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SECURITY-BY-DESIGN OPTIONS FOR ADVANCED AND SMALL MODULAR REACTORS

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Abstract:

The Department of Energy's Office of Nuclear Energy has tasked the Advanced Reactor Safeguards (ARS) program to develop and advance novel technologies and provide Advanced Small Modular Reactor (ASMR) vendors with recommendations and analysis for designing physical security systems that are cost-effective at protecting against acts of theft and sabotage committed by a malicious adversary. The ARS program works to develop and advance novel security technologies that can reduce the cost to implement and maintain a physical security system and improve its effectiveness. The ARS program develops holistic physical security systems and strategies that integrate these novel technologies to show their effectiveness at preventing malicious acts. Additionally, the ARS program is assisting both ASMR vendors and the Nuclear Regulatory Commission regarding the technological advancements and physical security system designs that might be used for an ASMR deployment.

Introduction:

The ARS program was established in 2020 through the Department of Energy's Office of Nuclear Energy. The goal of this program is to help address near term challenges that advanced nuclear reactor vendors face in meeting domestic Material Control and Accountancy (MC&A) and physical protection system (PPS) requirements for U.S. construction. The technical work in the program is meant to (1) support nuclear reactor vendors with advanced MC&A and PPS designs for next generation reactors, (2) provide technical bases for the regulator, and (3) promote the integration of Safeguards and Security by Design early in the design process. Existing domestic regulations for safeguards and security, as outlined in the Code of Federal Regulations, were written for large light water reactors; rule-making efforts are underway to develop regulations more suited to different reactor designs. The ARS program seeks to remove roadblocks in the deployment of new and advanced reactors by solving regulatory challenges, reducing safeguards and security costs, and utilizing the latest technologies and approaches for robust plant monitoring and protection.

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ASMRs face an ever-changing economical and regulatory landscape that requires detailed systems engineering approaches to create effective and economical PPSs that enable the deployment of ASMRs both in the U.S. and globally. This paper will highlight some of the options for PPS strategies and identify some of the benefits and drawbacks of each of these options.

Security System Design Options

Security systems should be designed in such a way that they achieve three key functionalities: (1) meet regulations, (2) are sufficiently effective, and (3) are cost-efficient. First, PPSs should be designed such that they either meet the regulations required by law or they meet the intent of the requirements by some other method. Secondly, security systems must be effective against insider threats and external adversary threats. Lastly, security systems should be cost-efficient. Cost-efficiency in a security system means the amount of money spent on the security system is used to continually improve security effectiveness and meet regulations. Cost-efficiencies can be gained when the PPS meets the regulations and does not degrade in effectiveness. Figure 1 is a Venn-diagram representing the intersection of these three functions, which is ultimately where security-by-design can be realized.

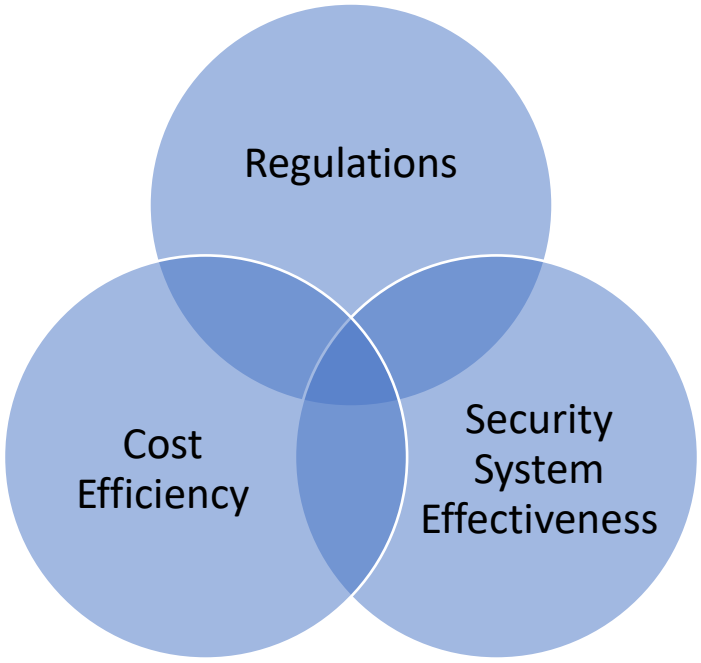

Figure 1 PPS Functions

Response Force Postures

One of the first ways this paper addresses security-by-design is by analyzing the case for security personnel needed to effectively defend against an adversary attack for a hypothetical small

