Small Break LOCA Analysis for YGN 5&6 RCP Trip Strategy in Power Mode Operation

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Abstract

A continued operation of Reactor Coolant Pumps(RCPs) during a Small Break Loss of Coolant Accident(SBLOCA) in all operation mode may increase unnecessary inventory loss from the Reactor Coolant System(RCS) causing a severe core uncovery which might lead to fuel failure. After Three Mile Island Unit 2(TMI-2) accident, the Combustion Engineering Owner Group(CEOG) developed RCP trip strategy called "Trip-Two/Leave-Two" (T2/L2). The T2/L2 RCP trip strategy consists of tripping the first two RCPs on low RCS pressure and then tripping the remaining two RCPs if a LOCA has occurred. This analysis demonstrates the inherent safety of RCP trip strategy during an SBLOCA for Yonggwang Nuclear Power Plant Unit 5 and 6(YGN 5&6). The trip setpoint of the first two RCPs for YGN 5&6 is calculated to be 1721 psia in pressurizer pressure based on the limiting SBLOCA with 0.15 ft^2 break size in the hot leg. The analysis results show that YGN 5&6 can maintain the core coolability even if the operator fails to trip the second two RCPs or trips at the worst time of minimum liquid inventory.

1. Introduction

The post accident operational strategy of the RCPs has great impact on the accident mitigation as well as operator's recovery actions. A continued operation of RCPs during a certain small break LOCA, in particular, may increase unnecessary inventory loss from the RCS causing a severe core uncovery. However, the advantage of continuous RCP operation during non-LOCA depressurization events is to maintain the forced convective decay heat removal capability through the steam generators and to maintain the availability of the main

spray flow to the pressurizer for a better RCS pressure control. In addition, the RCP operation provides better plant control by minimizing void formation in the upper head region of the reactor vessel due to the forced circulation flow through this region. RCP operation also provides better mixing in the reactor vessel downcomer and lower plenum regions minimizing pressurized thermal shock concerns.

After the TMI-2 accident, the importance of RCP operating strategy during the plant transients caused the United States Nuclear Regulatory Committee(U.S. NRC) to issue several regulatory requirements. In response to NRC requests, the CEOG developed an RCP trip strategy[Ref. 5] called "Trip-Two/Leave-Two" (T2/L2) and incorporated it in the generic Emergency Operation Guidelines(EOGs).

The purpose of this analysis is to demonstrate the inherent safety of the RCP trip scheme during a small break LOCA in power mode operation for YGN 5&6 plants with design changes of the RCP trip setpoints and system changes(CVCS etc.) compared with YGN 3&4. This RCP trip scheme with its trip setpoints determined by this analysis provides a basis for the development of YGN 5&6 EOGs.

2. Code and Methodology

The realistic SBLOCA evaluation model of CEFLASH-4AS/REM code (Reference [1]) is used to perform the RCP trip scheme evaluation analyses. In the CEFLASH-4AS/REM code, the Nuclear Steam Supply System (NSSS) is described as a series of volume nodes connected by flowpaths. The CEFLASH-4AS/REM code employs two continuity, two energy, and one momentum equations for two phase flows. The conservation equations of mass, energy, and momentum are integrated simultaneously at each time step using an implicit integration technique.

The CEFLASH-4AS/REM nodalization scheme used in these analyses is shown in Figure 1 and described in Tables 1 and 2. As shown in Figure 1, the nodalization scheme consists of 27 nodes and 51 flow paths to model the NSSS and related systems for the SBLOCA analysis.

In order to accomplish the purpose of this analysis, the following analyses are systematically performed :

- The selection of the worst break size,
- Determination of RCP trip setpoints,
- Demonstration of inherent safety of RCP trip strategy, and

- Evaluation of trip setpoint.

The specific analysis methodology and assumptions for each evaluation step are described in detail in the following sections.

3. Results

This section describes the main results obtained from the analyses prescribed in the previous section. Table 3 summarizes the case runs for the setup of YGN 5&6 RCP trip scheme. The calculation process and analysis result for each evaluation step is described below.

