Study Of The Impact On PSA Success Criteria Of The Variability Of The Initial Liquid Level In Case Of The Loss Of The RHR System Accident Scenario Under Mid-Loop Operating Conditions

J.F. Villanueva, S. Carlos, S. Martorell, V. Serradell
Department of Chemical and Nuclear Engineering
Polytechnic University of Valencia
Camí de Vera, s/n. 46022 Valencia, Spain
jovillo0@iqn.upv.es

F. Pelayo, R. Mendizábal
Spanish Nuclear Council
Justo Dorado, 11
28040 Madrid, Spain

C. Cirauqui, I. Sol
ANA-Vandellós II
Vandellós NPP, Edificio Sede
Hospitalet de L’Infant
43890 Tarragona, Spain

1 INTRODUCTION

Probabilistic safety assessment (PSA) is recognized nowadays as an important tool to support risk-informed decision-making aimed at providing both operational flexibility and plant safety [1]. Experience of current PSA studies shows the importance of some risky scenarios with the plant at low power and shutdown conditions as compared to the accident scenarios with the plant operating at full power. In particular, current low power and shutdown PSA (LPSA) studies shows that the loss of the Residual Heat Removal System (RHRS) transient is one of the most risk-significant events under low power conditions [2]. This accident type is supposed to occur for various plant operating states, of which mid-loop operation represents one of the main contributors [3].

LPSA has widely used methods for thermal-hydraulic analysis that play an important role in determining success criteria of safety-related functions involved to mitigate the severity of accident scenarios with the plant operating in such conditions. Various best estimate thermal-hydraulic analysis codes have been used to analyze the loss of the RHRS during low power and shutdown conditions [4, 5]. It is known that RELAP code can give
good results as derived after a number of benchmark exercises using results from experiments at research facilities (e.g. ROSA-IV, BETHSY, PKL). [6]

Previous research has shown how thermal-hydraulic phenomena after the loss of the RHRS, e.g. peak reactor coolant system pressure, are sensitive to the initial liquid level at the time of loss of the RHRS [2]. This paper presents the results of the study of the thermal-hydraulic analysis of the accident scenarios after the loss of the RHRS under mid-loop conditions paying particular attention to the analysis of the effect of the variability of the initial liquid level on the success criteria of the safety-related functions considered in a typical LPSA [3].

2 PROBLEM DESCRIPTION

2.1 Description of the accident scenario

The accident scenario in scope is the loss of the residual heat removal system while the plant is operating in mid-loop. The pressurizer is filled with air, atmospheric pressure in the Reactor Coolant System (RCS), and the temperature in the RCS is below 60º C. In these conditions, the low residual heat is removed from the core by one train of the RHRS. In addition, the RCS is open to containment by the pressurizer manway.

After the loss of one train of the RHRS the emergency procedures manual requires to check the availability of the remaining train to maintain heat removal capacity. In the case of the failure of this redundant train, the only way to remove heat from the core is injecting water into the primary since water inventory reduces significantly as the RCS is open. This water supply can be achieved either by one of two charging pump or by gravity from Refuelling Water Storage Tank (RWST). Charge pumps injecting water from RWST through the charge line or cold leg injection can recover the inventory lost and maintain the cooldown as the residual heat is evacuated through pressurizer vent, similar to a pseudo “Feed & Bleed”, where the “Bleed” is fulfilled by the pressurizer manway. Alternatively, the inventory can be recovered from RWST by gravity. In all cases it is necessary to restore the RWST to maintain the plant in a stable condition in the long run. Figure 1 shows the event tree for this accident scenario adapted from the LPSA of Asco NPP [3].

2.2 Safety functions: success criteria

According to the LPSA of Asco NPP, there are tree success criteria of the safety function (headers of the event tree) that need to be checked based on a thermal-hydraulic analysis, which intends to demonstrate under what conditions safety functions can perform the intended function. The safety functions of interest for this study and their success criteria are the following:

- Test 1. Check availability of the redundant RHR train (W2).

  From the point of view of the thermal-hydraulic analysis, it must be checked that the temperature at core outlet is less than 100 ºC, i.e. less than saturation temperature at atmospheric pressure, in order to ensure the redundant RHR train is operable.

  - Test 2. Charging pump injecting from the RWST (RP1)

    According to the success criteria for this safety function, it must be checked that water injection occurs before the core collapses.

    - Test 3. Injection from the RWST by gravity (G1)

Proceedings of the International Conference “Nuclear Energy for New Europe 2005”
When there is no alternative way to restore the water inventory in the RCS, the RWST isolation valves that connect it to the low pressure injection system or the valves at suction of the charge pumps can be opened to inject water by gravity thanks to the differential pressure between RWST and the primary. In consequence, the injection has to be done before the pressure in RCS prevents to do it. Since RCS is open there will not be any problem to fulfil such conditions and then the only condition that needs to be checked is that safety injection occurs by gravity before the core collapses, which is the same success criteria as for Test 2.

![Event Tree: Loss of RHR at Mid-loop conditions](image)

Figure 1: Event Tree: Loss of RHR at Mid-loop conditions [3]

3 THERMAL-HYDRAULIC ANALYSIS

The thermal-hydraulic analysis required to check the success criteria described in the previous section have been performed using RELAP5 Mod 3.3. This study has been repeated for three different initial conditions aimed at demonstrating the impact of the initial liquid level on such success criteria.