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modular reactor (SMR) facility. This facility consists of three reactors, a spent fuel storage building, three turbine buildings, and two entry control point buildings. In this scenario, only the hypothetical reactors and spent fuel storage locations are areas of concern that must be protected. Two different PPS strategies were considered. The first strategy was based on responders being located wherever was most feasible to increase system effectiveness and protect all the areas of concern. The second strategy was based on using internal responders only (meaning that armed responders must stay inside the buildings in hardened fighting positions). Figure 3 highlights efficient response strategy and Figure 3 shows the internal response strategy.

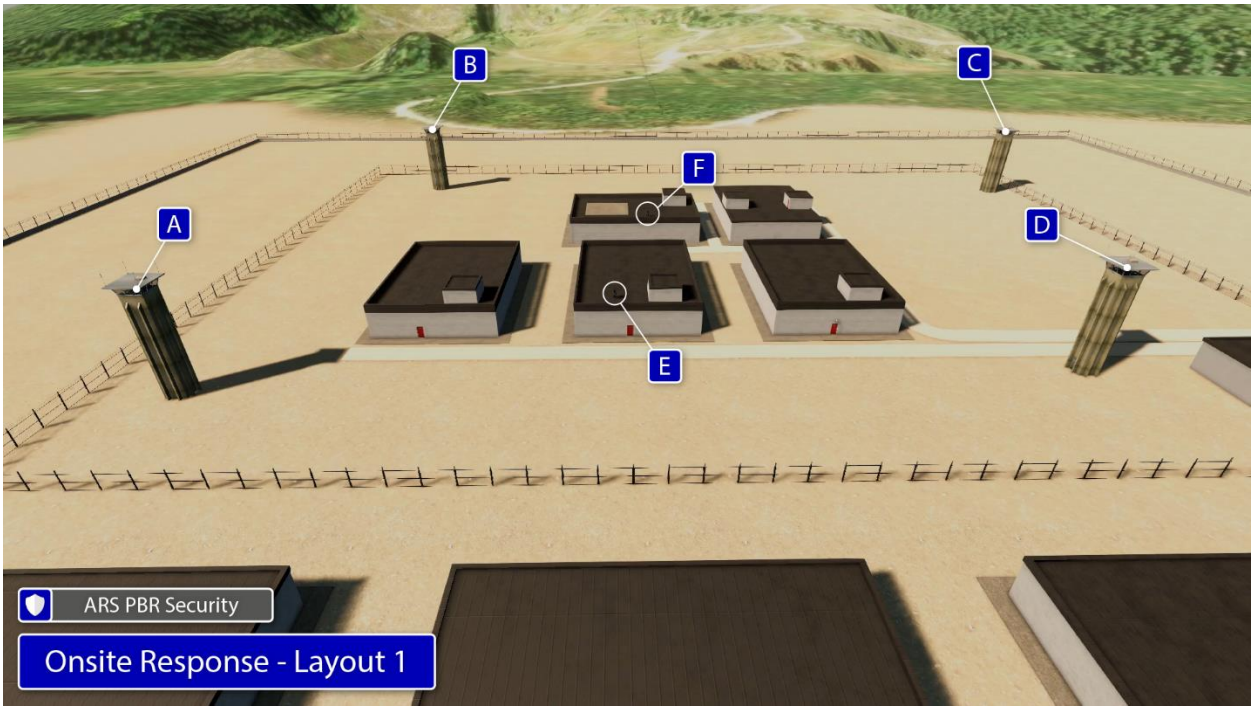

Figure 2 Efficient Response Strategy

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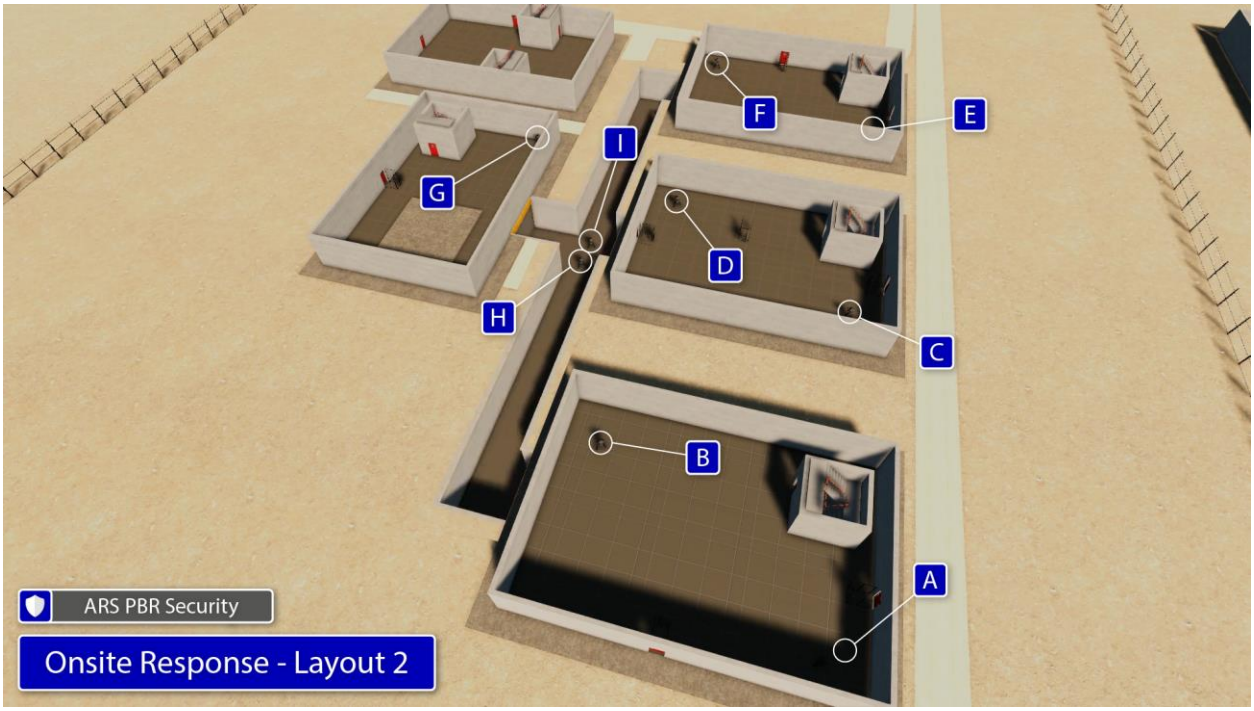

Figure 3 Internal Response Strategy

Error! Reference source not found. shows response force positions for strategy two for this hypothetical facility.

As shown in Figure 3 and **Error! Reference source not found.**, the response force strategies directly impact the number of responders needed to protect the facility. For the internal response strategy, nine dedicated responders are needed to protect all three reactor buildings. For the strategy that allowed responders to be placed efficiently, the total number of armed responders is only six. Table 1 compares the total number of full-time equivalent (FTE) persons needed to staff these positions in each strategy.

Table 1 FTE Estimates

Strategy	Number of Responders per Shift	FTE Multiplier	Total Responder Headcount
Internal Responders	9	4.5	40.5
Efficient Responders	6	4.5	27

As shown in Table 1, the second response strategy enables an effective response force, meets the regulatory intent of preventing or mitigating radiological sabotage, and is cost-efficient. The second strategy reduces the overall cost of the PPS by reducing the total headcount for responders while still being effective and maintaining regulations. This provides an example of how security-by-design can be used to meet the three functions of PPSs (cost-efficient, meet regulations, and provide high system effectiveness).

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Advanced Technology Integration

Figure 4 shows a traditional perimeter intrusion detection system (PIDS) design including an inner fence and outer fence separated by 10 meters, a triple stack microwave as a single line of detection, fixed cameras, and 100-meter sector lengths (except for the sector covering the entry portal). The conceptual design assumes a square perimeter with 1,600 meters at the inner fence and 1,680 meters for the outer fence.