3.1 The selection of the worst break size and assumptions for Conservative Best Estimate (CBE) analysis

As a first step for the RCP trip strategy evaluation, the worst break size is determined via a break size spectrum analysis using a CBE SBLOCA analysis method. CBE spectrum analysis was performed for the SBLOCA in the hot leg, which was the worst break location under the situation that all RCPs are in operation as described in References [2] and [3].

The main aspects of the CBE analysis assumptions are the use of the homogeneous equilibrium break flow model, a 1.0 multiplication factor on the YGN 5&6 specific decay heat with uncertainty which is the simplified 1979 ANS decay heat curve, the availability of only one high pressure safety injection pump (HPSIP), the minimum HPSIP flow curve and the main steam safety valves (MSSVs) for secondary heat removal.

The results of this spectrum analysis shown in Reference [4] indicated that the continued RCP operation could produce partial core uncovery for break size from 0.5 ft^2 to 0.1 ft^2.

For smaller breaks (0.08 ft^2 to 0.02 ft^2) core uncovery does not occur due to the sufficient HPSI flow to match the relatively low break flow.

For larger breaks (0.5 ft^2 to 0.1 ft^2), the vessel mixture level falls below the bottom of hot leg before the SIT actuation due to a much larger break flow compared to the HPSI flow. As the break size decreases from 0.5 ft^2 to 0.1 ft^2, the depressurization rate becomes slower and the SITs are actuated later, which causes more mass depletion and deeper core uncovery. Among these breaks, the 0.15 ft^2 hot leg break shows the minimum inventory, the deepest core uncovery, longest duration of core uncovery and the highest PCT.

3.2 Conservative determination of the RCP trip setpoints

Reference [4] provides the RCS pressure and subcooling setpoint values to trip the RCPs for SBLOCA. RCS pressure setpoint is used for tripping the first two RCPs and RCS subcooling margin setpoint is used for tripping the second two RCPs. Conservative analysis to determine the upper bound of pressure setpoint to trip the first two RCPs is described in Reference [4]. This analysis was based on the concept of tripping all four RCPs at a pressure setpoint which is lower than the safety injection actuation signal pressure but high enough to assure tripping of all RCPs for a SBLOCA.

In YGN 3&4 RCP trip analysis, the actual pressure setpoint was 1775 psia including the accident channel error of pressurizer pressure. However, for YGN 5&6 plants, the actual pressure setpoint of 1721 psia for tripping the first two RCPs is calculated. The setpoint difference is come from the difference of the pressurizer pressure channel uncertainty. The RCS subcooling margin is recommended as 27 °F (15 °C). Those are based on the value cited from EOG SBD (Setpoint Basis Document).

3.3 CBE analysis to demonstrate the inherent safety of RCP trip scheme

In this analysis, three case runs were performed to show the inherent safety of YGN 5&6 RCP trip strategy. In the first case (case 1(L4)), four RCPs were run throughout the transient to examine the effect of no RCP trip during a hot leg break LOCA. In the second case (case 2(T2L2)), the first two RCPs were tripped after the low RCS pressure setpoint (1721 psia) was reached and allowing a 60 second delay for operator action. The remaining two RCPs were left operating for the duration of the transient.

The results of this analysis were reviewed to determine the time at which minimum inventory on the hot side of the RCS occurred. The hot side inventory includes the liquid mass in the reactor vessel including the downcomer, the hot legs and the riser portion of the steam generators. The liquid inventory in these regions represents the fluid available for core cooling during a transient. Thus, the time at which the minimum liquid inventory occurs is the worst time to trip the RCPs. A third case (case 3(T2T2)) was run similar to the second analysis, but the second two RCPs were assumed to be tripped or failed at the time of minimum hot side liquid inventory.

