Facility Safeguardability Assessment of the i-SMR

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1. Introduction

Safeguards by design (SBD) is a concept that safeguards should be integrated with designing a new facility [1-4]. It provides advantages to the interest parties, including the IAEA and the operator. The IAEA can inspect the facility without delay, and the operator reduces the cost of design change due to safeguards issues by carrying out the SBD. SBD's principal and essential process are facility safeguardability assessment (FSA)[5]. Safeguardability is defined as 'the degree of ease with which a nuclear energy system can be effectively and efficiently placed under international safeguards'[6]. Suppose the FSA is applied during the conceptual design stage. In that case, state regulatory authority (SRA, or Safeguards Regulatory Authority) and the IAEA can engage early to resolve safeguards issues with minimal cost and project schedule. The FSA is a process to compare a new design facility with a reference facility whose safeguards approach is confirmed using the FSA screening questions. In South Korea, innovative Small Modular Reactor (i-SMR) is recently under development. It is an appropriate time to introduce the SBD and the FSA to examine the safeguards issues of this type of SMR. A preliminary FSA was performed in this paper using the FSA screening questions, and APR-1400 was adopted as a reference facility.

2. FSA process

2.1 Principle of FSA process

The FSA process is performed to identify differences in a cost-effective manner between a new facility design and a reference facility design with an established IAEA safeguards approach. Through this process, potential changes in safeguards tools and measures that are needed to accommodate the new design can be identified. Because the i-SMR design differs from the PWR, the safeguards tools and measures used for it will likely be slightly changed. It is needed for the i-SMR to make a tremendous effort to ensure facility safeguardability. New safeguards tools and measures should be adopted if potential changes in IAEA safeguards approaches are identified. The designer could modify the new design to eliminate the potential need for a change in safeguards approaches or would apply required changes to the current safeguards tools and measures. Communication with the SRA and the IAEA is essential to discuss the FSA process. The FSA process will enable the designer to communicate with the SRA and the IAEA on the potential IAEA safeguards impact early in the design process.

2.2 FSA Screening Questions

The authors used the FSA screening questions to identify aspects of the i-SMR design that may create potential safeguards issues by comparing it to the APR-1400, which the IAEA safeguards approach has confirmed and implemented. The questions are comprised of four top-level questions and 36 low-level questions. Question 1 is about the possible presence of different types, categories, or forms of nuclear material that can require new safeguards approach. Question 2 focused on design information examination and verification. It addresses new technologies and equipment that may hamper the evaluation and verification of design information. Question 3 highlights design changes that the IAEA may find challenging to verify if the diversion has occurred. Question 4 addresses design differences that impede the detection of facility misuse. The Top-level questions from 1 to 4 are in Table 1[5].

Table 1. FSA Screening Questions of Top-level

Facility Safeguardability Assessment Screening Questions
1. Does this design differ from the comparison design/process in ways that have the potential to create additional diversion paths or alter existing diversion paths?
2. Does this design differ from the comparison design in a way that increases the difficulty of design information examination (DIE) and verification (DIV) by IAEA inspectors?
3. Does this design/process differ from the comparison design/process in a way that makes it more difficult to verify that diversion has not taken place?
4. Does this design differ from the comparison design in ways that create new or alter existing opportunities for facility misuse or make detection of misuse more difficult?

3. Results and Discussion of the i-SMR's FSA

3-1 Characterization of the i-SMR

An overall feature of the i-SMR is needed to perform the FSA since the FSA process is based on comparing a new design with the reference one. The FSA is an iterative process that can be conducted in the pre-conceptual design stage. There might be several changes in a new facility design, and corresponding assessments should be done together. Table 2 shows the overall feature of the i-SMR and the APR-1400 as reference designs. The information on the i-SMR can be changed since the final design of the i-SMR has not yet been determined.

Table 2. An overall feature of the i-SMR and the APR-1400

Design Information	i-SMR	APR-1400
Electrical Output	170 MWe/Module	1400 MWe
Total Electrical Output	680 MWe	1400 MWe
Number of Modules	4	1
Fuel	UO2 (5-7% U235)	UO2 (<5% U235)
Number of FA	69 FAs	236 FAs
Active Core Height	2.4 m	4 m
Refueling Cycle	24 months	18 months
Coolant	Light Water	Light Water
Plant Design Life	80-100 yrs	60 yrs

3-2 FSA results of the i-SMR

The FSA of the i-SMR were conducted using Table 1 and 2. The design aspects affecting the safeguards approach are fuel features such as the enrichment, the active core height, the number of FAs(Fuel Assembly), the refueling cycle, and the number of modules(reactors). Spent fuel stacking methods, refueling areas, and procedures also affect the safeguards approach.

3-2-1 Results of FSA on Question 1

Although the i-SMR adopts a 17x17 type fuel assembly same as the APR-1400, it has different features, such as the enrichment (up to 7% U-235) and the active fuel length (2.4 m). There are no significant changes in diversion paths due to fuel, but the effect of increased enrichment should be analyzed further. Adopting module-type reactors may create new diversion paths, and a more detailed diversion path analysis is required. Especially the refueling area for multiple modules in the i-SMR decreases the safeguards' effectiveness if modules operate simultaneously. The modular design increases the difficulty of maintaining continuity of knowledge (CoK) of the inventory of the reactor vessels and the spent fuel pool. Therefore, more rigorous surveillance and monitoring equipment are necessary, and enhancing the current remote monitoring system is recommended.

3-2-2 Results of FSA on Question 2

There is no significant difference between the i-SMR and the APR-1400 in the safeguards approach because both reactor types are the same as pressurized water reactors (PWR). However, the refueling area for multiple modules and the frequency of refueling reduce the effectiveness of the safeguards approach in maintaining CoK. This modular design complicates design information examination (DIE) and verification (DIV). An analyst needs more information on the spent fuel storage area and the module unit transfer system to analyze their effect on the safeguards approach.

3-2-3 Results of FSA on Question 3

PIT(Physical Inventory Taking) and PIV(Physical Inventory Verification) are more difficult due to multiple modules refueling for the i-SMR than current LWRs. The time for PIT and PIV is not enough in normal operation when all fuel assemblies are visually accessible. The physical inventory cannot be 100% verified by visual inspection and NDA(Non-Destructive Assay). Thus, containment and surveillance(C/S) equipment are recommended to complete PIT and PIV. As the i-SMR design permits item accountability like the APR-1400, it does not make the plant accountancy measurement systems more complex.

3-2-4 Results of FSA on Question 4

The possibility of misuse in the i-SMR design increases due to the presence of multiple units, which creates possible opportunities to disguise the misuse of one unit. The operating records of one unit can be swapped or duplicated with those from other units that were operated according to declared activities. The i-SMR design does not adversely affect the ability of the IAEA inspectors to conduct adequate short notice or unannounced inspections (IAEA's methods of random inspection).

4. Conclusions

In this work, the FSA for the newly developing i-SMR is done by comparing it with the APR-1400. Though both reactors are categorized into a conventional PWR, the adoption of multiple modules in the i-SMR reduces the safeguards' effectiveness, and additional measures are needed. Complementary C/S equipment and the adoption of remote monitoring (RM) are recommended. The spent fuel storage has also influenced the safeguards approach. However, the FSA on the spent fuel storage cannot be performed due to insufficient information. A more detailed analysis should be carried out if the final design of the i-SMR is provided.

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