# Development of the COFUN-M Code for Multi-unit Level 2 PSA Uncertainty Analysis Code

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## 1. Introduction

The level 2 Probabilistic Safety Assessment (PSA) deals with the process of failure of containment buildings and the accident process of radiation source term groups probabilistically. The data used in the level 2 PSA and the prediction of severe accidents include uncertainties. Therefore, the level 2 PSA should not only be quantified point estimates, but also be performed uncertainty analysis.

The COFUN-M is a comprehensive calculation code that performs level 2 PSA for multi-unit as well as single unit. The COFUM-M performs level 2 PSA for internal and seismic events. In the case of single unit, quantification, importance analysis, and uncertainty analysis are performed, and in case of multi-unit, quantification and uncertainty analysis are performed. The results of quantification and uncertainty analysis are expressed in plant damage state logic diagram (PDS LD), containment event tree (CET), and source term category (STC), and can be expressed according to large early release frequency (LERF) or the type of damage to the containment building using a user-defined frequency function.

## 2. Process of the COFUN-M

A methodology is developed to reflect the uncertainty factors related to containment integrity as much as possible and to propagate the uncertainty factors related to core damage in the reactor to severe accident phenomena. Uncertainty analysis methodology using random sampling is developed so that uncertainty analysis can be performed varying variables of containment event tree and decomposition event tree (DET).

In this study, uncertainty analysis using statistical propagation method is progressed by random sampling of uncertainty input parameters. For determining the values of the variables, output parameters are obtained by performing the quantification through the statistical propagation method. The Monte Carlo sampling method is chosen as the sampling method because it can save considerable time and resources for calculation and it is easy to implement in a complex phenomenological model because of its simple algorithm. The input variables and output variables for uncertainty analysis process and the analysis process are shown in the Figure 1.

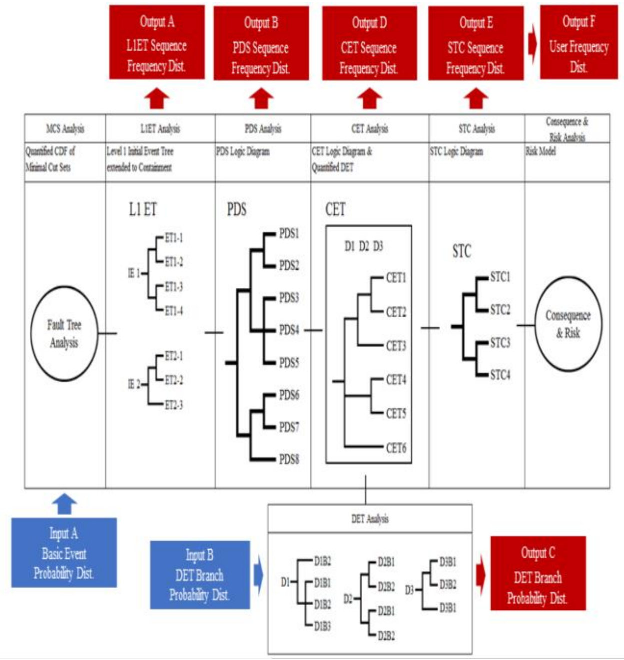


Fig. 1. The level 2 PSA uncertainty analysis process.

The probability values sampled from the probability distribution data of the basic event, input A, are used to quantify the frequency of accidents in the level 1 event tree, output A. The probability values sampled from the probability distribution data of the DET branch, input B, are used to quantify the probability of the DET branch, output C.

In multi-unit accidents, the level 2 PSA is performed using a method of fractional mapping of the plant damage groups for each unit derived from the quantification result of a single-unit level 2 PSA (Cho et al. (2018)). Since the CET/DET has uncertainty, the fractional mapping method also has uncertainty. Therefore, uncertainty analysis is performed using the random sampling so that the uncertainty of accident sequences of PDS corresponding to Output B can be statistically propagated to the uncertainty generated by the method of mapping table.

*(Figure 2~3 will be added)*

## 3. Display of the COFUN-M Results

Once the input variables to uncertainty analysis have been prepared, uncertainty analysis can be performed. When the analysis process is performed, the results are categorized as described below into the summary tab, samples tab, and uncertainty statistics tab on the UA Sampling screen.

