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Preliminary Analysis of Physical Protection and PSA-based Vital Area Requirements for SMRs in the United States

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1. Introduction

Small modular reactors (SMRs) and advanced reactors (ARs) are being explored by many member states of the International Atomic Energy Agency (IAEA) as potential solutions to mitigate climate change effects. These reactors also offer the potential for flexible energy production [1]. However, SMRs present unique security challenges. Unlike traditional nuclear power plant (NPP), SMRs are much smaller, which impacts their physical protection regulations and physical protection system (PPS) designs. From a physical protection perspective, SMRs require significantly less land than conventional reactors. However, their environmental impacts must be considered both in the design of PPSs and during facility operations, given the various locations where SMRs might be deployed. SMRs in the urban of city environments may pose different security threats than traditional pressurized water reactors (PWRs). Additionally, SMRs are typically minimally staffed, which means they rely heavily on external responders. This reliance could potentially increase response times, necessitating enhancements to delay mechanisms to prolong the intruder's time to target. SMRs installed in extreme environments also face unique challenges. For example, precipitation such as snow or rain can affect support infrastructure capabilities and pose difficulties in maintaining response capabilities and conducting simulation exercises in remote and harsh conditions [2]. This paper outlines the key requirements for the physical protection of SMRs, using U.S. cases as a study reference. It highlights how physical protection systems for SMRs differ from those for traditional NPPs, from design to implementation. Additionally, it considers the implications for physical protection in the context of future SMRs in Korea.

2. Physical Protection System for SMRs

This section details the detection, delay, and response measures for the physical protection of SMRs, explaining how these measures differ from those used in conventional power plants. It also compares the criteria for selecting vital areas in SMRs with those for traditional power plants and summarizes additional considerations for physical protection based on the SMR characteristics.

2.1 Security by Design

Security by Design (SBD) is an approach that integrates physical protection into the design of a reactor from the outset [3]. SBD aims to consider physical protection, safeguards, safety, and operations together, enhancing overall effectiveness and reducing costs. This approach is crucial for the cost-effectiveness of SMRs and can be implemented in several ways. For instance, construction materials can be chosen to make the reactor harder to penetrate, thereby delaying an intruder’s access time. Additionally, physical protection for critical facilities such as the reactor, spent fuel storage, and safety facilities should be factored into the site location design. By incorporating SBD into the SMR design process, life-cycle operating costs can be reduced, and budgets can be trimmed through improved physical protection. SBD also facilitates adaptation to design basis threat (DBT) changes. Achieving SBD involves regular communication and coordination among stakeholders, including facility designers, reactor designers, operators, and safety and security professionals during the design phase. Significant cost benefits are expected when physical protection is integrated into the early stages of design such as conceptual design and basic design. Fig. 1 illustrates the cost associated with not implementing SBD principles early in the design phase.

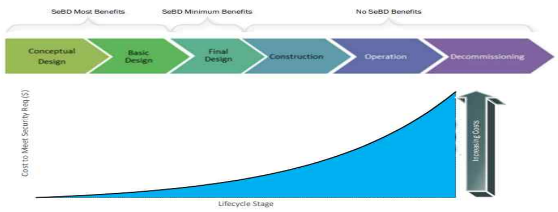

Fig.1. Costs of not implementing SBD principles early in the design phase [4]

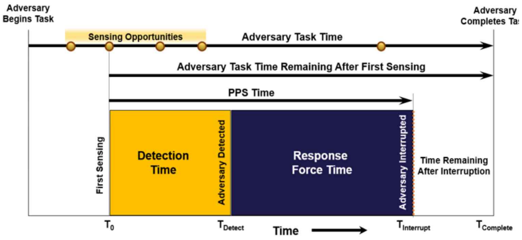

Fig. 2 Security system timeline comparison [2]

Fig. 2 highlights that the PPS response time must be shorter than the adversary's task time after detection. This timeline is important for designing the PPS for SMRs considering their unique characteristics.

2.2 Detection of SMRs

Intrusion detection systems (IDSs) integrate various components that monitor adversary activity and transmit a signal to a central monitoring station. Here the operator assesses the situation and initiates a response if necessary. IDSs typically consist of exterior and interior components. For SMRs, the design of exterior IDS can be challenging due to the need for a smaller site footprint and reduced infrastructure. Advanced detection technologies, such as LIDAR, RADAR and unmanned aircraft system (UAS), can enhance the effectiveness of external IDSs. These technologies help detect the adversaries at the facility perimeter and provide more time for response teams to get into position. While external detection sensors for SMRs can be similar to those used in conventional power plants, their design should adhere to principles established for traditional facilities, including a continuous line of detection, balanced detection, defense-in-depth, complementary sensors and alarm priority schemes. In the case of interior detection, SMRs typically have a smaller site area compared to traditional nuclear power plants, which reduces the number of potential attack points. Consequently, internal intrusion detection systems can be designed with fewer target sets. A smaller detection range minimizes the pints at which an intruder can be detected, making it easier for operators at central alarm station to monitor the intruder's location and movement. Typically, volumetric sensors are installed at doors, critical locations, and target areas, covering the entire facility area, including walls, ceilings, floors and all relevant dimensions. Since these sensors are installed indoor, environmental factors such as vibration and noise must be considered, as they can interfere with sensor performance.