A hot leg break of 0.15 ft^2 is also determined for YGN 5&6 since this was the worst break size for YGN 3&4 plants under all RCPs operating condition (Reference [4]). The analysis for the worst break size showed that the minimum liquid inventory for the two RCPs

operation case (case 2(T2L2)) was about 29,036 lbm at 483 sec as shown in Figure 2 and Table 4. Table 4 summarizes the results of main parameters obtained from the case runs for 0.15 ft^2 hot leg break.   When the second two RCPs were tripped at 483 sec, the two-phase mixture level in the inner reactor vessel decreased quickly (Figure 3). The rapid decrease in the core mixture level was due to the collapse of the two-phase frothy mixture created by the continued operation of the two RCPs. There is no significant influence on the total liquid mass inventory since only the core region contains a large amount of trapped bubbles in the two-phase mixture. The termination of the second two RCPs also had a minimal effect on the RCS pressure (Figure 4). The termination of the second two RCPs caused an increase in the duration of core uncovery from 49 seconds to 53 seconds (Figure 3) as well as an increase in the maximum depth of core uncovery from 6.0 ft to 7.1 ft. The reason why the duration of core uncovery did not have the difference more than 4 seconds is that the safety injection tanks (SITs) began to intermittently discharge into the RCS just before the minimum inventory time.

The best estimate PARCH (Ref. [6]) analysis for case 3(T2T2) in YGN 3&4 resulted in the core uncovery PCT of 859 °F. In YGN 5&6 analysis for case3(T2T2), the depth and duration of the core uncovery are less than the results(Ref. [4]) of YGN 3&4. Thus, the analyses showed that core cooling would not be jeopardized even if the second two RCPs were tripped or failed at the worst time during a small break LOCA, which demonstrates the inherently safe nature of the RCP trip strategy for the YGN 5&6 plants.

3.4 Evaluation of trip setpoints for LOCA event

For the worst hot leg break size of 0.15 ft^2, a conservative best estimate case run was performed to evaluate the RCP trip setpoints of YGN 5&6 plants (case 4(T4)).

Two RCPs were tripped at low RCS pressure trip setpoint of 1721 psia and two RCPs were tripped at the time when the hot leg subcooling margin reached to 27 °F (means LOCA occurred). However, from the results of the case with all RCPs were in operation (case 1), hot leg subcooling margin of 27 °F occurred at 3 seconds after the break and low pressure trip setpoint occurred at 16 seconds. For this analysis, 4 RCPs were tripped simultaneously by the low pressure RCP trip setpoint of 1721 psia. A 60-second delay time before trip actuation was used following the indication to trip the RCPs.

The analysis showed that the initial depressurization after the break occurrence resulted in the rapid RCS (pressurizer) pressure decrease to the setpoint value of 1721 psia at 16 sec (Figure 5). The RCS pressure continued to decrease to slightly above the MSSVs setpoint of 1331 psia, and remained at that pressure until the break was uncovered. The hot leg temperature decreased to the cold leg temperature value after reactor trip occurred at 14.1 seconds. After the reactor was tripped, decay heat was the primary heat input into the coolant. The cold and hot leg temperatures were approximately equal within the first 50 seconds, as shown in Figure 6. The hot leg subcooling fell below the setpoint value of 27 °F at 3 seconds. The hot leg was completely saturated by 12.5 seconds. The loss of RCS subcooling was mainly due to the drop in RCS pressure. The importance of this fact is that both RCS pressure and subcooling decrease at essentially the same time. The mixture level in the inner vessel is shown in Figure 7. The RCP trip strategy for this case(T4) resulted in no core uncovery and virtually no clad temperature heatup.

4. Conclusions

After the TMI-2 accident, U.S. NRC issued the importance of RCP operating strategy during the plant transients. A continued operation of RCPs during a certain small break LOCA(L4) may increase unnecessary inventory loss from the RCS causing a severe core uncovery. However, the disadvantage of loss of all RCPs operation during non-LOCA depressurization events(T4) is to lose the forced convective decay heat removal capability through the steam generators and to lose the availability of the main spray flow to the pressurizer for a better RCS pressure control. Thus, The CEOG developed an RCP trip strategy called "Trip-Two/Leave-Two" (T2/L2).

This analysis demonstrated the inherent safety of the T2/L2 RCP trip strategy during a small break LOCA in order to provide the bases for the YGN 5&6 EOGs. The analysis showed the results for the 0.15 ft^2 hot leg break LOCA case. Also, the trip setpoint for the first two RCPs is determined to be 1721 psia in the pressurizer pressure based on the plateau pressure for the 0.15 ft^2 small break LOCA.
 A confirmatory analysis performed to demonstrate the inherent safety of the YGN 5&6 RCP trip strategy showed that the YGN 5&6 plants can maintain the core coolability in the case that the operator fails to trip the second two RCPs or trips at the worst time. Therefore, it is concluded that the T2/L2 RCP trip strategy with the 1721 psia trip setpoint for YGN 5&6

plants can provide improved operator guidance for the RCP operation during small break accidents.