Summary: Shows basic information as inputs to the uncertainty analysis, such as analysis time, seed number, point estimate of core damage frequency, uncertainty analysis results, and warning messages.

Samples: Shows the point estimates, the probability values of the DET splitting branch for each sample, and the frequency values of the PDS accident sequences.

Uncertainty statistics: Shows the point estimates, the mean of the sample, the standard deviation of the sample, the percentile of the sample, and the graph for the above five items. The point estimates can be compared with sampled values to verify that random sampling has been successful. Figures 4~7 shows the uncertainty statistics screen for the selected detail category which represents the outputs A~E in Figure 1.

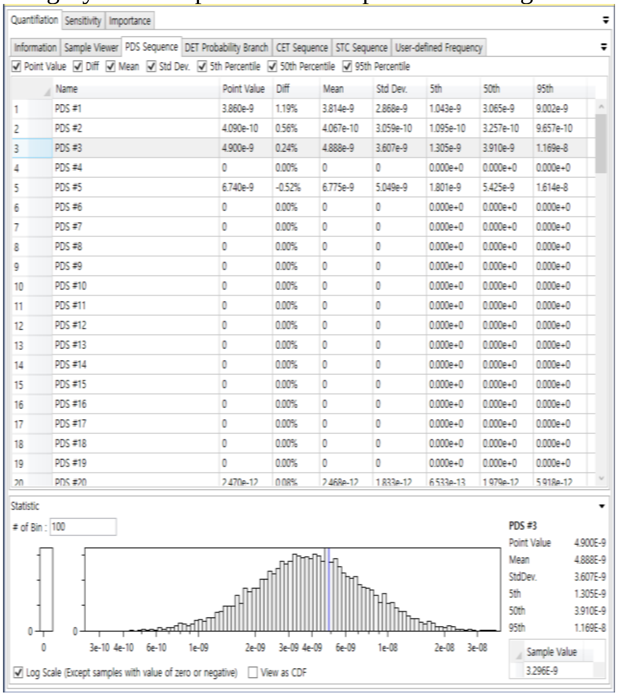


Fig. 4. Display of the result of PDS uncertainty analysis for single unit.

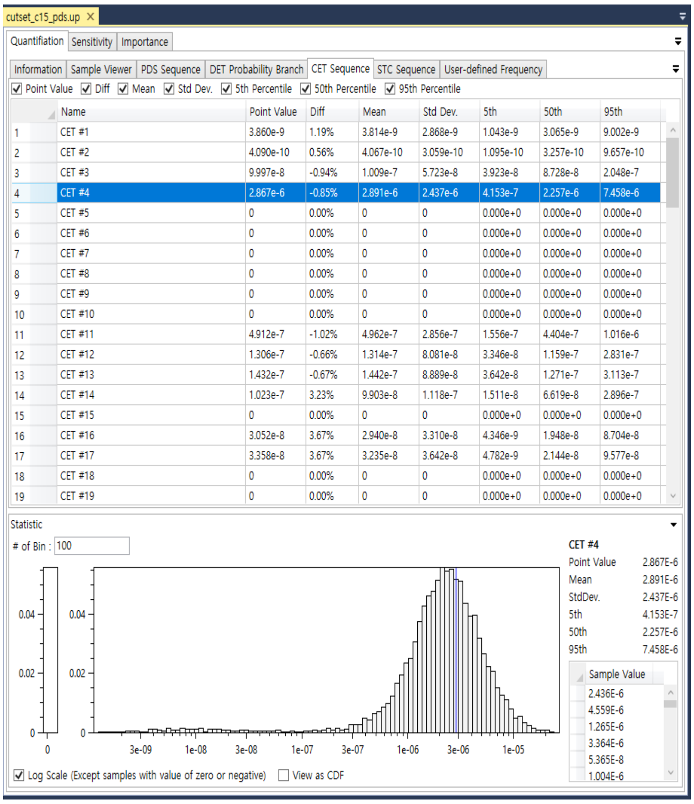


Fig. 5. Display of the result of CET uncertainty analysis for single unit.

