Sampling Methods for Uncertainty Analysis Using MAAP5

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1. Introduction

To support and improve SAMG operation, we are developing technologies for diagnosing and visualizing the progression of severe accidents. The importance of utilizing the results of severe accident analysis to support decision-making to prevent the entrance of and mitigate the consequences of severe accidents at a nuclear power plant is increasing. The various accident scenarios can be assessed through the severe accident analysis code, and the database can be used for the operation support system. However, the evaluations of physical phenomena of the progression of severe accident by using available computer code model has inherent limitations in accuracy and precision. There are uncertainties that limit the capability of any model to predict how a core damage accident will evolve at the scale of a nuclear power plant. And those make it difficult to draw appropriate conclusions with only a single scenario simulation. Therefore, the probabilistic assessment is necessary considering their uncertainties.

In a code-based analysis, a single combination of input variables can produce only one result. Many input variables change within uncertainty intervals, so a computer model must be calculated for all possible combinations of input variables to predict the range of the result values. However, it is practically impossible to run a model in all combinations of different input values. Therefore, a statistical method is used to estimate the distributions of the results by assuming input variables as probability variables that follow known probability distributions and sampling all input variables from a population of combinations.

In order to extract samples efficiently, it is important to ensure that the values of input variables are selected as evenly as possible throughout the range with randomness.

This paper focuses on the sampling methods to make uncertainty analysis more efficient. 2 different sampling methods are reviewed. One is Monte-Carlo (random) Sampling (MCS) which is independent of the other variables. The other is Latin Hypercube Sampling (LHS) which is a sampling method that provides sufficient reliability with smaller size of samples. Assuming the accident that only the Safety Injection Tanks (SITs) operate after the Loss of Cooling Accident (LOCA), the core damage time is calculated using MAAP5.03. And it is assumed that the specified uncertainty variables are probability variables that follow known probability distributions.

2. Methods and Results

2.1 Accident Scenario

Assuming 6-inch coldleg LOCA of APR1400 according to the LLOCA assessment of Level 2 PSA, the passive SITs are operated by pre-setting pressure and then the active safety injection system failure leads to core damage. (Figure 1)

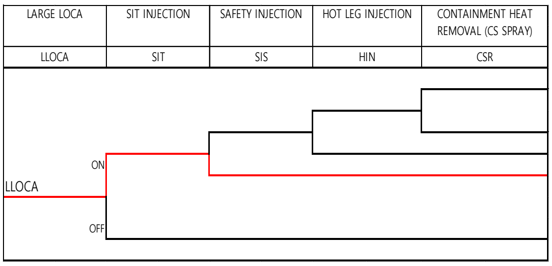

Fig. 1. Event Tree for Selected LLOCA Scenario.

For the combination of MAAP5 inputs in Table 1[1], it is assumed that the parameters follow triangular distributions with the recommended values as the peak. (Figure 2) Because triangular distributions are simple and easy to apply but, can balance the min-max probabilities effectively.

Table 1. Some Input Parameters for Uncertainty Analysis

Parameters	**Recommended**	**MIN**	**MAX**
FFRICX	0.25	0	1
TCLMAX	2500	100	3000
LMCOL0	53	48	54
LMCOL1	53	48	54
LMCOL2	53	48	54
LMCOL3	53	48	54
EPSCUT	0.1	0	0.25
EPSCU2	0.2	0.001	0.35
FGBYPA	1	0	1
…	…	…	…
FACT	0.3	0.1	1
TOTAL	**42**		

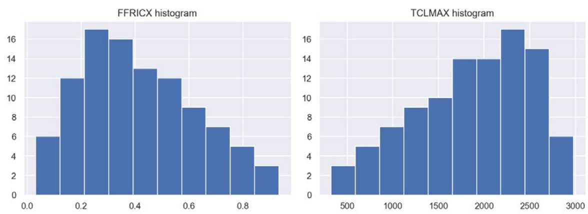

Fig. 2. Distributions of Some Input Parameters.

2.2 Monte-Carlo (Random) Sampling

Monte-Carlo sampling is a simple random sampling method. Each selection of a variable is independent of the others. Because each sample doesn't affect the other samples, the distribution would be easily concentrated on the mode.

2.3 Latin Hypercube Sampling

LHS, proposed by McKay et al in 1979[2], is a method designed for more even extraction than random sampling, dividing each S_1, S_2, ... and S_K into N probability sections in the entire population S to make the entire S into N_K rooms and extract one point from each of the different rooms, but extract one point from each of the selected N points into each section of the S_t.

The sampling is relatively even and may show the same accuracy with fewer samples statistically than random sampling.

Based on work by Wilks [3], for two-sided statistical tolerance intervals, the minimum number of random samples required is given by the equation (1):

$$1 - a^N - N(1-a)a^{N-1} \geq b \qquad (1)$$

where N is the number of samples and b×100 is the confidence level (%) that the maximum result will not be exceeded with the probability a×100 (%) of the corresponding output distribution. This formula yields 93 required samples to have a 95% confidence level that the code results encompass the 5th and 95th percentile of the population.

