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A Study of Safeguardability Evaluation Approach for implementation of SBD

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1. Introduction

The new nuclear facilities such as spent fuel interim storage facilities and small modular reactors are expected to be introduced in ROK. IAEA recommends safeguards by design (SBD) for new nuclear facility. SBD is defined as an approach whereby international safeguards requirements and objectives are fully integrated into the design process of a nuclear facility, from initial planning through design, construction, operation, and decommissioning [1]. The major benefit of SBD is cost effectiveness by reducing the cost of safeguards implementation to the operator and the IAEA [1]. Because, if safeguards are taken into account at the stage of construction completion, design changes may be inevitable for safeguards implementation. Thus, consideration of SBD from initial design stage provides effective and efficient safeguards for both facility operators and the IAEA. However, there is no domestic legal basis and system to consider SBD. Therefore, it is necessary to establish a legal basis for the implementation of SBD. In addition, it is required technical methods to evaluate whether safeguards system have been sufficiently considered in the design of new nuclear facility. Safeguardability is defined as the degree of ease with which a system can be effectively and efficiently safeguarded and is estimated for targets on the basis of characteristics related to the nuclear material, process implementation and facility design [2]. For that reason, estimation of safeguardability and estimation tools are required for SBD implementation at the design stage.

In this study, overall evaluation process and evaluation approach were suggested as a fundamental study to develop the evaluation program of safeguardability.

2. Safeguardability Evaluation Approach

The safeguardability evaluation approach developed in this work aims to utilize for safeguards regulatory agency, and designer should provide the required information to regulatory authorities for evaluation. The evaluation process and role of designer/operator and regulatory agency in the process were shown in Fig. 1.

Providing required facility design information to safeguards regulatory agency is the first step of the evaluation process. This information is used as an input data to produce diversion pathways for specific facility and to create sub-systems for safeguardability evaluation. Based on the IAEA safeguards guidelines, designer/operator incorporates safeguards considerations into the design and submits the draft. Then, regulatory agency sets the input values for evaluation based on the diversion pathways and draft of the safeguards design and evaluates the safeguardability of initial facility design. If the results are not sufficient by comparing the IAEA safeguards requirements, the regulatory agency provides review paper about design vulnerability and designer submits modified design by reflecting the review. This process is repeated until safeguardability is satisfied.

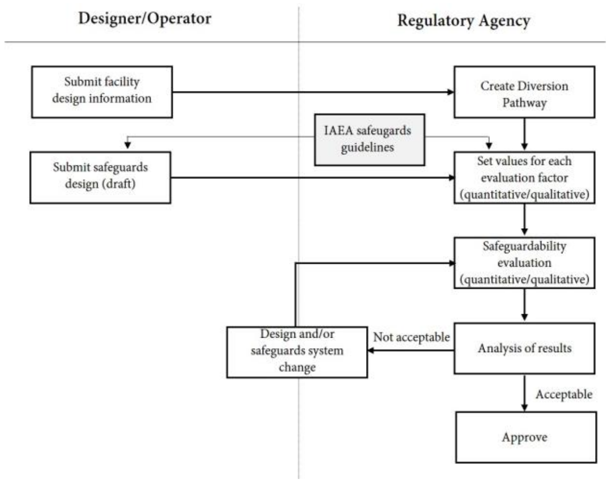

Fig. 1. Overall safeguardability evaluation process

According to the definition of safeguardability, achievement of IAEA safeguards objective, applicability of safeguards measures, and ease of IAEA inspection were determined as evaluation parameters for safeguardability [3]. The objective of IAEA safeguards is timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities [4] then quantitative evaluation is possible for this parameter. However, applicability of safeguards measures and ease of inspection are difficult to evaluate quantitatively. Then, qualitative evaluation is performed.

2.1. Quantitative evaluation

The parameters for quantitative evaluation are detection probability and diversion time according to the objective of IAEA safeguards and these parameters are evaluated for each diversion pathway. Therefore, vulnerable diversion pathway or unit process can be identified. The diversion time is the minimum time required to overcome the barriers to diversion or misuse [2].

$$D_T = \sum D_{Ts} \quad (1)$$

In equation (1), D_T is total diversion time of each diversion pathway and D_{Ts} is diversion time of specific diversion step. The non-detection probability is determined by probability of selection of the defects as an inspection sample (A_i) and probability of failing to classify it as a defect (B_i) and is given by:

$$\beta = \sum_{i=\max(0,n-(N-r))}^{\min(r,n)} A_i \cdot B_i \quad (2)$$

where,

$$A_i = \binom{r}{i}\binom{N-r}{n-i} / \binom{N}{n} \quad (3)$$

$$B_i = \left(\phi\left(\frac{3\delta x - M/r}{\delta\left(x - M/r\right)}\right)\right)^i \quad (4)$$

and where, r is number of defects, i is number of defects selected as inspection samples, N is total number of items in stratum, n is number of inspection samples, x is average amount of nuclear material per item, M is diverted goal amount, and δ is relative standard deviation of an operator-inspector difference for safeguards method. The detection probability is calculated for each stratum in the facility, and the overall non-detection probability is calculated as follows.

$$\beta_T = \prod_{st} \beta_{st} \quad (5)$$

The IAEA employs up to three measurement methods in the stratum to detect gross defects, partial defects, and bias defects, respectively. Then, the values n and δ are determined by considering the level of measurement methods. The values of n_j (number of inspection samples for method j) are determined by the IAEA sampling plan. The evaluation program to be developed based on this study will include a function to calculate n_j, when it calculates the detection probability.

In addition, parameters to estimate detection resource efficiency, such as manpower and cost, are included in quantitative evaluation factors and are calculated as a simple summation according to the safeguards system, such as the safeguards measures and the safeguards inspection activities.

2.2. Qualitative evaluation

The applicability of safeguards measures and the ease of IAEA inspection in the facility are evaluated qualitatively. The evaluation factors were specified in the previous work [3] and it was consisted of the ease of design information verification, nuclear material accountancy, and surveillance/containment. The development of specific sub-parameters is in progress and the evaluation is conducted in the form of a checklist (yes/no). The checklist is provided to designer to self-estimate the design. The designer checks the lists at all processes or points where the safeguards activities are implemented.

3. Conclusions

The SBD is recommended for introducing new nuclear facilities and the evaluation of safeguardability is necessary to implement SBD. The major evaluation parameters of safeguardability are achievement of IAEA safeguards objective, applicability of safeguards measures, and ease of IAEA inspection. The overall evaluation process and the approach for qualitative and quantitative evaluation was suggested in this study. Based on the evaluation approach in this study, the safeguardability evaluation program will be designed and developed to utilize for the effective and efficient design of new nuclear facilities.

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