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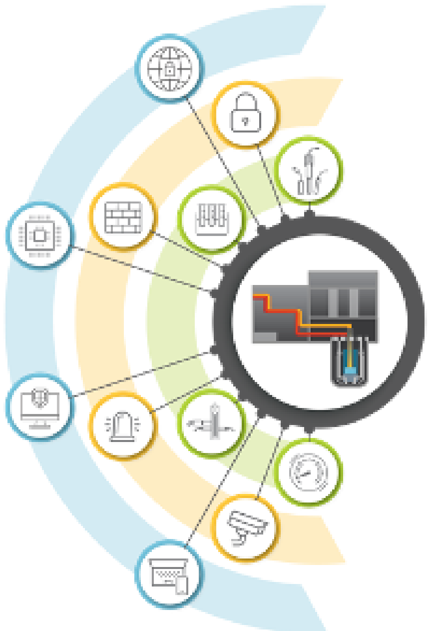

Modularization of Small Modular Reactor Facilities: Physical Protection Recommendations

Prepared for
U.S. Department of Energy

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ABSTRACT

U.S. nuclear power facilities face increasing challenges in meeting dynamic security requirements caused by evolving and expanding threats while keeping costs reasonable to make nuclear energy competitive. In consideration of the economic viability of small modular reactor (SMR) facilities, many designers and utilities are considering a modular approach to the construction and operation of these facilities. This modular approach considers building and operating a first unit; once the first reactor is in operation, construction will begin on a second reactor. This process would allow the vendor or utility to ensure production of energy and financial income while the second reactor is under construction. This project evaluates the feasibility of modular construction in terms of physical protection and identifies several recommendations for vendors and utilities considering this approach. To conduct this evaluation, a hypothetical three-unit SMR facility was developed, a physical protection system (PPS) was considered for the design, and a hypothetical design basis threat (DBT) was used to evaluate this PPS. Multiple outsider sabotage scenarios were examined, with adversary team sizes ranging from 4-to-8 to determine security system effectiveness. The results of this work will influence PPS designs and facility designs for U.S. domestic SMRs. This work will also demonstrate how a series of experimental and modeling capabilities across the Department of Energy (DOE) complex can impact the design and completion of security-by-design (SeBD) for SMRs considering modular construction. The conclusions and recommendations in this document may be applicable to all SMR designs.

ACKNOWLEDGEMENTS

The team would like to acknowledge the many subject matter experts who contributed their expertise to the development of this hypothetical facility, the design of the security system, and the analysis of the security system. The team would also like to thank the Department of Energy's Office of Nuclear Energy (DOE-NE) Advanced Reactor Safeguards and Security (ARSS) program for funding this work.

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EXECUTIVE SUMMARY

This study considered a hypothetical small modular reactor (SMR) that will be built using a modular construction approach. This means the first unit will be online and operating while the second unit is under construction, and this process would continue until the final reactor unit is online and operating. Many SMR vendors and utilities are interested in this approach, as the power sold from the first unit could offset some construction costs for the second unit. Additionally, this process would allow factory-built SMR reactors to be shipped to the facility and installed more quickly. This modularized build approach for SMRs may have an impact on the physical protection system (PPS) design, the efficiency of the PPS during operation of one reactor and construction of other reactors, and may result in ongoing adjustments to the PPS throughout the facility's operation and construction phase.

There are various methods and strategies that vendors and utilities could use to provide physical protection to modularized construction of SMR facilities; this project identified two such methods. The first considers a smaller initial security area as the first reactor is operating and the second reactor is under construction (Figure 1). In this method, a smaller protected area (PA) would be located around the first operational reactor, such that detection, delay, and response would all occur strictly within this one PA. The second reactor would be constructed inside the owner-controlled area (OCA). As the second reactor unit receives fuel and begins the startup process, the PA would expand to encompass it. This process would then continue until all reactor units are completed and operational. The second method is to develop a larger PA around all operating units that will eventually come online, with both operation and construction to be conducted inside this single PA (Figure 2). Both methods have various costs, benefits, and tradeoffs. Section 1 provides a more detailed analysis of these methods and this team's recommendation to build a larger PA.