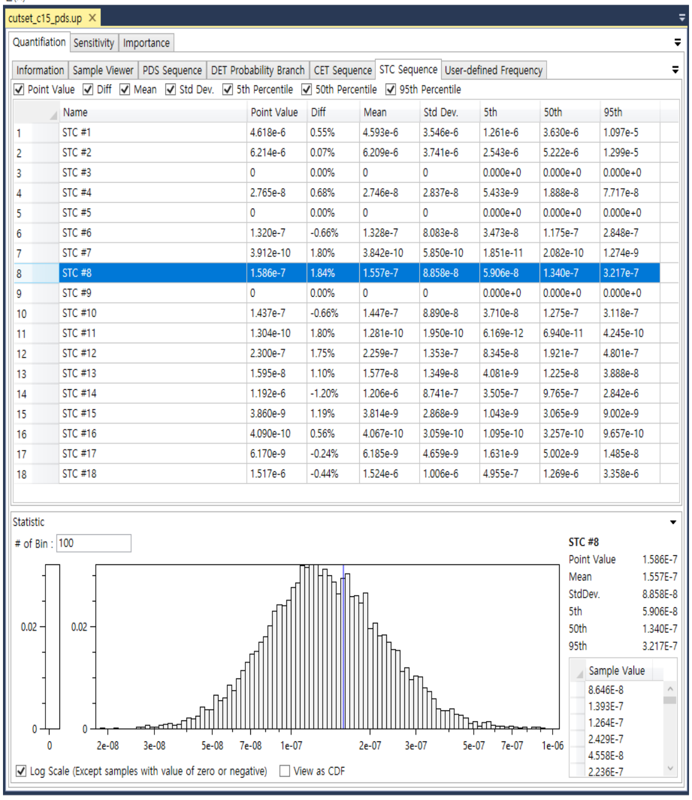


Fig. 6. Display of the result of STC uncertainty analysis for single unit

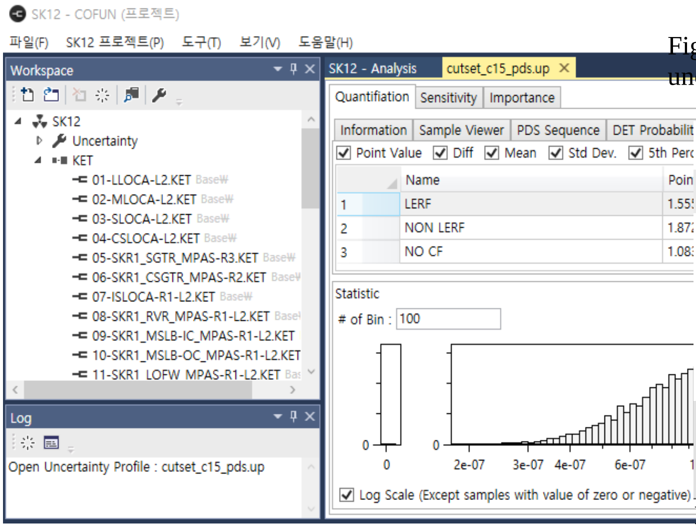

Fig. 7. Display of the result of the user-defined frequency uncertainty analysis for single unit

In the case of a single unit accident, the results are shown as source term category (STC), but in the case of a multi-unit accident, the final results are expressed as combinations of STCs, as shown in Figure 8, which makes it difficult to obtain a meaningful insight by itself. Therefore, in Figures 9 and 10, the combinations of STCs are classified using the rule, and the function of displaying the grouped STCs in the user-defined combination column is added. In Figure 7, NO CF means that frequency of the containment maintaining integrity for all reactors and large early release frequency (LERF) means that frequency of the large early release happened at least one reactor and NON LERF means the others.

