LOCA in Hot Leg.

The main steamline break transient was initiated at full power by a break of 34 inches in one of the steamlines. This led to the depressurization of the secondary side. There were also other failures which influenced the course of the transient. The transient was computed by using both TRAC-PF1 and RELAP5/MOD1.5 codes.

The TBVs stuck open transient was initiated by the failure of TBVs to close when the pressure decreased in the steamline. This was similar to a small steamline break and caused depressurization of the steam generator secondary side. However, the initial conditions (full power for TRAC, but zero hot power for RELAP5) and some additional failures were intentionally different for the two code calculations. The purpose of comparing this transient was, therefore, to investigate the effect of these differences on the final results.

The last transient discussed in this report is a small break (2-inch) LOCA in hot leg initiated at full power. The transient had no other failures or operator actions other than tripping the Reactor Coolant Pumps (RCPs) 30 seconds after the initiation of High Pressure Injection (HPI). Although the primary side did not repressurize, which made it less significant to PTS, the calculation showed the sensitivity of the results to the codes.

These three transients are described in detail in the next three chapters. In general, both the TRAC and RELAP5 codes computed these transients reason ably well. The crucial differences were not due to the thermal hydraulic models in the codes but to the way the plant, the control systems and the sequences of events were modeled. The only exception was the multi-dimensional reactor vessel thermal-hydraulics, which was modeled with TRAC but could not be modeled with RELAP5.

2. MAIN STEAM LINE BREAK

This is one of the set of transients in which the secondary side is depressurized. The initiating event is a (34-inch) diameter break in the steamline. The transient scenario is made more severe by an operator delay in isolating the feedwater (FW) flow to the affected steam generator coupled with a delay in throttling the High Pressure Injection (HPI) flow and restarting Reactor Coolant Pumps (RCPs) in each loop after 75F (42K) subcooling is attained in the primary loop. The scenario of this transient, as specified by ORNL and as shown in Table 2.1, was quite involved with various operator actions for the primary and secondary sides. This transient was computed using both TRAC and RELAP5 codes (Fletcher, et al 1984 and Bassett, et al 1983) and the results indicated that it could have severe consequence for vessel integrity. A comparison of the results of the two codes will also show the sensitivity of the code results.

In this transient the primary side loses energy to the steam generators, specifically to the steam generator with a break in the steamline. The depressurization of the steam generator caused a reduction in the saturation temperature which resulted in increased heat transfer from the primary side and a larger vapor generation. The failure of the operator to stop or throttle feedwater provided additional fluid to the steam generator for vaporization, and cooling of the primary side. The sequences of events as predicted by two codes have been summarized in Table 2.2. In the remaining section the results from the two calculations will be compared.

Figure 2.1 shows the primary side pressure. In general, RELAP5 not only computed higher pressures but also repressurized to PORV set point sooner than TRAC. However, in the very beginning of the transient, RELAP5 predicted a faster pressure drop due to an early Main Feedwater (MFW) pump trip and initiation of colder Emergency Feedwater (EFW). This is confirmed in Figures 2.2 and 2.3, in which secondary side pressures are compared. RELAP5 modeled the control systems on the basis of pressure differential between the top of the tube region and the bottom of the downcomer in the steam generator and was in closer agreement with the plant control system. On the other hand, TRAC modeled the control system on the basis of collapsed water level and therefore, missed the MFW pump trip which depended on the pressure differential. RELAP5, as expected, predicted a lower secondary side pressure than TRAC in the beginning of the transient, resulting in a lower saturation temperature and a larger heat transfer in the steam generator. The secondary side temperatures are shown in Figures 2.4 through 2.7.

The early rapid pressure drop calculated by RELAP5 also caused the initiation of HPI flows earlier than in TRAC. As the RCPs were tripped 30 seconds after the HPI flow, the loop flows were in the natural circulation mode. The heat transfer decreased and the system started to repressurize. However, when the subcooling in the hot legs reached 42K, the RCPs were restarted in loops A1 and B1 in both the calculations, which caused voids in the primary system to collapse, and the pressure dropped, as shown in Figure 2.1, at 300 seconds for RELAP5 and 526 seconds for TRAC. After 600 seconds, when both the steam generators were isolated, the heat transfer from the primary side decreased. This is shown in Figures 2.8 and 2.9 for RELAP5. It seems that after RCPs were restarted, there was some reverse heat transfer in Steam Generator B for RELAP5. This resulted in repressurization of the primary side. Also RELAP5

Table 2.1 Main Steam Line Break Scenario

Initial Conditions:

1. Full reactor power.
2. Nominal temperatures and pressures in primary/secondary.
3. Decay heat: 1.0 times the ANS standard.
4. Pressurizer spray/heaters operate as designed.

Sequence of Events:

1. Reactor trips, coincident with break of (34") steam line.
2. Turbine trips; TSVs close.
3. ICS functions as designed.
4. Protection systems on hotwell, condensate booster, and MFW/EFW pumps function as designed.
5. HPI actuates at set point (1500 psig).
6. Operator trips RC pumps 30 s after HPI actuation.
- * 7. EFW pumps start when low MFW pump discharge pressure is sensed.
- * 8. MFW/EFW system attempts to maintain 240" SG level.
9. Core flood tanks actuate at set point.
- *10. LPI actuates at set point.
11. (a) Operator isolates feedwater to both steam generators 10 min into the transient (close MFW, start-up-FW, EFW, and TBV systems).
    (b) Operator begins refilling unaffected steam generator to 240" level with EFW at maximum rate 15 min into transient.
    (c) Turbine bypass system on unaffected steam line opens at 15 min and maintains 1000 psi pressure.
12. Operator restarts one RC pump in each loop after attaining 75°F subcooling and throttles HPI to maintain 75 $\pm$ 25°F subcooling.
13. PORV opens at set point (2450 psig).
- *14. SRVs open at set point (2500 psig).
15. PORV/SRVs reseat at their set points (2400 psig).
- *17. EFW surge tank capacity (72,000 gal) is exhausted; and the two motor-driven EFW pumps trip.
- *18. Turbine-driven EFW continues to draw from hotwell.

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* Event is phenomenology dependent.

Table 2.2 Sequence of Events for MSLB Transient

ITEM	UPDATED TRAC-PF1 (LANL)	RELAP5/MOD1.5 (INEL)
1) Reactor & Turbine Trip	0.5 sec	0.0 sec
2) HPI Initiated	21.2 sec	5.3 sec
3) RCP Tripped, FW Realigned	51.2 sec	35.3 sec
4) EFW to SG-A (Affected)	29.4 sec, based on low level.	4.4 sec, based on low MFW pump discharge pressure.
5) EFW to SG-B (Unaffected)	48.7 sec, based on low level.	4.4 sec, based on low MFW pump discharge pressure.
6) MFW Pump Trip	47.8 sec, low suction pressure.	0.3 sec, high level in SG secondary.
7) Condensate Booster Pump Trip	51.2 sec	---
8) Vent Valve Flow	112 sec to 526 sec.	Valve did not open.
9) RCP restarted as 42K subcooling reached. HPI throttled.	526.0 sec	300 sec
10) EFW to SG-B terminated (or throttled) as a level of 240 inches is reached.	346.7 sec, valve closed.	320 sec

Table 2.2 Sequence of Events for MSLB Transient (Cont'd)

ITEM	UPDATED TRAC-PF1 (LANL)	RELAP5/MOD1.5 (INEL)
11) Hot well surge tank empty. Motor driven FW pump stopped.	---	513 sec
12) Accumulator On	530.9 sec	---
13) Accumulator Off	537.9 sec	---
14) SG-A,SG-B isolated, TBV, MFW, EFW stopped per specification.	600 sec	600 sec
15) EFW available to SG-B per specification.	900 sec	900 sec
16) Pressurizer level reaches top.	---	2354 sec
17) PORV set point for opening reached.	4678 sec on	2432.0 sec
18) Calculation terminated.	7200 sec	2697 sec
19) Minimum downcomer fluid temperature.	405K at around 526 sec .	493K at around 600 sec.