This project considered designing physical protection systems with a response force that could adequately defend the facility against a hypothetical design basis threat (DBT). This allows the results from this report to be specific for each method, and therefore, enables the methods to be compared against each other. By developing unique physical protection systems, this report also provides insights to vendors and operators regardless of which method they choose to adopt for modularized construction of an SMR facility.

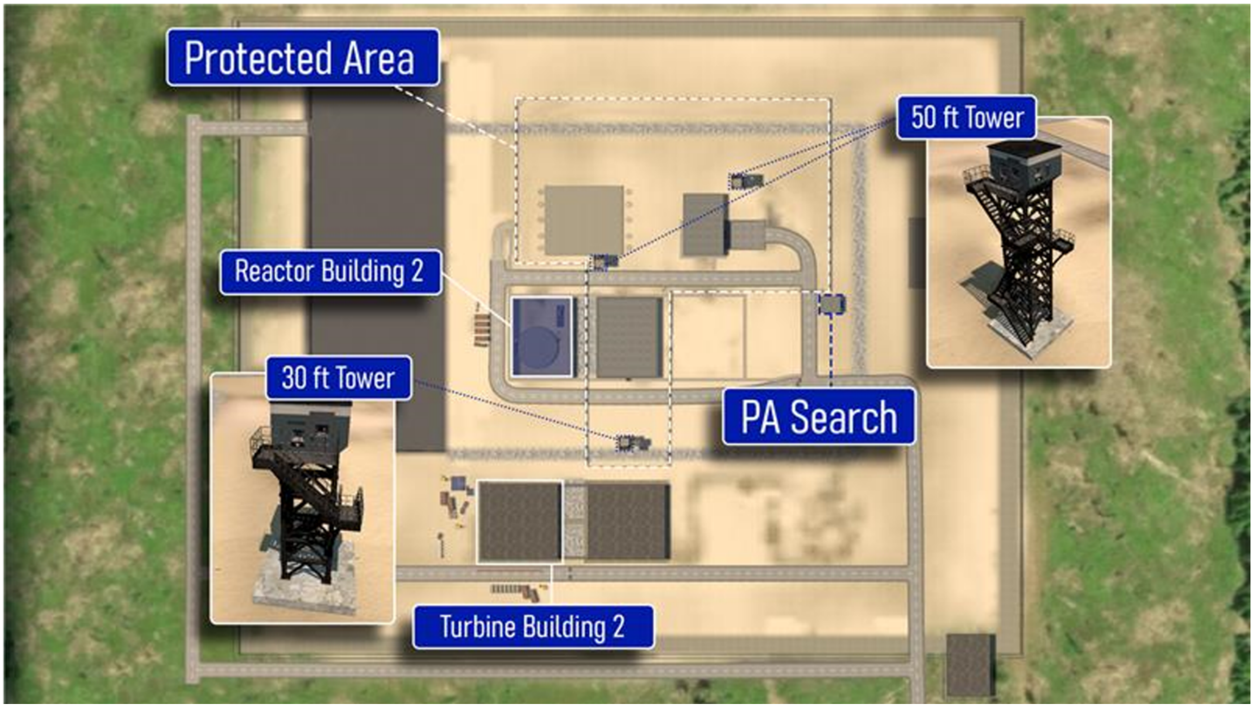

Figure 1. Expanding PA Method

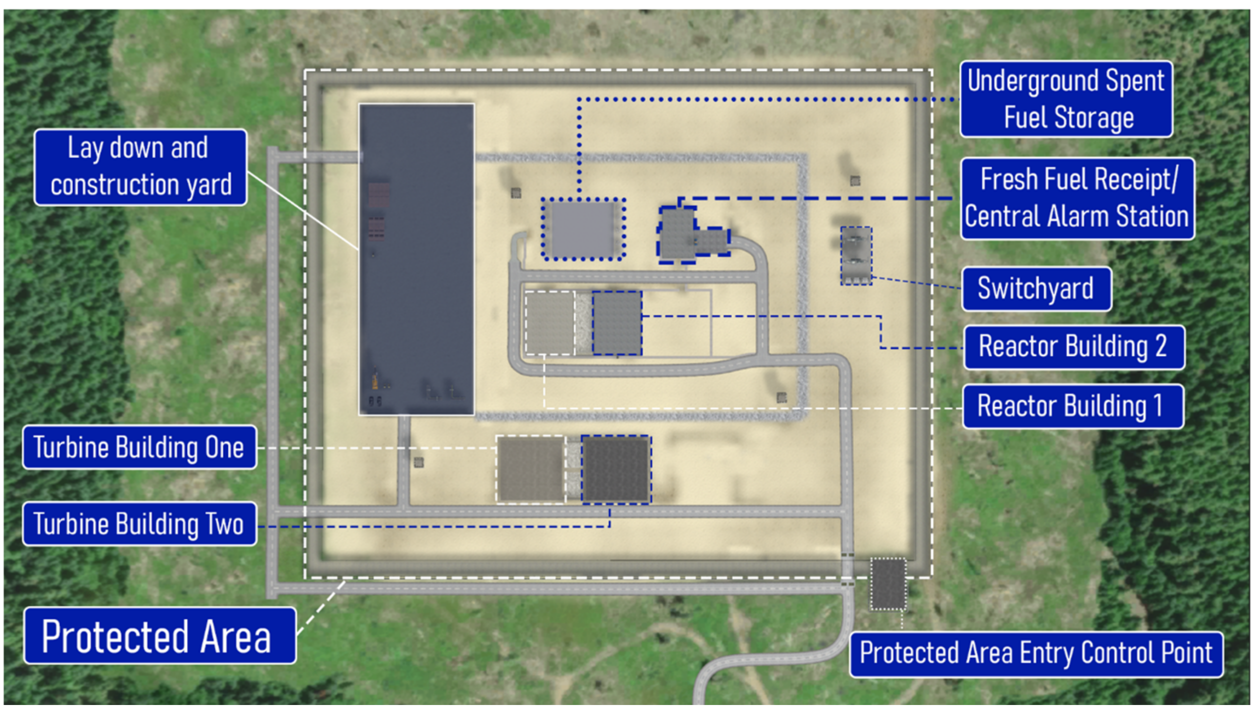

Figure 2. Initial Larger PA Method

This study compared the benefits and drawbacks for both potential modular construction design strategies; these benefits and drawbacks are as follows:

- Expanding Protected Area:
    - Benefit: Allows the physical protection system to be right-sized for the initial reactor deployment scenario and can lead to reduced up-front and long-term costs if no additional reactor units are constructed and operated.
    - Benefit: Enables easier access to the construction site for construction workers, reduces the number of personnel with access to the PA, reduces the number of individuals that need to be searched daily, and ensures the integrity of vehicle searches to mitigate VBEDs. This may reduce construction/build time compared to the larger PA method and reduce the costs associated with operating certain portions of the security program (e.g., insider threat mitigation).
    - Drawback: Increases the possibility of configuration changes to the AC&D system as each new reactors is brought online, as new intrusion detection sensors, access control devices, and cameras will be installed and require changes to the associated device management systems. In this design method, these configuration changes will have to be made for each reactor building and to the perimeter intrusion detection and assessment system as the PA boundary is expanded.
    - Drawback: Requires multiple design iterations of the physical protection system, which may lead to increased design costs and potential increased operational costs.
- Larger Protected Area:
    - Benefit: Enables the site to search all personnel and vehicles, including construction vehicles, which can ensure the integrity of standoff distances, and all reactors and responders can be protected from vehicle-borne explosive devices (VBEDs) and carriable explosive charges used by adversaries.
    - Benefit: Provides the response force with larger fields-of-view that would make it easier to interrupt and neutralize an adversary force and act as a compensatory measure if exterior sensors and assessment capabilities do not operate or function properly.
    - Benefit: Reduces the likelihood of cost overruns and configuration changes to the PA and its technologies, as well as to the alarm communication and display (AC&D) systems that will be necessary to operate the facility, because it supports building the PA and its associated technologies once rather than continuing to expand it.
    - Drawback: Increases costs associated with a larger number of sensors, a larger infrastructure, and long-term operation and maintenance.
    - Drawback: Increases the possibility of additional configuration changes to the AC&D system as each new reactor is brought online, as new intrusion detection sensors, access control devices, and cameras will be installed and require changes to the associated device management systems. In this design method these configuration changes will only have to be made for each reactor building, rather than the entirety of the PA.