2.3 Delay of SMR

For SMRs, delays must be significantly longer than the traditional NPPs due to their smaller footprint. This reduced size allows an intruder to reach their target more quickly, making rapid response crucial to prevent the intruder from achieving their objective. To provide additional delay, SMRs should employ various types of delay facilities. Delay mechanisms are designed to disrupt the intruder's progress. If an intruder encounters obstacles and cannot quickly breach the facility, they are forced to find alternate routes, which provides more time for the response. Delay systems can be categorized into two types: passive and active. Passive delay systems include fences, walls, gates, and doors. The choice and placement of these systems should be strategically planned to maximize their effectiveness. By increasing the neutralization time of these barriers, the overall response time is extended. Active delay systems include smoke, foam, irritants (through currently not in used), and barbed wire or razor wire strips (currently used). Active systems serve to increase the time required to breach a fixed barrier, thereby enhancing overall defense. In addition, they extend the time to neutralize an intruder, which can be either reduce the number of responding forces required or allow for a response when external help is far away. Implementing an active delay system can significantly enhance the effectiveness of the overall PPS. By extending the time needed to neutralize an intruder, these systems significantly improve response times and increase the overall security of the facility.

2.4 Response of SMRs

For SMRs, the staffing of security and response personnel is often minimized or eliminated to reduce costs. This presents a significant challenge compared to conventional NPP. Therefore, it is crucial for SMR facility designers, operators, and security managers to carefully plan and understand how the role of guard and response force members within the security system. Coordination with law enforcement (e.g., police or military) is essential, particularly if they will provide all or part of the response force. A formal agreement such as memorandum of understanding (MOU), between the SMR operator and law enforcement is necessary. Even if law enforcement does not provide on-site response, they may need to be involved in cases where sabotage causes an off-site release of radioactivity. In such scenarios, effective communication with law enforcement is important. Facilities should develop both emergency escape plans (for safety), and contingency plans (for security) as part of the initial design process. These plans must outline the role of law enforcement, ensuring they are fully aware of responsibilities. MOUs should cover the following points: (1) the role of on-site responders (if any) and law enforcement authorities; (2) the responsibilities of law enforcement at the site (e.g., arrests and use of force); (3) communication arrangements between law enforcement agencies (e.g., state and local) in the event of an off-site release of nuclear material; (4) law enforcement oversight of weapons qualifications for on-site responders (if any); and (5) law enforcement authorization regarding the use of force (e.g., lethal or non-lethal) against on-site responders (if any).

2.5 PSA-based Vital Area Requirement

A previous study of vital area identification [5] was applied to the latest SMR, the NuScale SMR, to assess its applicability. This evaluation involved applying the assumptions and rules from the prior study to the SMR. To adapt these the vital area identification methods for conventional commercial NPPs, additional key factors were identified based on the vital area identification procedure, probabilistic safety assessment (PSA) model characteristics, and physical protection design features. These 12 key factors and their relevance to SMRs are summarized in Table 1, which details their applicability and considerations for SMRs. Additionally, the unique operation and design characteristics of SMR plants that impact vital area identification are discussed.

Table 1. Twelve key factors for identifying vital areas applicability assessment results

No.	vital area identification keys	SMR
1	Acceptance Criteria for plant safety status	A (Requires review and application of both deterministic and PSA methods unique to SMR reactors)
2	Acceptance Criteria for plant safety holding time	N/A
3	PSA initial event de-selection	A
4	Optimization of vital area identification process	A
5	Considerations for yard-installed equipment	N/A
6	How to limit facilities subject to vital area identification	N/A
7	Mobile equipment application	N/A
8	Application of fail-safe rule	A
9	Criteria for applying shared facilities between units 1 and 2	N/A
10	Criteria for applying shared facilities between system	N/A
11	Application of high probability failure events	A (Requires establishment and application of unique criteria for SMR)
12	Application of operator recovery measures	A (Requires establishment and application of criteria specific to SMR)

3. Conclusions

This paper outlines strategies for detection, delay, and countermeasures for the physical protection of SMRs and summarizes their differences compared to conventional power plants in Table 2.

It also discusses the identification of vital areas for SMRs, comparing the application of 12 previously studied key factors with those specific to SMRs. This paper provides essential and comprehensive information for researchers focused on SMR physical protection.

Table 2. Differences in physical protection between conventional nuclear power plants and SMRs

Aspect	Conventional nuclear power plants	SMR
Installation location	Far from urban areas	In or near urban areas
Threat	DBT	Threats are higher than DBT (based on installation location)
Site size	Large	Middle/Small
IDS	Site-specific (for just-in-time detection)	Fewer installations than traditional, requiring additional technology for timely detection)
Delay	Site-specific	Enhanced delay systems needed (fewer perimeter detection systems, potential need for additional delay components depending on the insider involvement
Response	On-site security and response force	Minimum on-site security with off-site responders required

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