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Potential Concerns on the Realistic Evaluation of LBLOCA in APR-1400

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1. Introduction

The APR1400 is an advanced PWR developed by the Korean industry and has a 3983 MWt with two reactor coolant loops. The APR1400 has four separated hydraulic trains of an emergency core cooling system (ECCS) with direct vessel injection (DVI) which is different from the existing commercial PWRs. Therefore, the thermal-hydraulic phenomena during LB-LOCA of APR1400 show the different characteristics and several safety concerns is issued including ECC bypass and the downcomer boiling. Currently, the Shinkori Units 3&4 adopting APR1400 standard design is being reviewed including above safety concerns [1].

Nowdays, the best estimate methods with the uncertainty evaluation are broadly used worldwide in licensing of NPP. In APR1400, the LBLOCA analysis using the best estimate methods to replace the old conservative evaluation method (EM) is being performed in relative to the review of the construction permit for Shinkori Units 3&4. The KINS is also conducting the preliminary regulatory audit calculation by using the KINS-REM [2].

The present study aims to discuss some potential concerns to be experienced in BE calculation and uncertainty evaluation of LBLOCA in APR1400, which were found in the preliminary calculation [3]. Treatments of gap conductance of the fuel is one of the examples those concerns. Potential concerns included the following but not limited to them.

- Number of code run to lead a reliable PCT value of 95% confidence level
- Inclusion of the K-factor at the junction from the SIT to RCS as an uncertainty parameter to address the effect of fluidic device (FD)

This paper also describes a possible approach to those concerns which should be emphasized in the review process of the calculation.

2. Increase of the Number of Code Runs

The KINS-REM has adopted originally the Wilk's formula at the first order based on the nonparametric statistics and performed 59 code runs by using the simple random sampling. However, it has been found in recent studies and the present study that the 59 calculations have a possibility to obtain a different PCT result as the random sample changed. Therefore, the BEMUSE program recommended recently that the number of code runs may be increased to 124 runs based on 3rd order Wilk's formula instead of 59 calculations [4]. The increasing random sampling can make the uncertainty results reliable and the sensitivity results less dispersed. To strongly reduce the effect of reliability of tolerance limits of small code runs, the BEMUSE program even suggested that the uncertainty analysis is possible to use Wilks' formula at the order 4 or 5 for the unchanged tolerance limit and confidence level. Therefore, in order to solve above problems of small code runs, the Wilk's formula at the order 3 was used and thus 124 code runs was performed in this study.

3. Determination of Uncertainty Parameter

The determination of the uncertainties of input parameter is very important concern in LB-LOCA analysis. The input parameters are mainly consisted of system parameters and code model parameters. In the LB-LOCA analysis using KINS-REM, we had the difficulty on treating for uncertainty of gap conductance of the fuel in the condition that the fuel performance data was uncertain. In APR1400, the fluidic device was installed in the safety injection tank (SIT) to control passively the safety injection flow. Therefore, the uncertainty of K-factor of SIT should be chosen carefully.

3.1 Gap conductance

The gap conductance is not inserted directly as input data of RELAP5/MOD3.3 [5]. It is calculated using the mole fraction of gases, width of fuel-cladding gap, surface roughness of the cladding and temperature jump distance. To evaluate the uncertainty of gap conductance, the calculation of Westinghouse plants used the mole fraction of gases [6] while the surface roughness was applied to the analysis of KSNP [7]. In this study, the uncertainty of gap conductance was addressed using the empirical surface roughness equation in reference [7] since the fuel performance data were not clear in APR1400 and the surface roughness is only used for calculation. The uncertainty range of gap conductance was determined as 0.67 ~ 1.0 to fit the fuel centerline temperature for peak linear power rate in the steady state calculation. In 124 steady state code runs, the cladding temperatures were abnormally high for 6 cases because the fuel gap width was reduced significantly and thus the fuel was nearly contacted to the cladding. Of course, it had a severe impact on the subsequent transient run and PCT. The cladding-fuel pellet contact in steady state was not plausible even within 95% probability range.

Therefore, to address the gap conductance by using the surface roughness, the empirical equation on the surface roughness and the fuel performance data should be carefully treated. Also, the sensitivity study applying other parameters such as the mole fraction of gases, width of fuel-cladding gap and etc should be required to evaluate the effects for the gap conductance.

3.2 K-factor of SIT

To address the uncertainty of the FD, the uncertainty for injection line K-factor of SIT in APR1400 should be determined in careful by considering low flow region through the FD. Two methods can be used to model the SIT. Firstly, a SIT is divided as two SITs : high flow region and low flow region (FD operation). However, the number of uncertainty parameter is increased and the accurate determination of uncertainty range is difficult in this method. Secondly, the SIT was modeled as one using the accumulator component and the motor operated valve component. The accurate control logic is needed and only one uncertainty parameter for K-factor was used in second method. The second method was adopted in the present calculation and the uncertainty range was determined by evaluating the experiment which performed in KAERI [8]. The average K-factor for high flow region was suggested as 18.8 in the experiments [8]. Through the sensitivity study, the average K-factor was determined as 18 as shown in Fig. 1. The peak flow rate agreed with the experimental data. The time response difference for peak flow rates was considered due to the effect of valve opening time. The minimum value used the K-factor (25.2) including all experimental data of large injection flow and the maximum value was selected as the K-factor (10.8) including the flow conversion point in the experiments.

4. Conclusion

From the present study, it is concluded that, the design parameter and fuel parameter including gap conductance should be considered accurately to perform the preliminary best estimate calculation. The increase of code runs should be considered to reduce the effect of reliability of tolerance limits of 59 calculations in the BE calculation and uncertainty evaluation of LBLOCA in APR1400. Also, for new design features such as FD, the uncertainty of input parameter should be selected with the special attention. Others, not discussed in this study, should be also addressed reasonably.

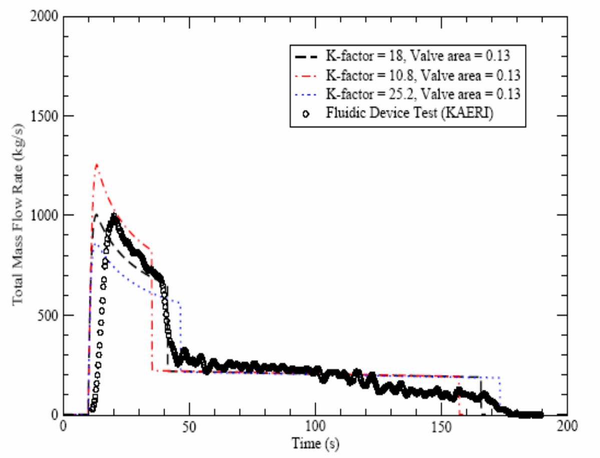

Fig. 1. Determination of Uncertainty Range for K-factor in SIT

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