Through this design process, initial security technology costs were identified for each design method and hypothetical staffing headcounts were also developed. Table 1 and Table 2 below highlight the security technology purchase costs and staffing headcounts for the design methods. As can be seen below the initial security technology purchase costs are slightly higher for the larger protected area design method compared to the expanding protected area method. It was also seen that the large protected area methodology utilizes one less armed security officer, which could lead to a reduced long-term costs to implement the security system and offset the upfront security technology purchase costs.

Table 1 Modularization Design Process and Technology Purchase Costs

Design Methodology	Total Technology Purchase Costs
Larger Protected Area	$15,561,287
Expanding Protected Area	$15,297,392

Table 2 Staffing Headcounts

Larger Protected Area			Expanding Protected Area		
Positions	24/7 12 hr. Rotating Shift	FTEs	Positions	24/7 12 hr. Rotating Shift	FTEs
Security Shift Supervisor	1	4	Security Shift Supervisor	1	4
Field Supervisor and Response Team Lead	2	8	Field Supervisor and RTL	2	8
Alarm Station Operators (CAS/SAS)	2	8	Alarm Station Operators (CAS/SAS)	2	8
Armed Responders	4	16	Armed Responders	4	16
Armed Security Officers (ASOs)	4	16	ASOs	5	20
Total	**13**	**52**	**Total**	**14**	**56**

Overall, based on the potential configuration changes that would need to be made for the expanding PA design and the long-term costs with the larger staffing headcount it is recommended for vendors to consider using one larger PA for a modularization construction approach.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AC&D	alarm communication and display
ARSS	Advanced Reactor Safeguards and Security
ASO	armed security officer
BBRE	bullet- and blast-resistant enclosure
BMS	balanced magnetic switches
BOP	balance of plant
CAS	central alarm station
CCTV	closed-circuit television
CFR	Code of Federal Regulations
CUI	controlled unclassified information
DBT	design basis threat
DG	draft guide
DOE	Department of Energy
ECP	entry control point
FDB	field distribution box
FHS	fuel handling system
FTE	full-time equivalent
IDS	intrusion detection system
IR	infrared
mph	miles per hour
MW	microwave
NRC	Nuclear Regulatory Commission
OCA	owner-controlled area
O&M	operation and maintenance
PA	protected area
PIDAS	perimeter intrusion detection and assessment system
PIN	personal identification number
PIR	passive infrared
POE	power over ethernet
PPS	physical protection system
PTZ	pan-tilt-zoom
RTL	response team lead
SAS	secondary alarm station
SMR	small modular reactor

Abbreviation	Definition
Sandia	Sandia National Laboratories
SeBD	security-by-design
UPS	uninterruptible power supply
U.S.	United States
VBED	vehicle-borne explosive device
VMS	video management system

1. INTRODUCTION

Many small modular reactor (SMR) vendors and utilities have expressed interest in developing their SMR facilities using a modularized approach, in which the utility constructs and operates the first reactor unit. Once the first reactor is operating, construction of the second reactor begins, and this process continues until the final reactor is built and operational. This will enable electricity production from the first reactor to offset some of the capital costs for constructing additional units; this also will support gathering lessons learned as subsequent units are built and installed. However, this approach comes with some unique challenges to securing the facility. It will require security for various stages of construction and operation for reactors across the site. These stages may include security for the construction site as a whole, security for the first reactor unit under construction (and then operating), security for construction of the second reactor, and security for subsequent reactors being built and ultimately operated.

