An Analytical Review of a SBLOCA Sequence for YGN 1&2 PSA

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1. Introduction

The YGN 1&2 PSA report[1] has been under review by the Korea Institute of Nuclear Safety (KINS) since January, 2008. Several technical issues are being discussed. One of them is about the justification of the categorization of the Source Term Categories (STCs). There are 17 STCs in the report, among which STC No. 1 deals with the case of melt stop before reactor vessel breach. For the sequences belonging to this category, the core is cooled through injection of cooling water into the reactor vessel or external reactor vessel cooling by water flooded into the reactor cavity.

The representative sequence is Seq. No. 1 of the CET 41 of the Ref. 1, i.e., a Small Break Loss-of-Coolant Accident (SBLOCA) followed by successful high pressure safety injection (HPSI) and secondary heat removal through auxiliary feedwater to the steam generators and failure of low pressure cold leg recirculation and successful containment heat removal. This has been found as one of the dominating sequences causing core damage; according to Ref. 1, the frequency (CDF) of this sequence is estimated to be 1.22E-6/yr, which occupies about 95% of the Plant Damage State (PDS) No. 41. It is noticeable that this PDS contributes 21% to the total CDF, 6.16E-6/yr, and that is the largest contribution among the 49 PDSs.

The judgment that melt stop can be achieved should be justified on the basis of the large amount of water collection in the cavity and sufficient cooling through it because failure of low pressure recirculation of sump water may lead to continuous core damage in the long term. Since the ST categorization method used for the YGN-3&4 PSA is similar to that of Kori-3&4[2], the same type of 950 MWe Westinghouse PWR, this study has been carried out to examine the possibility of melt stop inside the reactor vessel using the existing MELCOR 1.8.6 model for Kori-3&4[3]. This version of the MELCOR code can deal with the curved bottom of the lower head and the extended portion of the lower vessel cylinder.[4]

2. Analysis Methodology

A two-inch pipe break in the cold leg was selected to be analyzed. The analytical model includes the core, primary and secondary coolant systems, and the containment. The core is modeled as 5 radial rings, 14 axial levels including top and bottom end fittings. Fig. 1 shows the Reactor Coolant System (RCS) model, which has 19 control volumes and 51 flow paths to simulate down comer, lower and upper plenums, core, bypass, and three loops consisting of hot legs, steam generators, intermediate pipes, Reactor Coolant Pump suctions, and cold legs. The containment model consists of 17 control volumes, as shown in Fig. 2, 32 flow paths and 44 heat structures. In addition, there are several models simulating various systems and phenomena, for example, the Auxiliary Feedwater, containment spray, fan coolers, hydrogen burn and radionuclide behaviour.[5]

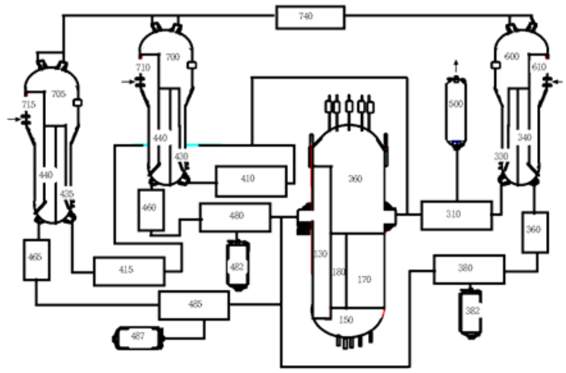
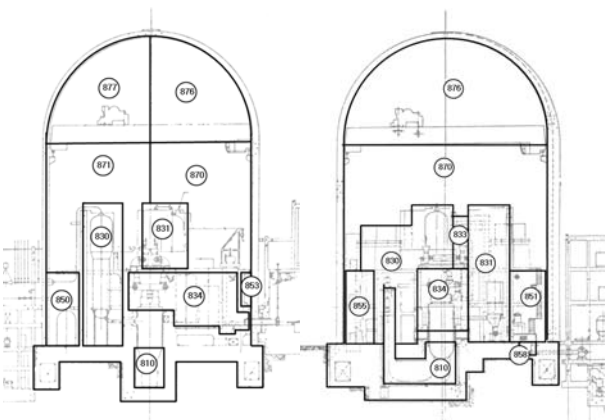