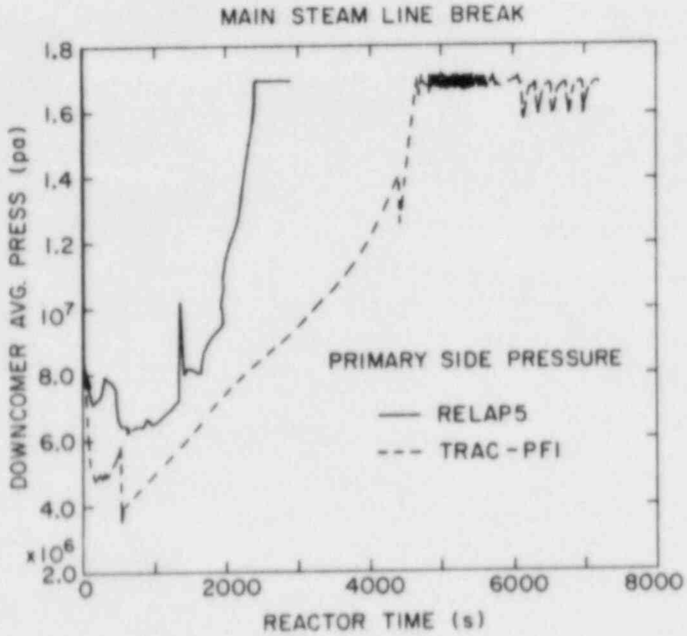

Figure 2.1 Primary Side Pressure

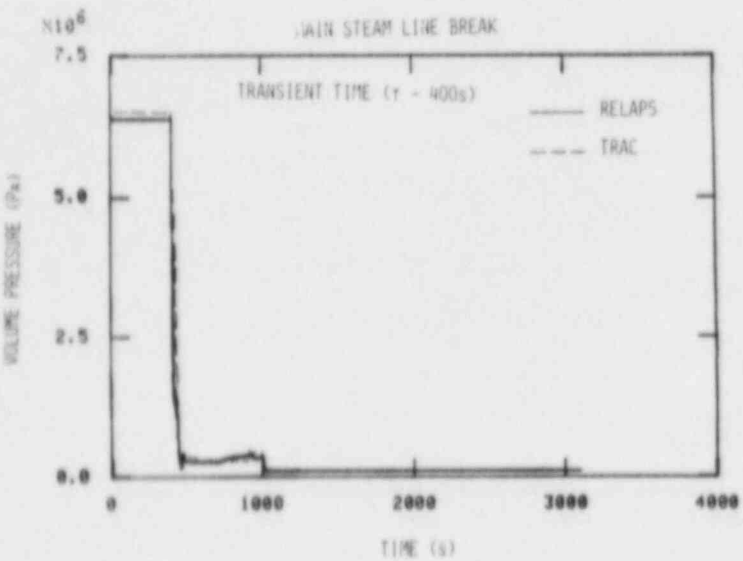

Figure 2.2 Steam Generator A Secondary Side Pressure

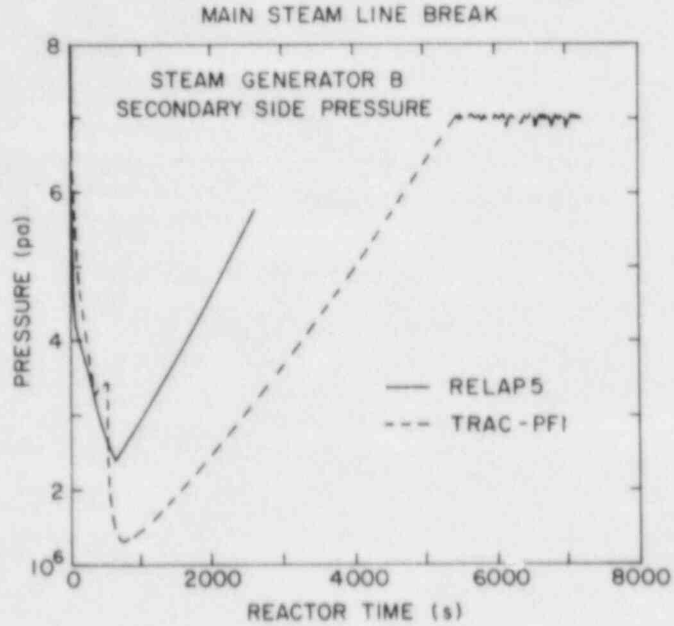

Figure 2.3 Steam Generator B Secondary Side Pressure

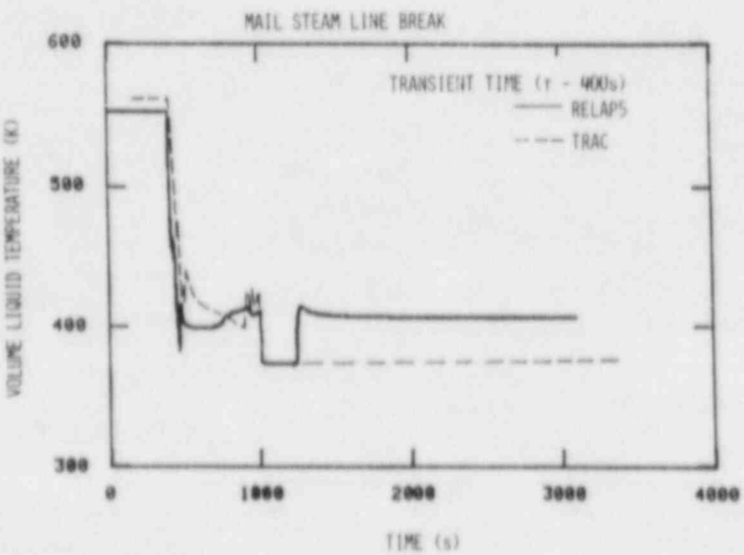

Figure 2.4 Steam Generator A Secondary Side Liquid Temperature

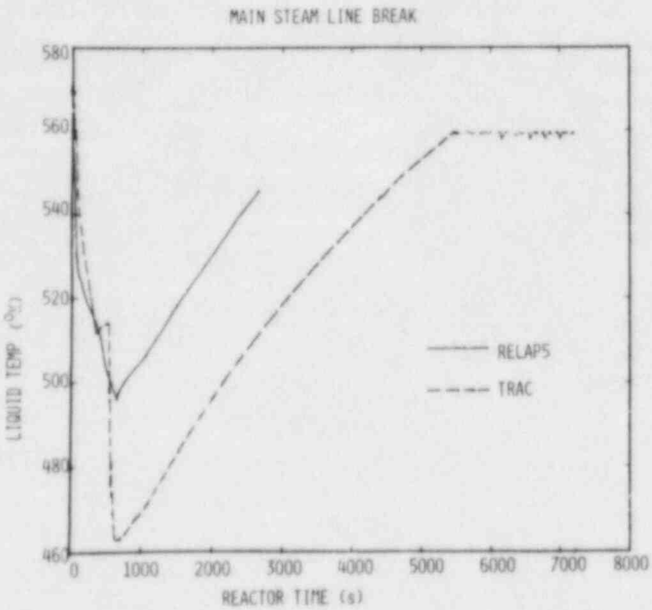

Figure 2.5 Steam Generator B Secondary Side Liquid Temperature

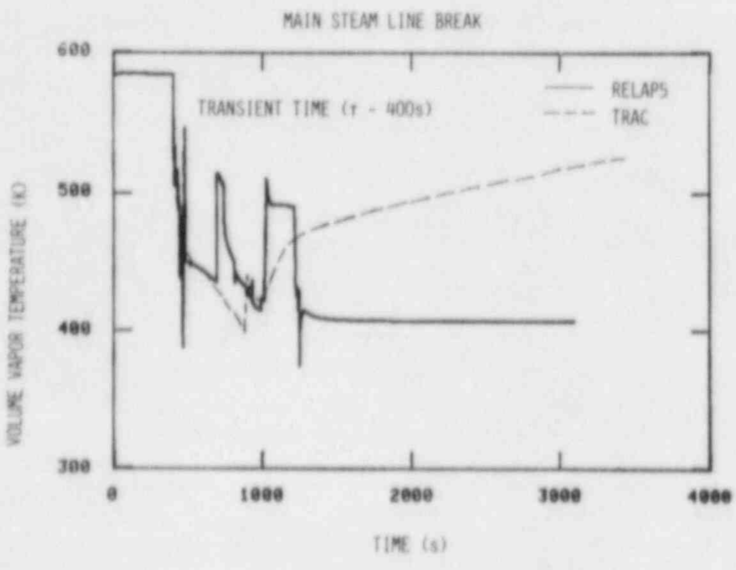

Figure 2.6 Steam Generator A Secondary Side Vapor Temperature

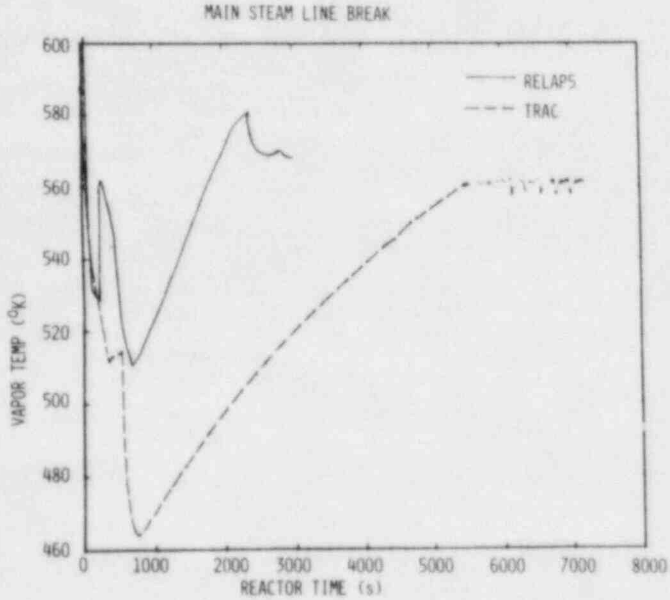

Figure 2.7 Steam Generator B Secondary Side Vapor Temperature

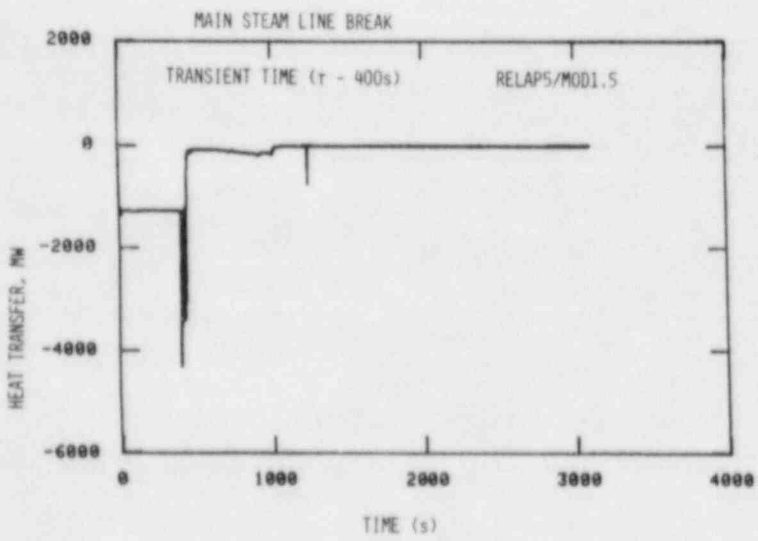

Figure 2.8 Heat Transfer Rate in SGA

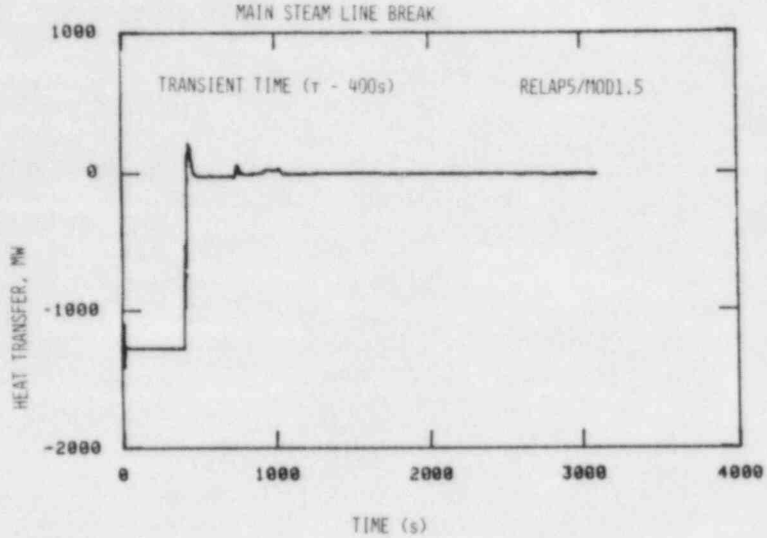

Figure 2.9 Heat Transfer Rate in SGB

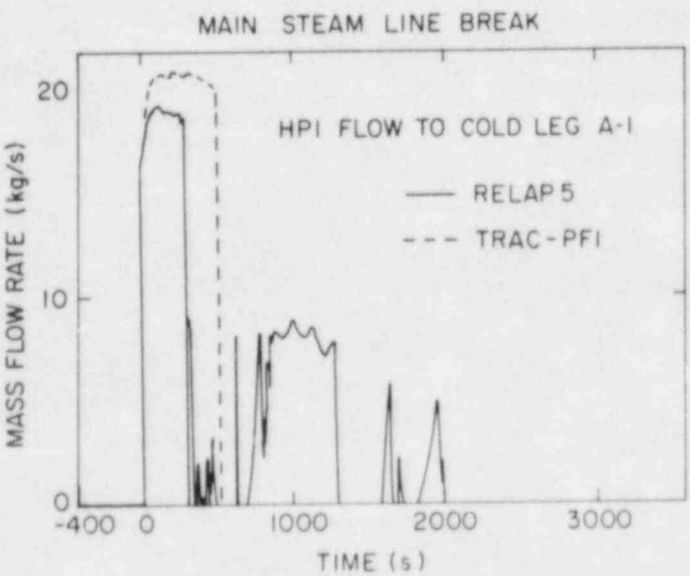

Figure 2.10 HPI Flow to Cold Leg A-1

computed an earlier repressurization as the RCPs were started when the primary side pressure was higher than in the TRAC calculations. Furthermore, the HPI flows were initially higher in TRAC, but RELAP5 continued HPI much longer as shown in Figures 2.10 through 2.12. This additional mass also increased the pressure in the primary side. The pressurizer became full much earlier in the RELAP5 calculation than in TRAC, and this is reflected as a rapid increase in pressure in Figure 2.1.

One of the most important parameters for PTS is the downcomer fluid temperature. A comparison of these temperatures as predicted by the two codes is shown in Figure 2.13. The first observation is that TRAC predicted a multi dimensional behavior, and the azimuthal spread in the downcomer temperature was about 30K. RELAP5 predicted only the average fluid temperature, because of the one-dimensional modeling. The downcomer fluid temperature is a combination of the cold leg and vent valve fluid temperatures. Figure 2.14 shows a comparison of the vent valve flows as predicted by the two codes. The vent valve did not open in the RELAP5 calculation because there was sufficient flow in both the cold legs due to natural circulation, as shown in Figures 2.15 through 2.18. Thus there was no warming effect due to the vent valve flow in the RELAP5 calculation, but the cold leg temperatures, as shown in Figures 2.19 through 2.22 were higher than in the TRAC calculation and were the cause of a higher downcomer fluid temperature in the RELAP5 calculation. Further more, the downcomer fluid temperature as well as fluid temperatures in cold legs A-1 and B-1 had jumps in both the calculations at the time of RCP restart due to the mixing of hotter fluid from the hot legs. There were also similar jumps in the fluid temperatures in cold legs A-2 and B-2 in both the calculations due to a circular flow between the cold legs with the common steam generator. The temperatures for all the cold legs and the downcomer started to increase after the steam generators were isolated in both calculations at 600 seconds. Thus the minimum downcomer fluid temperature was reached just before the RCPs were restarted in the TRAC calculation. In the RELAP5 calculation the downcomer fluid temperature started to decrease again after the jump at RCP restart time. The lowest downcomer fluid temperature was reached at 600 seconds, which was very close to the temperature at 300 seconds.

The RCP restart time, which depends upon achieving 42K subcooling in each hot leg of the system, is a critical event in this transient. It occurred at 300 seconds in the RELAP5 calculation, whereas it occurred at 526 seconds in TRAC. This difference is due to the way the voids were distributed in the primary system and the time when natural circulation started. Figure 2.23 shows a comparison of the predicted void fractions in the upper. It seems that there was an early void accumulation in the RELAP5 calculation but none in the TRAC calculation. Figures 2.24 and 2.25 show a comparison of the candy cane void fractions as predicted by the two codes. In loop A, the natural circulation was strong because of depressurization of Steam Generator A secondary side, and no voids accumulated in the candy cane. However, the natural circulation was slower in the unaffected loop (i.e., loop B), and most of the voids in the TRAC calculation accumulated in this candy cane, which resulted in the termination of natural circulation there. On the other hand, the voids accumulated in the upper head and upper plenum instead of candy can es in the RELAP5 calculation, and the natural circulation was maintained. This resulted in a good and uniform cooling of both loops in RELAP5. As RELAP5 also predicted a higher primary side pressure, both hot legs achieved the required subcooling of 42K at 300 seconds and the RCPs were restarted. However, TRAC had no natural circulation in loop B and the hot leg there remained warmer

