

# Feasibility Demonstration of SAMEVAL and MUFEVAL for National Safeguards Inspections

Haneol Lee\*, Sang Hyeok Lee, Hyun Ju Kim, Jung Youn Choi, Jinho Ryu  
Korea Institute of Nuclear Non-proliferation and Control (KINAC)  
Corresponding Author: haneol@kinac.re.kr

\*Keywords: Nuclear Safeguards, National Inspection, Information Analysis, MUF, Sampling Plan

## 1. Introduction

Korea Institute of Nuclear Non-proliferation and Control (KINAC), as a part of a state system of accounting for and control (SSAC) of the Republic of Korea (ROK), has been conducting national safeguards inspection for domestic nuclear facilities. As the ROK adopted state-level approach (SLA) as the IAEA safeguards approach, the ROK NSSC made amendments in domestic regulations. One of the amendments is that the range of national inspection includes “verification of the declared accounting information” and “evaluation of the significance of the material unaccounted for (MUF)” [1].

As a result, KINAC developed software for sampling plan (SAMEVAL) and MUF evaluation (MUFEVAL) for independent national safeguards inspection [2, 3]. KINAC demonstrated the feasibility of applying the both software packages in national inspections to identify practical and regulation requirements.

This study summarizes the results of preliminary application of the SAMEVAL and MUFEVAL software in national safeguards inspection for a domestic bulk handling facility. Results indicate that the technical capability of both software packages satisfies requirements. However, this study identifies additional requirements to apply the both software packages for national inspection: uncertainty quantification (UQ) procedure, manual adjustments in accounting information, and regulation documents (guides and procedures).

As a result, the KINAC revised the software to adjust accounting information (uncertainty, stratification, etc.). Future works include to publish regulatory guides on information analysis in national safeguards inspection and standard operating procedures (SOPs) of uncertainty quantification in nuclear material accounting and the developed software.

## 2. Software Overview

The KINAC developed standalone software for sampling plan and MUF evaluation: SAMEVAL and MUFEVAL. Both software packages are MATLAB-based GUI applications and can be run on any laptop regardless of MATLAB installation. An overview of both software packages is provided below.

### 2.1. SAMEVAL Overview

The SAMEVAL software calculates the sample sizes of each stratum, which satisfy the target detection probability for 1 SQ nuclear material diversion in a stratum. The software calculates sample sizes using two different modes: KINAC and IAEA. The KINAC mode calculates numerical solution for hypergeometric distribution, whereas the IAEA mode calculates the solution for binomial and regression-based adjusted hypergeometric distribution [2, 4].

The SAMEVAL software then tests the effectiveness of the calculated sample sizes by calculating the detection probability for all possible diversion cases. The software also performs effectiveness test for both deterministic (IAEA) and stochastic (MC-based) methods.

The SAMEVAL software was validated by comparing the results to the IAEA’s sample size calculation software. The configuration of the SAMEVAL software is depicted in Figure 1.

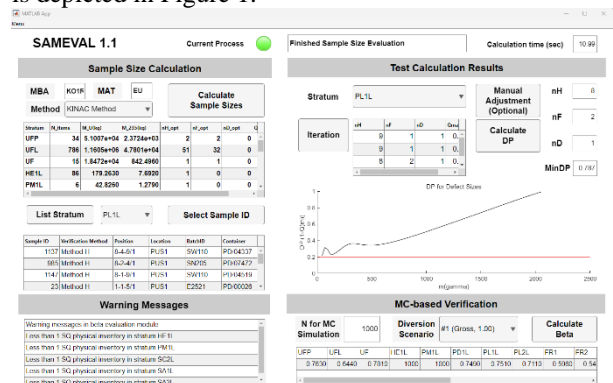


Fig. 1. SAMEVAL software overview

### 2.2. MUFEVAL Overview

The MUFEVAL software evaluates the significance of the MUF for a single material balance period (MBP) by comparing the calculated MUF to the given confidence interval. The confidence interval is calculated using the confidence level ( $z_{\alpha/2}$ ) and MUF uncertainty ( $\sigma_{MUF}$ ). The software calculates the MUF uncertainty using two different modes: KINAC and IAEA. The KINAC mode reflects detailed accounting information of target facility and GUM-based uncertainty quantification & propagation. The IAEA mode reflects the static  $\sigma_{MUF}$  calculation process in the IAEA technical report (STR-326) [3, 5, 6].

The MUF EVAL software then analyzes the contribution of each stratum or accounting process on  $\sigma_{MUF}$ . It also evaluates the significance of cumulative MUF (CuMUF) for a series of MBPs.

The MUF EVAL software was also validated by comparing the results to the IAEA's MUF evaluation software. The configuration of the MUF EVAL software is depicted in Figure 2.