There are various methods and strategies that vendors and utilities could use to provide physical protection to modularized construction of SMR facilities; this project identified two such methods. The first method is to develop a larger initial PA around all operating units that will eventually come online, with both operation and construction to be conducted inside this single PA. Method two considers a smaller initial security area as the first reactor is operating and the second reactor is under construction. In this method, a smaller security area (i.e., protected area or PA) would be located around the first operational reactor, such that detection, delay, and response would all occur strictly within this one PA. The second reactor would be constructed inside the owner-controlled area (OCA). As the second reactor unit receives fuel and begins the startup process, the PA would expand to encompass it. This process would then continue until all reactor units are completed and operational.

Each method should be evaluated for its associated costs, benefits, and tradeoffs based on numerous considerations. During this project, the team identified many factors that SMR vendors or utilities should take into account, including:

- Overall cost:
    - <u>Expansion of PA</u>: Expanding the PA to extend to each new reactor on startup will have specific costs, such as testing and validating the system with each new expansion, identifying technology that is no longer needed, and evaluating the potential cost reduction associated with no longer using that technology. Ultimately this could reduce the overall security costs and result in a correctly sized facility PA.
    - <u>Larger initial PA</u>: Building a larger PA that encompasses all potential units from the beginning will have higher initial costs, and then increasing costs during construction, because this larger PA will have to be continually accessed by construction personnel.
- Line-of-sight for onsite response forces:
    - <u>Expansion of PA</u>: Traditionally, use-of-force has been applied only inside the PA. Starting with a smaller PA could mean shorter line-of-sight for the response force, decreased adversary task times to reach target locations, and ultimately minimize the overall defense-in-depth structure of the response force. Additionally, this method may require the response force strategy to be adjusted as each additional reactor unit is brought online and the PA boundary is changed.

    - Larger initial PA: A larger PA boundary around all units may enable clearer line-of-sight for the onsite response force, create longer delay times, and enable an easier application of defense-in-depth. This strategy may support more flexible applications of the response force, protection over the construction areas, and may not require the response strategy to be redesigned for each reactor that comes online.
- Construction operations:
    - Expansion of PA: By expanding the PA around each reactor as it is completed and brought online, the utility or operator may be able to reduce the burden on construction operations and have a reduced number of personnel inside the PA. However, the utility or operator may not have as much security control over construction equipment as it would if it was located inside the PA.
    - Larger initial PA: A larger PA around all the units in operation and under construction would require a large number of personnel to be granted access into the PA and, therefore, increase overall costs for the construction project. However, implementing this method would ensure greater control of the construction equipment and personnel during the construction phase.

This list is not comprehensive, and unique considerations may arise for each vendor and each utility based on its own circumstances and design principles.

2. HYPOTHETICAL FACILITY

The hypothetical SMR facility is depicted in Figure 3. The facility is comprised of three security layers: the OCA, PA, and vital areas. The OCA includes the outer fence line and an OCA entry control point (ECP) where preliminary vehicle searches are conducted.