5. References

[1]   CEN-373-P, "Realistic Small Break LOCA Evaluation Model" :
       Volume 1 ; Calculational Models, April 1988.
       Volume 2 ; Application of Evaluation Model, December 1988.
       Volume 3 ; Computer Program Input and Output Description, December 1988.

[2]   CEN-114-P, Amendment 1-P, "Review of Small Break Transients in Combustion Engineering Nuclear Systems", 1979 July.

[3]   CEN-115-P, "Response to NRC IE Bulletin 79-06 C items 2 and 3 for Combustion Engineering Nuclear Steam Supply Systems", 1979 August.

[4]   J.T.Seo and K.H.Bae, "Small Break LOCA Analysis for RCP Trip Strategy for YGN 3&4 Emergency Procedure Guidelines", Journal of the Korea Nuclear Society, Vol.27, Number 2, 1995 April.

[5]   CEN-268, Rev.1, "Justification of Trip Two/Leave Two (T2/L2) Reactor Coolant Pump Trip Strategy during Transients", 1987 May.

[6]   CENPD-138P, "PARCH : A FORTRAN-IV Digital Program to Evaluate Pool Boiling, Axial Rod and Coolant Heatup", 1974 August.
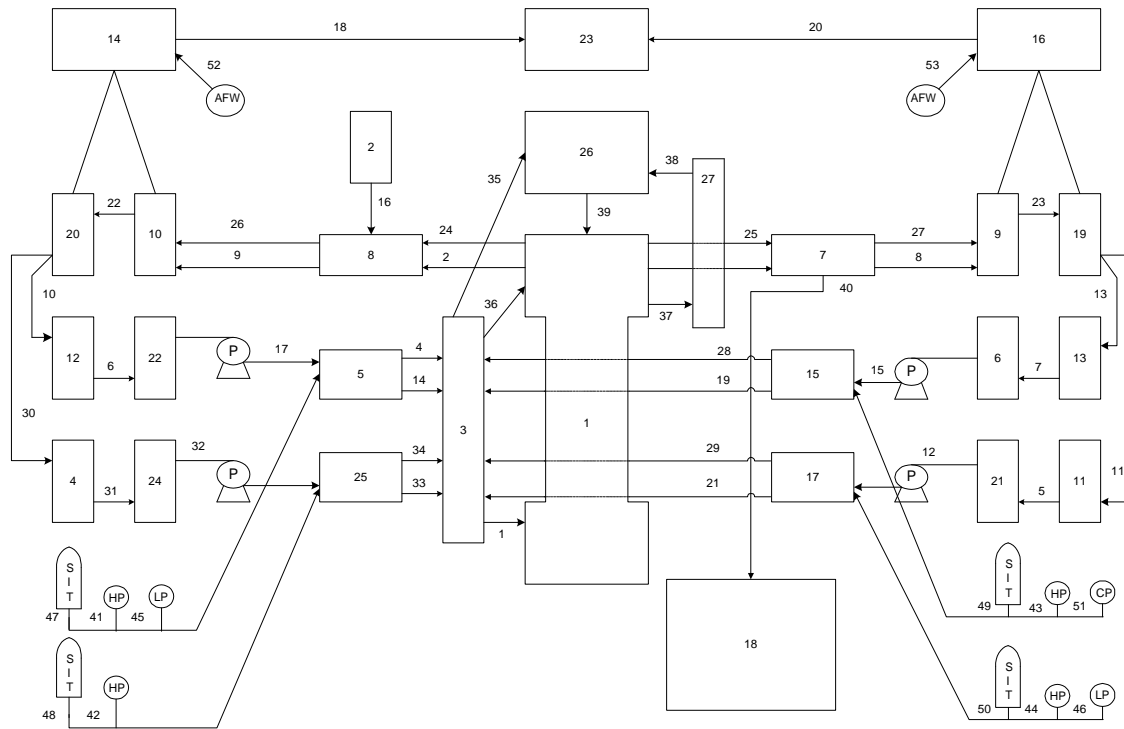
Fig. 1. CEFLASH-4AS/REM Nodalization Scheme for Hot Leg Break LOCA

