[PO11C12] Considerations on the application of IAEA safeguards in SMRs

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Introduction

Nuclear power is gaining attention as a carbon-neutral energy source, and Small Modular Reactors (SMRs) are gaining attention worldwide due to their economic and safety aspects. Various types of SMRs are being developed in this trend, and various operating conditions and facility layouts are being proposed. These new approaches can pose new challenges to traditional safeguards. Therefore, we will analyze the advantages and disadvantages of SMRs regarding conventional safeguards approaches and assess their applicability to International Atomic Energy Agency (IAEA) safeguards.

IAEA Safeguards Considerations

- The IAEA's safeguards approach is to verify the correctness and completeness of the declared nuclear activities in the member states as a supplementary measure that, unlike mandatory safety requirements, does not affect the safety of the nuclear facility. [1] It means that it cannot be presented as a requirement at the design stage and that the basic design layout must be determined before appropriate safeguards can be applied. Therefore, it is impossible to provide specific considerations for SMRs now, but we would like to review the issues that can be foreseen from a general perspective.
- The general definition of SMRs refers to reactors of 300 MWe, with iPWR, MSR, SFR, and VHTR as the main types of reactors. Based on this, we summarize the implications for applying IAEA safeguards. [2], [3], [4], [5]

- **Downscaled Reactor:** SMRs have a lower power output than conventional reactors, resulting in a smaller physical footprint and reducing the physical surveillance area for dedicated pathways. On the other hand, the dedicated pathway will likely become more complex to accomplish the same function in a smaller physical space, requiring closer design information verification
- **Long refueling design concept:** Some reactor types have high burnup due to their long refueling design concepts. While this increases the yield of plutonium itself, it can also have adverse proliferation characteristics, such as degraded plutonium quality and increased fission products. The more extended cooling period before the spent fuel is transported for final disposal or reprocessing can also decrease the frequency of nuclear material inventory change reporting (ICR).
- **Sealed cores:** Sealed cores refer to the sealing of nuclear fuel during reactor fabrication. It can make it challenging to misuse or divert nuclear material because there is no direct access to the fuel. However, additional verification of the reactor fabrication facility and measures are needed to ensure the integrity of the nuclear material from fabrication to operation.
- **High-assay low enriched uranium (HALEU) fuel:** Higher enriched uranium requires closer management because it requires fewer resources and less time to divert to weapons-grade nuclear material.
- **Load-following operation:** Load-following operation can cause defects in burnup by module or fluctuations in the operating cycle, making it difficult to specify the cycle of physical inventory verification (PIV). In particular, since the spent fuel pool is shared, it may be challenging to maintain Continuity of Knowledge (CoK) due to overlapping reload cycles for each module due to load-following operation.

[Table 1] Evaluation of the applicability to nuclear non-proliferation

Index		Advantages	Disadvantages
Reactor scale-down	Lower physical footprints	• Reduction of surveillance target area	• Acquisition paths become more complex
	Lower fissile inventories	• Nuclear material accounting becomes easier	•
	Number of units per site	•	• It is difficult to maintain the CoK
	Low thermal signature	•	• Difficulties in utilizing remote monitoring technology
Burn-up	High burn-up	• Low quality of plutonium	• High plutonium production
	Low burn-up	• Low plutonium production	• High quality of plutonium
Refueling design concepts	Sealed core	• Acquisiton path is simplified • Easy management of spent nuclear fuel • No PIV required	• Additional verification is required when designing a nuclear reactor • Verification of the integrity is required while the reactor module is being transported
	long refueling design concepts	•	• Requires design verification for excess reactivity • As the PIV cycle becomes longer, information gaps become longer
	On-load refueled reactors	•	• The reload cycle is very short, making it difficult to maintain CoK
	Load-following operation	•	• Difficult to specify timing of PIV
Digital instruments	Remote monitoring	• Remote monitoring system can be reflected from the design stage	• Technology is needed to ensure the integrity of information • High requirements for cybersecurity are needed
	Nuclear material accountancy	• Reduced risk of human error due to automated system	• In the case of fast reactors, it is necessary to verify the resistance of digital sensors to high-energy neutrons
Construction site	Remote location	• Easy to prevent access by unauthorized individuals • Easy detection with remote monitoring system	• SNRI or UI is difficult due to physical accessibility.
	Underground designs	• Difficult to use due to lack of physical accessibility • Easy detection with remote monitoring system	
	FNPP, Floating Nuclear Power Plant		• As the nuclear material flow path is unclear, proliferation scenarios need to be evaluated. • Because the site of the facility is not fixed, it is difficult to apply traditional safety measure verification methods.
Enrichment	Enrichment(≃0.71%)	•	• Higher plutonium production compared to nuclear reactors using enriched uranium
	Enrichment(<20%)	• Advantageous for long refueling operation	• The resources and time required for enrichment to highly enriched uranium are reduced [Table 2]
	Enrichment(>20%)	• Advantageous to sealed reactors	• The resources and time required for enrichment to highly enriched uranium are dramatically reduced [Table 2]
Reactor design	Fuel element size	•	• The size of the nuclear fuel rods is small, making them easy to deodorize and conceal
	Breeders	•	• Pu-239 conversion rate verification required • When designing the core structure, verification of structures such as blankets is required. • Periodic verification of structures around the core is required during PIV
Coolant	Coolant opacity	•	• It is difficult to visually identify the inside of the core when using metal coolant
	Large structural gap	•	• Use of external ion chambers is limited • A detector with heat-resistant and radiation characteristics is required
Spent Nuclear Fuel management	Sharing a single SNF pool	•	• Acquisition paths may become complex. • Difficult to maintain CoK due to mixed use of spent nuclear fuel for each module
	SNF storage geometry	•	• As the size of nuclear fuel rods becomes smaller, visual identification is difficult when stored in a stack, so separate verification equipment is required
Proficient in technology		•	• In the case of SMRs that are not based on light water reactors, inspectors lack experience and information about the facility

[Table 2] Comparison of enrichment capacity required for HEU

Feed Enrichment (%)	Product Enrichment (%)	Tail Enrichment (%)	Feed Mass (kg)	Product Mass (kg)	SWU for 1SQ [HEU 25kg] (kg-SWU)
0.711	90	0.3	8,905	25	4,823
5	90	0.711	634	25	1,077
20	90	5	137	25	235
60	90	20	50	25	56

Conclusion

As shown above, applying IAEA safeguards to SMRs requires several factors to be considered in advance. While a smaller facility capacity can be assumed to result in a lower stockpile of nuclear material, which would be difficult to proliferate, a more complex facility layout would require additional factors to be considered, such as identifying pathways to detect the diversion of nuclear material and determining the frequency of verification. It is in the interest of the international community and individual states to implement reasonable IAEA safeguards. Therefore, to ensure a more effective and efficient application of safeguards states designing reactors should be able to provide design information about their facilities at the earliest possible stage so that best practices can be established to ensure that safety, security, and safeguards are considered from the design stage.

References

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