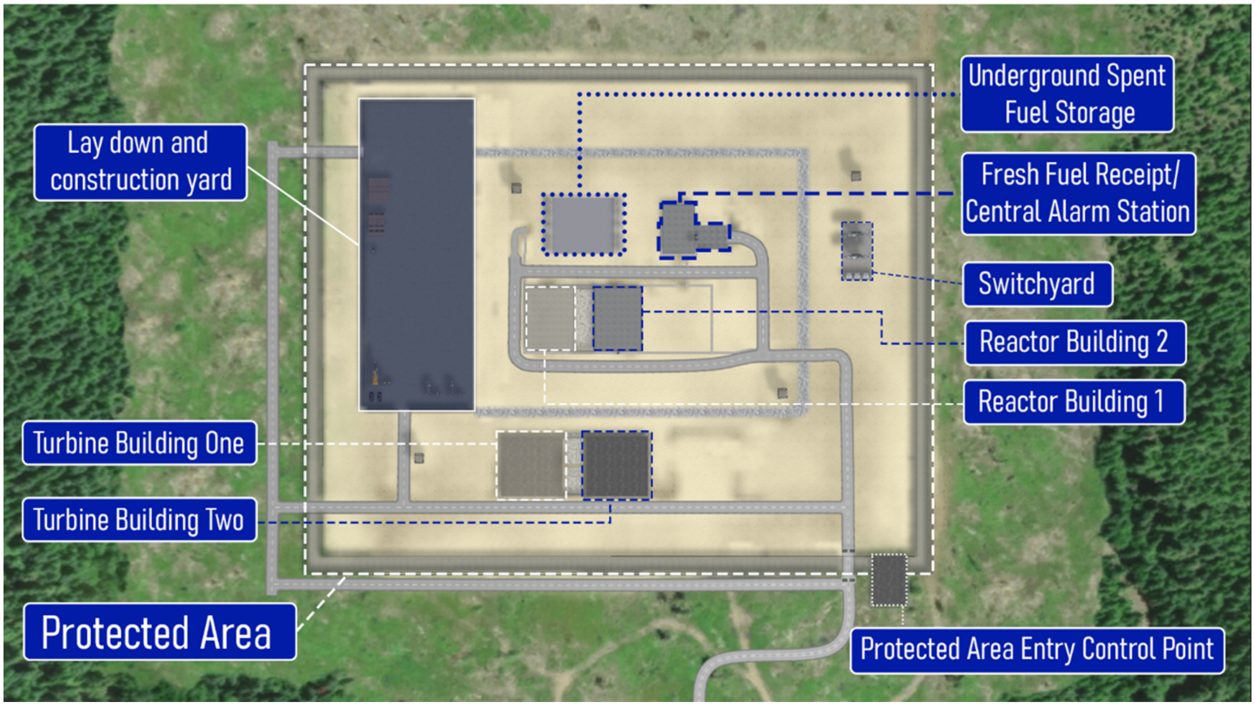

Figure 3. Hypothetical Facility

Figure 3 shows the site with two reactor and two turbine buildings; the final construction would consist of three reactor buildings, three turbine buildings, a building that stores fresh fuel, the central alarm station (CAS) and control room building, and an underground spent fuel storage location to the left of the CAS/fresh fuel storage building. The site also has a PA ECP for both vehicles and personnel.

Figure 4 shows the reactor core and the fuel handling system (FHS), represented by blue pipes. The top of the blue piping system is where fresh fuel is inserted into the reactor core; spent fuel pebbles exit the reactor core at the bottom of the reactor structure (where the blue piping exits).