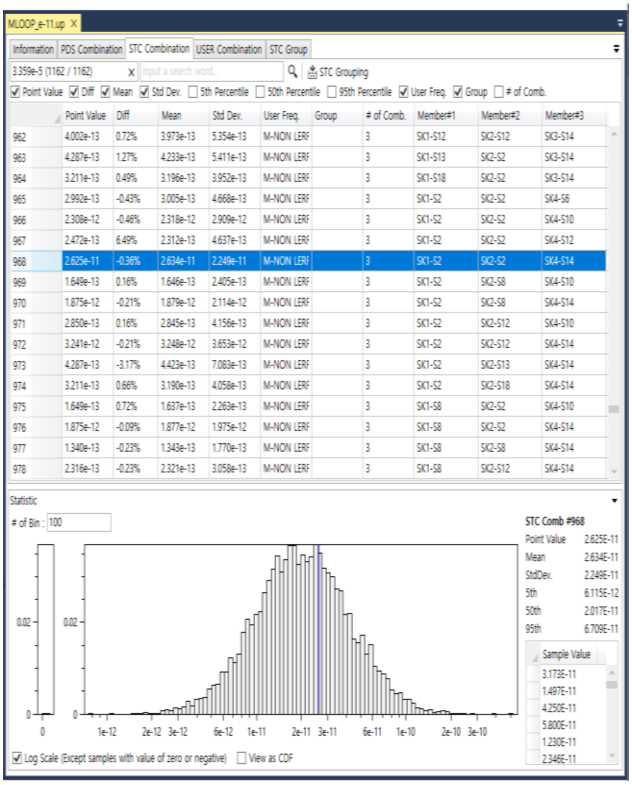

Fig. 8. Display of the result of STC combinations uncertainty analysis for multi-unit.

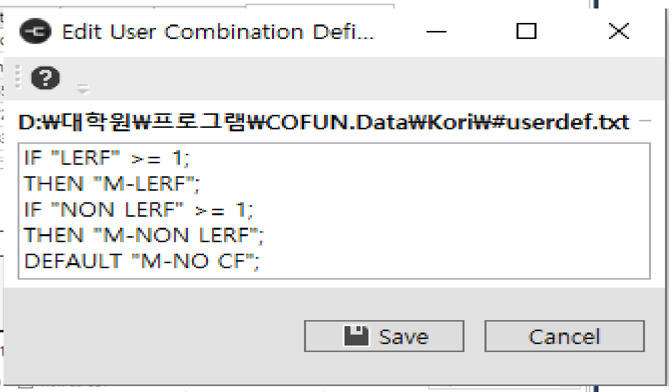


Fig. 9. The user frequency definition by rule.

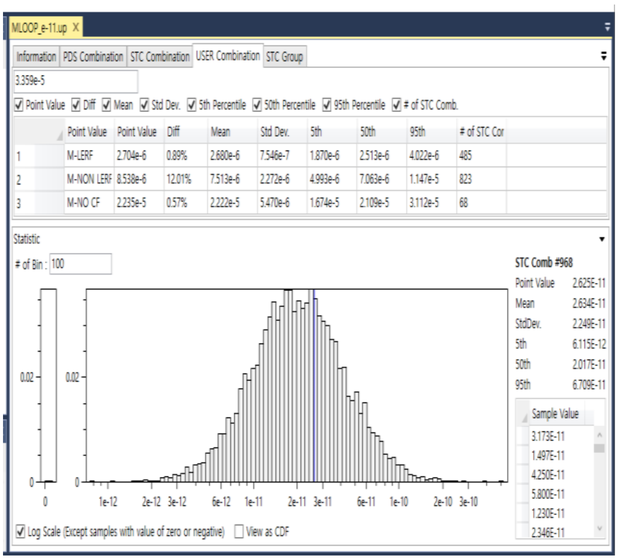

Fig. 10. Display of the result of the user-defined frequency uncertainty analysis for multi-unit.

## 3. Conclusions

In this paper, COFUN, a level 2 PSA program, is developed. The features of the COFUN code include quantification of the containment state by point estimate value, importance analysis, sensitivity analysis and uncertainty analysis. The uncertainty analysis is performed for the end point of the PDS, CET, STC and LERF. The Monte Carlo sampling method is selected for the uncertainty analysis.

Compared to previous level 2 PSA codes, the characteristics of the COFUN code is to perform the level 2 PSA for multi-unit accident. One of the formats of multi-unit level 2 PSA is a combination of STCs but the combinations could be too excessive to acquire insight by itself. So, the COFUN code provides user-defined combinations which makes STC combinations classified into specific groups.

## Acknowledgements

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