Effects of Delayed RCP Trip during SBLOCA in PWR

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ABSTRACT

After TMI accident, the issue of when tripping the RCPs in case of SBLOCA became very important. The results obtained from the analysis of different vendors showed that the RCPs should be tripped early in the accident. This analysis have been reviewed by the group of the Energy System Department of the Universidad Politecnica de Madrid (UPM) with the Almaraz NPP (Westinghouse 3-loop) model for TRACE 5.0 patch 1 code in order to compare the results obtained for a Best Estimate (BE) code with the results obtained previously by Westinghouse for a conservative code. Since the BE model has not showed a damage region for any case, it has been decided to implement some conservatism in the model. With this new model, a similar region such as in the Westinghouse case has been found, confirming that it is convenient to trip the RCPs early in the accident in order to avoid the damage. The results also show that the analysis performed by Westinghouse is more conservative than the analysis performed with TRACE code.

1 INTRODUCTION

The reactor coolant pump trip was a key parameter in Three Miles Island (TMI) accident. After shutdown of the last two Reactor Coolant Pumps (RCPs), the level of water decreased and core uncovery happened, [1]. Therefore the time in which the RCPs should be tripped in case of Small Break Loss of Coolant Accident (SBLOCA) was an important issue that led to analyze three different possibilities:

• RCPs off. The pumps are shut down at the time in which the SBLOCA takes place. The forced convection is lost and hence, the core cooling is reduced.

• RCPs on. The pumps remain operating during the accident. In the event of SBLOCA in which the RCPs are not tripped, a good cooling would exist by forced convection. In TMI accident, before stopping the last pump core cooling was being maintained by a two-phase mixture.

• RCPs trip delay. The pumps are tripped at any time during the accident. If the system evolves to a high void fraction because of RCPs operation, and then they are tripped for any reason (i.e high vibration), the void collapse could lead to substantial core uncovery and the temperatures could exceed the acceptance criteria (2200F /1477K), [2].
The continuous operation of the RCPs during SBLOCA was considered as the most acceptable mode for operating. For this reason the USNRC instructed the operators to keep the RCPs running in case of SBLOCA with actuation of High Pressure Safety Injection (HPSI). [4],[5] and [6].

Later, exhaustive evaluations performed by Babcock & Wilcox (B&W), Combustion Engineering (CE) and Westinghouse concluded that both, delayed RCP trip and continuous operation of RCPs could lead to excessive temperatures in the fuel, [2]. Each vendor provided an exhaustive delayed RCP trip analysis using a conservative model which met the 10 CFR 50 appendix K requirements. The purpose was to identify which combinations of break size-RCP trip would lead to excessive peak cladding temperatures (PCTs). Then the USNRC required an immediate manual pump trip following reactor trip and indication of HPSI actuation, [7] and [8].

Westinghouse calculations for a three-loop plant showed that the range of break size diameters in which the PCT could exceed the permitted limits were between 2 and 4 inches, [2]. It was observed that if the pumps remained running throughout the entire accident, no excessive cladding temperatures would be achieved. Figure 1, points out that for 3 inch break in the cold leg, the maximum available time for the operator to trip the RCP is less than 600 seconds.

![Figure 1: Westinghouse analysis for delayed RCP trip. Data obtained from [3]](image)

2 ANALYSIS OF RCP TRIP DELAY WITH A TRACE MODEL OF ALMARAZ NPP

2.1 Almaraz-1 TRACE model

Almaraz NPP located in Cceres (Spain), has two PWR units, each of them are three loop PWR Westinghouse design. Almaraz Unit 1 TRACE model has 255 thermal-hydraulic components (2 VESSEL, 73 PIPE, 43 TEE, 54 VALVE, 3 PUMP, 12 FILL, 33 BREAK, 32 HEAT STRUCTURE and 3 POWER component), 740 SIGNAL VARIABLES, 1671 CONTROL BLOCKS and 58 TRIPS, Figure 2.
2.2 Cold Leg SBLOCA reference case. Best Estimate model

In the first analysis, a best estimate model have been used in order to check how the RCP trip affect the sequence evolution. Only the cases for RCP ON/OFF have been performed.

In this first group of simulations several conditions were imposed in the model: 2 inches break in the cold leg, only 1 HPSI train available, 3 of 3 accumulators and no secondary side depresurization. The break takes place at t= 5000 seconds.

As it can be seen in Figure 3 no high values of PCT are obtained either, for the case with RCP ON and RCP OFF. It was observed that pressure in the case with RCPs ON is slightly greater than the case with RCPs OFF and the mass flow through the break was higher in the case in which the pumps are running. When RCP ON, the core level was very low, however the RCPs were able to maintain forced circulation in order to cool the core. When the RCPs were tripped there was enough amount of coolant in the core for maintaining low temperatures. This result is mainly due to use of a best estimate model. Therefore it was decided to use a conservative model in a similar way as the previous vendors analysis.