In this study, the sample size is chosen as 100 so that it can have tolerance interval of 95 percent or more.

2.4 Results

The core exit temperature (CET) after the initial event is calculated in this study and the spectra of core damage time are evaluated according to the sampling methods. Based on the time core damage, the results of 100 analyses, highlighting 5%, 50%, and 95%, are as follows.

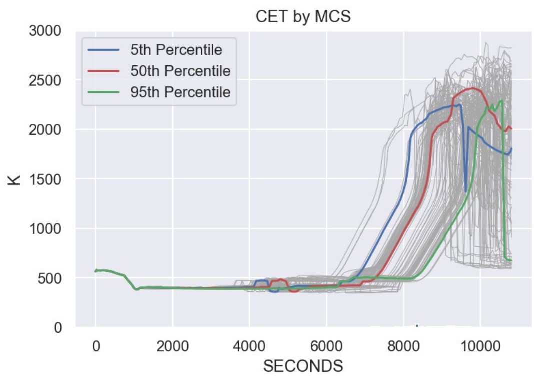

Fig. 3. CET Uncertainty Analysis, by MCS

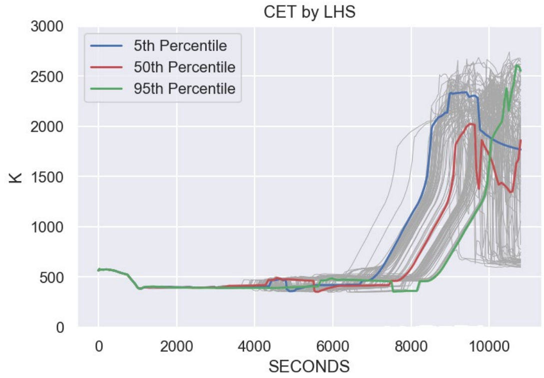

Fig. 4. CET Uncertainty Analysis by LHS

The results of the uncertainty analysis of core damage time are as follows.

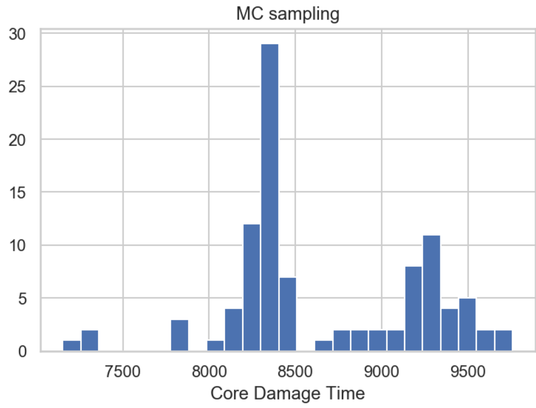

Fig. 5. Core Damage Time Distribution by MCS

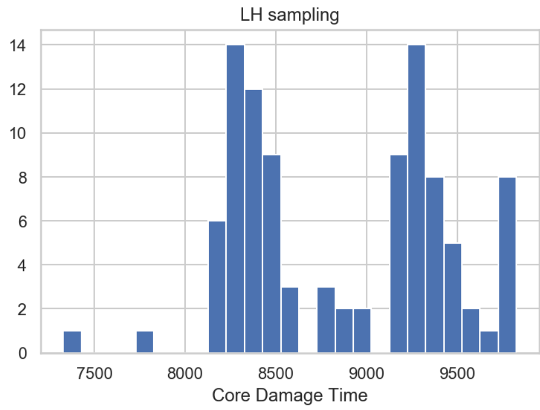

Fig. 6. Core Damage Time Distribution by LHS

While the MCS method shows more concentrated distribution at the mode, the LHS method results in a more uniform distribution.

Table 2: Summary of Analysis Results

	MCS	**LHS**
Mean	8653.39	8868.22
Std.	565.50	561.32
Min	7151.87	7328.82
Median	8390.73	8905.97
Max	9759.17	9824.98

3. Conclusions

As expected, the LHS method is able to cover the regular range of results, while the MCS method concentrates on relatively narrow ranges.

This confirmed that the random sampling method requires a larger number of samples in order to take greater reliability in the uncertainty analysis.

Despite the core damage occurred at 9,819 seconds in the analysis using the recommended combination of parameters, the MCS range doesn't include this result. In addition, most uncertainty analysis results indicate earlier core damage time, indicating that uncertainty analysis is essential for a more conservative evaluation.

Furthermore, the results of this uncertainty analysis show that each parameter and core damage time have a weak correlation and that core damage time does not change depending on a particular parameter.

A further study will be performed to expand the calculation after core damage to analyze uncertainty about various phenomena throughout severe accidents, such as core relocation time, corium generation, and vessel failure time. And it will be used as data for operator decision making in case of severe accident.

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[3] S. S. Wilks, Princeton University, Determination of Sample Sizes for Setting Tolerance Limits, The Annals of Mathematical Statistics, Vol. 12, No. 1 (Mar., 1941), pp. 91-96, 1942