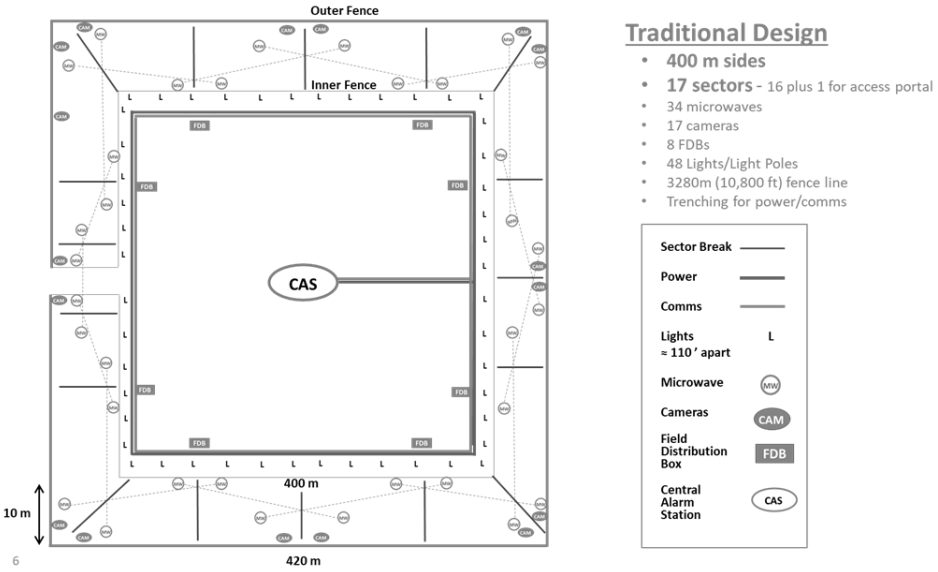

Figure 4 Traditional PIDS Design

For simplicity, this conceptual design does not include a secondary alarm station, delay barriers, entry control details, or power coming into the site. Power and communications are shown emanating from the central alarm station (CAS) to indicate that both must be run to the perimeter to support cameras, sensors, and lights. The microwave sensors are used in this example because they are common at many sites.

The estimated cost to design and build the traditional perimeter is $4,500,000. Several data sources for this cost estimate were used to approximate construction costs, including the RSMeans[1] and construction costs from the internet. The inner fence length is 400 meters on a side or 1,600 meters for the total property protection area (PPA) boundary. The 1,600-meter PPA boundary equates to 5,248 feet. In addition to the total cost to build a PIDS, a useful metric for cost analysis and comparison is the cost per foot. In this example $4,500,000/5,248 feet equates to $860 per foot.

Figure 5 shows an example of an updated PIDS that takes advantage of new "enabling" technologies. The concept depicted is called the "Centralized Radar-PTZ Module," consisting of

[1] "Deliberate Motion Analytics Fused Radar and Video Test Results: Deployed Beyond the Perimeter Fence in a High Noise Environment." Russel. John. Et. al. Sandia National Laboratories. April 2021. SAND2021-5413.

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a frequency modulated continuous wave (FMCW) radar, a bi-spectral pan-tilt-zoom (PTZ) camera, and deliberate motion analytics. Sandia National Laboratories' Global Security Analysis and Simulation department, in collaboration with Management Sciences Inc. (MSI), has taken a deterministic approach that identifies and scores features of intruder motion to distinguish alarms caused by intruders from nuisance alarm sources, i.e. weather, foliage, wildlife, etc. This approach is called deliberate motion analytics (DMA). DMA is a multiple intelligence fusion algorithm for intrusion detection and tracking using a distributed, multi-layer tracking and classification algorithm.[1] DMA's motion pattern recognition algorithms have demonstrated the ability to, 1) identify potential intruders inside and outside of the PIDS, 2) issue alarms against tracks with the correct motion features, and 3) filter out background noise and non-threatening tracks from weather, foliage, and background traffic.