2.3 Conservative TRACE Model for Almaraz NPP and comparison with the BE analysis

In this section an analysis with the conservative model have been performed. Its results have been compared with the obtained for the Best Estimate model. In order to obtain a conservative model, several hypothesis have been implemented in it. Most of this hypothesis are typical from final safety analysis report (FSAR) such as reduction of the safety injection set point or failure of the steam dump control,[9].

Once the hypothesis have been implemented into the model, some differences are observed, see Figure 4. In the conservative model with RCP OFF, high PCT is obtained. With RCPs ON (BE and conservative) the simulations showed that the core level was lower than in the cases with RCPs OFF but the forced circulation was able to prevent high PCT values. The core liquid level in the case with RCPs OFF and using the conservative model was slightly lower than in the BE case. These differences make possible that high PCTs can be reached. After this analysis, it was considered that the model was ready to perform an exhaustive analysis regarding RCP trip issue.
This section presents the analysis performed with the conservative Almaraz NPP TRACE model. The scope of this analysis was to find out a break spectrum in which the RCP trip during SBLOCA could produce undesirable results.

2.4 RCP Trip Delay Analysis. Conservative model

Figure 3: Comparison RCP ON/OFF. SBLOCA 2inch cold leg. PCT

Figure 4: Comparison BE vs conservative. RCP on/off. SBLOCA 2inch cold leg. PCT
Such as in the analysis performed by Westinghouse, SBLOCA sequences for different RCP trip times and different break sizes were simulated. The results obtained were very similar to the results obtained by Westinghouse. The cases in which the limit is exceeded, are bounded for break sizes between 2 and 3 inch in cold leg with RCP trip times beyond 1000 seconds.

In order to compare the Westinghouse analysis with the ones performed by the Universidad Politécnica de Madrid (UPM), Figure 5 shows the main results obtained. As in Westinghouse analysis, if the RCP trip takes place at any time during the transients for 2 and 3 inches break size diameter, the PCT limit could be exceeded. For 4 inches break diameter this situation does not occur for both, Westinghouse analysis and UPM analysis, the reason is that the break is large enough to depressurize the system until the accumulator setpoint and to allow the discharge of them; this action avoids the core damage.

The main difference between both analyses is the RCP trip time in which the maximum PCT is reached. For the UPM group analysis this time is about 700 seconds later than for Westinghouse analysis, see Figure 5. Since the Westinghouse analysis was performed with a conservative code such as WFLASH, the differences in PCTs and the time in which they are reached, come from the nature of the code as well as possible differences in the model.

![Damage curves-RCP trip delay-Almaraz NPP vs Westinghouse analysis](image)

Figure 5: Damage curves-RCP trip delay-Almaraz NPP vs Westinghouse analysis

In Figures 6 and 7 the main results for SBLOCA 2 inch in cold leg are shown. The RCP trip times in which the PCTs are exceeded, are between 3500 seconds and 4000 seconds after the break occurs. Looking at Figure 7, the core liquid volume fraction, it is clear that for these RCP trip times the core is uncovered longer, and the pressures are not low enough for allowing the actuation of the accumulators. For 4500 RCP trip time after the break, the pressure falls to the accumulators setpoint (≈ 45 bar) and the core is immediately covered due to the flow discharge, this action avoid the damage in this case.

Figure 8 shows the PCT observed for each break diameter as function of RCP trip time. The highest band (red area) represents the points in which the acceptance criteria (1477K) is exceeded while the points of the second band (in yellow) represent the region close to damage. The other regions are far enough from the limit.
Figure 6: Conservative analysis. RCP trip delay times. SBLOCA 2 inch cold leg. PCT

Figure 7: Conservative analysis. RCP trip delay times. SBLOCA 2 inch cold leg. Core level
3 CONCLUSIONS

The main conclusions arisen from this analysis are:

- With a best estimate code it is not possible to reproduce a conservative analysis unless some conservative hypotheses are implement in the model. Once the model becomes a conservative model, similar results than in the previous analysis performed by Westinghouse are obtained, confirming that it is convenient to trip the RCPs early in the accident in order to avoid the damage, however due to the fact that the Westinghouse analysis was performed with WFLASH code, their results are more conservative.

- It has been demonstrated for Almaraz NPP TRACE model that there is enough time (around 1000 seconds) in order to trip the RCPs in case of SBLOCA, before the limit is exceeded.

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Figure 8: PCT as function of RCP trip time and break size