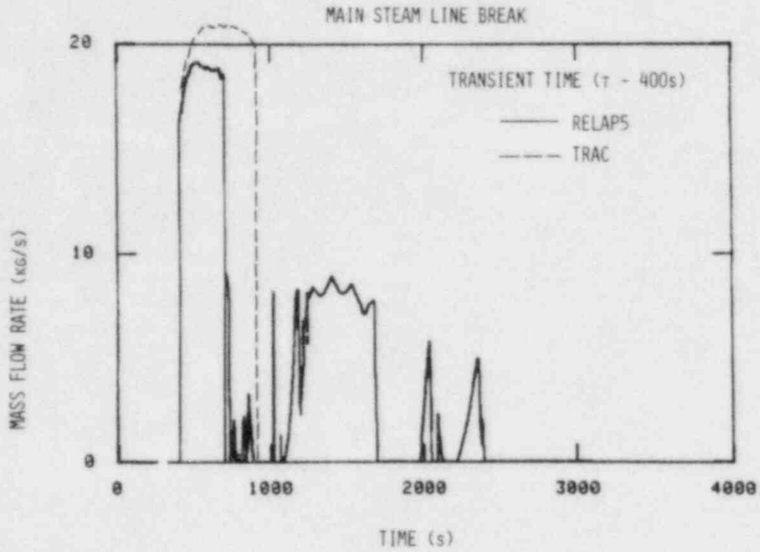

Figure 2.11 HPI Flow to Cold Leg A-2

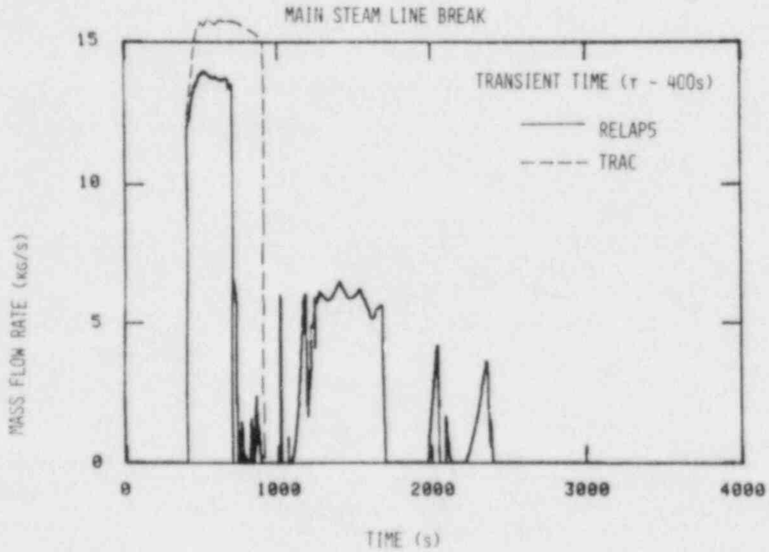

Figure 2.12 HPI Flow to Cold Leg B-2

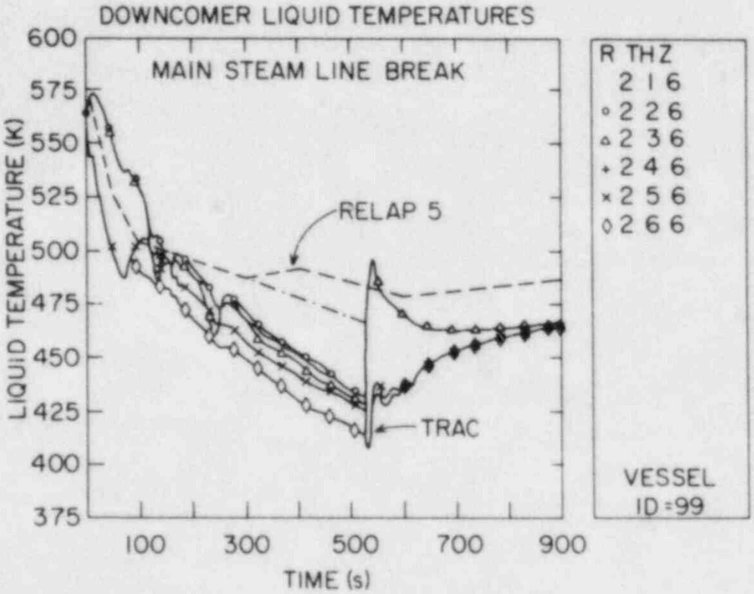

Figure 2.13 Downcomer Fluid Temperature

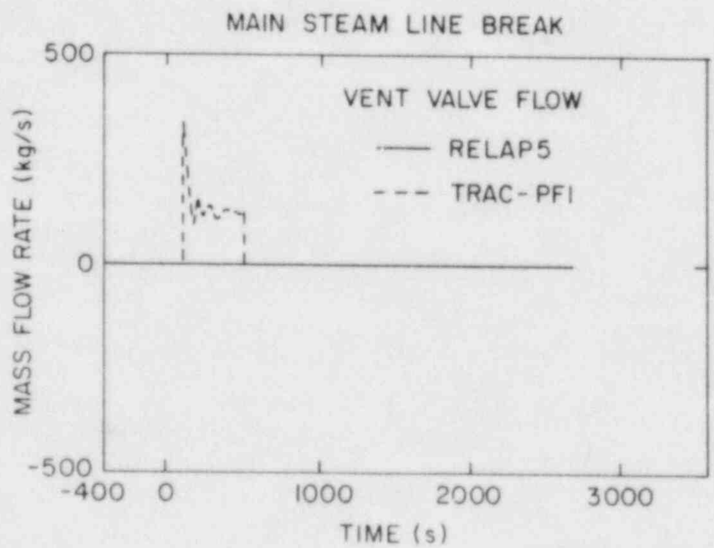

Figure 2.14 Vent Valve Flow

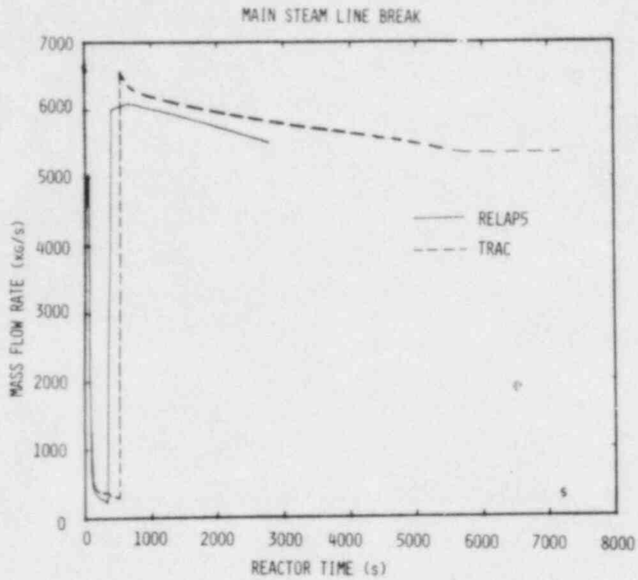

Figure 2.15 Cold Leg A-1 Flow Rate

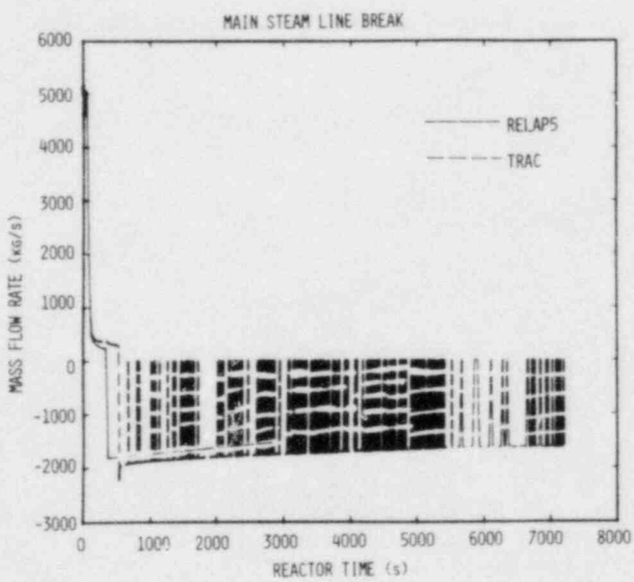

Figure 2.16 Cold Leg A-2 Flow Rate

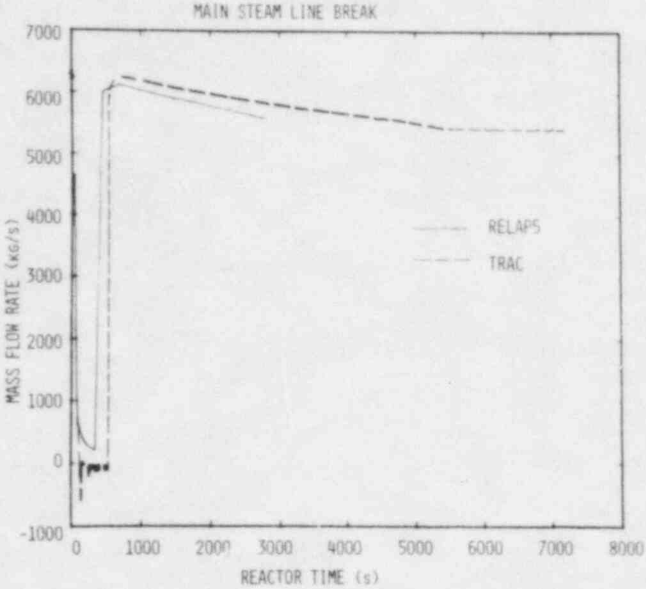

Figure 2.17 Cold Leg B-1 Flow Rate

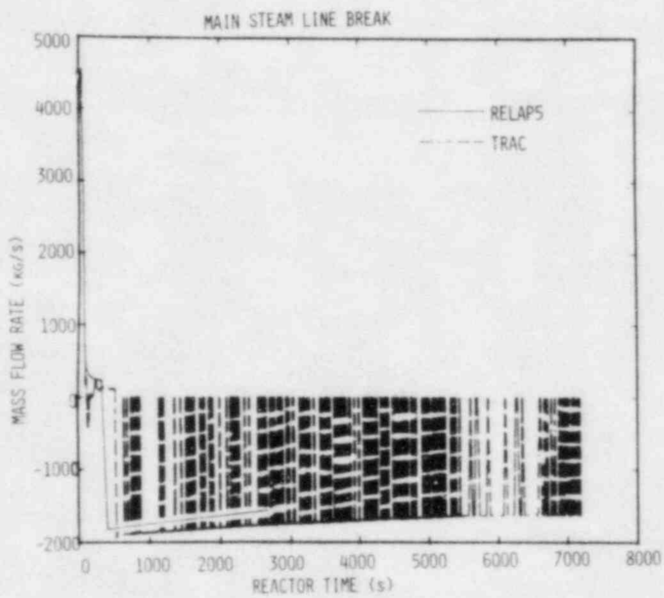

Figure 2.18 Cold Leg B-2 Flow Rate

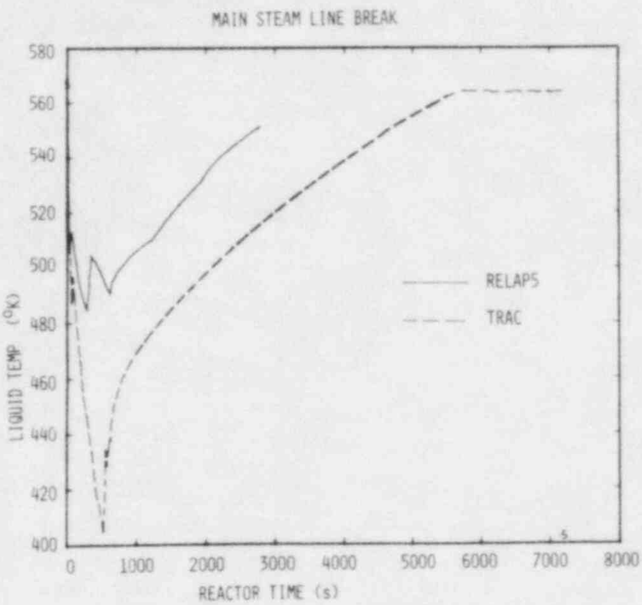

Figure 2.19 Cold Leg A-1 Fluid Temperature

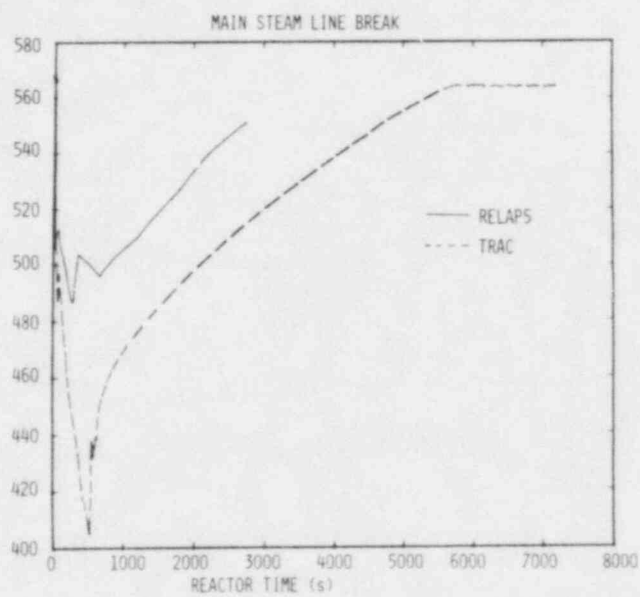

Figure 2.20 Cold Leg A-2 Fluid Temperature

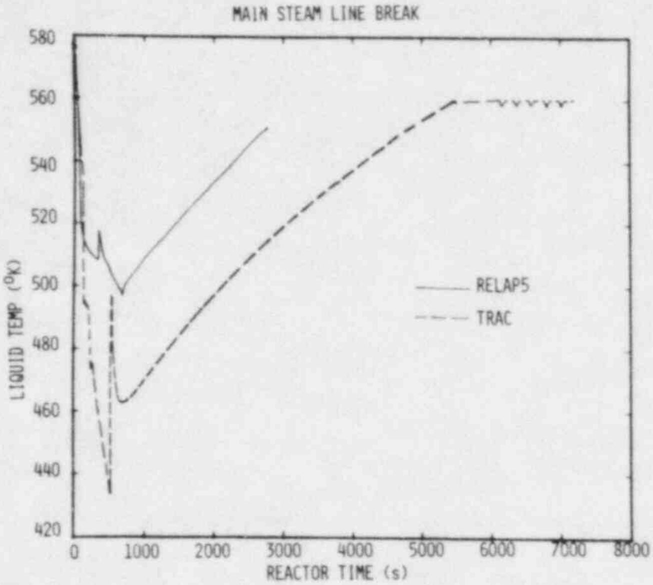

Figure 2.21 Cold Leg B-1 Fluid Temperature

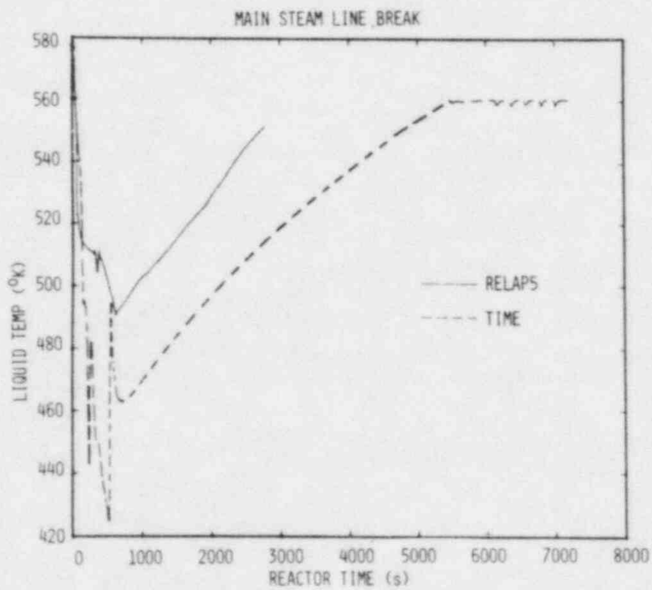

Figure 2.22 Cold Leg B-2 Fluid Temperature

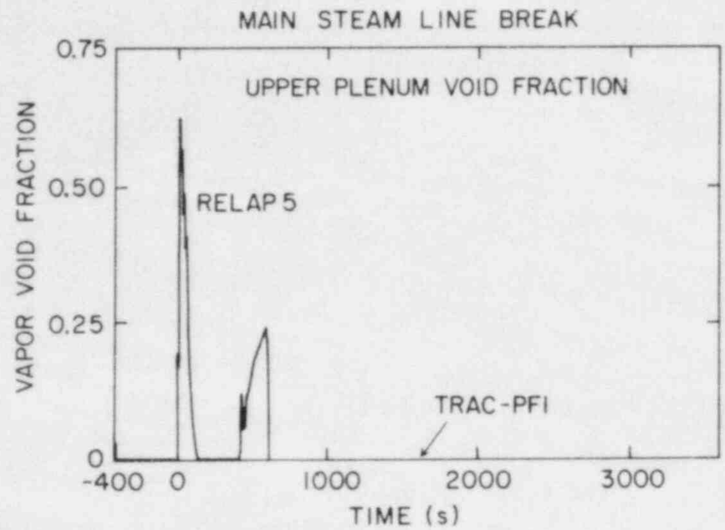

Figure 2.23 Upper Plenum Void Fraction

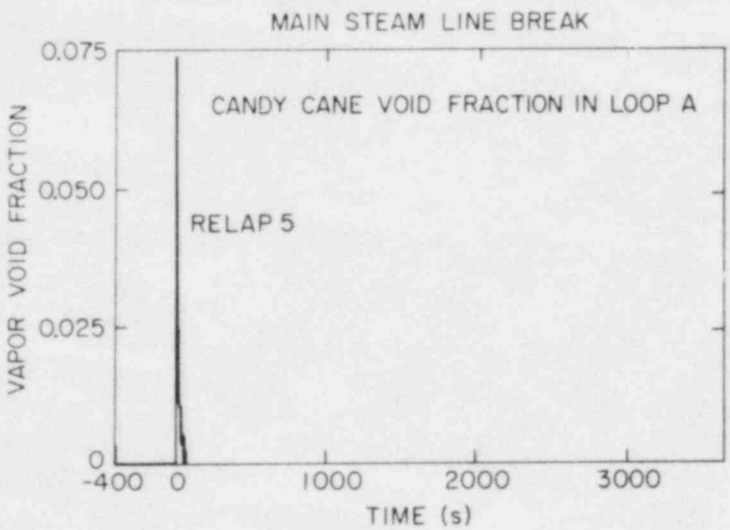

Figure 2.24 Candy Cane Void Fraction in Loop A

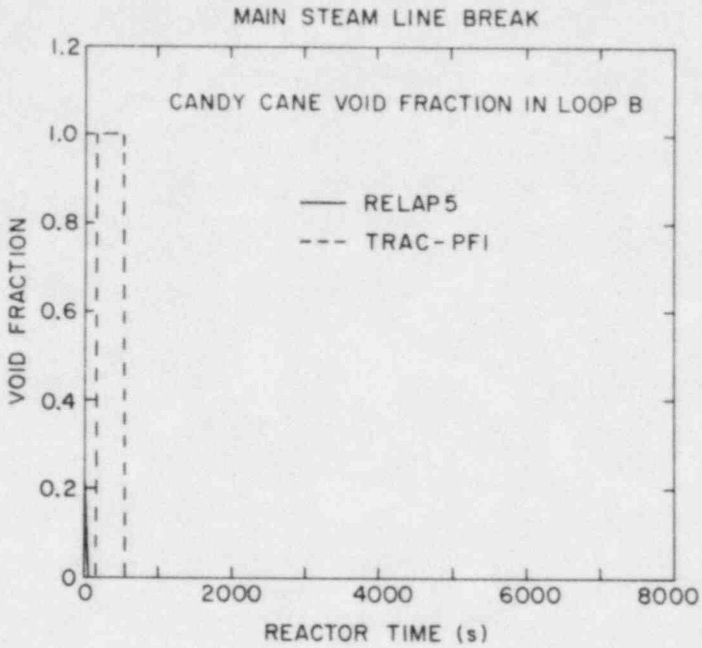

Figure 2.25 Candy Cane Void Fraction in Loop B

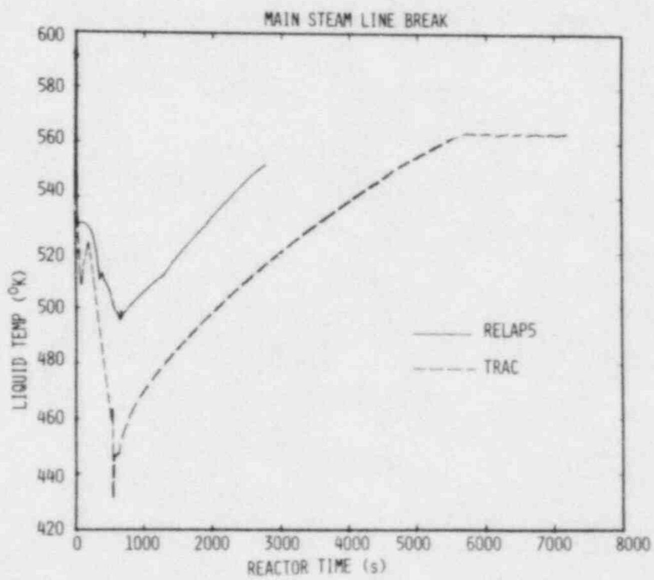

Figure 2.26 Hot Leg Temperature in Loop A

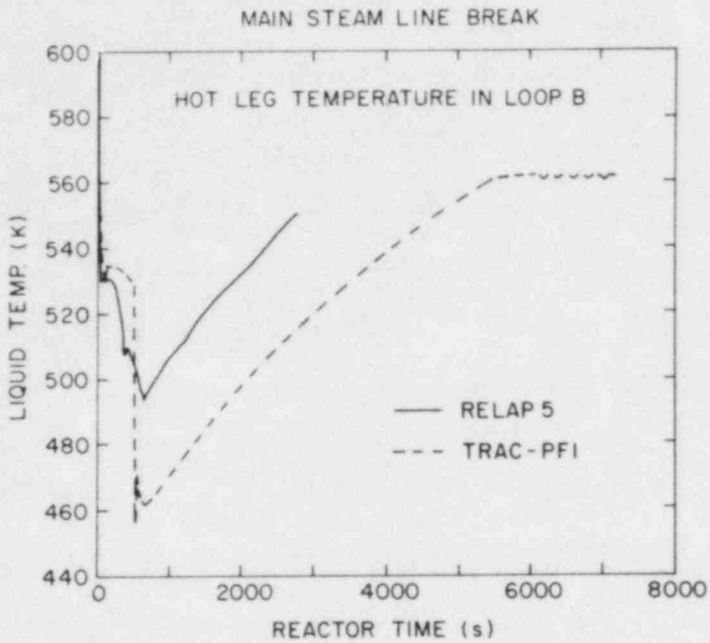

Figure 2.27 Hot Leg Temperature in Loop B

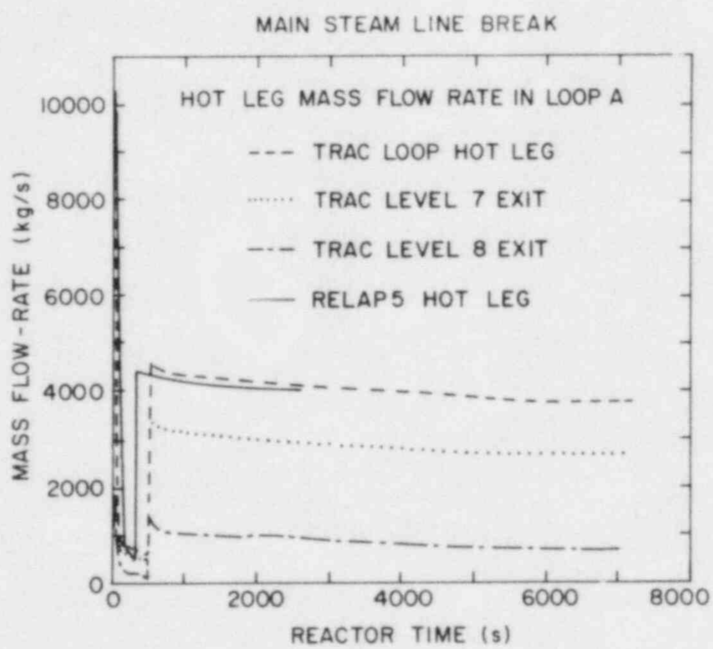

Figure 2.28 Hot Leg Mass Flow Rate in Loop A

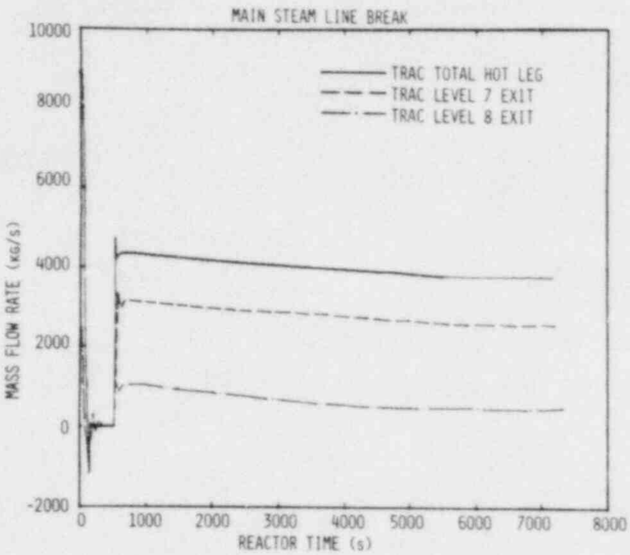

Figure 2.29 Hot Leg Mass Flow Rate in Loop B

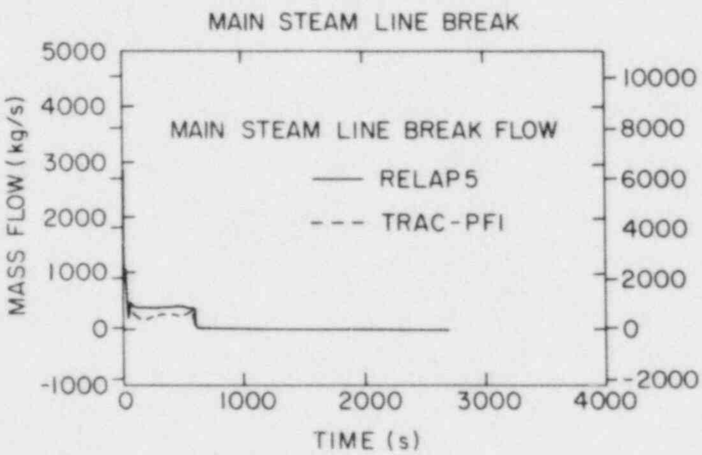

Figure 2.30 Main Steam Line Break Flow

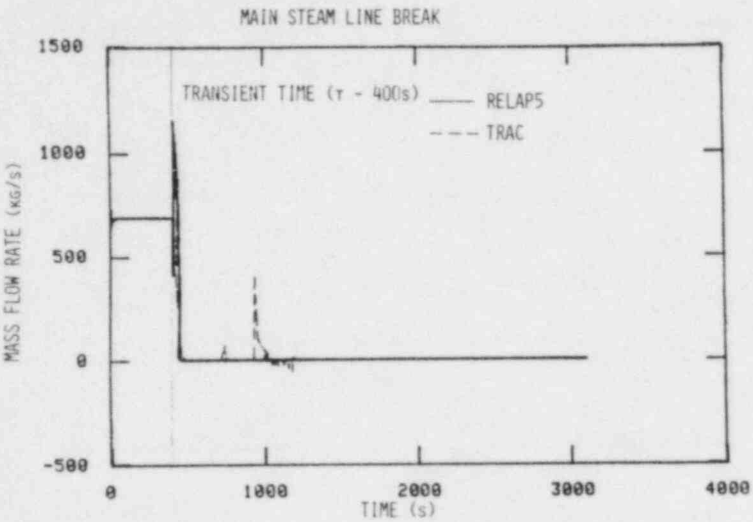

Figure 2.31 Main Feedwater Flow to SGA

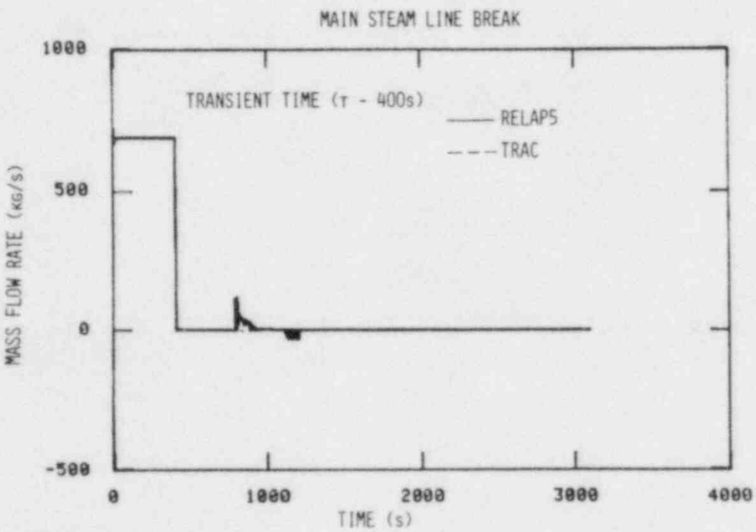

Figure 2.32 Main Feedwater Flow to SGB

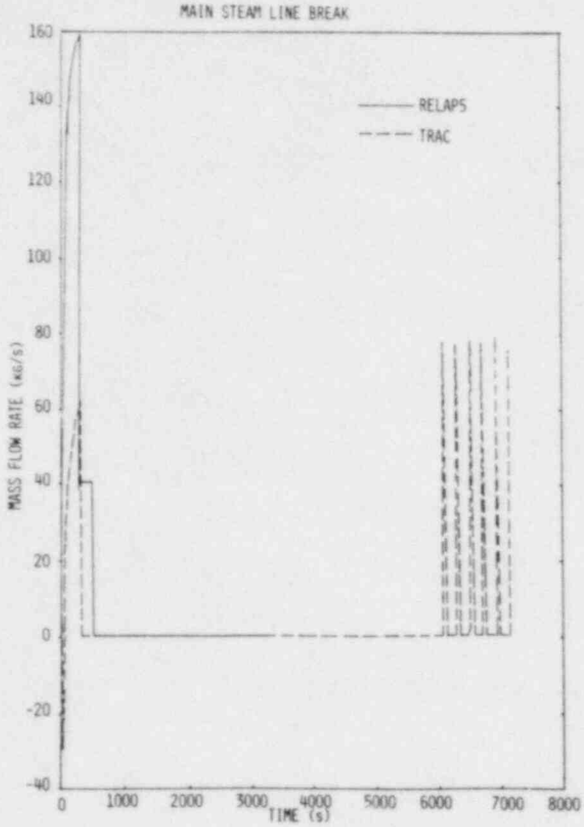

Figure 2.33 Emergency Feedwater Flow to SGB

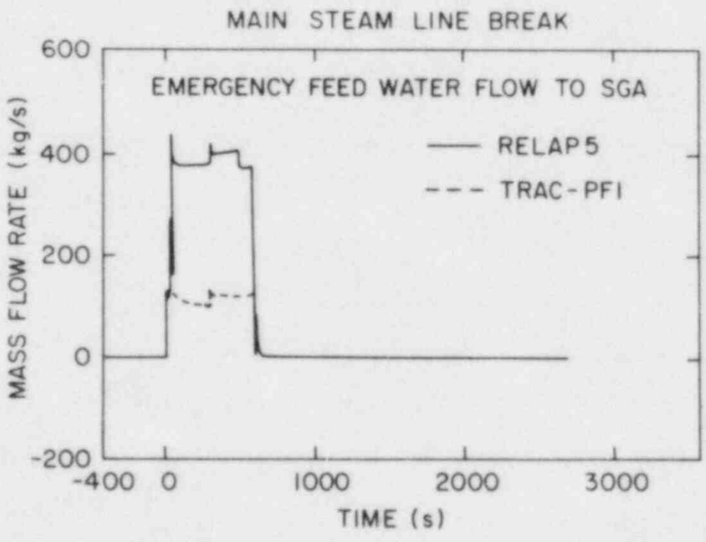

Figure 2.34 Emergency Feedwater Flow to SGA

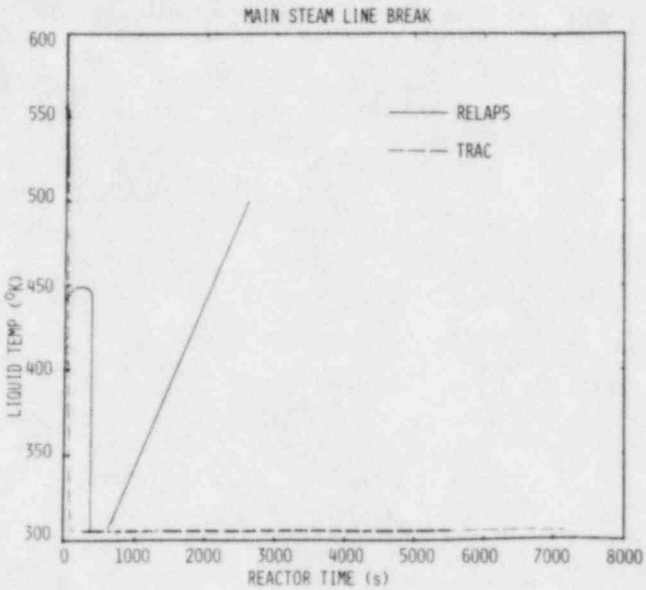

Figure 2.35 Temperature of Emergency Feedwater to SGA

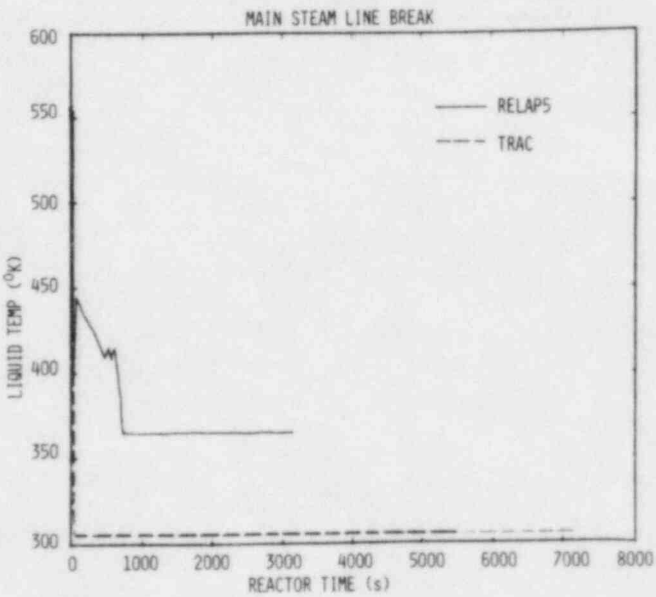

Figure 2.36 Temperature of Emergency Feedwater to SGB

than in loop A. The hot leg in loop A achieved the 42K subcooling even before it did so in the RELAP5 calculation, but, the loop B hot leg was slower to cool and took longer to achieve the required subcooling. This delayed the restart of RCPs in the TRAC calculation and resulted in a lower downcomer fluid temperature. There were some multidimensional effects as reflected in the differences in the two hot leg behaviors. Figures 2.26 and 2.27 show a comparison of the hot leg temperatures as predicted by the two codes. The RELAP5 calculation did not show much difference between the two hot leg temperatures as they started from the same branch but the TRAC calculation showed significant differences, which seems to be more reasonable.

Beside the multi-dimensionality of the transient, there were also important differences in the way the upper head was modeled in these two calculations. In the TRAC calculation the upper head had an artificial connection to the hot leg and there was no volume at the top of the reactor pressure vessel with a dead end. There was significant flow through the upper head to the hot leg, as shown in Figures 2.28 and 2.29. (The level 8 exit in these figures represents the upper head connection.) This flow probably prevented the accumulation of voids in the upper head in the TRAC calculation. However, if the upper head in the TRAC had been modeled as a dead end space, the voids pro bably would have accumulated there instead of migrating to the candy cane, and the natural circulation would have continued in loop B. This would have resulted in a lower hot leg fluid temperature in this loop, and the difference between the times of achieving the subcooling in two hot legs would also have been less. The RCPs would have started earlier in TRAC, resulting in a higher downcomer fluid temperature. Changing the RELAP5 model to have a flow through the upper head would probably terminate the natural circulation in loop B, but the cooling of hot leg B would not be delayed as much as in the TRAC calculation as both the hot legs were connected to the same branch component. The RELAP5 approach of modeling the upper head as dead-end volume is more realistic.

The performance of the steam generator as a heat sink can be assessed by comparing the EFW, MFW, and break flow rates calculated by the two codes. Figure 2.30 shows a comparison of the break flow rates as predicted by the two codes. TRAC computed a smaller break flow rate than RELAP5. Figures 2.31 and 2.32 show the main feedwater flows as computed by the two codes. The time scale is too large to show the effect of the early MFW pump trip and realignment of MFW. Figures 2.33 and 2.34 show the EFW flow rates. RELAP5 had larger EFW flow than TRAC. However, the EFW temperature was much higher in RELAP5 than in TRAC, as shown in Figures 2.35 and 2.36. Furthermore, the break flow quality or enthalpy was not provided by the TRAC calculation, and it was difficult to compare the heat transfer in the steam generator. On the basis of limited information, it can be concluded that the codes were consistent in their prediction of flow parameters for the primary and secondary sides.

The conclusion from this transient is that the most crucial event in determining the minimimum downcomer fluid temperature was the RCP restart time which should have been somewhere between the RELAP5 (300 sec.) and TRAC (526 sec) calculated values. The initial MFW trip and EFW modeling in RELAP5 were more appropriate than in TRAC. Therefore, for a conservative yet realistic estimate one should delay the RCPs restart time in the RELAP5 calculation until the TRAC RCP restart time. This would yield the lowest average

