Development of analysis tool to calculate detection probabilities under various conditions of safeguards system

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1. Introduction

IAEA objective is described as "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of the other nuclear explosive devices or for purpose unknown, and deterrence of such diversion by the risk of early detection" [1,2]. According to that, the numerical factors associated with safeguards objectives are significant quantity, detection time, detection probability, and false alarm probability [3]. Therefore, detection probability is one of the important quantitative factors to evaluate safeguards. For a simple system, the detection probability can be easily calculated by commercial numerical analysis software using general function. However, in complex conditions such as a large number of strata in a facility, a complex safeguards system, various scenarios to be considered, etc., it is necessary to develop a dedicated code to reduce calculation time and effort.

In this study, an analysis tool was developed to calculate the detection probability under these complex calculation conditions.

2. Methods and Results

The detection probability calculation tool was developed using a MATLAB code. A basic formula for detection probability using one measurement method is described in the previous work [4]. Based on this formula, a detection probability calculation code was developed considering multiple measurement methods and strata in this work. To validate the developed code, calculations were performed on the example cases published in the IAEA report [5], and the results were compared. Table 1 presents the conditions of the example cases. The detection probability depends on the diversion size, that is, how many items are diverted in a stratum, and the minimum detection probability among them is determined as the final detection probability. As shown in Fig.1, the consistency between two results was confirmed. This tool has four main functional characteristics.

Table I: Example cases conditions

Case	M	x	N	δ1	δ2	δ3
1	8	0.5	278	0.15	0.12	0.023
2	8	0.5	647	0.15	0.0099	-

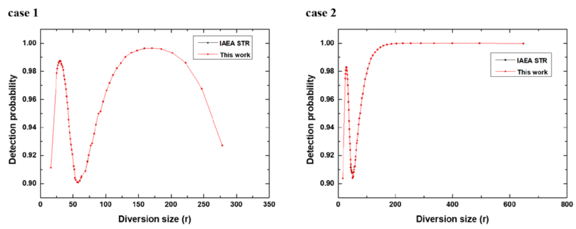

Fig. 1. Detection probability code verification results (sample sizes were determined by following the IAEA sampling plan)

First, for a large number of strata, the individual stratum and the facility's total detection probability can be calculated.

Second, this tool provides to calculate the optimal sample size, that is, the number of samples to be taken to satisfy the desired detection probability for each stratum considering the applied safeguards measurement methods. In addition, the number of samples may be input by the user as a desired value, so that the detection probability for a specific number of samples may be calculated conversely. For calculating the optimal sample size in this tool, the algorithm to calculate sample sizes for IAEA sampling plan [5] was implemented using MATLAB code. The effect of the detection probability of the facility according to the change in the sample sizes can be evaluated using this function under specific safeguards system.

Third, this tool can be applied for various facility types. From the perspective of IAEA safeguards, facility type is classified as item facility and bulk facility. The item facility is facility where all nuclear material is kept in item form and the integrity of the item remains unaltered during its residence at the facility and the bulk facility is a facility where nuclear material is held, processed or used in bulk form [2]. In most cases, both item and bulk materials co-exist in a bulk facility. The diversion size for each facility was determined in different way. In the case of an item facility, the diversion size is determined as a specific one value according to the target amount of diversion and average amount of nuclear material per item, and in the case of a bulk facility, it is necessary to evaluate the detection probability for all possible diversion sizes.

Forth, using this tool, the detection probability for multi-stratum diversion scenario can be calculated. A target amount diversion may occur from a single stratum or through several strata. In this manner, diversion is possible in numerous cases, and evaluating these cases is necessary. This calculation capability can be utilized to derive approaches for enhancing the safeguards system efficiently.

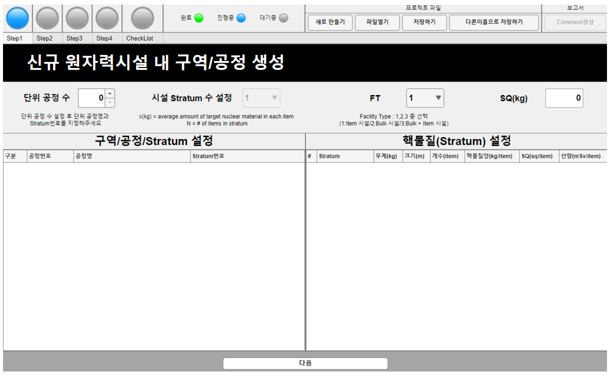

Fig. 1. Input window of the calculation tool

3. Conclusions

An analytical tool was developed to calculate detection probability under various complex conditions. Using this tool, it is possible to calculate detection probabilities for a facility with a large number of strata, various types of facility, and multi-stratum diversion scenarios. Furthermore, optimal sample sizes can be calculated to achieve the target detection probabilities. These functional characteristics have been developed in the form of several sub-tools and further work is planned to integrate them into one tool. It is expected that this tool can be applied to evaluate and strengthen safeguards system for inspections or safeguards-by-design.

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