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QUALITY ASSURANCE OF PTS THERMAL HYDRAULIC CALCULATIONS AT BNL*

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Rapid cooling of the reactor pressure vessel at high pressure has a potential of challenging the vessel integrity. This phenomenon is called overcooling or Pressurized Thermal Shock (PTS). The Nuclear Regulatory Commission (NRC) has selected three plants representing three types of PWRs in use for detailed PTS study. These are Oconee-1 (B&W), Calvert Cliffs (C.E.), and H. B. Robinson (Westinghouse). Oak Ridge National Laboratory (ORNL) is the lead contractor for this study and they have identified several groups of possible transients 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.

The Brookhaven National Laboratory (BNL) has been requested by NRC to review and compare the input decks developed at LANL and INEL, and to compare and explain the differences between the common calculations performed at these two laboratories. However, for the transients that will be computed by only one laboratory, a consistency check will be performed. So far only Oconee-1 calculations have been reviewed at BNL, and the results are presented here.

In the first part of the task, BNL checked and compared 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 description. 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 PTS study participants.

Calculations for twelve transients selected by ORNL for Oconee-1 were divided between LANL and INEL. Some of these transients such as Main Steam Line Break (MSLB), 2-Inch Hot Leg Small Break Loss-of-Coolant Accident (SBLOCA), and Turbine Trip transient for Oconee-3 were common to both the laboratories. The TRAC and RELAP5 results for these transients were compared at BNL(1). It was also observed that MSLB and 2 and 4 Turbine Bypass Valves (TBVs) stuck open at full power and at hot standby were relatively severe transients. Therefore, 4 TBVs stuck open transients were also investigated. The review of Oconee-3 transient indicated the 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.

MASTER

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MAIN STEAM LINE BREAK

This is one of the set of transients where the secondary side is depressurized. The initiating event is a break (34 inch) in the steamline. The 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 High Pressure Injection (HPI) flow and restarting Reactor Coolant Pumps (RCP) in each loop after 42°K subcooling is attained in the primary loops. The scenario of this transient was specified by Oak Ridge and is quite involved with various operator actions for the primary and secondary sides. This transient was computed by using both TRAC and RELAP5 codes 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 results to the codes.

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 larger vapor generation and increased heat transfer from the primary side. 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 sequence of events as predicted by two codes have been summarized in Table 1. In the remaining section the results from two calculations will be compared.

Figure 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 Figure 2 where secondary side pressures have been compared. RELAP5 modeled the control systems based on pressure differential between the top of the tube region and the bottom of the downcomer in the steam generator and was closer to the control system in the plant. On the other hand, TRAC modeled the control system based on collapsed liquid and so it missed the MFW pump trip which depended on the level based on the pressure differential. RELAP5 as expected, predicted lower secondary side pressure than TRAC in the beginning of the transient, resulting in lower saturation temperature and larger heat transfer in the steam generator. The early rapid pressure drop in RELAP5 also caused the initiation of HPI flows earlier than in TRAC.

RCPs were tripped 30 seconds after the HPI flow were started and the loops were in 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 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. 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 computed 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. This additional

TABLE 1
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 Realignment	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. - 526 sec.	Did not
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.
11)	Hot well surge tank empty motor driven FW 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.

mass also increased the pressure on the primary side. The pressurizer was full much earlier in RELAP5 than TRAC and it shows up as a rapid increase in pressure in Figure 1.

