



PROBABILISTIC SAFETY ANALYSIS OF LOSS OF COMPONENT COOLING WATER SYSTEM (LOCW) INITIATING EVENT FOR 300 MWE PWR NUCLEAR POWER PLANTS (NPPS)

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The probabilistic safety analysis (PSA) is an important tool in ensuring the design safety of a nuclear power plant in relation to potential initiating events that can be caused by random component failures and human errors etc. It estimates the risk in the form of core damage frequency (CDF) and enables us to identify systems for which design improvements or modifications to operational procedures could reduce the probabilities of severe accidents or mitigate their consequences. LOCW initiating event analysis for 300 MWe PWR NPP was evaluated by using small event tree and large fault tree technique. The objective of this analysis was to compare the results of the LOCW initiating event with similar NPPs PSA results. The core damage frequency of LOCW initiating event comes out to be $1.08E-07$ /yr with total of eleven sequences out of which 06 sequences are leading to Core Damage (CD) state. The failure probabilities of SAF & SMF systems are comes out to be $8.27E-03$ & $7.85E-03$ respectively. The comparison of results with similar NPPs PSA results showed that the CDF contribution of LOCW is highly sensitive to the initiating event frequency. Similarly it is also observed that the CDF of LOCW event can be improved significantly by taking the credit of SMF after failure of SAF.

Keywords: PSA, LOCW, Core damage frequency, PWR, SAF, SAM

1. Introduction

The concept of initiating events (IEs) was introduced in the United States Nuclear Regulatory Commission's Reactor Safety Study (RSS) in 1975 [1] together with the event tree methodology. An initiating event (IE) is one that creates a disturbance in the plant and has the potential to lead to core damage, considering successful operation or failure of the various mitigating systems in the plant. The following definition of IE [2]. "An initiating event is an incident that requires an automatic or operator initiated action to bring the plant into a safe and steady-state condition, where in the absence of such action the core damage states of concern can result in severe core damage. Initiating events are usually categorized in divisions of internal and external initiators reflecting the origin of the events". These events can generally be divided into three basic categories:

1. Loss of SRC integrity ---- Rupture or break of the SRC pressure boundary resulting in a loss of primary coolant. This class of events may be subdivided by break size, location, or other

special effects.

2. Transients ---- Accidents that increase the power output in the core or that restrict the heat removal from the core and/or those could create the need for a reactor power reduction or shut down and subsequent removal of decay heat without any loss in primary coolant..
3. External events ---- Events resulting from occurrences not directly related to reactor operation. Examples include earthquakes, tornadoes, floods and fires.

In present study a second category initiating event (IE) i.e. analysis of loss of component cooling water (LOCW) system was considered. LOCW will not cause a direct reactor trip but will lead to immediate reactor shutdown due to the required tripping of the charging pumps and the RCPs upon loss of cooling.

2. Analysis Approach

LOCW initiating event analysis for 300 MWe PWR NPP was evaluated by using small event tree and large fault tree technique. The objective of this analysis was to compare the results of the

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LOCW initiating event with similar NPPs PSA results i.e. Chasma-1 PSA [3], Chasma-2 design PSA [4] and Qinshan Nuclear Power Plant (QNPP) PSA [5].

After the occurrence of loss of component cooling water transient at NPPs three safety functions are required in response for mitigation i.e. reactivity control, secondary-side heat sink and maintaining of integrity of reactor coolant system. . The main systems that are affected after the occurrence of loss of component cooling water initiating event are a part of Auxiliary Feedwater System, whose two motor driven pumps suffer the loss of cooling from component cooling water, High/Low Pressure Safety Injection Pumps, Reactor Coolant Pumps (RCPs) and Residual Heat Removal Heat Exchangers.

In this critical condition at NPP to satisfy the above mentioned safety functions seven function headers are selected for event tree modeling of LOCW as shown in Fig. 1 which include safety systems Reactor Trip System (RTS), Steam Relief (SR), Auxiliary Feedwater System (SAF), Main Feedwater System (SMF), RCP Seal Integrity (SPS), Pressurizer PORV set point not reach (PZPORVSN) and an operator action Pressurizer PORV Reset/Close (PZPORVRS). LOCW event tree have eleven sequences of these function headers in total, 5 sequences are OK while 6 sequences are going towards CD.

To support LOCW event tree two fault trees of Main Feedwater System (SMF) and Auxiliary Feedwater System (SAF) are modeled. While for other function headers like Reactor Trip System (RTS), RCP Seal Integrity (SPS), Steam Relief (SR), Pressurizer PORV set point not reach (PZPORVSN) and Pressurizer PORV reset (PZPORVRS) the values are incorporated in the form of basic events from QNPP & C-1 PSA reports.