Fig. 2. MUF EVAL software overview

### 3. Feasibility Demonstration

The feasibility of applying the SAMEVAL and MUF EVAL software was demonstrated for national safeguards inspection in 2025. Target facility was a domestic fuel fabrication plant and the relative standard deviation (RSD) of accounting systems was considered to be the ITV level [7].

#### 3.1. SAMEVAL Results

This study calculated and tested sample sizes for the target facility for the two calculation modes (KINAC, IAEA) using the SAMEVAL software. The calculated sample sizes were compared to the IAEA results for the same accounting information (list of inventory item (LI)). However, the IAEA's results were calculated using the IAEA's independent RSD database for the target facility, which is classified data. Results are summarized in Table 1. The difference between SAMEVAL IAEA mode and IAEA sample size calculation comes from the differences in RSD. The IAEA's sample sizes for a stratum (SC2L) are manually adjusted by coordination inspector.  $n_H$ ,  $n_F$  and  $n_D$  in Table 1 indicate the sample sizes for gross, partial and bias defect verification respectively.

Table 1. SAMEVAL & IAEA software results

| Strat. Name | SAMEVAL    |       |       |           |       |       | IAEA  |       |       |
|-------------|------------|-------|-------|-----------|-------|-------|-------|-------|-------|
|             | KINAC mode |       |       | IAEA mode |       |       |       |       |       |
|             | $n_H$      | $n_F$ | $n_D$ | $n_H$     | $n_F$ | $n_D$ | $n_H$ | $n_F$ | $n_D$ |
| FF1         | 2          | 1     | 0     | 1         | 2     | 0     | 1     | 2     | 0     |
| FF2         | 3          | 2     | 0     | 2         | 3     | 0     | 2     | 3     | 0     |
| FF3         | 0          | 1     | 0     | 0         | 1     | 0     | 0     | 1     | 0     |
| FFP         | 3          | 0     | 0     | 3         | 0     | 0     | 3     | 0     | 0     |
| FR1         | 0          | 1     | 0     | 0         | 1     | 0     | 1     | 0     | 0     |
| FR2         | 1          | 1     | 0     | 1         | 1     | 0     | 1     | 1     | 0     |

|      |    |    |   |    |    |   |    |    |   |
|------|----|----|---|----|----|---|----|----|---|
| HE1L | 1  | 0  | 0 | 1  | 0  | 0 | 1  | 0  | 0 |
| PD1L | 5  | 0  | 1 | 5  | 0  | 1 | 4  | 1  | 1 |
| PL1L | 8  | 2  | 1 | 8  | 2  | 1 | 8  | 2  | 1 |
| PL2L | 0  | 0  | 1 | 0  | 0  | 1 | 1  | 0  | 0 |
| PM1L | 1  | 0  | 0 | 1  | 0  | 0 | 1  | 0  | 0 |
| SA1L | 1  | 0  | 0 | 1  | 0  | 0 | 1  | 0  | 0 |
| SA2L | 1  | 0  | 0 | 1  | 0  | 0 | 1  | 0  | 0 |
| SC1L | 4  | 1  | 1 | 4  | 1  | 1 | 4  | 1  | 1 |
| SC2L | 0  | 0  | 1 | 1  | 0  | 0 | 1  | 0  | 0 |
| SD1L | 1  | 3  | 0 | 0  | 4  | 0 | 3  | 1  | 0 |
| UF-  | 1  | 1  | 0 | 1  | 1  | 0 | 1  | 1  | 0 |
| UFL  | 49 | 34 | 0 | 51 | 32 | 0 | 49 | 34 | 0 |
| UFP  | 2  | 2  | 0 | 2  | 2  | 0 | 2  | 2  | 0 |

#### 3.2. MUF EVAL Results

This study also evaluated whether the MUF is acceptable or not for the two calculation modes (KINAC, IAEA) using the MUF EVAL software. Since the IAEA's  $\sigma_{MUF}$  calculation results are also classified data, MUF EVAL results for the both modes are summarized in Table 2. Since the IAEA mode calculates static  $\sigma_{MUF}$ , the  $\sigma_{MUF}$  of the IAEA mode is much higher than the results of the KINAC mode. The contribution analysis results of the KINAC and IAEA modes are summarized in Table 3, Figures 3 and 4. Table 3 summarizes the variance of top 5 contributors of  $\sigma_{MUF}$  for the both modes.

Results indicate the KINAC mode can analyze the contribution of  $\sigma_{MUF}$  in accounting system (or process) level, whereas the IAEA mode can analyze the contribution in stratum level.