One of the most important parameters for PTS is the downcomer fluid temperature, and a comparison of these temperatures as predicted by two codes is shown in Figure 3. First observation is that TRAC predicted multidimensional behavior and the spread in the downcomer temperature was about 30°K. RELAP5 predicted only the average fluid temperature due to one-dimensional modeling. The downcomer fluid temperature is a combination of cold leg and vent valve flows. The vent valve did not open in RELAP5 calculation as there was sufficient flow in both the cold legs due to natural circulation. So there was no warming effect due to vent valve flow in RELAP5 calculation but the cold leg temperatures were higher than TRAC calculation and were the cause of higher downcomer fluid temperature in RELAP5 calculations. Furthermore, the downcomer fluid temperature had jumps in both the calculations at the time of RCP restart due to the mixing of hotter fluid from the hot legs. 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. So the minimum downcomer fluid temperature was reached just before the RCPs were restarted in the TRAC calculation. In the case of 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 is a critical event in this transient and it depends upon achieving 42K subcooling in each hot leg of the system. RELAP5 attained this at 300 seconds while TRAC did it at 526 seconds. This difference is due to the way the voids distributed in the primary system and the time when natural circulation started. Figure 4 shows a comparison of void fractions predicted for upper plenum in two calculations. It seems that there was early void accumulation in the RELAP5 calculation but none in the TRAC calculation. In loop A, the natural circulation was strong due to depressurization of Steam Generator A secondary side and so 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 unlike the RELAP5 calculations. This resulted in the termination of natural circulation in loop B in the TRAC calculation. However, natural circulation was maintained longer in RELAP5 which resulted in good and uniform cooling of both loops. As RELAP5 also predicted higher primary side pressure, the 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 than in loop A. The hot leg in loop A achieved 42K subcooling even before the RELAP5 calculation but the loop B hot leg was slow to cool. This delayed the restart of RCPs in the TRAC calculation and resulted in lower downcomer fluid temperature.

Beside the multidimensionality of the transient, there was also important differences in the way the upper head was modeled in these two calculations. In the TRAC calculation the upper head had an extra connection to the hot leg and there was no volume with dead end. There was significant flow through the upper head to the hot leg as shown in Figure 5. (The level 8 exit in this figure represents the upperhead 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 was modeled as a dead end space, the voids would probably not migrate to candy cane and 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 be less. The RCPs would have started earlier in TRAC resulting in higher downcomer temperatures. 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 conclusion from this transient is that the most crucial event was the RCP restart time and it should have been somewhere between the RELAP5 (300 sec.) and the TRAC calculation (526 sec.). The initial MFW trip and EFW modeling in RELAP5 were more appropriate than in TRAC. It would still be a conservative estimate to delay RCPs restart in the RELAP5 calculation until TRAC RCP restart time and this would give the lowest average downcomer fluid temperature of 465K or 379F as shown in Figure 6. It was found from the TRAC calculation that there was a temperature distribution in the downcomer and the spread was around 30K. This multidimensional effect could also be taken into account in estimating the lowest downcomer fluid temperature which would then be 15K lower than the average downcomer fluid temperature. So the most probable minimum fluid temperature in the downcomer would be 450K. This is also conservative as the time of RCP restart would be earlier than TRAC time, if the upper head had a dead end volume which could accumulate voids as discussed previously.

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 gives the largest break while TBV stuck open is 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 (9MW + RCPs power) whereas the transient assigned to LANL started from full reactor power. Both scenarios had further operator failures of not throttling HPI and restarting RCP when needed. Additionally, in LANL case, ICS failed to runback FW and EFW level control failed. In INEL scenario FW did not align to EFW header. The hot standby condition assumed in the INEL scenario also implied that initially there was no steam supply to feedwater heaters and the main feedwater was going through the start-up line. Furthermore, INEL scenario also required closing of all TBVs at 600 seconds. These differences are summarized in Table 2.

These differences in the initial conditions and scenarios resulted in quite different responses during the transient. The purpose of comparing two calculations is to indicate the effect of differences in initial conditions and scenarios on the transient. The sequences of events as computed by the two codes have been summarized in Table 3. Figure 7 shows a comparison of primary pressures. The pressure in the TRAC scenario initially decreased faster than in the RELAP5 case probably due to a larger energy transfer to the steam generator. This was the case, as in the TRAC calculation, the steam

TABLE 2
COMPARISONS OF SCENARIOS

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 fails to throttle HPI and restarts RCP as needed.	Yes	Yes
c) SG liquid level controls for EFW fails	Yes	No
d) FW fails to realign to EFW header after RCP trip.	No	Yes
3) Operator Action		
a) TBVs closed after 600 sec.	No	Yes

TABLE 3
SEQUENCE OF EVENTS IN 4 TBVs STUCK OPEN TRANSIENT

	ITEM	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, pumps coasts down & stops at 228.6 sec.
4)	EFW on	147. 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 sec. & 1030.4 sec. for SG-B. Between 1070.5 sec. & 1074.6 sec. for SG-A.
9)	Lowest Downcomer Fluid Temperature	350K (170.6°F)	402.6K (260°F)

generators had larger (~200 inch) liquid inventory and also larger mass flow rates at the TBVs than in the RELAP5 calculation as shown in Figure 8 for example for loop A. Figure 9 shows a comparison of downcomer fluid temperatures. Here again the fluid cools down at almost the same rate in both cases except it started at a higher temperature in TRAC calculation. HPI began earlier in the TRAC calculation than RELAP5 due to a faster decrease in the pressure in the TRAC calculation.