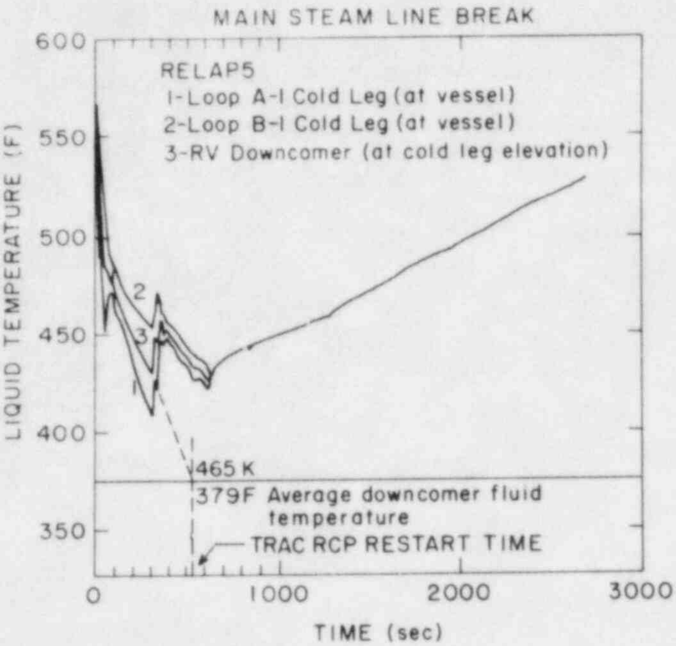

Figure 2.37 Estimate of Lowest Average Downcomer Fluid Temperature

downcomer fluid temperature of 465K or 379F, as shown in Figure 2.37. It was found from the TRAC calculation that there was an azimuthal temperature distribution in the downcomer and the spread was around 30K. This multidimensional effect should also be taken into account in estimating the lowest downcomer fluid temperature, which would then be 15K lower than the average downcomer fluid temperature of 465K. Thus the minimum fluid temperature in the down comer would probably be 450K. Even this value is slightly conservative as the actual time of RCP restart could be earlier than that predicted by TRAC if the voids can accumulate in the upper head as discussed earlier.

3. FAILURE OF ALL TURBINE BYPASS VALVES AT FULL OPEN POSITION

The steam generator secondary side can be depressurized either by a steamline break or by failure of turbine bypass valves at open position. Steamline break yields the largest break; TBV stuck open produces a smaller break. Two different transients initiated by all four TBVs stuck open were specified. INEL was assigned to calculate a transient starting from the hot standby condition (9 MW + RCPs power) whereas the transient assigned to LANL started from the full reactor power. Both scenarios had further operator failures of not throttling the HPI and not restarting the RCPs when needed. Additionally, in the LANL case, the Integrated Control System (ICS) failed to runback FW, and the EFW level control failed. In the INEL scenario, the feedwater did not align to the EFW header. The hot standby condition assumed in the INEL scenario also implied that initially there was no steam supply to the feedwater heaters and the main feedwater was going through the start-up line. Furthermore, the INEL scenario also required closing of all TBVs at 600 seconds. These differences between the LANL and INEL Scenarios are summarized in Table 3.1.

The differences in the initial conditions and scenarios resulted in a quite different response during the transient. The purpose of comparing the two calculations is to indicate the effect of the differences in the initial conditions and scenarios on the transient. The sequences of events as computed by the two codes are summarized in Table 3.2. Figure 3.1 shows a comparison of the primary side pressures. The pressure in the TRAC calculation initially decreased faster than in the RELAP5 case probably, because of a larger energy transfer to the steam generator. This is reasonable, as in the TRAC calculation the steam generators had a larger liquid inventory (200 inch) and also a larger mass flow rate at the TBVs, as shown in Figures 3.2 and 3.3, than in the RELAP5 calculation. Figure 3.4 shows a comparison of the downcomer fluid tempertures. Here again the fluid cools down at almost the same rate in both cases except that it started at a higher temperature in the TRAC calculation. HPI began earlier in the TRAC calculation than in the RELAP5 because of a faster decrease in the pressure in the TRAC calculation.

Main feedwater was lost earlier in the TRAC scenario than in the RELAP5 case as shown in Figures 3.5 and 3.6. This caused a slower rate of energy transfer in the Steam Generator (SG) in the TRAC calculation than in the RELAP5 calculation. This is reflected in the change in the slope of the pressure curve in Figure 3.1. The secondary sides of steam generators were almost full by 500 seconds, and the primary side had also cooled sufficiently to reduce the heat transfer in the steam generator. The secondary side inventories as predicted by TRAC are given in Figures 3.7 and 3.8. Similar information for RELAP5 is given in Figures 3.9 and 3.10, where secondary sides were filled by 1000 seconds. This led to a rapid increase in the primary side pressure, as shown in Figure 3.1, due to a decrease in heat transfer rate in steam generators. The TBVs were closed in RELAP5 calculations at 600 seconds as per operator action, and the secondary side inventory started to increase. This also caused reduced heat transfer in the steam generator for the RELAP5 calculation.

Table 3.1 Comparison of the LANL and INEL Scenarios for All TBVs Stuck Open Transient

ITEM	UPDATED TRAC-PF1 (LANL)	RELAP5/MOD1.5 (INEL)
1) Initial Conditions		
a) Core Power.	Full Power (2568MW)	Hot Standby (9MW+power of 4 RCPs)
b) Steam to FW Heaters.	Yes	No
c) FW temperature at SG.	510K	305K
2) Failures		
a) All Four TBVs failed open.	Yes	Yes
b) Operator failed to throttle HPI and restart RCPs when needed.	Yes	Yes
c) SG liquid level controls for EFW failed.	Yes	No
d) FW failed to realign to EFW header after RCP trip.	No	Yes
3) Operator Action		
a) TBVs closed after 600 sec.	No	Yes

Table 3.2 Sequence of Events for All TBVs Stuck Open Transient

ITEM	UPDATED TRAC-PF1 (LANL)	RELAP5/MOD1.5 (INEL)
1) HPI Flow Initiation	87.5 sec	125.1 sec
2) RCP Trip	117.5 sec	155.1 sec
3) MFW Pump Trip	91.2 sec. due to high SG-B liquid level (6.2m).	168.5 sec. due to low suction pressure.
4) EFW on	147.0 sec. due to low level in SG.	155.1 sec. due to low level in SG.
5) Accumulator Injection	Did not come on.	383.5 sec. to 391.6 sec.
6) TBV Isolated	Did not.	600 sec.
7) PORV Open	1175.7 sec.	950.0 sec.
8) EFW Off	SG level control for EFW did not work; EFW always on.	Between 1010.2 and 1030.4 sec. for SG-B Between 1070.5 and 1074.6 sec for SG-A.
9) Lowest Downcomer Fluid Temperature	350K (170.6°F)	402.6K (260°F)