Table 1. Description of CEFLASH-4AS/REM Nodes

Nodes	Description
1	Reactor core. lower and upper plenum
2	Pressurizer and surge line
3	Reactor vessel downcomer region
4. 11. 12. 13	3/5 loop seal (SG side) including 1/2 of SG outlet inactive U-tubes and outlet plenum
5. 15. 17. 25	Discharge leg including part of RCP and reactor vessel inlet nozzle
6. 21. 22. 24	2/5 loop seal (RCP side) including part of RCP
7. 8	Hot leg including reactor vessel outlet nozzle, SG inlet plenum, and inlet inactive U-tubes
9. 10	1/2 of active U-tubes
14. 16	SG secondary side
18	Containment
19. 20	1/2 of SG active U-tubes
23	Atmosphere
26	Reactor vessel upper head region
27	Reactor vessel CEA shroud region

Table 2. Description of CEFLASH-4AS/REM Flow Path

Flowpaths	Description
1	Downcomer to midpoint of active core
2, 3	Lower path connection from midpoint of active core to midpoint of hot leg
4, 28, 29, 34	Upper path connection from midpoint of discharge leg to downcomer
5, 6, 7, 31	1/2 suction leg
8, 9	Lower path connection from midpoint of hot leg to 1/4 of SG active U-tubes
10, 11, 13, 30	1/4 of SG active U-tubes to suction leg
12, 15, 17, 32	Suction leg through RCP to midpoint of discharge leg
14, 19, 21, 33	Lower path connection from midpoint of discharge leg to downcomer
16	Pressurizer surge line
18, 20	SG secondary side relief valves
22, 23	1/2 of SG active U-tubes
24, 25	Upper path connection from midpoint of active core to midpoint of hot leg
26, 27	Upper path connection from midpoint of hot leg to 1/4 of SG active U-tubes
35	Reactor vessel alignment key leakage
36	Reactor vessel outlet nozzle gap
37	Core to CEA shroud center
38	CEA shroud center to Rx head
39	Rx head to active core

Table 3

Description of Case Runs for YGN 5&6 RCP Trip Scheme

Case Number	RCP Trip Status	Trip Description	
		Rx. Trip psia	RCP Trip Status
1	L4 (Leave-Four)	1762	4 RCPs ON
2	T2L2 (Trip-Two/Leave-Two)	1762	T2 @ 1721 psia L2
3	T2T2 (Trip-Two/Trip-Two)	1762	T2 @ 1721 psia T2 @ 483 sec
4	T4 (Trip-Four)	1762	T4 @ 1721 psia