Main feedwater was lost earlier in the TRAC scenario than in the RELAP5. 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 7. 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 sides of the steam generators were filled by 1000 seconds in RELAP5. This led to a rapid increase in the primary side pressure as shown in Figure 7 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 increasing. This also caused reduced heat transfer in the steam generator for RELAP5 calculation.

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

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 HPI initiation. Such a transient was specified by ORNL, and both LANL and INEL computed the same transient using TRAC and RELAP5, respectively. Note that the ICS is assumed to work as designed.

There were several differences between the TRAC and RELAP5 results. First difference was the criterion for reactor trip. TRAC tripped the reactor at 0.5 seconds while RELAP5 tripped it based on 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 summarizes the timings of various events such as HPI initiation or RCP trip etc. for two calculations. It also indicates that the method of modeling the plant and the 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 cold HPI mixed with the primary coolant. Most of the differences between two calculations could be explained in terms of these heat sinks. Figure 10 shows the primary side pressures as computed by TRAC and RELAP5. The TRAC calculation showed faster decrease in the pressure than RELAP5 in the first 300 seconds and slower decrease in the remaining transient. The initial rapid pressure drop in TRAC was consistent with early reactor trip and with larger break flow rate prediction than RELAP5 as shown in Figure 11. 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 only be consistent 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, void fraction in the TRAC calculation and static quality in the RELAP5 calculation for the volume at which the break was connected, was provided. In the first 1000 seconds, TRAC computed very low void fractions while RELAP5 had predicted high static quality and subsequently high void fractions. Based on 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 in the RELAP5 calculation whereas the break flow rate in TRAC was approximately twice of RELAP5. Specific energy at the break was only, at the most, 25% less than in the RELAP5 calculation. The HPI flows, as expected, were initiated slightly early in TRAC calculations. However, the differences between the HPI flows in two codes were not significant. Therefore, the cause of this apparent inconsistency lies with the steam generator heat transfer.

The heat transfer in the steam generator was governed by the primary side flow and temperature, and 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. Figure 12 compares the upper head voiding as predicted by 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. 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 SUFCV (Start Up Flow Control Valve). The main feedwater was lost in RELAP5 due to MFW pump trip on 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 SUFCV was closed. The EFWs were started at the time of RCP trip in both codes but TRAC terminated them earlier. The EFW was over 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 temperature to be lower as shown in Figure 14. So the warmer fluid in

TABLE 4
SEQUENCE OF EVENTS IN 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 Feed Water	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.	554 sec.
11) EFW Trips Off	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.
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.

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 were compared with SG secondary exit temperatures, the TRAC had reverse heat transfer in steam generator after 300 seconds while RELAP5 had heat transfer in the normal direction. Both the codes predicted continuous decrease in the primary side pressure as the break flow exceeded the HPI flows. This made this transient less severe for PTS considerations.

Both the codes computed comparable downcomer fluid temperatures as shown in Figure 14. This fluid temperature was a function of cold leg and vent valve flows. The 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 calculations were small, the effect of HPI flow was more pronounced. This cold leg fluid mixed with warmer vent valve flow. The net effect was initially colder fluid in the downcomer in TRAC calculation. Furthermore, fluid temperature in the downcomer in the TRAC calculation recovered when the code predicted flow oscillations between cold legs, steam generator and the downcomer after natural circulation was lost. The RELAP5 calculation did not show similar oscillation, but a stable circular flow between the cold legs with common steam generator and the downcomer. The downcomer fluid temperature kept decreasing in the RELAP calculation as the primary side energy continued to be lost through the break and steam generator.

In conclusion, both codes computed reasonable results for this transient. There were differences in break flows, 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.