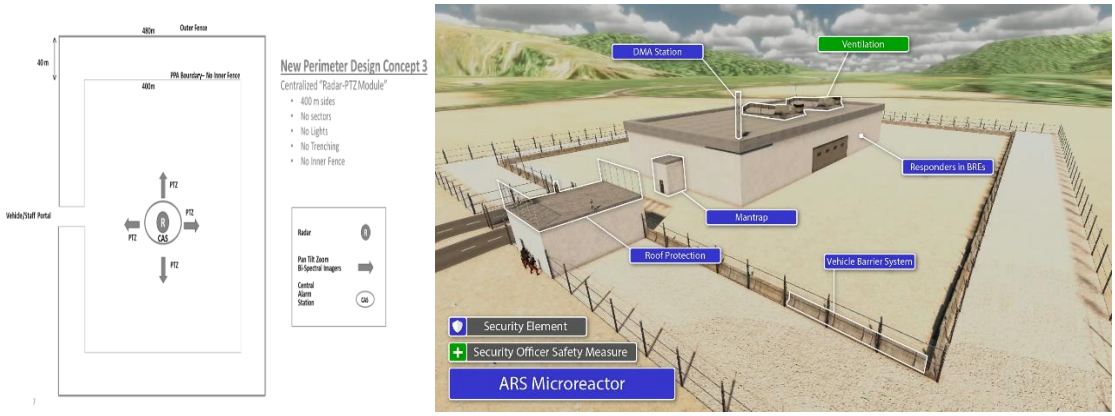

Figure 5 New PIDS Design

This design uses a radar capable of reliable detection out to 700 meters. In the proposed design, the radar needs to provide reliable detection out to 240 meters, so the detection range necessary in this design concept is well within the radar's detection capability. The DMA algorithm allows the detection sensitivity of the radar to be increased to enable reliable detection of walkers, crawlers, and runners attempting to cross the 40-meter clear zone while producing an estimated one nuisance alarm or less per 24 hours. This concept also provides significantly improved detection of bridging attacks because the detection height of the radar is approximately 65 feet at the perimeter boundary.

The bi-spectral PTZ imager is capable of imaging intruders day or night, negating the need for lights. The DMA enhanced radar will declare an alarm on an intruder making deliberate motion toward the site within the clear zone. When a DMA/radar alarm is declared, a switch closure will be actuated, allowing DMA to be integrated with existing monitoring systems. The DMA output will look like the output generated by microwaves or other commonly used sensors. Upon receiving a DMA/radar alarm, the DMA controller will move the bi-spectral PTZ imager to the DMA alarm coordinates and continue to track the intruder as they traverse the 40-meter clear zone, allowing the CAS operator to visually assess the cause of the alarm.

Preliminary testing of the centralized radar-PTZ (CR-PTZ) concept shows the ability to detect design basis threat (DBT) intruders at 90% probability with a 95% confidence level and less than

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one nuisance alarm per day. It is important to note that additional nuisance alarm data collected in different environments over extended periods of time is needed before a conclusive statement can be made. Sandia is currently in the process of collecting more field test data to show this sensor system can provide reliable detection in harsh weather conditions, including hot, dry, windy conditions in the New Mexico desert; cold, snowy conditions on the shores of Lake Michigan in March; and hot, humid conditions in Louisiana in July. After assessing the performance of the CR-PTZ concept, a follow-on report will be released with more conclusive results.

There are several notable differences between this design and the traditional design, including:

1. No trenching is required to run power and communications to the perimeter
2. No lights are needed for assessment
3. No inner fence is needed (an outer fence is still required as a "demarcation" of a protected area, to include appropriate posting or signage)
4. Minimal geotechnical changes are required—only rough grading is required to allow drainage and prevent pools of water forming in the clear zone
5. The clear zone is 40 meters as opposed to the 10-meter clear zone in the traditional design (the 1,600-meter dimension of the PPA boundary is the same)

The estimated cost for the CR-PTZ concept is $2,650,000. The same references were used to estimate this cost as those used to estimate the traditional PIDS cost. The inner fence PPA boundary remains the same at 1,600 meters, or 5,248 feet. The cost per linear foot for the PPA boundary is $2,650,000/5,248 feet, or $502 per foot.