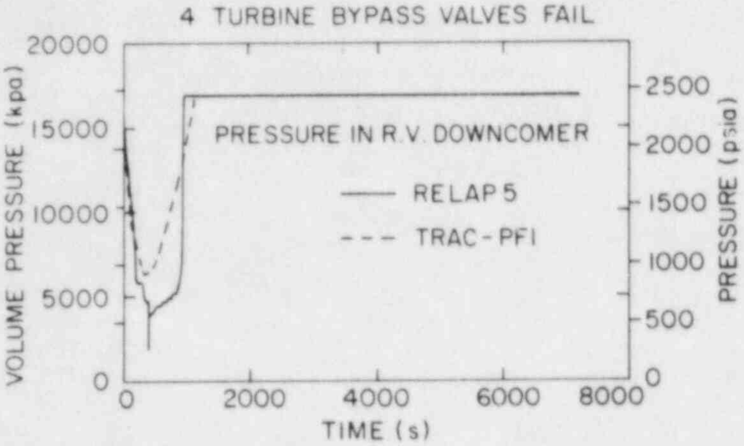

Figure 3.1 Pressure in R.V. Downcomer

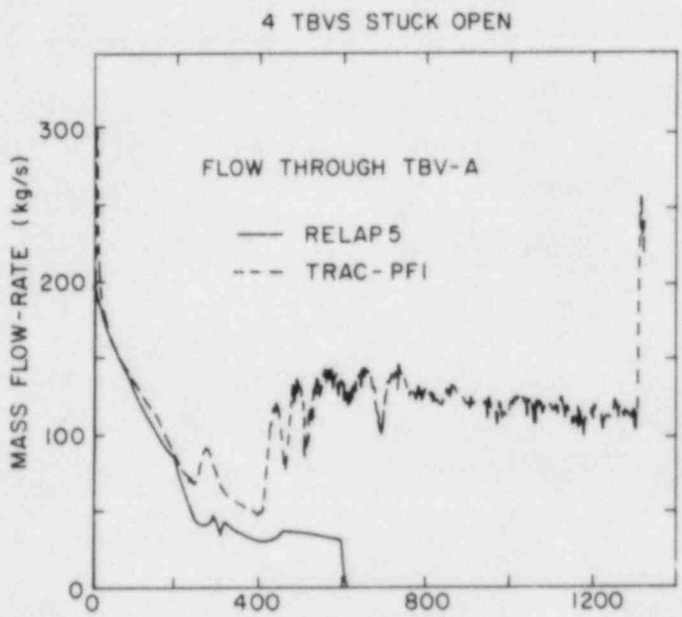

Figure 3.2 Flow Through TBV-A

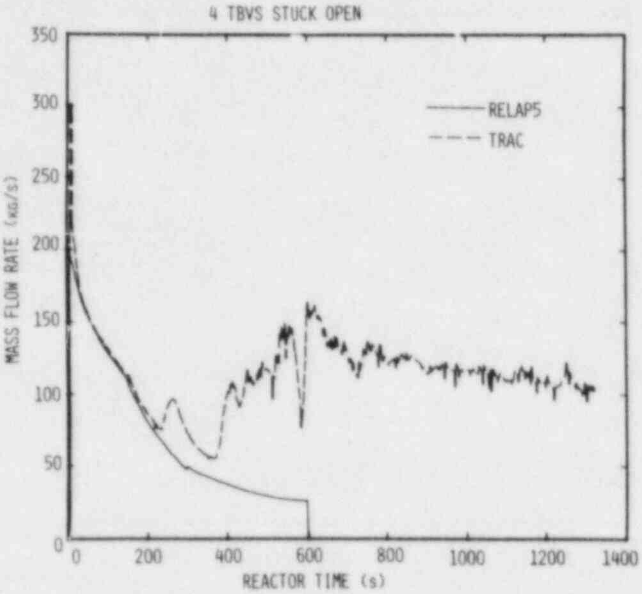

Figure 3.3 Flow Through TBV-B

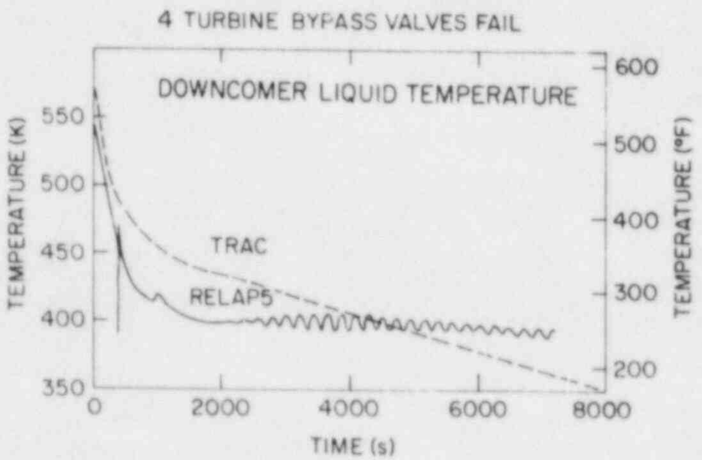

Figure 3.4 Fluid Temperature in R.V. Downcomer

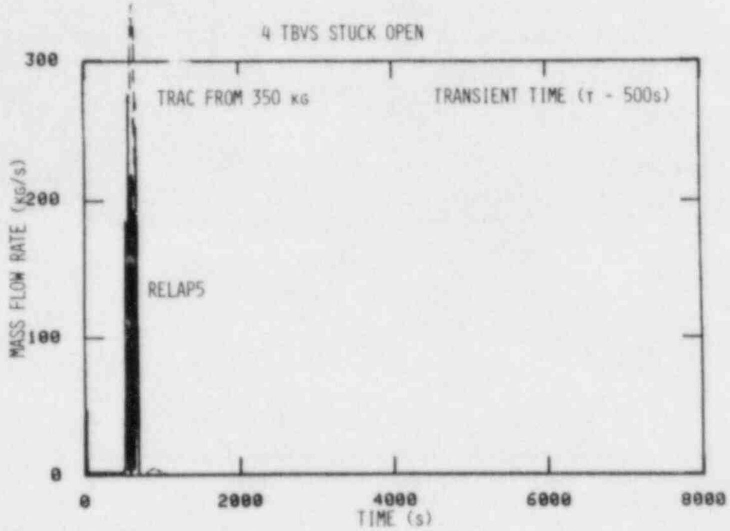

Figure 3.5 Main Feedwater Flow to SGA

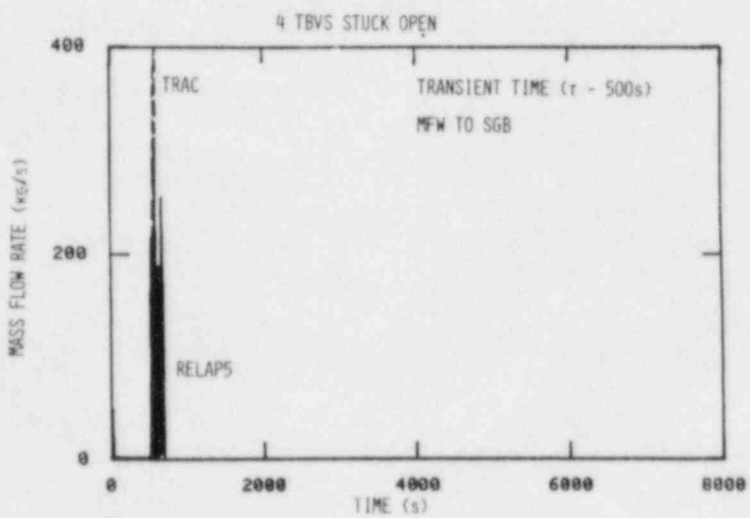

Figure 3.6 Main Feedwater Flow to SGB

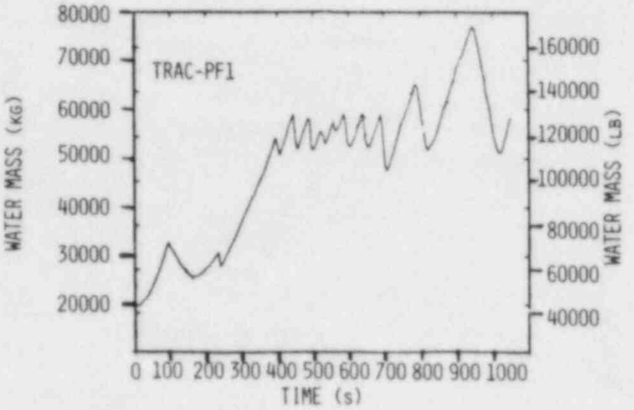

Figure 3.7 Steam Generator Secondary Inventory - Loop A

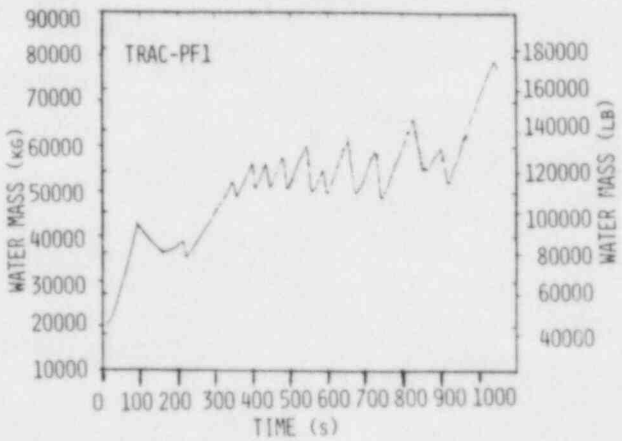

Figure 3.8 Steam Generator Secondary Inventory - Loop B

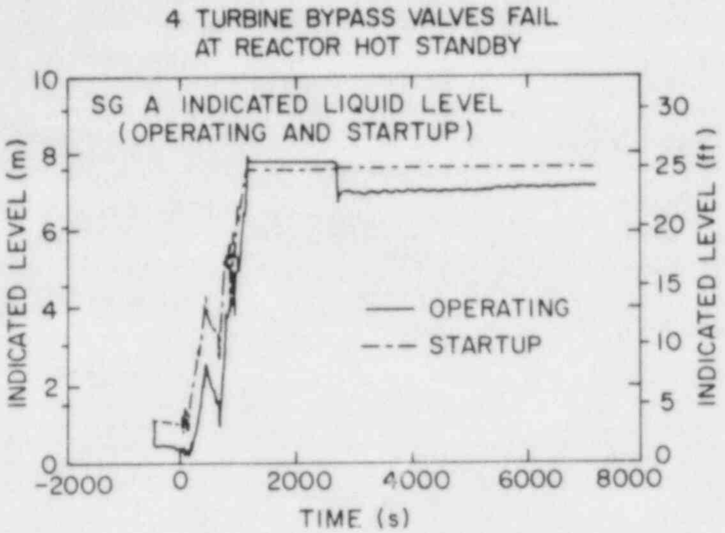

Figure 3.9 SGA Indicated Liquid Level (Operating and Startup)

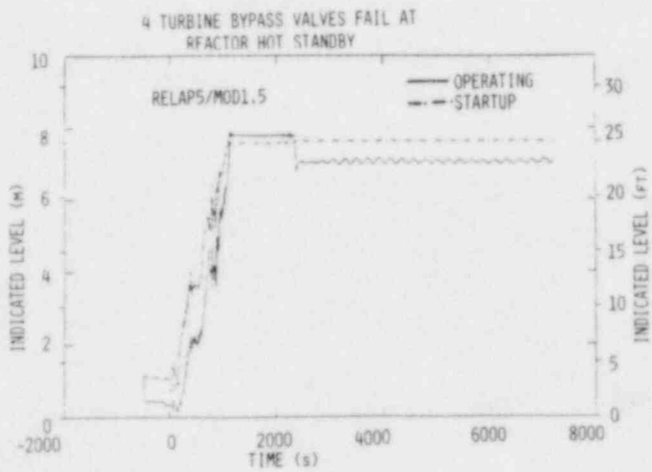

Figure 3.10 SGB Indicated Liquid Level (Operating and Startup)

In summary, the primary side was repressurized, while the temperature kept decreasing for some time in both the calculations. The primary reasons for the two different temperature predictions were the differences in the emergency feedwater control and the time of isolation of steam generators. In the case of the RELAP5 calculation, the steam generator was lost as a heat sink, and any possible cooling was due to the HPI and PORV flows, which maintained a stable temperature of 402.6K. In the TRAC calculation, the EFW flow controller, which was based on the secondary side water level was assumed to fail, and that caused the emergency feedwater (EFW) to continue until the condensate tanks were empty. As a result, TRAC calculated a continuous decrease in the primary side temperature to 350K, which was lower than the RELAP5 prediction. Therefore, although the differences in the initial conditions caused some differences in the early part of the transient, the failure of the EFW control based on the SG secondary level and the failure to close the TBVs after 600 seconds were the major contributors to the lower downcomer fluid temperature in the TRAC calculation. In general, both the TRAC and RELAP5 calculations look reasonable for the specified transients. Note that there were no multidimensional effects for all TBVs stuck open transients discussed above.

4. SMALL BREAK (2-INCH) LOCA IN HOT LEG

A primary side small break can initiate an overcooling transient if the only allowed operator action is to trip the RCPs at 30 seconds after the HPI initiation. Such a transient was specified by ORNL, and both LANL and INEL computed the same transient using TRAC and RELAP5, respectively. The specified scenario is presented in Table 4.1. Note that the ICS is assumed to work as designed.

There were several differences between the TRAC and RELAP5 results. The first difference was the criterion for reactor trip. TRAC tripped the reactor at 0.5 seconds while RELAP5 tripped it on the basis of the low primary side pressure and was more realistic. Both codes ran back MFW pumps after the reactor trip as designed in ICS. The purpose of modeling the same transient with two codes was to determine the sensitivity of the results to the codes.

The transient was initiated by assuming a break in the pressurizer surge line, and an asymmetric loop behavior was expected. Table 4.2 summarizes the timings of various events such as HPI initiation, RCP trip, etc. for two calculations. It also indicates that the method of modeling the plant and the modeling differences of codes do affect the results.

In this transient, the primary side lost energy through the break and the steam generators. The primary side fluid temperature further decreased when the cold HPI water mixed with the primary coolant. Most of the differences between the two calculations could be explained in terms of these heat sinks. Figure 4.1 shows the primary side pressures as computed by TRAC and RELAP5. The TRAC calculation showed a faster drop in pressure than RELAP5 during the first 300 seconds, and a slower drop thereafter. The initial rapid pressure drop in TRAC was consistent with the early reactor trip and with the larger break flow rate prediction than in RELAP5, as shown in Figure 4.2. However, during the time period between 300 and 1100 seconds, TRAC predicted a higher break flow rate and a higher primary side pressure than RELAP5. This could be consistent only if there was either more HPI flow or lower energy loss through the steam generators. The energy loss through the break was not provided. However, the void fraction at the break for the TRAC calculation and the static quality at the break for the RELAP5 calculation were provided, and are shown in Figures 4.3 and 4.4, respectively. During the first 1000 seconds, TRAC computed a very low void fraction while RELAP5 predicted a high static quality and consequently a high void fraction. On the basis of these results and rough estimates of energy loss, it can be concluded that the energy loss through the break in the TRAC calculation was higher than that in the RELAP5 calculation. The TRAC break flow rate was also approximately twice that in RELAP5. The specific energy at the break in the TRAC calculation was only, at the most, 25% less than in the RELAP5 calculation. The HPI flows, as expected, were initiated slightly early in TRAC calculations, as shown in Figures 4.5 to 4.8. However, the differences between the HPI flows in the two calculations were insignificant. Therefore, the cause of the apparent inconsistency between 300 and 1100 seconds lies with the steam generator heat transfer.

Table 4.1 Small Break LOCA in Hot Leg Scenario

Initial Conditions:

1. Full reactor power.
2. Nominal temperatures and pressures in primary/secondary.
3. Decay heat: 1.0 times ANS standard.
4. Pressurizer spray/heaters operate as designed.

Sequence of Events:

1. SBLOCA.
2. Reactor trips, turbine trips, TSVs close.
3. HPI actuates at setpoint (1500 psi).
4. TBVs/SRVs in secondary function as designed.
5. Operater trips RCPs 30 seconds after HPI.
6. ICS controls MFW as designed.

Table 4.2 Sequence of Events in the 2-Inch Hot Leg Break

ITEM	UPDATED TRAC-PF1 (LANL)	RELAP5/MOD1.5 (INEL)
1) Break	0.0 sec.	0.0 sec.
2) Reactor Scram and MFW Pump Runback	0.5 sec.	45.2 sec.
3) TBV Opens	4.2 sec.	47.0 sec.
4) TBV Closes	75.7 sec.	117.0 sec.
5) SRV Opens SRV Closes	No No	50.0 sec. 69.0 sec.
6) HPI Initiation	43.1 sec.	78.5 sec.
7) Loss of Main Feedwater	350 sec. (Closing SUFCV)	70 sec. (MFW pump trip)
8) RCP Trip	73.1 sec.	108.5 sec.
9) EFW Begins	73.1 sec.	108.5 sec.
10) Vent Valve Opens	100 sec.	55 sec.
11) EFW Trips	loop A 350 sec. loop B 400 sec.	loop A 503 sec. loop B 500 sec.
12) Loss of Natural Circulation	loop A 750 sec. loop B 600 sec.	loop A 815 sec. loop B 1020 sec.
13) Circular Flow and Flow Oscillation Between Cold Legs.	loop A 1200 sec. loop B 1200 sec.	loop A 872 sec. loop B 1100 sec. (No oscillation)
14) Accumulator Injection	None	2215 sec.
15) LPI	--	5124 sec.
16) Minimum Downcomer Fluid Temperature	470K at 750 sec. (based on calculation up to 1800 sec.)	355-361K at 7200 sec. (estimated)

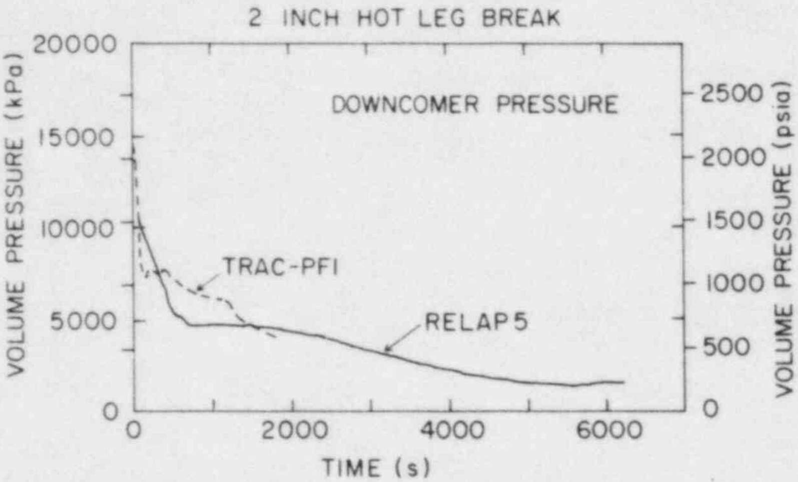

Figure 4.1 Downcomer Pressure

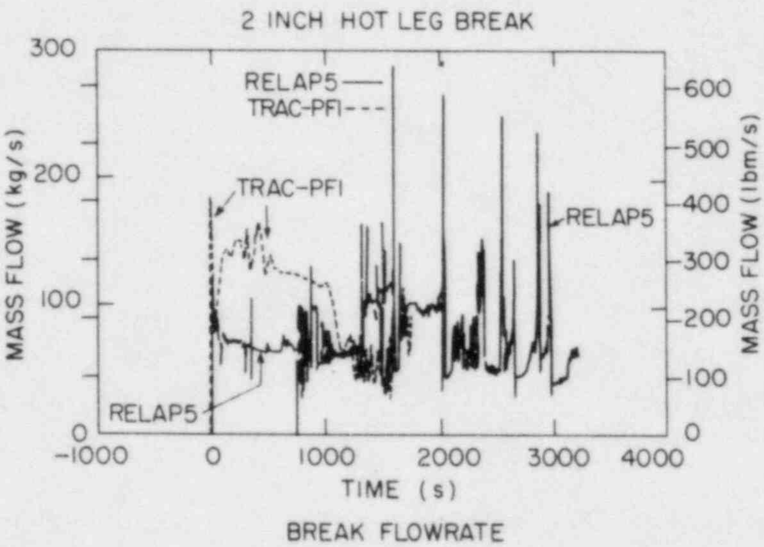

Figure 4.2 Mass Flow Rate Out of Break

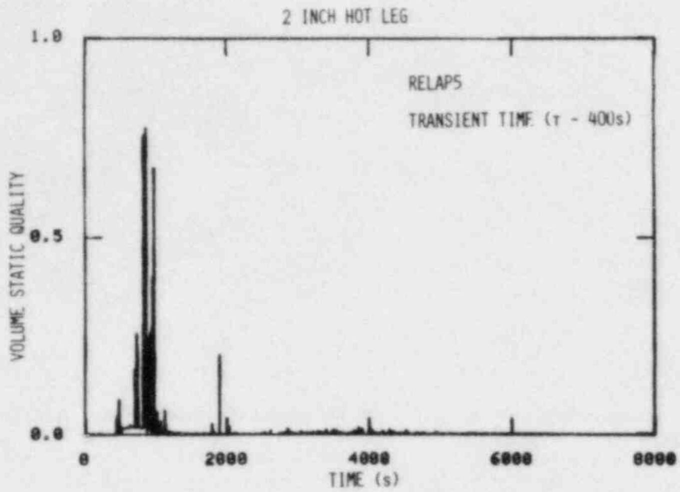

Figure 4.3 Static Quality in the Surge Line Volume With Break

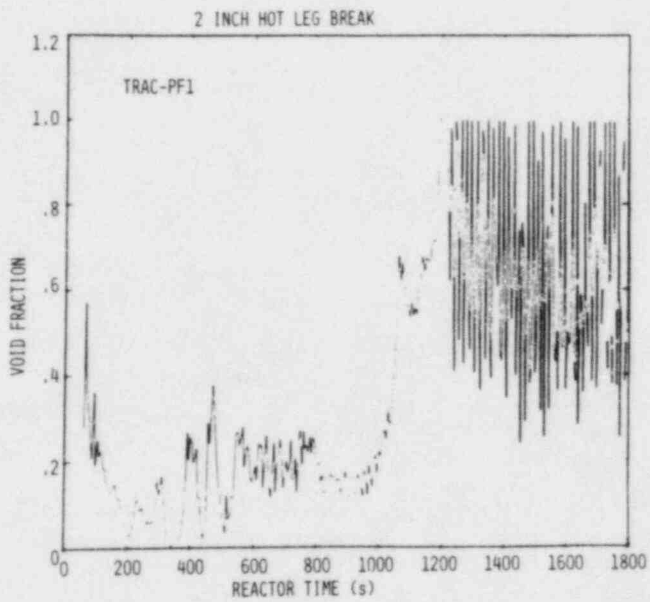

Figure 4.4 Void Fraction in the Surge Line Volume With Break

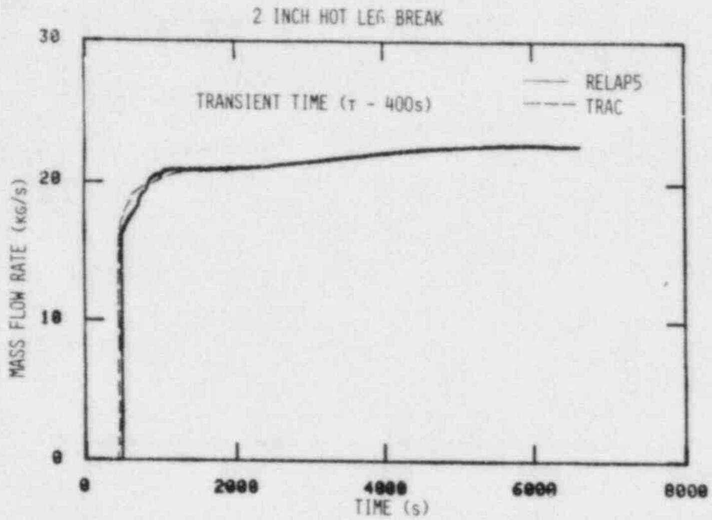

Figure 4.5 HPI Flow to Cold Leg A-1

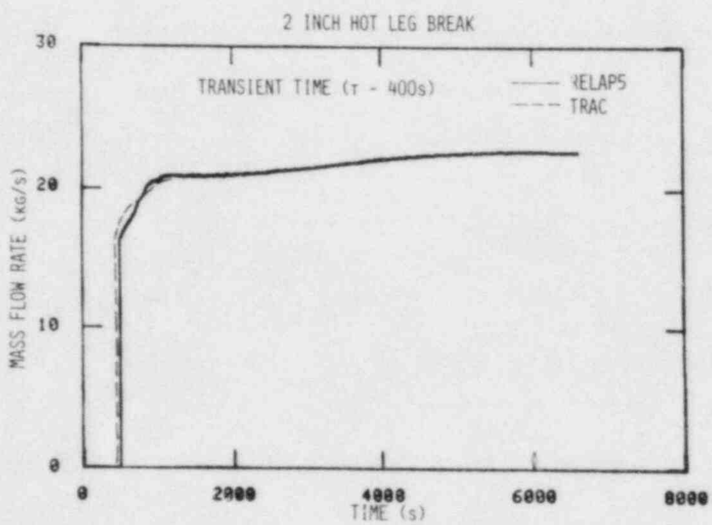

Figure 4.6 HPI Flow to Cold Leg A-2

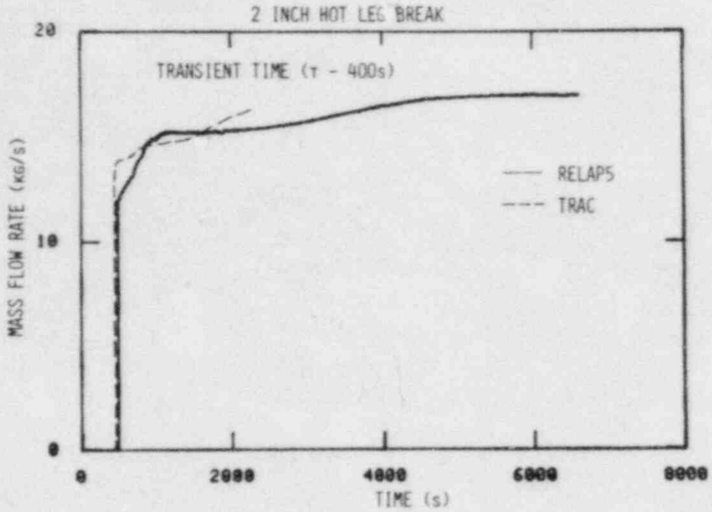

Figure 4.7 HPI Flow to Cold Leg B-1

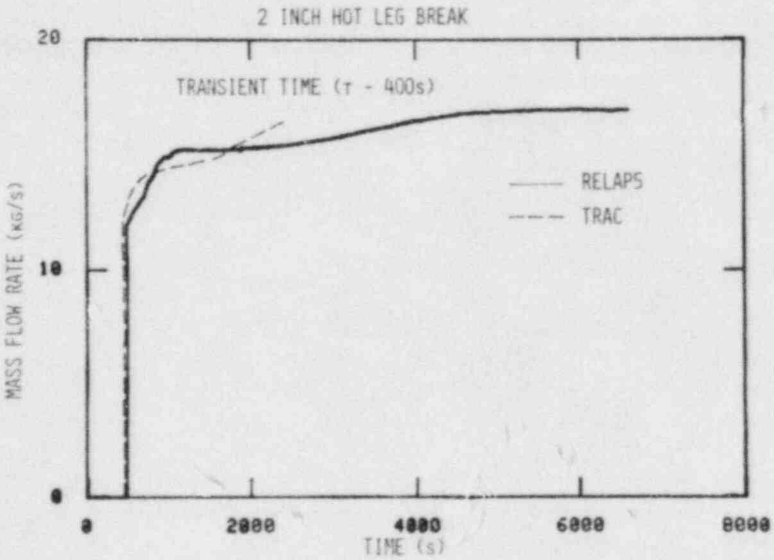

Figure 4.8 HPI Flow to Cold Leg B-2

The heat transfer in the steam generator was governed by the primary side flow and temperature and by the secondary side fluid conditions. The RCPs were tripped in both the calculations, and the primary side was in natural circulation mode. The natural circulation lasted until the candy cane voided as shown in Figures 4.9 and 4.10. Figure 4.11 compares the upper head voiding as predicted by the two codes. The RELAP5 computed complete voiding of the upper head by 300 seconds while TRAC calculated only 50% voiding in the upper head. More vapor went to the candy cane than to the upper head and caused earlier termination of natural circulation in the TRAC calculation than in the RELAP5 calculation. (This is consistent with the main steam line break transient discussed in Chapter 2.)