In summary, three of the several transients for Oconee-1 computed by LANL and INEL using the latest versions of TRAC-PF1 and RELAP5/MOD1.5 have been reviewed 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 the one-dimensional modeling of the reactor vessel by RELAP5.

REFERENCE

1. Rohatgi, U. S., Pu, J., Saha, P., and Jo, J., "Assessment of Selected TRAC and RELAP5 Calculations for Oconee-1 Pressurized Thermal Shock Study," BNL Draft report July, 1983.

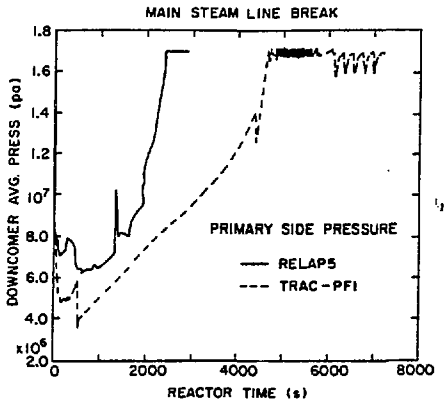

Figure 1. Primary Side Pressure in MSLB

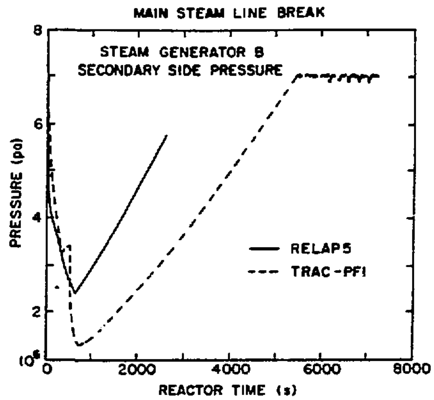