3.1 Transient Specifications: Initial conditions and liquid level

Table 1 summarizes the initial conditions that have been simulated with the RELAP5 Mod3.3.

In the study of success criteria of the safety functions described in section 2, the initial liquid level is an important factor that influences significantly the evolution of the transient and the capability of these safety systems to perform their intended functions.

The PSA normally assumes the most conservative scenario which may not always be the same, then it is considered to be useful the study of that kind of accidents under
uncertainty in the initial liquid level. Thus, three different scenarios are considered with regard to the initial liquid level as shown in Table 1: ML, ML6 and ML12.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
<td></td>
</tr>
<tr>
<td>RCS pressure</td>
<td>Atmospheric (primary open)</td>
</tr>
<tr>
<td>RCS temperature</td>
<td>60 °C (334K)</td>
</tr>
<tr>
<td>RCS initial liquid level</td>
<td>ML = Hot Leg Mid-loop</td>
</tr>
<tr>
<td></td>
<td>ML6 = Low RHR level (ML+6”)</td>
</tr>
<tr>
<td></td>
<td>ML12 = High RHR level (ML+12”)</td>
</tr>
<tr>
<td>RCS mass flow rate</td>
<td>0.0 kg/s per loop</td>
</tr>
<tr>
<td>Residual Heat</td>
<td>12.88 MW (0.44 %)</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
</tr>
<tr>
<td>Steam generator 1</td>
<td>Wet preservation and ready for operation</td>
</tr>
<tr>
<td>Steam generator 2</td>
<td>Wet preservation and isolated</td>
</tr>
<tr>
<td>Steam generator 3</td>
<td>Empty (full of air)</td>
</tr>
<tr>
<td>Steam Generators Pressure</td>
<td>1 bar</td>
</tr>
</tbody>
</table>

3.2 Transient results

The results of the simulations of the three scenarios using RELAP 5 Mod 3.3 are presented in the following paragraphs grouped according to the success criteria tested.

a) Test 1
The variables of interest herein are liquid temperature and saturation temperature of the volume next to the suction the RHR pump. We have to check when the liquid temperature in this volume equals the saturation temperature (i.e. achievement of saturation conditions). Figures 2, 3 and 4 show the evolution of both temperatures for the three initial liquid levels, ML, ML6 and ML12 respectively. As one can observe, the upper the initial level in the RCS the larger the delay to reach saturation conditions, with a variation of 2420 s between the first (1710 s) and the last (4130 s) situations.

b) Tests 2 & 3
The time available to inject water from the RWST to the RCS using the charging pump (Test 2) or by gravity (Test 3) can be derived from Figure 5, where it is presented the evolution of the liquid level in the vessel. In this figure, it can be observed that there is a significant difference depending on the initial liquid level. Thus, one can observe how the most favourable scenario, which correspond to the highest RHR level (ML12), does not present a significant difference in the time available with regard to the following RHR level (ML6), while there is a significant difference between both and the most unfavourable scenario that corresponds to the lowest level ML.
Figure 2: ML: Liquid vs saturation temperatures at RHR suction volume.

Figure 3: ML6: Liquid vs saturation temperatures at RHR suction volume.
Figure 4: ML12: Liquid vs saturation temperatures at RHR suction volume.

Figure 5: Evolution of the level in the vessel
4 DISCUSSION

Table 2 summarizes the results of the study of the impact in PSA success criteria of the variability of the initial liquid level in case of the loss of the RHR system accident scenario under mid-loop operating conditions.

Table 2. Summary of results for the case of application.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSA [3, 7, 8]</td>
<td>780 s</td>
<td>1800 s</td>
</tr>
<tr>
<td>ML</td>
<td>1710 s</td>
<td>1930 s</td>
</tr>
<tr>
<td>ML6</td>
<td>1920 s</td>
<td>2260 s</td>
</tr>
<tr>
<td>ML12</td>
<td>4130 s</td>
<td>2280 s</td>
</tr>
</tbody>
</table>

It is not possible to assure, at least in this case of application that, one initial liquid level yields to the most conservative results in all circumstances as it may depend on the particular success criteria being checked.

In addition, one can observe differences between the results found in the LPSA and the ones derived in this example of application, which yield to less restrictive results for all tests 1-3. However, it is not possible to compare both two groups of results in an absolute way mainly due to the fact that the best-estimate thermal-hydraulic code used is different and also due to variability of the input data (e.g. residual heat, boundary conditions, etc.).

Therefore, above discussion can made one think about the impact that uncertainties associated with thermal-hydraulic codes and input data can have on the determination of success criteria for the PSA, which requires further research as it could influence directly the defence-in-depth principle and also safety margins and risk contributions (e.g. CDF).

5 ACKNOWLEDGEMENT

The authors wish to thank Andrea Buccalosi from AV Nuclear for his contribution to formulate the problem and help in simulating the transients.

6 REFERENCES


Proceedings of the International Conference “Nuclear Energy for New Europe 2005”
