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Safeguardability Assessment of Hypothetical Example Small Modular Reactor

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1. Introduction

To evaluate a safeguardability, safeguardability evaluation tool (SET) was developed [1]. This program was developed to support regulatory activities for safeguards by design (SBD), and the construction of a facility model of a new nuclear facility is necessary to conduct case studies aimed at deriving methodologies for strengthening SBD.

In this study, the facility model is based on a light water small modular reactor (SMR) that has high potential for commercialization in Korea. Based on existing IAEA safeguards approaches for nuclear facilities, a safeguards system was established for the facility model, and a safeguardability evaluation was conducted using SET.

2. Design of Facility Model

2.1 Selection of the Target Facility for Facility Model Design

The SMR technologies with high commercialization potential in Korea are SMART and i-SMR, both of which are light water reactor (LWR) types. Accordingly, a light water SMR was selected as the target facility for the facility model. Although i-SMR is currently regarded as the most promising for domestic deployment, it remains at the conceptual or basic design stage, and thus lacks sufficient publicly available design information for research application. Consequently, this study established a facility model based on the publicly available design data of SMART [2-6], which is the most technologically advanced among domestic SMRs and has obtained standard design approval. For design elements not disclosed in the SMART documentation, reference was made to design information from existing commercial LWR in Korea.

2.2 Design of the Facility Model

The facility model developed in this study is a hypothetical facility reconstructed based on the design of SMART and commercial LWR, for the purpose of conducting case studies. This hypothetical facility is hereafter referred to as the example small modular reactor (ESMR).

The scope of the facility model developed in this study encompasses all elements necessary for the evaluation of safeguardability. These include the types and quantities of nuclear material, process procedures, nuclear material flow, the spatial arrangement of key processes and areas, and the implementation of the safeguards system. The following presents the key facility design parameters and information on the implemented safeguards system for ESMR.

1)Information on facility and process design parameters

Table I: ESMR stratum information

#	Stratum	Nuclear material amount (kg/item)	
		U-235	Pu
1	Fresh fuel assembly	10.4	0
2	Spent fuel assembly	3.2	2.5

Table II: Information on nuclear material handling areas within the ESMR reactor building

#	Code	Area
1	HA	Fuel loading & unloading hatch
2	FFS	Fresh fuel storage
3	RC1	Reactor 1
4	RC2	Reactor 2
5	RC3	Reactor 3
6	RC4	Reactor 4
7	SFS	Spent fuel storage
8	CLA	Cask loading area
9	CWA	Cask wash-down area

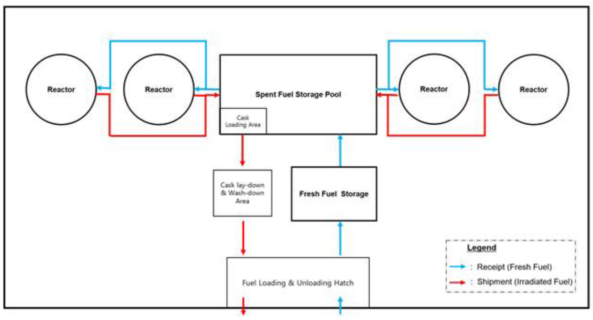

Fig. 1. Fuel assembly transfer path

2) Design of safeguards system

The entire facility is designated as a 1 material balance area (MBA) and is composed of 3 flow-key measurement points (F-KMPs) and 6 inventory-key measurement points (I-KMPs).

Table III: ESMR KMP information

KMPs		Description
Flow KMPs	1	- Location: fresh fuel storage - Type of NM: fresh fuel assembly - Verification: Item counting, ID check
	2	- Location: reactor core - Type of NM: spent fuel assembly - Verification: Item counting, ID check
	3	- Location: spent fuel loading area (CLA, CWA) - Type of NM: spent fuel assembly (in the cask) - Verification: Item counting, ID check
Inventory KMPs	A	- Location: fresh fuel storage - Type of NM: fresh fuel assembly - Verification: Item counting, ID check, NDA (HM-5)
	B,C,D,E	- Location: reactor core - Type of NM: spent fuel assembly - Verification: N/A
	F	- Location: spent fuel storage - Type of NM: spent fuel assembly - Verification: Item counting, ID check, NDA (ICVD)

The containment and surveillance (C/S) system for maintaining the continuity of knowledge (CoK) during nuclear material transfers was designed based on the layout and structural information of the facility's access points and physical barriers (Fig. 2).

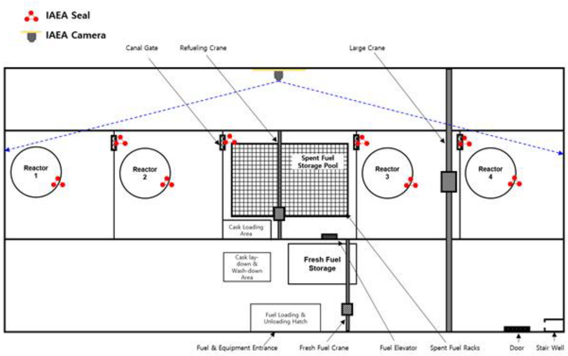

Fig. 2. Design of ESMR C/S system

3. Safeguardability Evaluation of ESMR

Based on the SET methodology, a total of 65 basic diversion pathways were generated. When additional scenarios are considered-1) diversion pathway using dummy, 2) diversion pathways by safeguards neutralization, and 3) pathways combining dummy use and safeguards neutralization-the total number of diversion pathways increases to 260.

With the facility design and safeguards system presented in Chapter 2, a safeguardability assessment was conducted. By analyzing the most frequently appearing strata and processes/routes among the 260 diversion pathways, the facility's vulnerabilities were evaluated. The spent fuel assemblies, fuel handling hatch, the transfer route between the SFS and reactor, and the SFS pool were identified as relatively vulnerable points. The probability of successful diversion was evaluated using a fault tree and event tree analysis. Among the identified pathways, those involving the neutralization of the safeguards system were found to be the most vulnerable. In particular, the fuel handling hatch, FFS, SFS pool, and areas for cask loading and decontamination were identified as relatively susceptible under the neutralization strategy. Therefore, reinforcement of the safeguards system in these areas is necessary.

4. Conclusions

The facility model developed in this study, ESMR, is a hypothetical installation reconstructed from the SMART and conventional LWR design. The safeguards system of the ESMR was designed based on the IAEA safeguards approach for commercial nuclear reactor. The diversion pathways for the ESMR were identified and a safeguardability assessment was conducted in accordance with the SET methodology. A total of 260 diversion pathways were identified, and the probability of successful diversion was evaluated for each pathway to analyze their relative vulnerabilities.

Acknowledgements

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