The steam generator secondary side conditions were controlled by the feedwater conditions. After the reactor trip, the MFW pumps were run back to maintain proper flow, and the main feedwater was aligned to the EFW header through the SUFCV (Start Up Flow Control Valve). The main feedwater was lost in the RELAP5 calculation because of MFW pump trip on the high discharge pressure at 70 seconds while in the TRAC calculation the MFW lasted until 350 seconds when the SG secondary level control was exceeded and the SUFCV was closed. The EFW was started at the time of RCP trip in both calculations, but TRAC terminated it earlier, as shown in Figures 4.12 and 4.13. The EFW was more than 100°C colder than MFW. Consequently, the steam generator secondary side had warmer fluid in the TRAC calculation. The colder fluid in the RELAP5 calculation caused the secondary side pressure to be lower, as shown in Figures 4.14 and 4.15. This was also confirmed in Figures 4.16 and 4.17, where SG secondary exit temperatures are compared. Thus the warmer fluid in the SG secondary side caused less heat loss in the TRAC calculation and therefore resulted in a higher pressure in the primary side. In fact, when the steam generator primary side inlet temperatures, as shown in Figures 4.18 and 4.19, were compared with the SG secondary exit temperatures, TRAC had reverse heat transfer in the steam generator after 300 seconds while RELAP5 had heat transfer in the normal direction. Both codes predicted a continuous decrease in the primary side pressure as the break flow rate exceeded the HPI flow rate. This made this transient less severe for the PTS consideration.

Both codes computed comparable downcomer fluid temperatures, as shown in Figure 4.20. This fluid temperature was a function of cold leg and vent valve flows. Figures 4.21 through 4.24 show a comparison of the predicted cold leg temperatures. TRAC computed lower cold leg temperatures than RELAP5 even though there was some reverse heat transfer in the steam generator. This is due to the mixing of cold HPI with the cold leg flows. As the cold leg flows in the the TRAC calculation were small, the effect of HPI flow was more pronounced. This cold leg fluid mixed with the warmer vent valve flow. The net effect was the initially colder fluid in the downcomer in the TRAC calculation. Furthermore, fluid temperature in the downcomer in the TRAC calculation recovered when the code predicted flow oscillations between the cold legs, the steam generator, and the downcomer after natural circulation was lost, as shown in Figures 4.25 and 4.26. The RELAP5 calculation did not show any oscillation, but a stable circular flow between the cold legs with the common steam generator and the downcomer. The downcomer fluid temperature kept decreasing in the RELAP5 calculation as the primary side energy continued to be lost through the break and the steam generator.