Figure 1 The Reactor Coolant System model



a) Section A b) Section B

Figure 2 The containment model

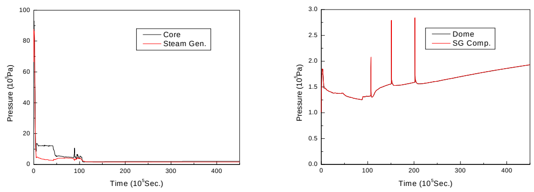
3. Analysis Results

For the selected sequence, all emergency core cooling (ECC) water is injected, following the initiation of loss of coolant, until the Refueling Water Storage Tank (RWST) water is depleted, but thereafter recirculation is not carried out. Secondary heat removal can be achieved through auxiliary feedwater pumps, but its role is appeared to be limited for this low-pressure sequence. After running out of ECC water rapid loss of water inventory in the core leads to clad failure. The fuel rapidly heats up and melts, and then relocates to the lower plenum and fails the lower head of the reactor vessel. A summary of predicted sequence of key events and their time is provided in Table 1.

Table 1 Key event timings

Key event	Time (Sec.)
Accident initiation	0
Reactor trip, Main Feedwater stop, and MSIV closed	116
RCP trip and start of safety injection	157
Beginning of core uncovery	1,333
Start of AFW supply	3,000
Start of accumulator injection	3,124
Start of LPSI	4,411
Exhaustion of RWST	42,128
Exhaustion of Accumulator	44,948
Start of Gap release	87,193
Start of clad melting	88,217
UO_2 relocation to lower head	94,864
Beginning of debris ejection to cavity	101,918
Hydrogen burn	151,343
Hydrogen burn	202,029

Fig. 3 shows pressure responses of the RCS and the containment following the accident. It should be noted that sensitivity study on the nodalization effect has not been carried out yet.



(a) Reactor Coolant System (b) Containment

Figure 3 Pressure response of the plant

Fig. 4 shows that while the reactor cavity is filled with water up to the lower part of the core, that is higher than the top of the lower head, reactor vessel comes to breach. However, there are uncertainties concerning water distribution inside the containment under the post-accident condition and the role of the reactor vessel insulation. Fig. 5 shows total internal energy in the core and cumulative heat transferred from the lower head to water pool. Figure 6 shows the distribution of core materials inside and outside of the reactor vessel; they melt and relocate to the lower head and then are ejected to the reactor cavity. These results show that melting of the core does not stop until the vessel breach even with flooded cavity, which is contrary to the PSA reports.

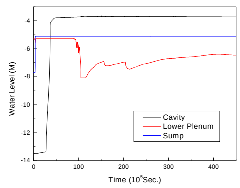


Figure 4 Water level in the containment

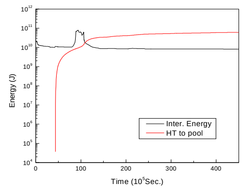


Figure 5 Total internal energy and heat transfer

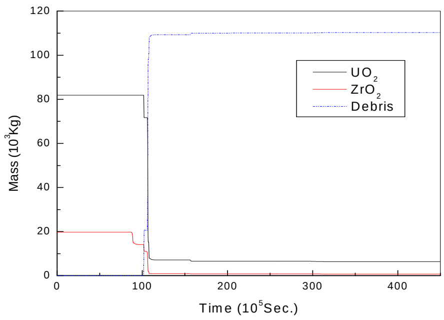


Figure 6 Debris mass distribution

4. Conclusion

The possibility of melt stop inside the reactor vessel following a SBLOCA, which was judged positively in the PSA reports for YGN-3&4 and Kori-3&4, has been examined using the MELCOR 1.8.6 code. The result leads to an opposite judgment such that fuel melts continuously and relocates to the lower head and ejects to the reactor cavity. Therefore, it is suggested that rearrangement of this dominating sequence to another proper STC be considered. Further study may be required to confirm the appropriateness of the Source Term categorization.

Acknowledgments

This work is based on the results from the Long-Term Nuclear Research and Development program of Korea Ministry of Education, Science and Technology.

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