Development of Evaluation Code for MUF Uncertainty

Byung Hee Won*, Bo Young Han, Hee Sung Shin, Seong-Kyu Ahn, Geun-Il Park, and Se Hwan Park
Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong, Daejeon, 305-353
**Corresponding author: wonbh@kaeri.re.kr*

1. Introduction

Material Unaccounted For (MUF) uncertainty is an important factor to evaluate in order to ensure safeguardability of a bulk handling facility such as pyroprocessing facility. MUF is the material balance evaluated by measured nuclear material in a Material Balance Area (MBA). Assuming perfect measurements and no diversion from a facility, one can expect a zero MUF. However, non-zero MUF is always occurred because of measurement uncertainty even though the facility is under normal operation condition. Furthermore, there are many measurements using different equipment at various Key Measurement Points (KMPs), and the MUF uncertainty is affected by errors of those measurements. Evaluating MUF uncertainty is essentially required to develop safeguards system including nuclear measurement system in pyroprocessing, which is being developed for reducing radioactive waste from spent fuel in Korea Atomic Energy Research Institute (KAERI).

In this study, the evaluation code, which can calculate and analyze MUF uncertainty according to various measurement systems, was developed using MATLAB program. Graphical User Interface (GUI) in MATLAB was used for user conveniences and intuitive understanding.

2. Methods and Results

2.1 Principle of the Evaluation Model

Error propagation presented in IAEA reference [1] has been applied in the algorithm of the evaluation code to calculate the MUF uncertainty. This method calculates the MUF uncertainty using mathematical formulae for the combination of measurement uncertainties. There are two kinds of measurement uncertainties caused by random error and systematic error. MUF uncertainty generated by random errors of measurement system is shown in Eq. (1) derived from error propagation. In case of systematic errors, MUF uncertainty is calculated by Eq. (2). The final MUF uncertainty is indicated by the combination of uncertainties from random errors and systematic errors as shown Eq. (3).

$$\sigma_R = \sqrt{\sum_{i=1}^{I} c^2 \cdot m_i^2 \cdot \frac{\sigma_{ri}^2}{n}} \qquad (1)$$

$$\sigma_S = \sqrt{\sum_{i=1}^{I} [(\sum_{k=1}^{K} A_k \cdot c \cdot m_i)^2 \cdot \sigma_{si}^2]} \qquad (2)$$

$$\sigma_{MUF} = \sqrt{\sigma_R^2 + \sigma_S^2} \qquad (3)$$

where, σ_r = Standard Deviation of Random Error
σ_s = Standard Deviation of Systematic Error
c = Number of Campaign
i = Measurement Equipment ID
n = Number of Item
m = Nuclear Material Mass
A_k = 1(Input, Beginning)
-1(Output, Ending Inventory),
in Case of Same Equipment ID

2.2 Function of the Evaluation Code

Figure 1 shows the main screen consist of input data and analysis results of MUF uncertainty. Users who want to evaluate the MUF uncertainty in any bulk facility can input data such as measurement errors and campaign on the left-hand side of main screen. Then, the evaluation results are displayed as graph and table on the right-hand side.

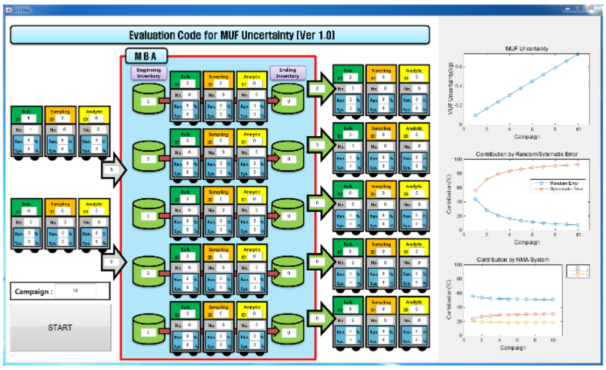


Figure 1. Main Screen of the Evaluation Code

Input data such as nuclear material mass at input, output, and inventory, measurement equipment ID, standard deviation of random/systematic errors, number of item to be measured, and number of campaign are required to calculate and analyze the MUF uncertainty based on Eq. (1)~(3).

In general, each measurement equipment has component of bulk, sampling, and analytic methods as shown Figure 2. These measurement methods can be flexibly considered by users according to measurement approaches of a facility.