Table 2 summarizes a cost comparison between the traditional and the new CR-PTZ intrusion detection system, showing a 40% cost reduction for the CR-PTZ concept as compared to the traditional design. A detailed breakdown of the PIDS costs is not provided in this discussion, but it is worth noting that the differences described earlier are the key reasons for the cost reductions.[2]

Table 2 Cost comparison between traditional and new PIDS

	PIDS Length	Estimated PIDS Construction Costs	PIDS Cost Per Foot
Traditional Design	5280 ft	$4,544,000	$860
Centralized Radar-PTZ	5280 ft	$2,654,000	$502

As noted in the above discussion, DMA provides an opportunity for integration of advanced technologies into a PPS that meets the intent of regulatory requirements, provides enhancements to security system effectiveness, and is cost-efficient.

[2] "Advanced Reactor Safeguards: 2022 Program Roadmap." Cipiti. B, et. Al. Sandia National Laboratories. SAND2022-1114R. August 2022.

Integrating Advanced Technology and Response Strategies

For security-by-design to be successful the three functions of meeting the intent of regulations, increasing system effectiveness, and increasing cost-efficiencies must be met. This can be done by using advanced security system technologies and designing an efficient and effective onsite response force strategy. Advanced technologies such as DMA support a decrease in the necessary infrastructure. DMA enables the detection of adversary forces much like traditional external intrusion detection technologies (e.g., microwave sensors, infrared sensors, etc.). DMA creates an advantage for a site in that it requires less security hardware and components to be installed in the field and less trenching to run communication and power to these devices. This creates two benefits to a site, 1) it reduces the up-front capital cost for purchasing security technology and 2) it reduces the long-term cost for operations and maintenance over the lifetime of the facility. DMA also can create an extended layer of detection beyond the protected area (PA) of the facility, resulting in earlier detection of an adversary force, which can lead to a higher system effectiveness. Therefore, DMA alone enables all three goals of security-by-design to be met. Using an efficient response force strategy reduces the number of FTEs needed to provide an adequate response within the PPS. An efficient response force results in a high probability of neutralization, which in turn can lead to a high system effectiveness for the PPS. The response force strategy decreases the necessary number of responders, which decreases both the upfront capital cost and long-term operations and maintenance costs for the site.

When both advanced technologies and an efficient response force strategy can be used to increase the effectiveness of a PPS, meet the intent of the regulations (i.e., be effective at preventing acts of theft and sabotage), and be cost-efficient, the technologies can lead to an effective security-by-design approach. Security technologies, both traditional and advanced, must be integrated so the PPS can be effective in neutralizing an adversary force. In this example, it is important that the advanced technology be set up to provide detection early enough (based on the response force strategy) to enable the response force to effectively interrupt and neutralize an adversary force. This results in efficiencies in the overall PPS design.

Conclusions

Security-by-design should incorporate the three functions of security systems: (1) meet regulations, (2) be sufficiently effective, and (3) be cost-efficient. The first is either to meet the regulations defined by the State or to meet the intent of the regulations provided by the State. Secondly, the PPS should be designed to be effective at neutralizing a nuclear security event with characteristics based on the DBT. Finally, physical protection systems should be cost-efficient. This means the technology, personnel, and procedures implemented within the PPSs help the system satisfy the other two functions of meeting the regulation requirements or the intent of the regulations and increasing or maintaining the effectiveness of the PPS.

The reactor and plant should be designed using materials to support the implementation of an effective PPS, and the plant layout should be designed with considerations for an effective

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response that does not increase the cost to operate the PPS or create cost increases later in the facility lifetime.

Integrating advanced security technology and response force postures and positions can lead to meeting all three key functions of a security system. The use of advanced technology can result in reductions in up-front capital costs (due to the decreased need for multiple technologies) and long-term costs (related to the operation and maintenance of the PPS infrastructure). Considering the plant layout and facility design enables the efficient use of response force personnel (i.e., reducing the amount of personnel needed to implement an effective strategy) and increases responder survivability. Advanced technology presents opportunities for earlier detection and additional command and control information, which can lead to an increase in the effectiveness of the response force and ultimately a more effective PPS.

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