Figure 2. Secondary Side Pressure for Unaffected Steam Generator

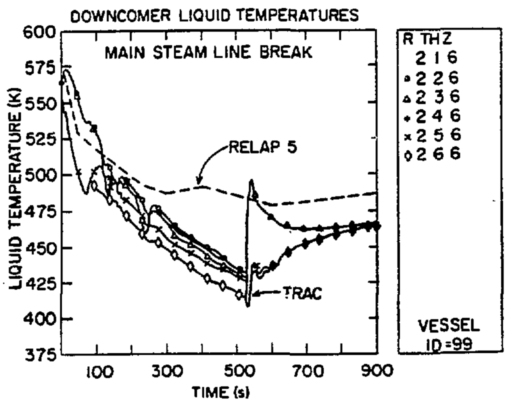

Figure 3. Downcomer Liquid Temperature Prediction

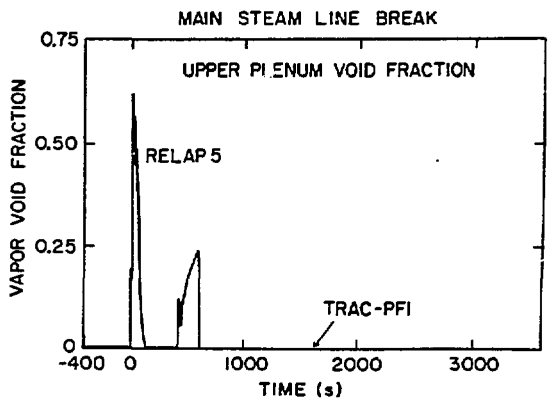

Figure 4. Void Fraction in Upper Plenum

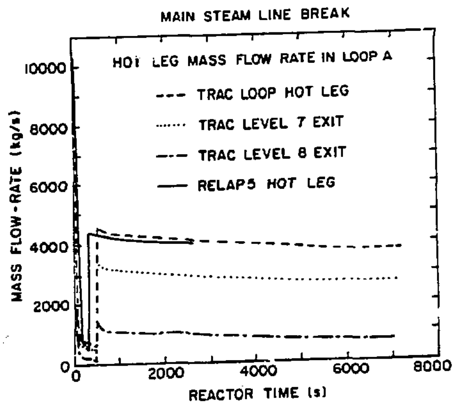

Figure 5. Hot Leg Mass Flow Rate in Affected Loop

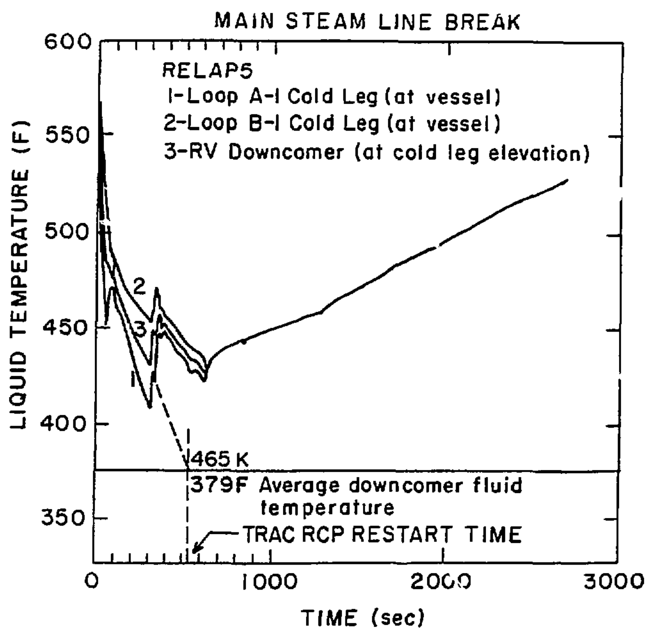

Figure 6. Downcomer Liquid Temperature in RELAP5 Calculation

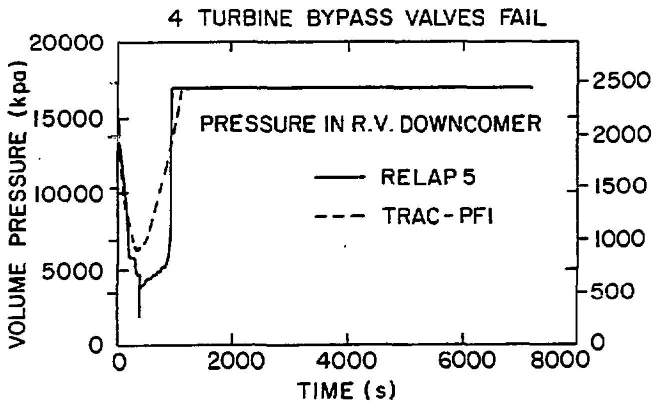

Figure 7. Primary Side Pressure for 4 Turbine Bypass Valve

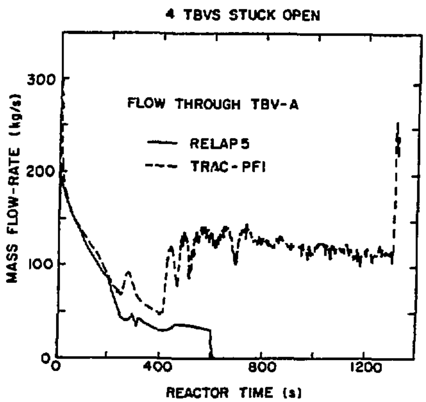

Figure 8. Flow Through Turbine Bypass Valves in Loop A