Table 4

Results of Main Parameters for 0.15 ft^2 Hot Leg Break

Cases	Min. Inventory Hot side (lbm)	Time (sec)	Min. I.V. 2ϕ Level (ft)	Time (sec)	Core Uncovery Duration (sec)	SIT ON (sec)
1	21518	488	13.5	553	39.5	486
2	29036	483	14.1	542	49.3	480
3	29036	483	13.0	536	52.9	480
4	94653	463	23.8	463	0.0	461
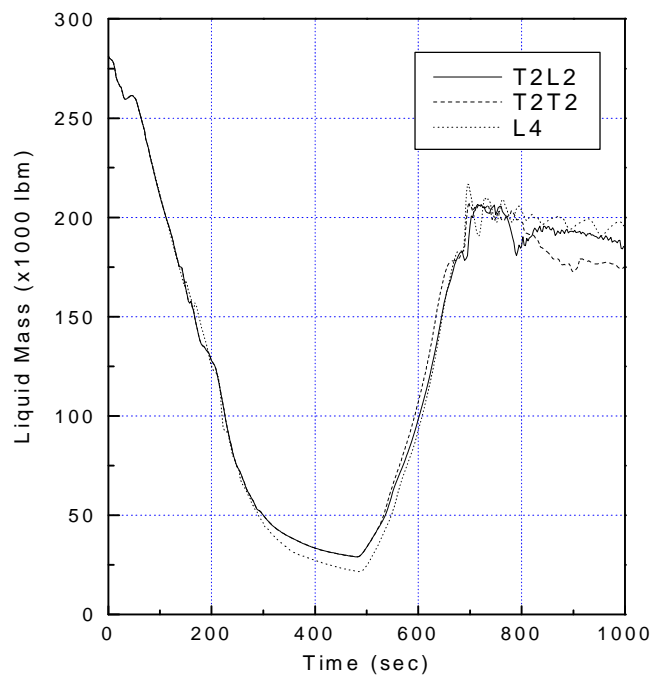
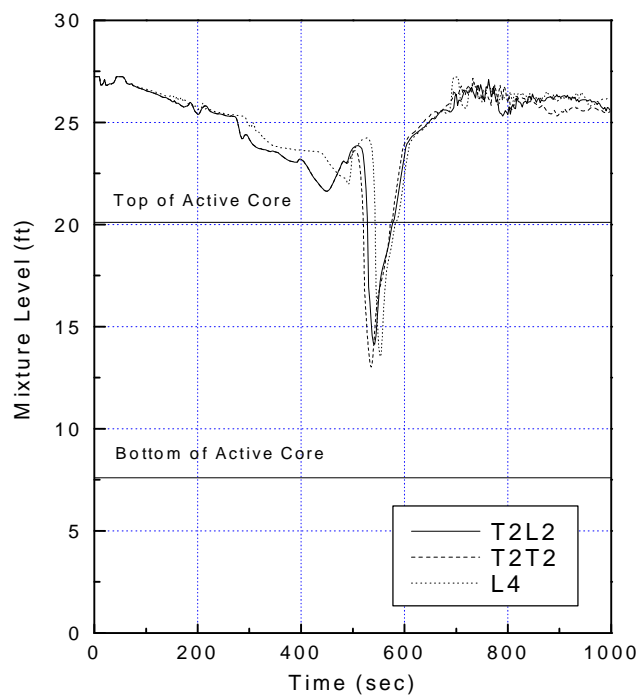Figure 2. Hot Side Liquid Mass for 0.15 ft^2 SBLOCA

Figure 3. Inner Reactor Vessel Mixture Level for 0.15 ft^2 SBLOCA
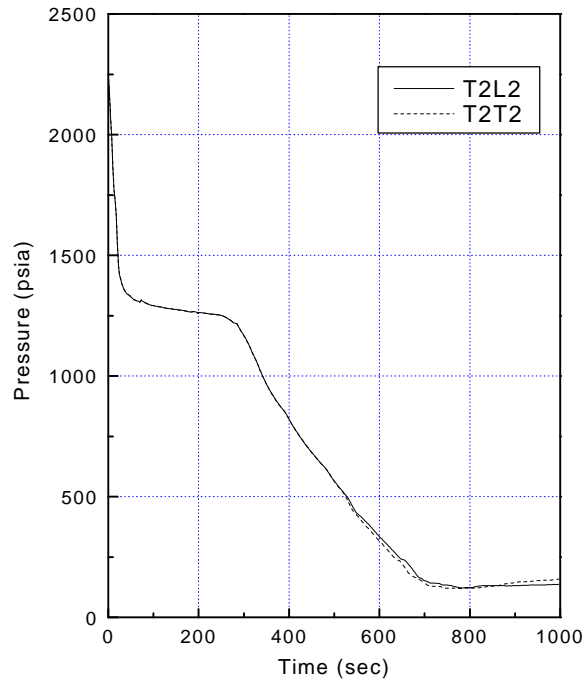
Figure 4. Pressurizer Pressure for 0.15 ft^2 SBLOCA
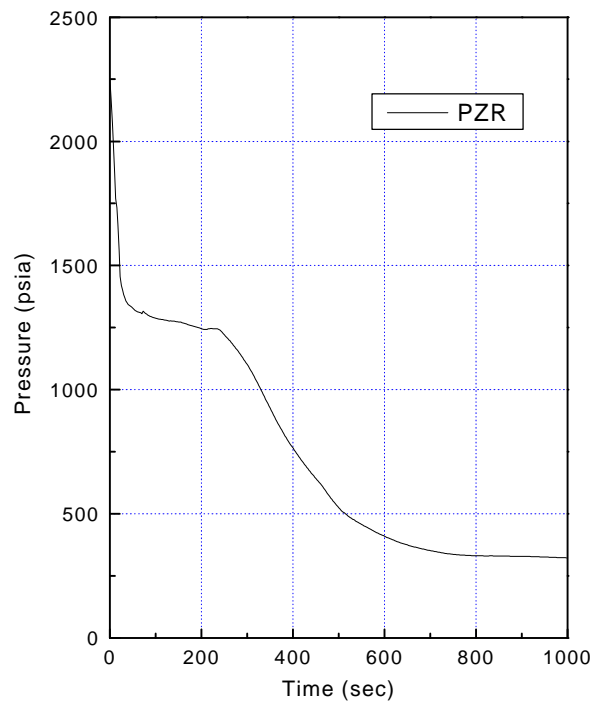

