ANALYSIS OF APR1400 LBLOCA AND UNCERTAINTY QUANTIFICATION BY MONTE-CARLO METHOD, COMPARING WITH WILKS' FORMULA APPROACH

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1. Introduction

The main motivation for development of uncertainty analysis was that licensing based on evaluation model has been moved to the use of "best estimate" calculation with uncertainty estimates. Different licensing authorities have different requirements and it influenced the nature of uncertainty analysis needed to satisfy them. One of the uncertainty methods was based on the Wilks' formula[1] to find the number of calculations required to get desired statistical tolerance limit. The method was initially suggested by GRS and became the most popular method for LBLOCA. Since the numbers of calculation were limited by the computer capability at that time, it was inevitable to limit the calculation number. The contemporary PC speed and resources enable to break out the limit of the previous approach. This report describe the analysis of MARS[2] code for LBLOCA of APR1400 and uncertainty quantification with the Monte Carlo calculation. The MARS input generation and execution works are performed by using the MOSAIQUE program[3].

2. Model Description

The APR1400 system was modeled as one-dimensional components. Total 284 hydraulic volumes and 382 junctions, and 427 heat structure nodes are modeled. The upper plenum guide tubes are modeled as a pipe connecting the upper head and core outlet space. The reactor core flow path is modeled as two vertical pipes representing average core channel and hot channel, respectively. The average core channel is summation of 240 fuel assemblies. And the hot channel is representing one fuel rod. The number of node for vertical core channel is 20.

The core downcomer is divided into 6 pipes connected by lateral junctions. 10 vertical nodes are designed for the downcomer pipes. The direct vessel injection line is connected to the downcomer pipe node at 2.1 m above the cold leg connection. The flow rate control function of fluidic device is equivalently modeled by the combination of valve and trip logic. It is assumed that only 2 emergency pumps are working on the LBLOCA scenario. The emergency core cooling water injection by the intact pump actuation is connected at the break and opposite peripheral locations in the downcomer.

The break condition is assumed as double ended guillotine break. The conventional problem splitting of steady preparation and transient scenario calculation is not available for the MOSAIQUE program. Thus the break junction is modeled as valve which closed at the break initiation.

No credit is assigned to the scram reactivity table after the LOCA initiation. Because of the merged run of steady and transient, the bias reactivity is calculated during the calculation. The poison reactivity worth of boron is assumed as -8 pcm/ppm. The boron concentration is assumed as 220 ppm in the SIT tanks.

3. Calculation Results of APR1400

The steady state calculations were performed for 500 second simulation time. Actually, it is steady state preparation calculation. Right after the steady state preparation calculation at 500 second, the break junction to the ambient is open and the valve connecting the cold leg is closed. Because the core power is a member of the uncertainty parameters, the end state of the steady preparation calculation is different for all runs. The PSAR[4] of SKN 3/4 plant is referred for the design values.

Uncertainty quantification process starts from the establishment of input uncertain parameters. Previous CSAU[4] PIRT ranking has been utilized to select the important key parameters. Input parameters related to the PIRT phenomena were chosen. The uncertainty range and distribution of each input parameters associated with phenomena are considered. Most of them were taken from literature, such as CSAU report[5] and RELAP5 Models and correlation manual[6].

The variance of each parameter was determined by simple random sampling method within the uncertainty range of each distribution function. For uniform distribution, the minimum and maximum values are boundaries of sampling. For normal distribution, the sampling boundaries were truncated at mean $\pm 1.96\sigma$ value. Any dependencies between parameter were not considered in sampling, since it was not able to find the existing dependencies or correlation between parameters.

Wilks' formula in unilateral at the first order was used to get 95%/95% tolerance limit value. A set of 59 peak clad temperature history samples is required according to this formula. In order to get 95%/95% tolerance limit value of peak clad temperature, each single value are aligned in increasing order: Y(1)<Y(2)…….<Y(58)<Y(59). According to Wilk's 1st order formula, the bottom tolerance limit value is Y(1), and upper value is Y(59). Figure 1 shows the final results of the limit value comparing with 3,500

samples Monte-Carlo 95% confidence level for every time step. It shows the applicability for Wilks' approach to LBLOCA. However the statistical variation is inevitable with low number of calculation, and it is worthful to compare the exact 95% probability upper value using Monte-Carlo method.

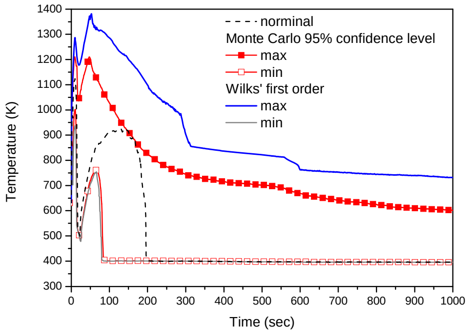

Figure 1. Comparison of peak cladding temperature with respect to the quantification methods

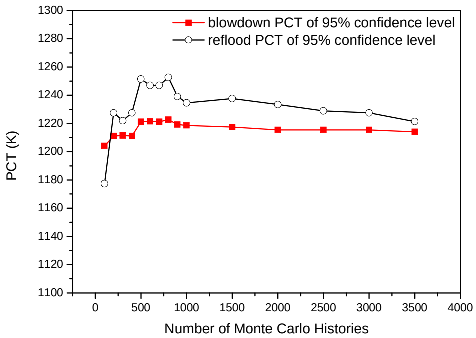

Figure 2. Trends of 95% upper limit of Blowdown and Reflood PCT during Monte Carlo Histories

Figure 2 show that the mean and 95% upper PCTs in Monte-Carlo iterations converge quickly after 1,000 calculation. The 95% upper limit value was obtained by direct counting of aligned PCT values at the level of 95% population. According 1^{st} order Wilks' formula, the 95%-95% unilateral tolerance limit values can be considered as a highest value within 59 sample data. Using 2^{nd} order Wilks' formula, the value will be a second highest value within 93 sample data. For the 3^{rd} order, 124 samples are needed. The Wilks' 1^{st} order upper limit was evaluated in every 59 samples, and 2^{nd} order was evaluated in every 93 samples, and so on. These values were compared with the actual 95% upper value during Monte-Carlo histories.

The trends of blowdown and reflood PCTs with respect to number of calculations. These results shows that 95% upper limit value can be obtained using Wilks' formula at 95% confidence level, although we have to endure 5% risk of PCT under-prediction. The statistical fluctuation of limit value using Wilks' 1^{st} order is as large as PCT uncertainty itself. The fluctuation can be diminished significantly by increasing the order of Wilks' formula.

4. Conclusion

Monte-Carlo exercise shows that the 95% upper limit value can be obtained well with 95% confidence level by Wilks' formula, although we have to endure 5% risk of PCT under-prediction. However the statistical fluctuation of limit value using Wilks' 1st order is as large as PCT uncertainty itself. The fluctuation can be diminished significantly by increasing the order of Wilks' formula, but 2nd order formula is not sufficient enough.

As designer's point, the exact knowing of current safety margin is as important as the decision of regulatory satisfaction. Both Monte-Carlo method and response surface method can provide the exact 95% limit value, and identified safety margin can be utilized to power uprating or ECCS design change. Wilks' formula approach as an interim of full Monte-Carlo calculation seems to be reasonable at the present computational capability. However we have to reduce the random statistical variation in sampling with limited numbers by Wilks' formula. In order to get the reliable safety margin of current design feature, it is necessary to increase the order of Wilks' formula to be higher than the second order.

Acknowledgements

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