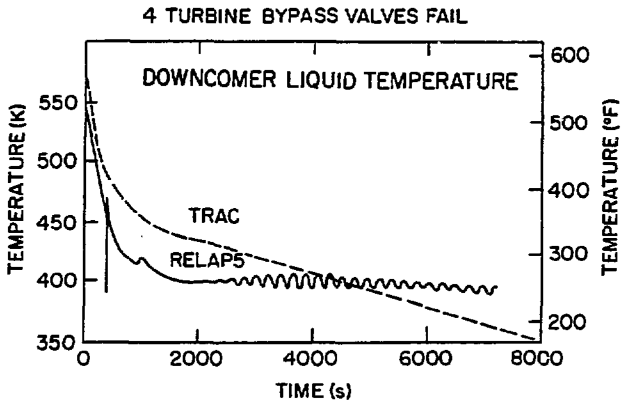

Figure 9. Downcomer Fluid Temperature Prediction

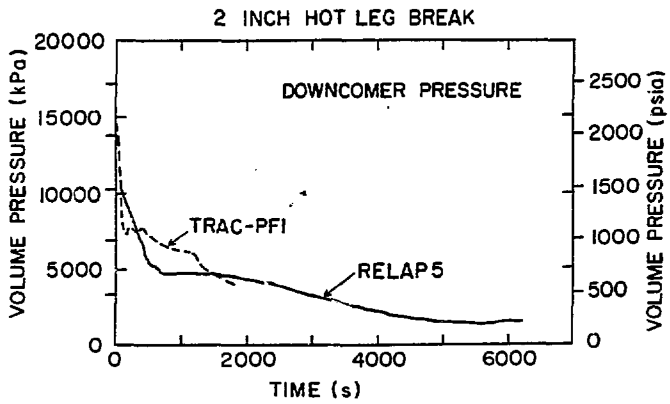

Figure 10. Primary Side Pressure for 2-Inch Hot Leg SBLOCA

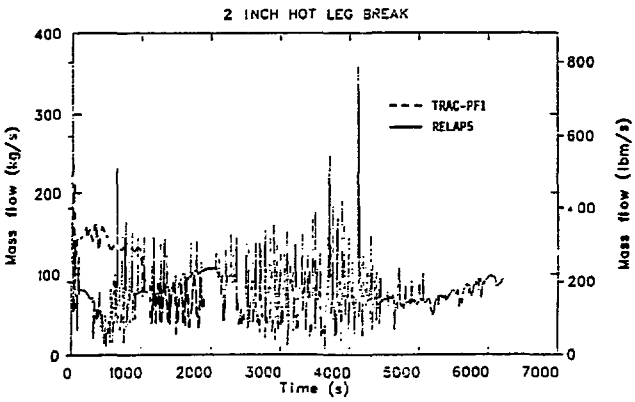

Figure 11. Break Flow Rate in 2-Inch SBLOCA

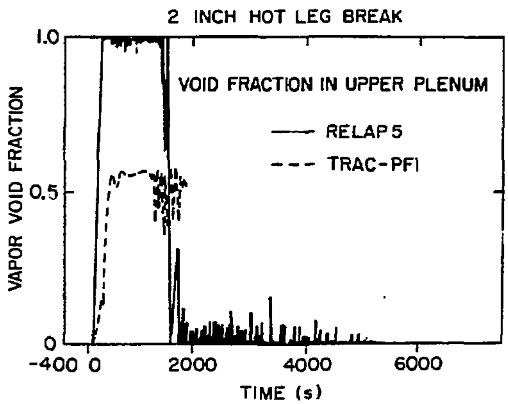

Figure 12. Void Fraction in Upper Plenum

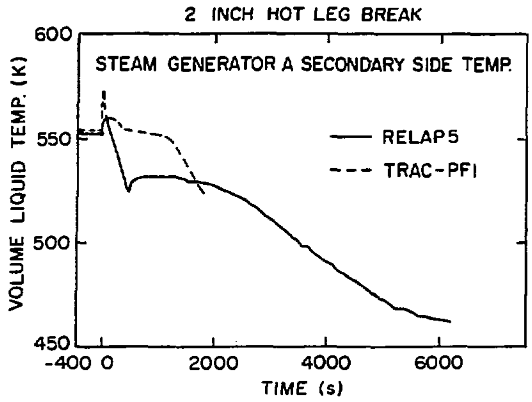

Figure 13. Secondary Side Liquid Temperature in Affected Loop Steam Generator

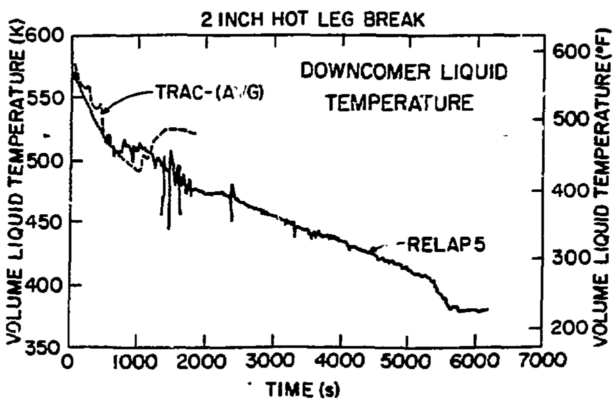

Figure 14. Downcomer Liquid Temperature Prediction