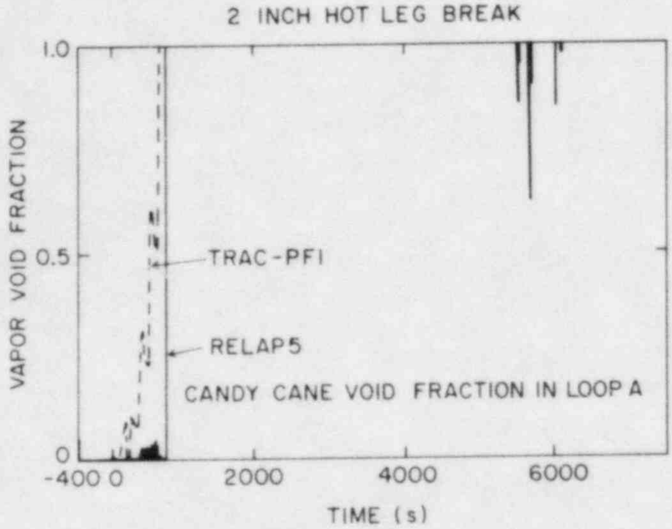

Figure 4.9 Candy Cane Void Fraction in Loop A

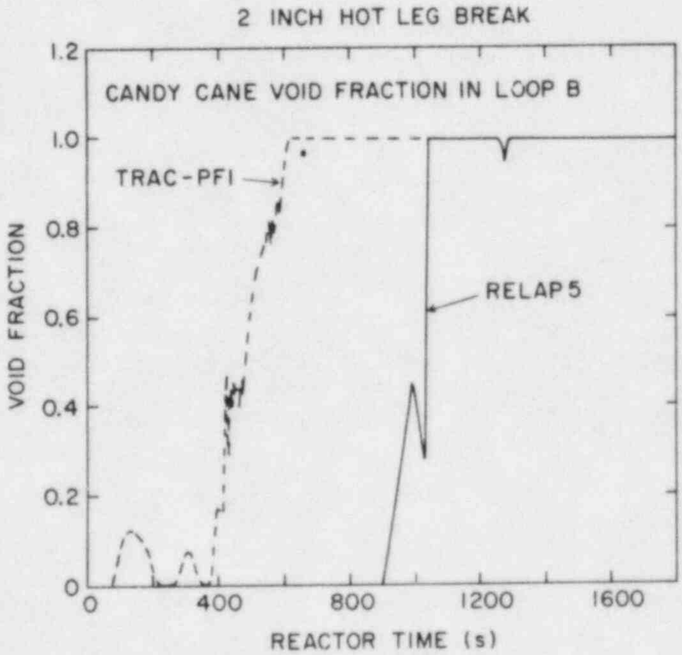

Figure 4.10 Candy Cane Void Fraction in Loop B

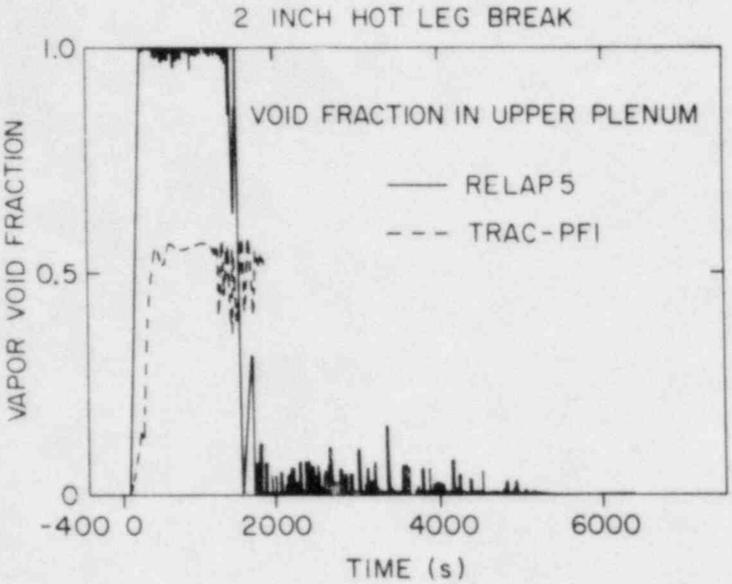

Figure 4.11 Void Fraction in Upper Plenum

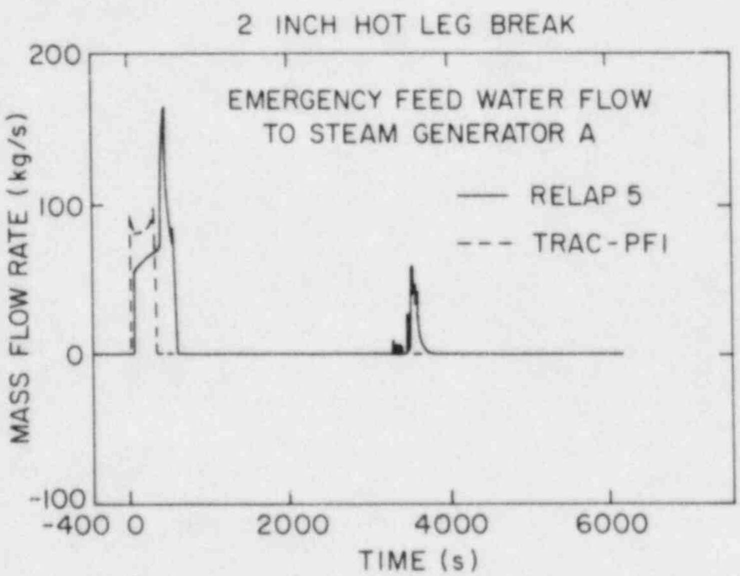

Figure 4.12 Emergency Feedwater Flow to Steam Generator A

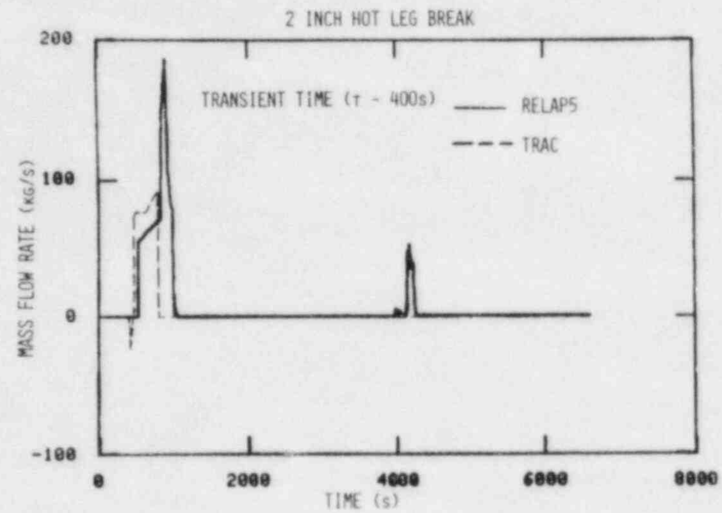

Figure 4.13 Emergency Feedwater Flow to Steam Generator B

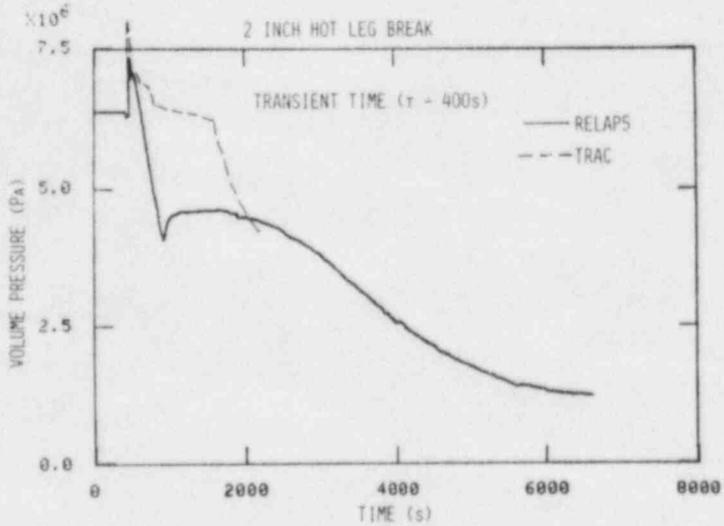

Figure 4.14 Steam Generator A Secondary Side Pressure

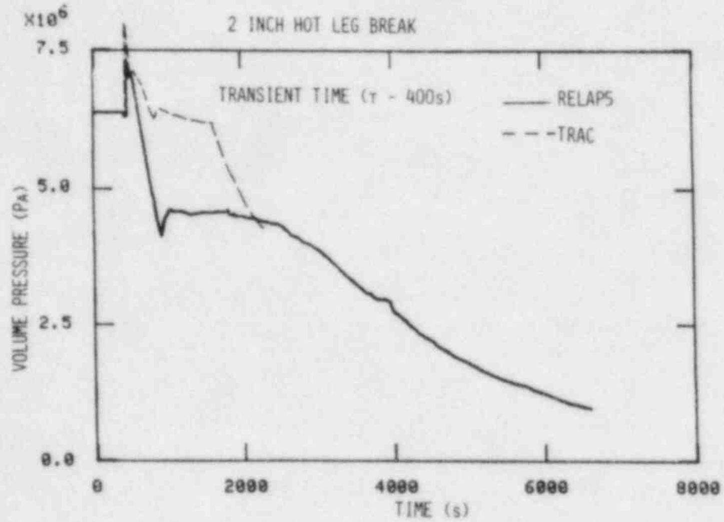

Figure 4.15 Steam Generator B Secondary Side Pressure

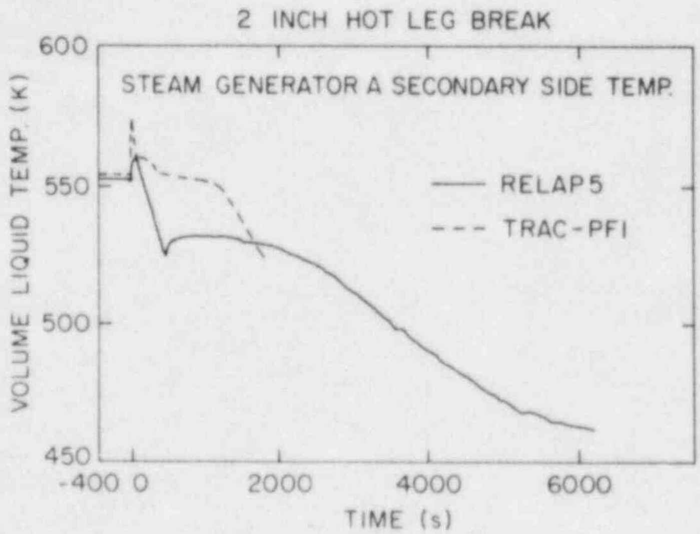

Figure 4.16 Steam Generator A Secondary Side Temperature

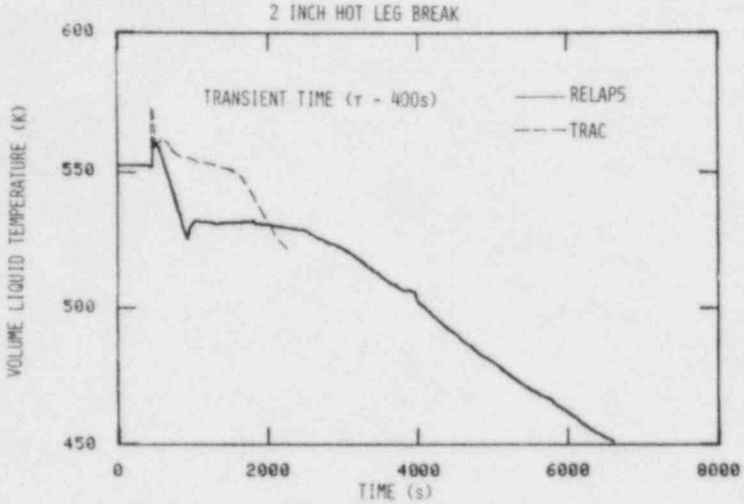

Figure 4.17 Steam Generator B Secondary Side Temperature

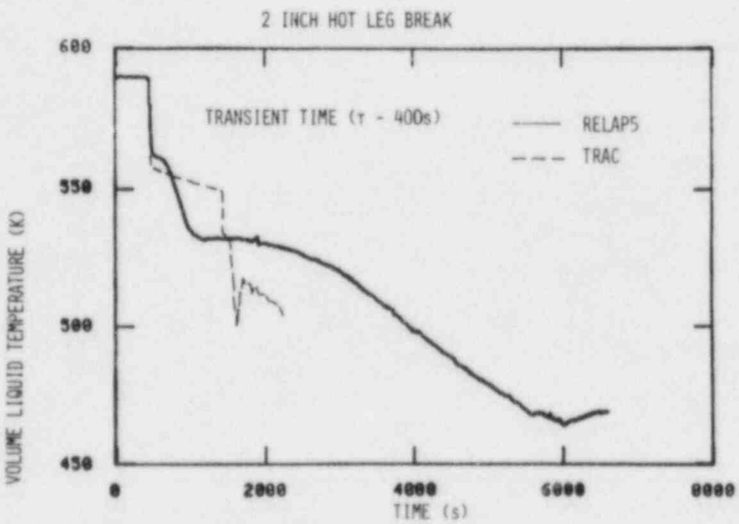

Figure 4.18 Steam Generator Primary Side Inlet Temperature in Loop A

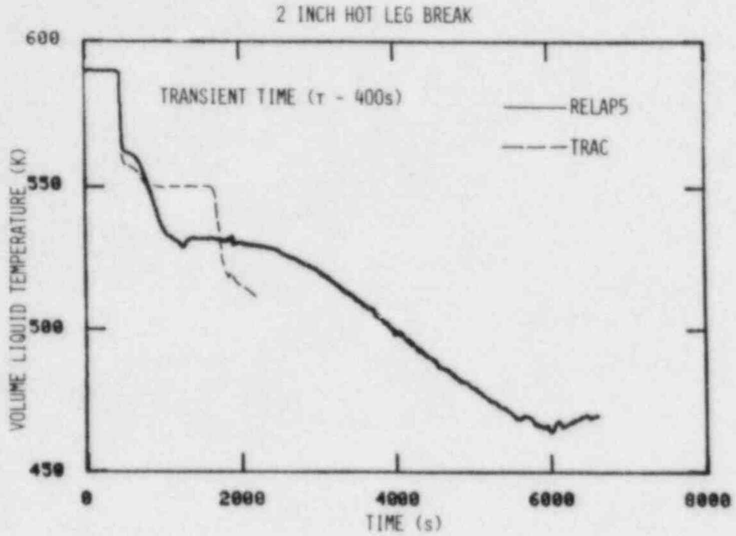

Figure 4.19 Steam Generator Primary Side Inlet Temperature in Loop B

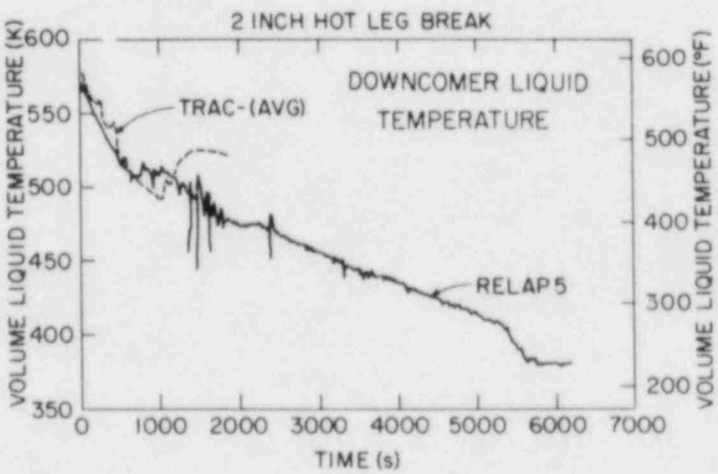

Figure 4.20 Downcomer Liquid Temperature

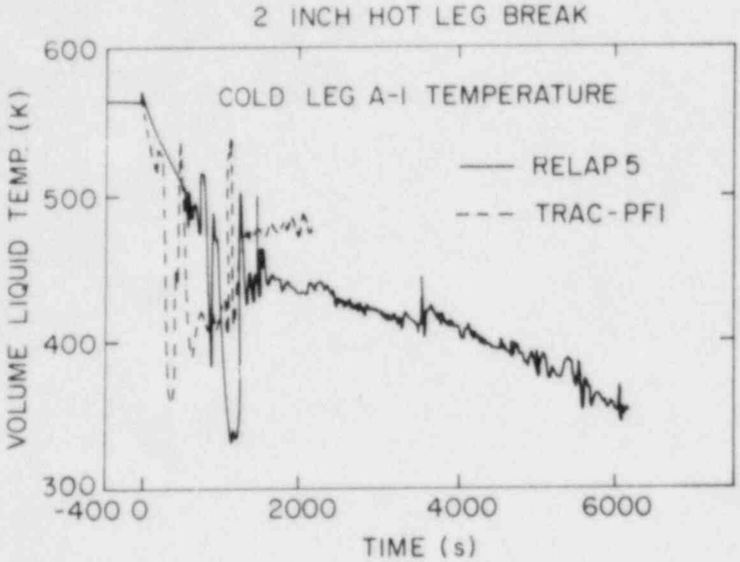

Figure 4.21 Cold Leg A-1 Temperature

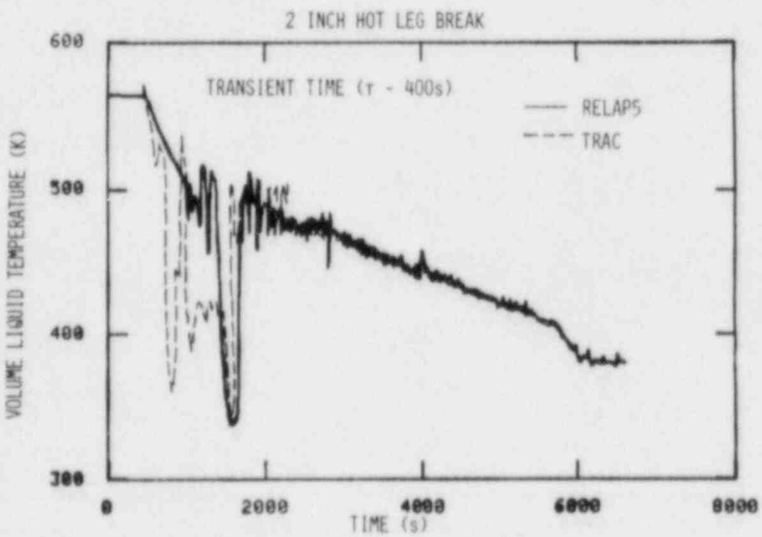

Figure 4.22 Cold Leg A-2 Temperature

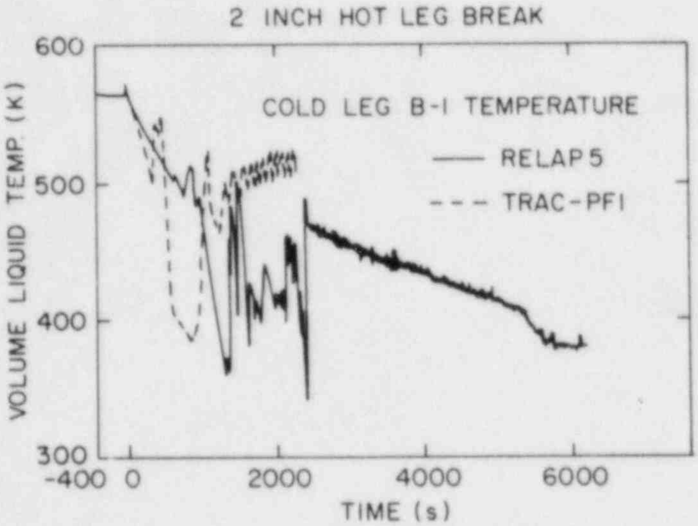

Figure 4.23 Cold Leg B-1 Temperature

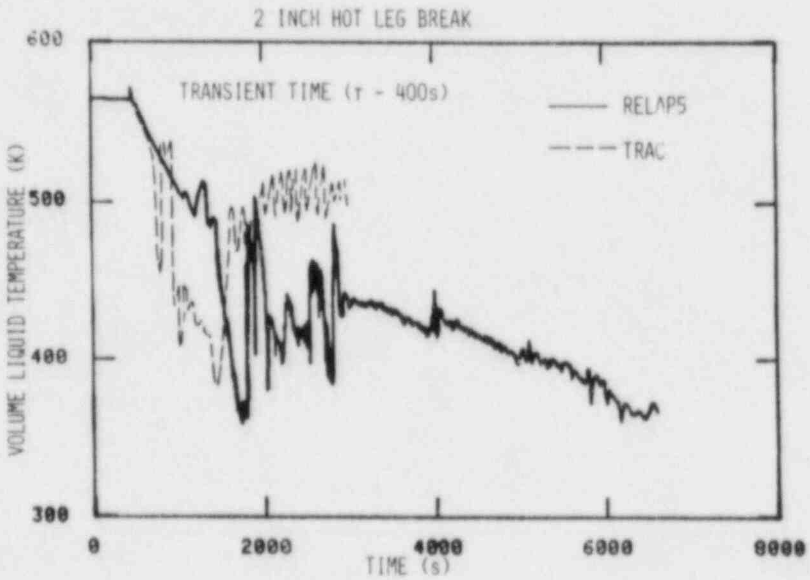

Figure 4.24 Cold Leg B-2 Temperature

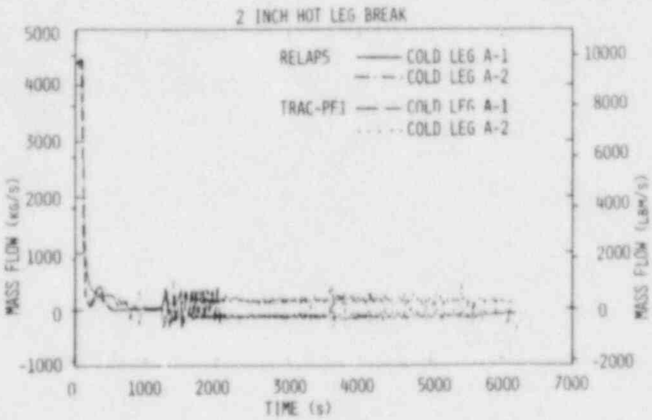

Figure 4.25 Loop A Cold Leg Flow

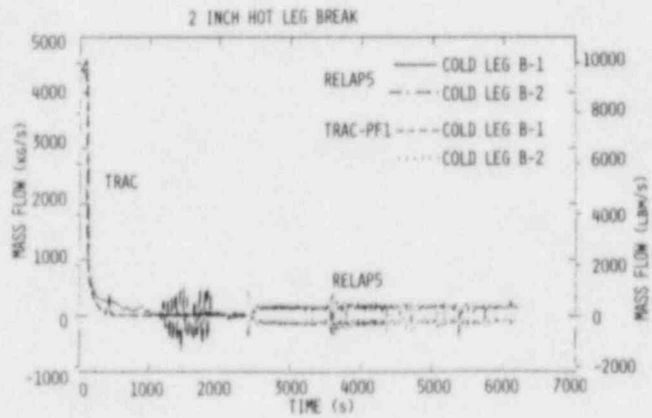

Figure 4.26 Loop B Cold Leg Flow

In summary, both codes computed reasonable results for this transient. There were differences in the break flow rates, reactor trip criterion, upper head voiding and flow oscillations. The flow oscillations in the TRAC calculation were very important as they caused the downcomer fluid temperature to increase. As the TRAC calculation was terminated at 1800 seconds it is difficult to guess the downcomer fluid temperature at 7200 seconds into the transient. Also, it is not clear whether the loop oscillation predicted by TRAC is real. The RELAP5 calculation, on the other hand, was carried out until 6100 seconds and looks more reasonable.

5. SUMMARY AND CONCLUSIONS

Three of the several transients computed by LANL and INEL using the latest versions of TRAC-PF1 and RELAP5/MOD1.5 have been reviewed in detail at BNL. Both the codes were reasonably successful in modeling these transients. The major differences in their results were due to the difference in modeling the plant, control systems, and event sequences, and to the one-dimensional modeling of reactor vessel thermal hydraulics by RELAP5.

Comparison of the computations of the Main Steamline Break (MSLB) transient indicated that the difference in the minimum downcomer fluid temperature predictions was due to the modeling of the control system that regulated the MFW and EFW pumps, and to the multi-dimensional effects, which resulted in different temperature histories for the hot legs and the RCP restart times. The RELAP5 model of the control system, which was based on the secondary side pressure drop, was closer to the plant control system than the TRAC model based on the collapsed water level in the SG downcomer. The other major difference was the way the upper head was modeled in the two calculations. TRAC had no dead end volume for the upper head; therefore, the void accumulation did not occur in the upper head, but instead migrated to the candy cane which resulted in the termination of natural circulation in the unaffected loop B. However, if this natural circulation was maintained a little longer in loop B, the differences in the two hot leg fluid temperatures would be less and the multi-dimensional effect would be less significant. The RELAP5 model of the upper head was more appropriate. Based on the comparison of the two calculations, a reasonable yet conservative procedure would be to delay the restart of RCPs in the RELAP5 calculation until TRAC's RCPs restart time of 526 seconds, which would result in a minimum downcomer fluid temperature of 450K.

The second transient compared was initiated by the failure of all four TBVs at the full open position after a turbine trip. This transient is like a small break in the steamline. Here the initial conditions (full power for TRAC and hot standby for RELAP5) and additional failures were different. The codes predicted the transients reasonably well. However, the important reasons for the differences in the calculations were the controller failure to throttle EFW based on the secondary side level and the failure of the operator to close the TBVs at 600 seconds in the TRAC calculation.

The third transient compared was the Small Break (2-inch) LOCA in a hot leg. The ICS was assumed to work as designed. Both TRAC and RELAP5 computed a continuous drop in the primary side pressure during the transient. This made the transient less critical for PTS. However, comparison of the two calculations indicated that there were many differences. The codes modeled the reactor trip differently. RELAP5 correctly based it on the low primary side pressure while TRAC assumed it to occur at 0.5 second. Furthermore, after the loss of natural circulation due to candy cane voiding, TRAC computed flow oscillations in the cold legs while RELAP5 predicted a stable circular flow be tween the cold legs connected to the common steam generators. The loop oscillations in the TRAC calculation warmed up the cold leg and the downcomer fluids. However, it is not clear if these oscillations are real. Moreover, the TRAC calculation was not carried out far enough in time to determine the minimum downcomer fluid temperature with confidence. The RELAP5 calculation, on the other hand, is more complete and looks reasonable.

6. REFERENCES

1. Bassett, B., Boyack, B., Burkelt, N., Ireland, J., Lime, J., and Nelton, R., (1983), "TRAC Analysis of Severe Overcooling Transients for the Oconee-1 PWR," LA-UR-83-3182, November, 1983.

2. Fletcher, C. D., Bolander, M. A., Stitt, B. D., and Waterman, M. E., "RELAP5 Thermal-Hydraulic Analysis of Pressurized Thermal Shock Sequences for the Oconee-1 Pressurized Water Reactor," NUREG/CR-3761, June 1984.

APPENDIX

This section includes copies of all Brookhaven National Laboratory formal communications with the Nuclear Regulatory Commission regarding the Oconee-1 PTS study during the period August - October 1982.

bnl
aui

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August 31, 1982

Dr. Louis M. Shotkin
Analytical Models Branch
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Washington, DC 20555

Subject: Quality Assurance of TRAC-PF1 Calculations for Oconee Pressurized Thermal Shock (PTS) Study

Dear Lou:

This letter presents the BNL comments on the TRAC input listing and steady-state calculation for the Oconee plant as received from Dr. Nelson S. DeMuth of LANL with his letter dated August 20, 1982. The information was received at BNL on August 23, 1982.

In view of the tight schedule and as agreed upon between the NRC and BNL staff on July 30, 1982, the main emphasis at BNL was to check the consistency of the input parameters such as correct component connections, symmetry of the two primary loops, order-of-magnitude of the component volumes and flow parameters, and the correct input options. The steady-state output was checked for the symmetry, correct thermal-hydraulic conditions and any unexpected or unusual numbers. The steady-state thermal-hydraulic parameters, i.e., pressure, temperature, flow rate, etc., and the overall steady-state heat balance were compared to the 100% operating condition for the Oconee plant as reported in the Oconee FSAR.

The code used for the LANL calculation was an interim version of TRAC-PF1/MOD1. Although BNL was provided with an interim input manual, some sections of the manual were not consistent with the input listing. A more complete input description would have been more helpful for the Q/A activity.

Although no gross error was discovered either in the input listing or in the steady-state output, there are several areas which need further attention before the transient calculations should begin. They are grouped in two parts: (1) input listing, and (2) steady-state output.

1. Comments on the Input Deck

a) The Oconee plant has two loops with two cold legs in each loop. In the LANL input deck the two cold legs of loop B were combined into one single loop while the two cold legs of loop A were left separate. This in turn caused a non-symmetric nodalization of the 3-D vessel module. However, one of the ORNL-specified event sequences (SB1 to SBA2 in the letter from R. C. Kryter dated June 9, 1982) would require restart of one reactor coolant pump in each loop. Therefore, we suggest that both loops be modeled with two separate cold legs with separate RC pumps.

b) For some components, the volume was not equal to the product of the length and the flow area. This may be due to the presence of internal structures in the components like plena, steam generator, pressurizer, etc. The same type of discrepancy also exists in the feed water train components such as condensate booster pumps (component 50), hot well pumps (component 51), branch between C and D heaters (component 52) and condenser (component 55). Also, the volumes of component 14 and 19 were interchanged by mistake.

c) For some components the input data of the two loops were not symmetric.

Specific examples are:

(i)	TWTOLD = 0.8	for component 9 in Loop B
	" = 0.9	for component 19 in Loop A
	" = 0.8	for component 39 in Loop A

This may cause unexpected non-symmetric boundary conditions when the HPIS is triggered.

(ii)	GRAVITY = 0.419	in the first cell of primary tube of component 12 (steam generator) in Loop A.
	" = 0.5655	in the first cell of primary tube of component 2 (steam generator) in Loop B.

This appears to be due to the actual difference of the two loops.

(iii)	FRIC = 0.02	in the last cell of secondary tube of component 6 (TEE).
	" = 0.0	in the last cell of secondary tube of component 16 (TEE).

(iv) The maximum rates of valve flow area adjustment (VARMX) for the accumulator check valves (component 90 and 80) are different (1.0 and 4.0, respectively).

d) Exit flow area of the PORV (component 25) on the pressurizer was set to zero. Since the pressurizer was isolated from the rest of the system during the steady-state calculation, it did not affect the steady-state results. However, this error must be corrected for the transient calculation, otherwise, no fluid will leave the system even if the PORV opens.

e) Initial void fraction in the feedwater lines, i.e., the secondary pipes of components 47 and 57 should be 0.0 instead of 1.0 as used in the input deck. Although a void fraction of zero was obtained in the steady-state, correction of this initial value of void fraction might help in the steady-state calculation.

f) The input deck specified the steam generator exit conditions for the steam and the hot well exit temperature for the liquid in the FILL component at the condenser inlet. Although this is inconsistent and incorrect, it did not significantly affect the steady-state result as the code employed the liquid temperature for the steam for the constant mass flow option used in the FILL. Specification of correct inlet conditions is, however, recommended for the reason given later (see Items 2(f) and 2(g)).

2. Comments on the Steady-State Output

a) A reasonably good steady-state was obtained. The mass, energy and heat balances for the primary and the secondary sides matched within 1%. However, the calculated steady-state gave about 5% larger flow rate and 5% less temperature rise across the core than the 100% operating condition given in Oconee FSAR. However, the actual plant operating condition could be slightly different than that in the FSAR.

b) The vapor entering the steam generator downcomer through the aspirator did not completely condense even at the bottom of the downcomer. This resulted in a reduction of water inventory in the downcomer and may cause higher primary fluid temperature in the case of a loss of feedwater transient. In that case, the code results will be non-conservative. The same phenomenon was observed in the BNL TRAC-PF1 calculation of the B&W OTSG tests and it was suggested that the rate of condensation be increased.

c) The steady-state results of the two loops were not very symmetric. In some components (for example, in two steam generators) differences of a few degrees in temperature were observed. However, this may not have any significant effect on the transient calculation.

d) The fluid velocity in the surge line was still substantial (v_ℓ = 0.4777 m/sec). Considerably longer steady-state calculation may be required to reduce this further. Again, this may not have any significant effect on the transient calculation.

e) A significantly high liquid velocity (4.2 m/sec) was observed at the liquid-vapor interface in both accumulators or core flood tanks. This did not affect the steady-state calculation because the accumulators were isolated from the rest of the system during the steady-state calculation. However, the cause of this irregular behavior should be studied before the transient calculation begins. It may be related to the interface sharpener.

f) The calculated steady-state pressure at the top of the condenser was approximately 1.1 bar, whereas that at the hot well exit was approximately 0.48 bar. Both are considerably higher than the desired values. From the Oconee FSAR and the SAI-supplied information, it can be determined that the pressure in the condsenser should be in between 0.228 and 0.1 bar. Further attention should be paid to the condenser calculation since one of the ORNL-specified event sequences (FW13 to FO12) would require an accurate prediction of the condenser pressure for the Turbine Bypass Valve (TBV) closure.

g) The calculated feedwater conditions were close to the SAI-specified values. Various parameters such as the condenser heat transfer coefficient, the ambient temperature, the feedwater heater heat sources and the form loss coefficients were adjusted to achieve this. However, if the steam and liquid conditions at the condenser inlet were corrected and the correct condenser pressure were obtained, the feedwater conditions would have been different from the desired values with the current parameters. Therefore, further adjustment of the various parameters, mentioned above, is needed for the desired steady-state conditions at both the condenser and the feedwater inlet to the steam generator.

Most of the above comments have been communicated to Mr. Britt Bassett of LANL over the telephone on August 27, 1982. It must be reiterated that the above comments are not exhaustive and a more thorough quality assurance effort would require more time. In addition, we would require information on all model changes between Version 7.0 and the version being used for the LANL calculation to perform an in-depth review of the end results.