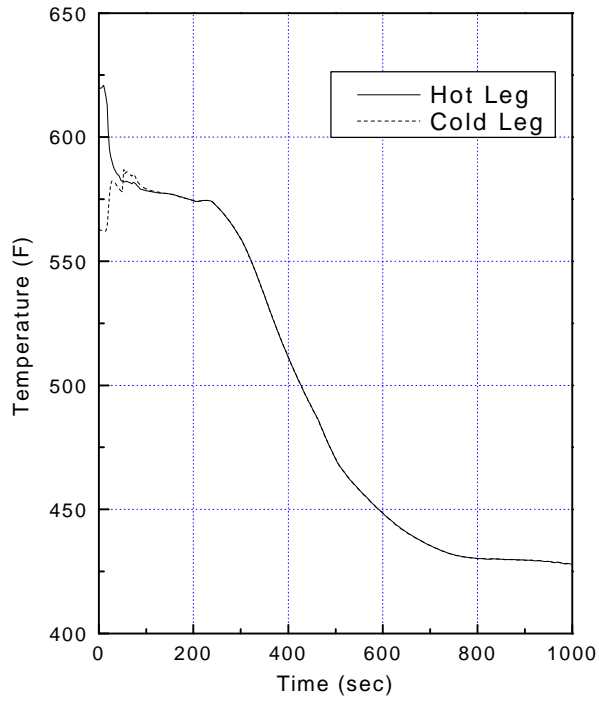Figure 5. Pressurizer Pressure for 4 RCPs Trip after 0.15 ft^2 SBLOCA

Figure 6. RCS Fluid Temperatures for 4 RCPs Trip after 0.15 ft^2 SBLOCA
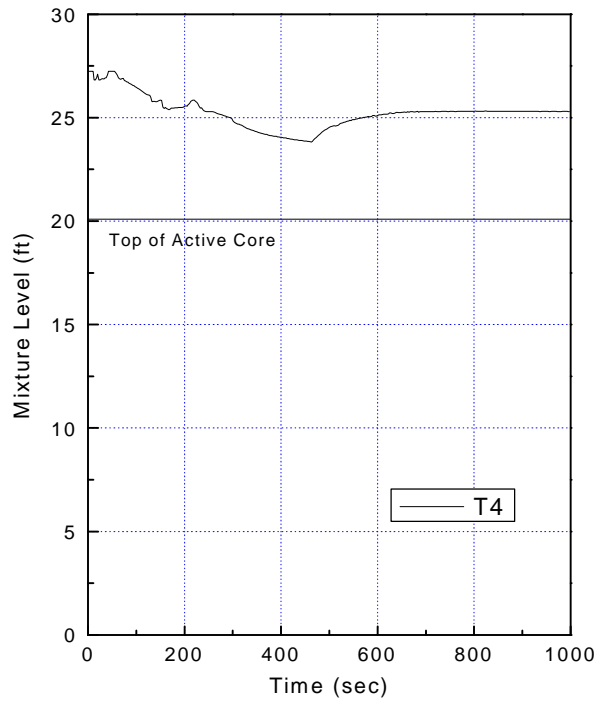

Figure 7. Inner Reactor Vessel Mixture Level for 4 RCPs Trip after 0.15 ft^2 SBLOCA