Table 2. MUF EVAL results

|                     | KINAC mode | IAEA mode |
|---------------------|------------|-----------|
| MUF (kg)            | 26.040     |           |
| $\sigma_{MUF}$ (kg) | 42.5631    | 97.3375   |
| Significance?       | No         | No        |

Table 3.  $\sigma_{MUF}$  contribution results

| KINAC mode          |                         | IAEA mode          |                         |
|---------------------|-------------------------|--------------------|-------------------------|
| Contributor         | Var. (kg <sup>2</sup> ) | Contributor        | Var. (kg <sup>2</sup> ) |
| TIMS <sub>KNF</sub> | 428.8217                | UFL <sub>PB</sub>  | 3827.6749               |
| TIMS <sub>Ref</sub> | 413.6295                | UFL <sub>PE</sub>  | 3776.0588               |
| TITR <sub>Ref</sub> | 408.8742                | FF2 <sub>v</sub>   | 951.1229                |
| GRAV <sub>GdU</sub> | 325.8350                | UFL <sub>X</sub>   | 651.3052                |
| EBAL <sub>UF6</sub> | 103.3937                | PL1L <sub>PB</sub> | 43.6564                 |

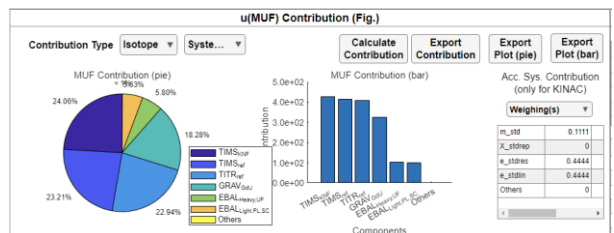


Fig. 3.  $\sigma_{MUF}$  contribution analysis for KINAC mode

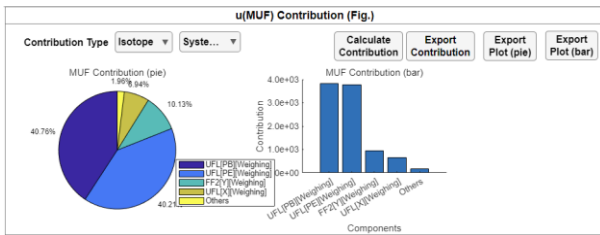


Fig. 4.  $\sigma_{MUF}$  contribution analysis for IAEA mode

### 3.3. Key Findings

The results of the feasibility demonstration indicated that the technical capability of both software packages meets the requirements. However, this study identified three additional requirements for applying the SAMEVAL and MUFVAL software in national inspection as well.

The first requirement is to establish standard UQ procedures for accounting systems. Both software requires the RSD of accounting systems of a target facility. However, the RSD values in the ITV document do not reflect the characteristics of the accounting systems of the target facility. Therefore, an independent standard UQ procedure is required.

The second requirement is to adjust accounting information manually. Both software contains the accounting information (stratification rules, RSD information, etc.) of a target facility. Since the inventory characteristics changes for each MBP, the stratification rules and accounting - verification system need to be adjusted manually. Therefore, manual adjustments in accounting information are required for the both software packages.

The third requirement is to establish regulation documents. The results of both software are used to satisfy the requirements of national inspection. Considering the purpose of the software, SOPs for the both software are essential.

The KINAC has revised the structure to load the accounting information of the SAMEVAL and MUFVAL software to satisfy the second requirement. The two other requirements are planned to be reflected in the future.

## 4. Conclusion

The KINAC developed SAMEVAL and MUFVAL software to strengthen the technical capability of national safeguards inspection in the ROK. This study demonstrated the feasibility of applying both software for national inspection. The study first compared the sampling plan results of SAMEVAL to the results of an IAEA software. It then compared the MUF evaluation results of MUFVAL for both KINAC and IAEA modes.

Results indicated that both software packages satisfy the technical requirements for national inspection. However, the results also identified that three additional

requirements exist for the software to be applied: UQ procedure, manual adjustment in accounting information, and regulation documents. The KINAC has been revising the software considering the requirements.

## ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS) using the financial resources granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea. (No. 2106015)

## REFERENCES

- [1] Article 4 of Regulations on the Safeguards Inspection of Special Nuclear Materials of the ROK, NSSC Notification No. 2025-02, 2025.
- [2] H. C. Lee et al., Evaluation of MUF uncertainty based on GUM method for benchmark bulk handling facility, Nuclear Engineering and Technology, Vol. 56, pp. 2937-2947, 2024.
- [3] H. Lee et al., Examination of SAMEVAL: Software to calculate and evaluate sample sizes for national safeguards inspection in the Republic of Korea, Vol. 57, 103718, 2025.
- [4] H. Lee et al., Development of Sample Size Calculation and Evaluation Software (SAMEVAL) for National Safeguards Inspection, NSTAR-24PS12-089, 2024.
- [5] H. Lee et al., Statistical Evaluation of the Uncertainty of the Material Unaccounted for (MUF), Symposium on the International Safeguards: Reflecting on the Past and Anticipating the Future, IAEA-CN-303, 2022.
- [6] M. Williams et al., Material Balance Evaluation, STR-326 (Rev. 0), IAEA, April, 2002.
- [7] IAEA, International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials, STR-368 (rev. 1.1), IAEA, Vienna, September, 2022.