Please feel free to contact me at FTS-666-2438 if you need any further clarification. We are now reviewing the RELAP5 input listing for the Oconee plant and a separate letter will follow shortly. We received the RELAP5 input listing from INEL on August 30, 1982.

With best regards,

Sincerely,

Pradip

JJ/USR/PS:af

Pradip Saha, Group Leader
LWR Code Assessment & Application

cc: F. Odar, NRC
N. Zuber, NRC
C. E. Johnson, NRC
N. S. DeMuth, LANL
B. Bassett, LANL
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September 15, 1982

Dr. Louis M. Shotkin
Analytical Models Branch
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Mail Stop 1130 SS
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Quality Assurance of RELAP5 Calculations for Oconee Pressurized Thermal Shock (PTS) Study

Dear Lou,

This letter presents the BNL comments on the RELAP5 input listing for the Oconee plant as received at BNL on September 1, 1982. This input listing supersedes the previous RELAP5 input listing received on August 30, 1982. Our comments are, of course, based on the latest input.

In view of the tight schedule and late arrival of the input listing, we concentrated on checking the consistency of the input parameters such as correct component connections, symmetry of two loops, order-of-magnitude of the component volumes, flow parameters and the correct input options. Efforts were also made to compare the TRAC-PF1 and the RELAP5 input listings and to look for any significant differences in modeling various components. Trips relevant to the steady-state calculation were checked; however, the remaining trips related to the transient calculation will be reviewed after the final input listing is received.

We were told by the INEL staff (M. Waterman and D. Fletcher) that the input listing was of preliminary nature and it was still being modified at INEL. Furthermore, the code version to be used for the PTS calculation at INEL is different from the RELAP5/MOD1 code, and no updated manual was sent with the input. The task of reviewing and comparing the RELAP5 and TRAC listings became even more time consuming because different units were used in these listings. The LANL staff used the SI units for TRAC, whereas the INEL staff used the British units for RELAP5. It is recommended that both laboratories (LANL and INEL) provide results in the <u>same</u> units. Otherwise, a direct comparison between the TRAC and RELAP5 results would be very time-consuming. It is our understanding that RELAP5 results could be obtained in either the

British or the SI units, whereas the TRAC results are always in the SI units. Because the plant data are usually in the British units, the RELAP5 results should probably be obtained in both SI and British units.

No major error was discovered in the RELAP5 input listing. However, some differences between the TRAC and RELAP5 inputs were found and there are several areas which need further attention before the transient calculations should begin. Our comments, given below, are in two parts. The first part deals with the RELAP5 input and the second part describes the differences between the TRAC and RELAP5 inputs.

1. Comments on the RELAP5 Input Deck

a) Primary Loop:

(i) There is a connection between the lower outer upper plenum (component 545) and the downcomer inlet annulus (component 565). It is not clear what feature of the reactor is being modeled with this connection since the vent valve is already being modeled by another connection (component 536).

(ii) There is a big jump in the hydraulic diameters for the last two volumes of the downcomer (component 570). The reason for this is not clear.

(iii) The accumulator model is using a junction flag of 0020 while the recommended value in the RELAP5/MOD1 manual is 0000. It is not clear whether this is due to the change in the code version.

(iv) The homogeneous equilibrium option is being used in the secondary side of the steam generators. This is not appropriate for the expected flow situation in the steam generator secondary side.

b) Feedwater Train:

(i) The input deck does not have a model for the condenser and the hot well. The secondary loop will, therefore, not be closed. Either the flow or pressure boundary condition along with the fluid temperature and quality at the exit of the hot well has to be specified. It is not clear how the code can calculate some of the ORNL-specified transients without a condenser and hot well model.

(ii) The hot well exit pressure used in the input is 5.7 psi (0.393 bar) which is larger than the SAI recommended value of 0.103 bar.

(iii) D and E heater drains have been modeled with time dependent junctions with velocity boundary conditions. It will be more accurate to use the flow boundary condition which is allowed in the code.

(iv) Input description contains some apparent errors in the pump models. The rated torques for the hot well, booster and main feedwater pumps are specified as 10^{-6} lb-ft which is unrealistically low. Also, the rated fluid density and motor torque have been specified as 0.0 for all three pumps. These should be changed prior to the steady-state calculations.

c) Control System:

The control system for the feedwater, emergency feedwater, and the turbine bypass valve in the RELAP5 input deck was reviewed and compared with the SAI version of the control system which was reviewed earlier at BNL. Several discrepancies between the two were detected. However, we were informed on September 7, 1982 by the INEL staff (M. Waterman) that the RELAP5 control system was substantially modified from the input listing received by us. Therefore, our review of the RELAP5 control system does not seem to be applicable anymore, and it will not be discussed here.

2. Comparison Between the RELAP5 and TRAC Inputs

Both inputs are quite similar in their description of the plant. However, there are a few exceptions where either some components are missing or there is more than 5% difference in the dimensions of the same component in the two inputs. These are discussed below:

a) TRAC-PF1 input has a condenser and hot well model which RELAP5 input does not have. However, the RELAP5 deck accounts for the safety relief valve on the pressurizer which is missing in the TRAC input.

b) Both codes are using different characteristics for the same primary loop recirculation pumps. The TRAC input contains the pump model based on the LOFT pump, while the RELAP5 model is based on the Westinghouse pump. The recirculation pump in the Oconee plant has a specific speed of 4000 which is higher than that of the LOFT pump (specific speed 3300) but lower than that of the Westinghouse pump in RELAP5 (specific speed 5200). It will be more appropriate to use the

Bingham pump characteristics of RELAP5, as it has a specific speed of 4200. Furthermore, the TRAC model will compute coastdown while RELAP5 will use a table.

c) RELAP5 accounts for the heat stored in the shell wall of the steam generator which is not possible in TRAC. This is an additional energy available to the feedwater and will make the primary loop cooling rate less severe. However, the quantitative impact of neglecting this stored energy in TRAC will depend on the scenario and it is not known at this time.

d) The feedwater heaters have been modeled differently by the LANL and the INEL staff. The TRAC input combines the A & B heaters and does not account for the energy input into the demineralizer. The following table presents a comparison of the heater powers used in the two inputs.

Heater Number	TRAC Input MW	RELAP5 Input MW
A	227.5 (A and B combined)	79.9
B		77.4
C	213.0	251.1
D	113.6	146.4
E	79.7	130.8
F	78.4	120.7
Demineralizer	--	9.3
TOTAL	712.2	815.6

Because of the tight schedule, we could not determine which input better represents the plant conditions.

e) There are some differences in the component sizes which are summarized in the following table along with the values suggested by the Duke-Power in their letter dated January 12, 1982 to R. C. Kryter of ORNL:

Component	TRAC	RELAP5	Duke-Power Data
Vessel			
Downcomer Volume	21.89 m^3	21.36 m^3	
Lower Plenum Volume	24.45 m^3	19.39 m^3	
Core Volume	22.91 m^3	23.21 m^3	
Upper Plenum Volume	47.21 m^3	43.62 m^3	
Total Vessel Volume	116.5 m^3	107.6 m^3	114.9 m^3
Downcomer Hydraulic Dia.	0.55 m	0.29 m	
Downcomer Inner Wall Thickness	0.0762 m	0.0507 m	
Pressurizer			
Pressurizer Volume	42.51 m^3	45.15 m^3	42.47 m^3
Level	5.6 m	6.47 m	5.59 m
Surge Line Volume	0.56 m^3	0.59 m^3	0.57 m^3
Surge Line Diameter	0.254 m	0.222 m	
Steam Generator			
Feedwater inlet Area	0.04 m^2	2.164 m^2	
Secondary side Flow Area	4.345 m^2	1.688 m^2	
Hydraulic Dia.	0.006 m	0.02 m	
Aspirator area	2.167 m^2	0.972 m^2	

Both codes use approximately equal volumes for similar components. The above table shows the major differences found in the geometric parameters in the two inputs. The differences in the volumes will affect the liquid inventory and, therefore, the primary side cooling rate. The differences in the steam generator feedwater inlet area, hydraulic diameter and aspirator area are probably due to adjustments of the additive friction factors to achieve the correct steady-state pressure drops. The differences in the secondary side flow area and other volumes may be due to the differences in the internal structures used. The quantitative impact of the above differences is scenario-dependent and not easy to determine a priori. It is recommended that the INEL and LANL staff resolve these differences before they proceed with the transient calculations.

Most of the above comments have been transmitted to the INEL staff (Mike Waterman and Don Fletcher) on September 9, 1982. It must be emphasized that these comments are not exhaustive and a more in-depth quality assurance will require more time. For the future review and quality assurance of the TRAC and RELAP5 calculations it is strongly recommended that: (1) all inputs and calculations are in the same units, (2) all pertinent information on the code/model changes since the last released version be supplied, and (3) no work is sent for Q/A unless it is reasonably complete.

Please feel free to contact me at FTS-666-2438 if you need any further clarification. With best regards,

Sincerely yours,

Pradip

Pradip Saha, Group Leader
LWR Code Assessment and Application

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QUALITY ASSURANCE PROGRAM FOR PTS CALCULATION

PREPARED BY

J. JO, U. S. ROHATGI AND P. SAHA
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PRESENTED AT

OCONEE PTS ASSESSMENT MEETING
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE
SEPTEMBER 22, 1982

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ASSOCIATED UNIVERSITIES, INC.

OBJECTIVES OF BNL Q/A PROGRAM

- REVIEW NEW THERMAL-HYDRAULIC MODELS
- REVIEW PLANT DECKS
- REVIEW THE THERMAL-HYDRAULIC CALCULATIONS
- COMPARE TRAC AND RELAP5 CALCULATIONS FOR OCONEE

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REVIEW OF PLANT DECK

- ASSURE THE CORRECT AND COMPLETE MODELING OF THE PLANT
  - ACCOUNTING FOR ALL COMPONENTS NEEDED FOR A SPECIFIC SCENARIO
  - DIMENSIONS, LENGTH, AREA AND VOLUME, ELEVATIONS
  - INTERNAL STRUCTURES
  - HEAT STRUCTURES
  - COMPONENT CONNECTIONS
  - CORRECT OPTIONS
  - VALVE SETTINGS - PRESSURIZER, ACCUMULATOR, HPI, LPI, VENT
  - PUMP CHARACTERISTICS
  - LOSS COEFFICIENTS
  - CONTROLS
  - BOUNDARY CONDITIONS, HPI AND LPI FLOW AND TEMPERATURE, VALVE EXIT PRESSURES, ETC.

REVIEW OF THERMAL-HYDRAULIC CALCULATIONS

1. STEADY-STATE

- SYMMETRY OF TWO LOOPS
- MASS AND ENERGY BALANCES FOR PRIMARY AND SECONDARY SIDES
- COMPARISON WITH PLANT CONDITIONS
  - PRESSURE (PRIMARY AND SECONDARY)
  - TEMPERATURE
  - FLOW RATE
  - PRESSURIZER LEVEL
  - STEAM GENERATOR LEVEL, STEAM GENERATOR EXIT TEMPERATURES

2. TRANSIENT

PRIMARY LOOP

- PRESSURE
- FLUID TEMPERATURE AND H.T. COEFFICIENT IN DOWNCOMER
- COLD AND HOT LEG TEMPERATURE AND FLOW RATE
- PRESSURIZER LEVEL
- SAFETY/RELIEF VALVE FLOW RATES
- HPI, ACCUMULATOR, LPI FLOW RATES

SECONDARY LOOP

- PRESSURE
- S.G. INLET FLOW RATE, TEMPERATURE AND QUALITY
- EMERGENCY FEEDWATER FLOW RATE
- S.G. LEVEL
- S.G. EXIT FLOW RATE, TEMPERATURE AND QUALITY
- TURBINE BYPASS AND RELIEF VALVE FLOW RATES
- HOT WELL PRESSURE, TEMPERATURES AND LEVEL
- FEEDWATER HEATER EXIT TEMPERATURES

COMMENTS ON TRAC INPUT

- NO MAJOR ERRORS
- MINOR ERRORS TRANSMITTED TO LANL (BNL LETTER DATED 8/31/82)
- SAFETY RELIEF VALVE ON PRESSURIZER MISSING
- MODEL MAY BE IMPROVED WITH 4 COLD LEGS

COMMENTS ON TRAC STEADY STATE

- REASONABLY GOOD STEADY STATE
- LOW WATER INVENTORY IN S.G. DOWNCOMER DUE TO INSUFFICIENT CONDENSATION
- SIGNIFICANT LIQUID VELOCITY AT THE INTERFACE IN THE ACCUMULATOR
- CONDENSER MODEL NEEDS FURTHER ASSESSMENT. COMPUTED PRESSURE TOO HIGH.

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COMMENTS ON RELAP5 INPUT

- NO MAJOR ERRORS
- EXTRA CONNECTION OTHER THAN THE VENT VALVE BETWEEN UPPER PLENUM AND DOWNCOMER
- HOMOGENEOUS EQUILIBRIUM OPTION FOR SECONDARY SIDE OF THE STEAM GENERATOR
- NO CONDENSER/HOT WELL MODEL
- PUMP MODEL HAS ERROR IN RATED TORQUE AND VALUES.

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COMPARISON OF TRAC AND RELAP5 INPUTS

- MOST OF THE COMPONENT MODELS ARE SIMILAR.
- FEW DIFFERENCES

ITEM	TRAC	RELAP5	PLANT
1) R.C. PUMP	LOFT SP SPEED 3300	WESTINGHOUSE SP SPEED 5200	SP SPEED 4000
2) FEEDWATER HEATER TOTAL POWER	712.2 MW	815.6 MW	
3) PRESSURIZER LEVEL	5.6 M	6.47 M	5.59 M
4) VESSEL VOLUME	116.5 M^3	107.6 M^3	114.9 M^3
5) S.G. WALL STORED ENERGY	NOT MODELED	MODELED	

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SAI CONTROL SYSTEMS

1. SEVERAL ERRORS DETECTED AND COMMUNICATED TO SAI WHICH HAVE BEEN CORRECTED BY SAI.

2. MODEL ONLY APPLICABLE DURING THE PTS TRANSIENT AFTER REACTOR AND TURBINE TRIP.

3. DISCONTINUITY IN SOME CONTROL VARIABLES IS EXPECTED WHEN CONTROL SYSTEM IS ACTIVATED.

4. PRESENT CONTROL SYSTEM CANNOT MODEL OPERATOR ACTION AND EQUIPMENT FAILURES.

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RECOMMENDATIONS

1. TRAC CONDENSER MODEL SHOULD BE ASSESSED. A CONDENSER MODEL SHOULD BE ADDED IN RELAP5.

2. COMPLETE CONDENSATION SHOULD BE ACHIEVED IN THE STEAM GENERATOR DOWNCOMER AT STEADY STATE.

3. INPUTS AND CALCULATIONS SHOULD BE IN THE SAME UNITS FOR BOTH TRAC AND RELAP5.

4. ALL THE DESCRIPTIONS OF MODEL CHANGES AND UPDATES SINCE THE LAST RELEASED VERSION SHOULD BE PROVIDED.

5. NO WORK SHOULD BE SENT FOR Q/A UNLESS IT IS REASONABLY COMPLETE.

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Department of Nuclear Energy

(516) 282
FTS 666 2438

October 14, 1982

Mr. J. D. White
ORNL PTS Integration
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37380

Subject: Control System for the PTS Study

Dear Mr. White:

The purpose of this letter is to clarify the BNL comments made at the PTS study meeting at ORNL on September 22, 1982, concerning the SAI control system. We (BNL) stated that:

1. The SAI control system is applicable only after the reactor and/or turbine trips. It is not applicable during the initiating events, i.e., between the steady-state and the reactor and/or turbine trips.

2. Discontinuity in some control variables may occur when the control system is activiated.

Clarification on Comment 1

According to the SAI [1], some components and subsystems were not included in the control system model. Among them are:

- Unit Load Demand Development subsystem, including loss of feedwater pumps or reactor coolant flow, since "these conditions were judged to be the initiating events." This subsystem was replaced by the Unit Load Demand Trip. Unit Load Demand ramps down at a rate-limited 20% per minute on the triggering of this trip from full power.

- Turbine control since all cases of interest involved early turbine trip. The only aspect of turbine control modeled was the turbine by-pass valve control.

---

[1] R. A. Hedrick, Letter to R. C. Kryter of ORNL on July 23, 1983.

The above statements clearly indicate that the control system developed was intended to be activated at the point of reactor and turbine trips and not to be used during the initiating events, i.e., between the steady-state and the reactor/turbine trips. We were merely pointing out that the users (INEL and LANL) should be aware of this limitation and be prepared to provide proper boundary conditions during the initiating event calculation, i.e., between the steady-state and the reactor/turbine trips.

Among the eleven scenarios or event sequences proposed by ORNL [2], for the Oconee PTS study, seven involved immediate reactor and turbine trips (3 steamline breaks, 2 turbine bypass valve failures and 2 feedwater overfeed transients). For these transients, the real time between the steady-state and the reactor/turbine trip is either zero or very short so that the SAI control system is applicable. However, in four other scenarios (2 small break LOCAs and 2 loss of main feedwater), the real time between the steady-state and the reactor/turbine trip may not be very short and the "proper" boundary condition may not be obvious. The overcooling transient which occured at Rancho Seco on March 20, 1978 [3] is similar to two ORNL-specified loss-of-feedwater transients with subsequent restoration. This incident was initiated by the loss of main feedwater which was triggered by the loss of power to the control system. The loss of feedwater caused the reactor coolant temperature and primary side pressure to increase. After approximately 15 seconds from the loss-of-feedwater, the reactor was tripped by the high pressure trip, which in turn tripped the turbine. During this period ($\sim$15 seconds) one needs the boundary condition at the steam generator exit side. We do not know how the users (INEL and LANL) will provide these boundary conditions and whether they will significantly impact the final results.

Clarification on Comment 2

This is a general caveat for numerical instabilities which may be triggered when the control system is suddenly activated at some mid-point of calculation. Again, we do not know if this will occur in this particular control system or what effect it will have on the calculation if it does. However, we felt that this might be a useful point to keep in mind if the calculation exhibits difficulty in converging or produces unreasonable results at the activation of this control system.

---

[2] T. J. Burns, "Status of Event Sequence Specification," Presented in the meeting at ORNL on September 22, 1982.

[3] R. Lobel, "Summary of Meeting held at Rancho Seco Nuclear Power Plant on June 10, 1978 to Discuss a Recent Cooldown Event," Memorandum for Paul S. Check, Chief, Reactor Safety Branch, DOR, (1978)

Should you have any further questions on this issue, please call Dr. Jae Jo at FTS-666-2337 or me at FTS-666-2438. With best regards.

Sincerely yours,

Pradip.

JJ/PS:af

Pradip Saha, Group Leader
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16. ABSTRACT (200 words or less) Several Oconee-1 overcooling transients that were computed by LANL and INEL using the latest versions of TRAC-PF1 and RELAP5/MOD1.5 codes have been reviewed by BNL. Three of these transients were selected for detailed review as they either had the potential of challenging the integrity of the pressure vessel or highlighted the effect of code differences. These are (1) Main Steam Line Break (MSLB), (2) All Turbine Bypass Valves Stuck Open, and (3) 2-Inch Small Break LOCA.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Pressurized Thermal Shock
Downcomer Fluid Temperature
Downcomer Pressure
HPI
Vent Valve Flow

17b. IDENTIFIERS/OPEN-ENDED TERMS

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