The data values for the basic events of the fault trees and event trees including common cause failure (CCF) events are taken from different data sources according to the preference order given below:

- a. Nureg-4550 [6]
- b. C-2 design PSA report [4]
- c. QNPP PSA report [5]

- d. C-1 PSA report [3]
- e. Nureg-5497 [7]

3. Results and Discussion

The consequence analysis for Core Damage (CD) in case of LOCW event tree was run on risk spectrum software and a list consisting of 28131 Minimal Cut Sets (MCS) was generated. CD Consequence analysis basically evaluates the total CDF from all the CD sequences of a particular IE. Core Damage Frequency (CDF) evaluated from the consequence analysis of LOCW event tree was found to be 1.08E-07 per year. Six out of eleven sequences were leading to core damage state during the accident while five gave successful mitigation of the initiating event. Top three sequences are LOCW-SPS, LOCW-SAF-MFW and LOCW-RTS giving 81.7 %, 11 %, and 4 % contribution to Core Damage Frequency (CDF) respectively.

3.1. Sequence 1

Sequence 1 is the failure of Seal water injection (SPS) to reactor coolant pump alongwith the initiating event of LOCW during the propagation of the accident. The failure of SPS gives the maximum contribution to the CD. The contribution of this sequence to overall LOCW Core Damage Frequency (CDF) is 81.7 %.

3.2. Sequence 2

2nd sequence highlights the importance of secondary heat sink in accident progression of LOCW. The failure of two successive secondary systems, which are SAF (Auxiliary Feed Water System) and SMF (Main Feed Water System) leads to 2nd major contribution to CDF that is 11 % of the total.

3.3. Sequence 3

3rd important sequence in the LOCW event is the failure of RTS (Reactor Trip System). Due to failure of this system the reactor cannot shutdown on time and its contribution to CDF is 4 % for LOCW.

MCS analysis of SAF and SMF fault trees were also performed by using Risk Spectrum software, which yielded the result in the form of mean unavailability of systems, which came out to be 8.27E -03 per demand, 7.85E-03 per demand respectively.

The importance analysis results of overall CD consequence and both fault trees shows that basic events of SAF ventilation failure and SMF alignment failure by operator are very important and it is important to take some measures to reduce the probability of failure of these basic events. This can be achieved by improving the reliability of SAF ventilation system through surveillance and by improving the operator's training on simulator for the alignment of SMF after the failure of SAF in transient.

4. Conclusions

Core Damage Frequencies (CDF) evaluated for LOCW in C-1 PSA [3], C-2 design PSA [4] and QNPP PSA [5] reports are enlisted in Table 1. After comparing these results with present study it is observed that the CDF obtained in present study is reduced approximately of the order of 10. The reduction in CDF for LOCW is mainly due to the as built plant design modeling i.e. the credit of all possible mitigating systems are taken which are available after the loss of component cooling water initiating event.

Table 1. Core Damage Frequencies (CDF) for LOCW initiating event.

Sr. No.	Plant Name	CDF (per year)
1	C-2 Design PSA Report	1.79E-06
2	QNPP Level-1 PSA Report	2.86E-06
3	C-1 Level PSA Report	1.47E-06

In comparison with C-2 design PSA report it is observed that the reduction in CDF value is mainly due to the credit of SMF. While in case of C-1 one extra operator action is modeled conservatively but the opening & closing of Pressurizer PORV's are not modeled although due to the tripping of reactor coolant pumps the possibility of increase in primary pressure after LOCW initiating event is very high. Similarly in case of QNPP secondary steam relief system is not modeled pessimistically which is also required for the safe mitigation of LOCW. In view of the above discussion it can be concluded that by modeling as built plant design with best estimate approach the CDF of the plant can be reduced significantly.

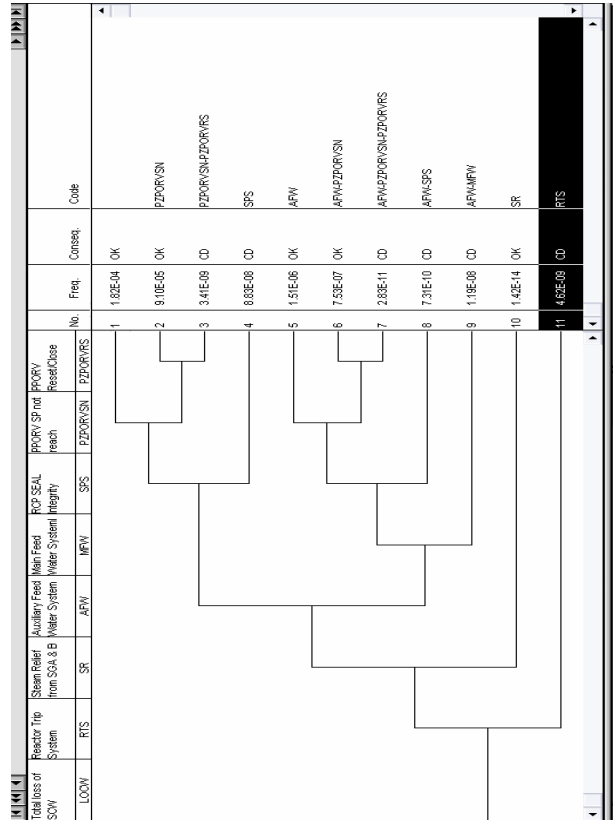


Figure 1. Event tree of loss of component cooling water (LOCW) initiating event.

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