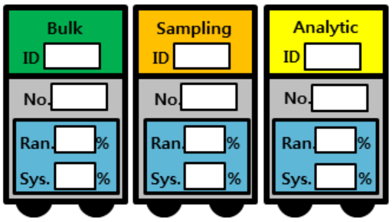
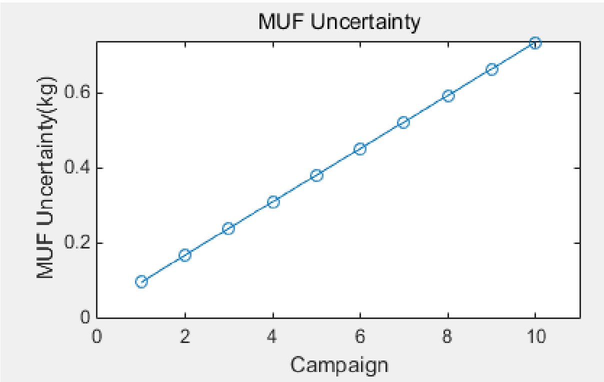
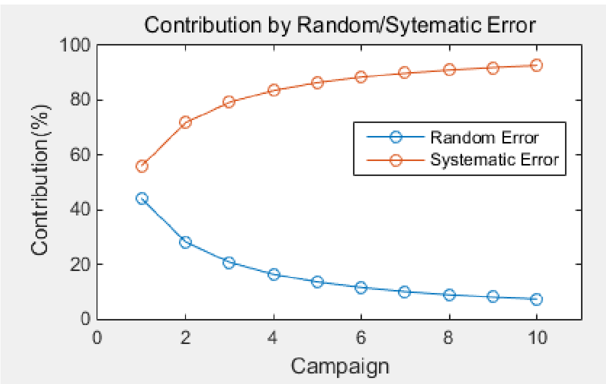


Figure 2. Input Data Form for a Measurement Equipment

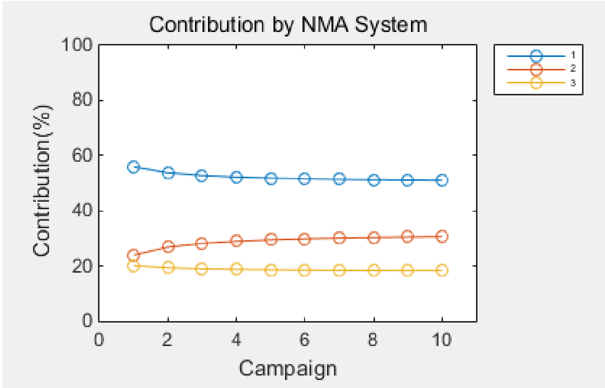
Figure 3 shows the results displayed as graph in the evaluation code. Users can check the values and tendency of MUF uncertainty by using the graph shown in figure 3-(a). Additionally, level of contribution according to the kind of error (random error, systematic error) can be identified by figure 3-(b). It shows that which error gives major influence to MUF uncertainty. Also, contribution of nuclear measurement equipment affecting MUF uncertainty can be analyzed by figure 3-(c). The evaluation code separately provides a table to confirm and save the accurate values of the results.



(a) MUF Uncertainty as Function of Campaign



(b) Level of Contribution according to Ran./Sys. Error



(c) Level of Contribution according to Measurement Equipment

Figure 3.The Results Displayed as Graph

2.3 Code Verification

Code verification was performed by using sample problems to identify the function and bug. Table 1 shows the input data of uranium measurement system from one of example on the IAEA reference [1]. In the example, there are one input material, two inventory materials, two output materials, and measurement equipment in each material as shown Table 1. MUF uncertainty calculated by these input data is 212.16 kg U.

Table 1. Input Data of Facility Handling Uranium Materials*

		Input	Output (Product)	Output (Waste)	Inventory (Dirty Sludge)	Inventory (Grinder Sludge)
Uranium Mass (kg)		240,000	238,800	1,200	7,200	4,000
Bulk	ID.	11	21	-	41	41
	No.	12,000	47,760	-	1,800	800
	Random Error (%)**	0.0658	0.0877	-	0.250	0.250
	Systematic Error (%)**	0.0439	0.0175	-	0.167	0.167
Sampling	ID.	12	-	-	42	52
	No.	400	-	-	60	48
	Random Error (%)**	0.0531	-	-	1.81	4.18
	Systematic Error (%)**	0	-	-	0	0.444
Analytic	ID.	13	23	33	43	43
	No.	400	240	2,770	60	48
	Random Error (%)**	0.0433	0.0568	5.77	2.74	2.74
	Systematic Error (%)**	0.0571	0.0341	4.62	0.896	0.896

* Campaign = 1.
** is expressed as relative standard deviation.

The evaluation code calculated the MUF uncertainty based on the same example and gave the same value, 212.16 kg U, as the result in the example.

3. Conclusions

The evaluation code for analyzing MUF uncertainty has been developed and it was verified using sample problem from the IAEA reference. MUF uncertainty can be simply and quickly calculated by using this evaluation code which is made based on graphical user interface for user friendly. It is also expected that the code will make the sensitivity analysis on the MUF uncertainty for the various safeguards systems easy and more systematic. It is suitable for users who want to evaluate the conventional safeguards system as well as to develop a new system for developing facilities.

The function that gives users a notice or warning on the inapposite input data will be included in the evaluation code to prevent incorrect use or mistakes in future.

Acknowledgment

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