Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Monte Carlo Calculation for Uncertainty Quantification for LOFT L2-5 LBLOCA, Comparing with Wilks' Formula Application

Bub Dong Chung
Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong, Daejeon, 305-353,Korea.
bdchung@kaeri.re.kr

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. The KREM submitted by KEPRI was also developed on the basis of Wilks' formula and approved by regulatory authority many years ago. Since the numbers of calculation were limited by the computer capability at that time, it was inevitable to limit the calculation number to be affordable. The contemporary PC speed and resources enable to break out the limit of the previous approach. This report describes the Monte Carlo calculation and assessment of the Wilks' formula for the LBLOCA experiment LOFT L2-5[2].

2. Analysis Method

The entire LOFT system was modeled as MARS2.3 one dimensional loop model and multidimensional vessel model. The one-dimensional model represented the intact and broken loops, the steam generator secondary of intact loop, the pressurizer, the ECC system. A cylindrical three-dimensional model was applied to LOFT vessel. The qualification process during the OECD BEMUSE program shows the developed nodalization and base calculations were well within the acceptance level. Uncertainty quantification process starts from the establishment of input uncertain parameters. Previous CSAU[3] 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 listed in Table 1. Most of them were taken from literature, such as CSAU report and RELAP5 Models and correlation manual.

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 $\pm 2\sigma$ value. Any dependencies between parameter were not considered in sampling, since it was not able to find the existing dependencies or correlation between parameters.

Table 1. The uncertainty range and distribution of each input parameters associated with phenomena

Number	Parameter (xi)	Associated phenomenon	Distri-bution	Range $\pm 2\sigma$
1	Liquid heat transfer	Reflood heat transfer	Normal	± 20%
2	Nucleate boiling heat transfer	Reflood heat transfer	Normal	± 20%
3	AECL Lookup CHF Table	Rewet	Normal	± 74%
4	Transition boiling	Rewet	Normal	± 32%
5	Film boiling heat transfer	Reflood heat transfer	Normal	± 36%
6	Vapor heat transfer	Reflood heat transfer	Normal	± 20%
7	Peaking Factor(Fq)	Stored Energy	Normal	± 14.96%
8	Cold Gap Size	Stored Energy	Uniform	± 20.98μm
9	Gap conductance	Gap conductance	Uniform	± 80%
10	Fuel conductivity	Stored Energy	Normal	± 10%
11	Decay Heat	Decay Heat	Normal	± 6.6%
12	Break Area	Critical Flow	Uniform	0.7 ~ 1.15
13	pump two phase performance	pump two phase performance	Uniform	0.0 ~ 1.0
14	Downcomer Lateral Loss Coeff.	ECC Bypass	Uniform	0.0 ~ 1.0

Direct Monte-Carlo calculations (around 10,000 for example) may be performed in order to have direct histogram of the values of an output parameter. The calculation of 150 second L2-5 simulation can be done within 600 CPU second with a current commercial PC (3 GHz Pentium CPU, Window XP). If 10,000 Monte-Carlo calculations are needed, we have to wait 3 months to finish with single PC. Fortunately, resources of PC are enough to utilize them simultaneously. Cluster PC system with Linux OS would be an ideal environment for these Monte-Carlo calculations. The calculations have been performed with 6 node cluster PCs. 10,000 input files with random sampling were generated utilizing automatic input generator, L25SEN.exe. All cases were load into the cluster PC system as a batch job, expecting to finish off within 2 weeks. When 4,000 calculations were achieved to get interim results during the running, we supposed that the number of calculation is sufficient to process statistical treatment and decided to terminate the further calculations.

Obtained 4,000 output files contained the time trends of key parameters, such as clad temperature, pressure and so on. Key single-valued outputs were obtained by output file processor, LOFT-sum.exe. The post-processor was designed to sort out the failed cases and discard them. The failure rate was about 7% and 3,500 success cases were used for statistical treatment.

3. Results

Figure 1 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 1st order Wilks' formula, the 95%-95% unilateral tolerance limit values can be considered as a highest value within 59 sample data. Using 2nd order Wilks' formula, the value will be a second highest value within 93 sample data. The Wilks' 1st order upper limit was evaluated in every 59 samples, and 2nd order was evaluated in every 93 samples. These values were compared with the actual 95% upper value during Monte-Carlo histories. Figure 1 represents the trends of 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. As shown in figures, 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.

The histogram of reflood PCT was presented at Figure 2. It was plotted by counting the occurrence numbers within each 10 degree windows. Similar graph was obtained for blowdown PCT. The distribution shows two distinct peaks in both blowdown and reflood phase. In some cases, the blowdown CHF can be delayed during initial depressurisation period and blowdown rewet occurs before the start of reflood phase. The CHF and rewet characteristics often lead the bifurcation of clad temperature, and is considered to result in the two peaks. This bifurcation effect cannot be handled properly using the conventional response surface method, and it represent the strength of Monte-Carlo approach.

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.

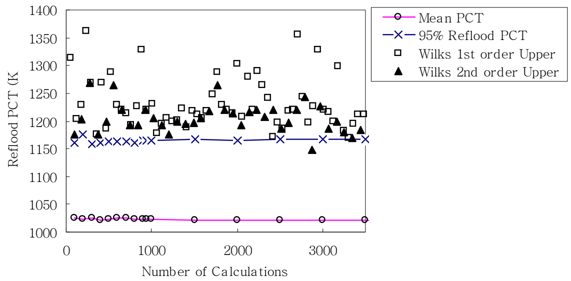

Figure 1. Comparisons of 95% upper reflood PCTs with limit value of Wilks' formula

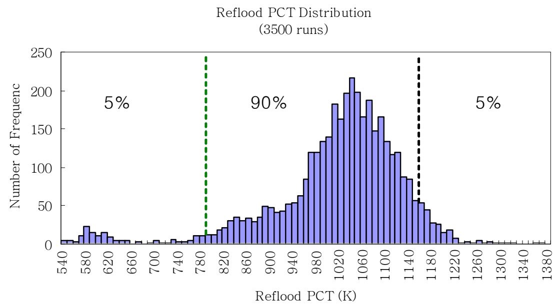

Figure 2. Histogram of Reflood PCTs

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.

REFERENCES

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