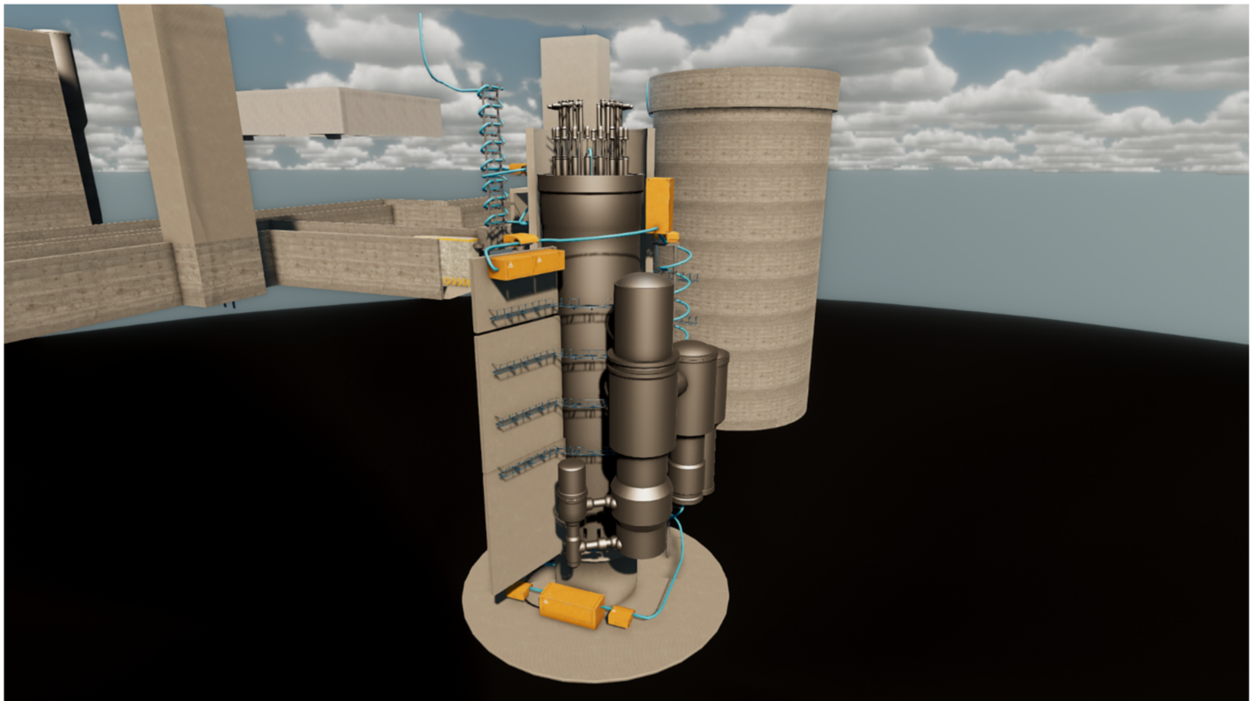

Figure 4. Hypothetical Small Modular Reactor

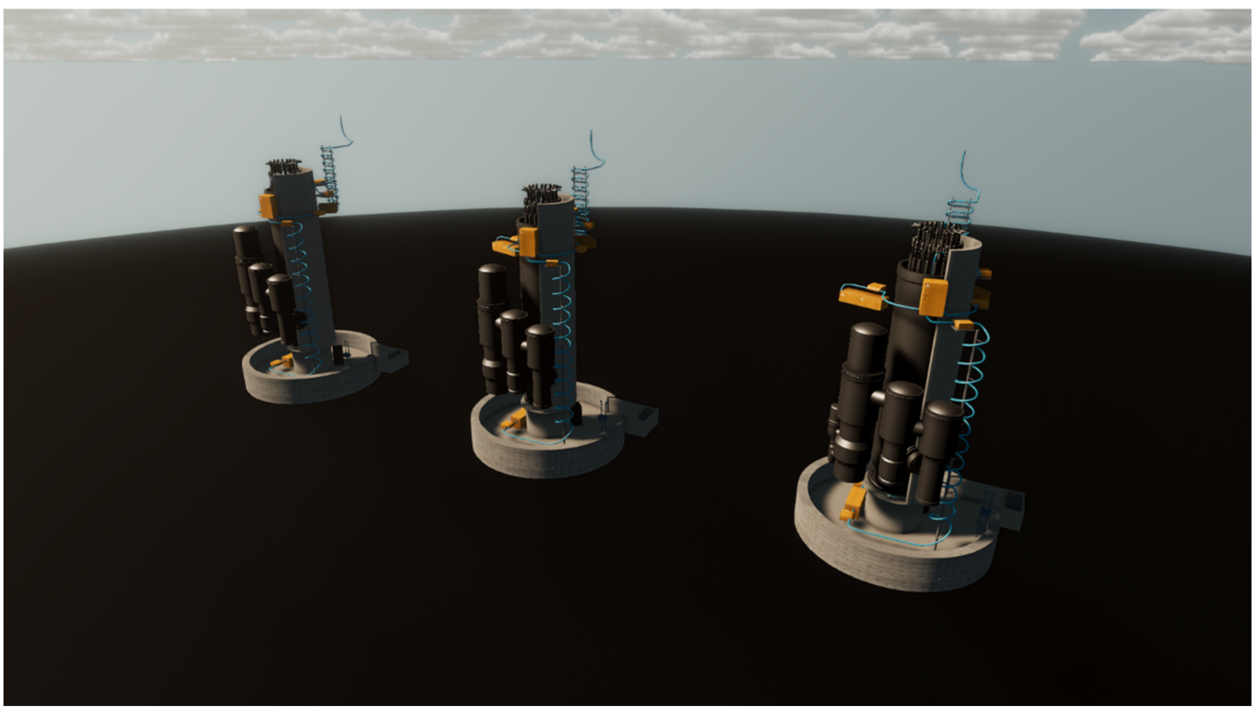

Figure 5. Multiple Small Modular Reactors

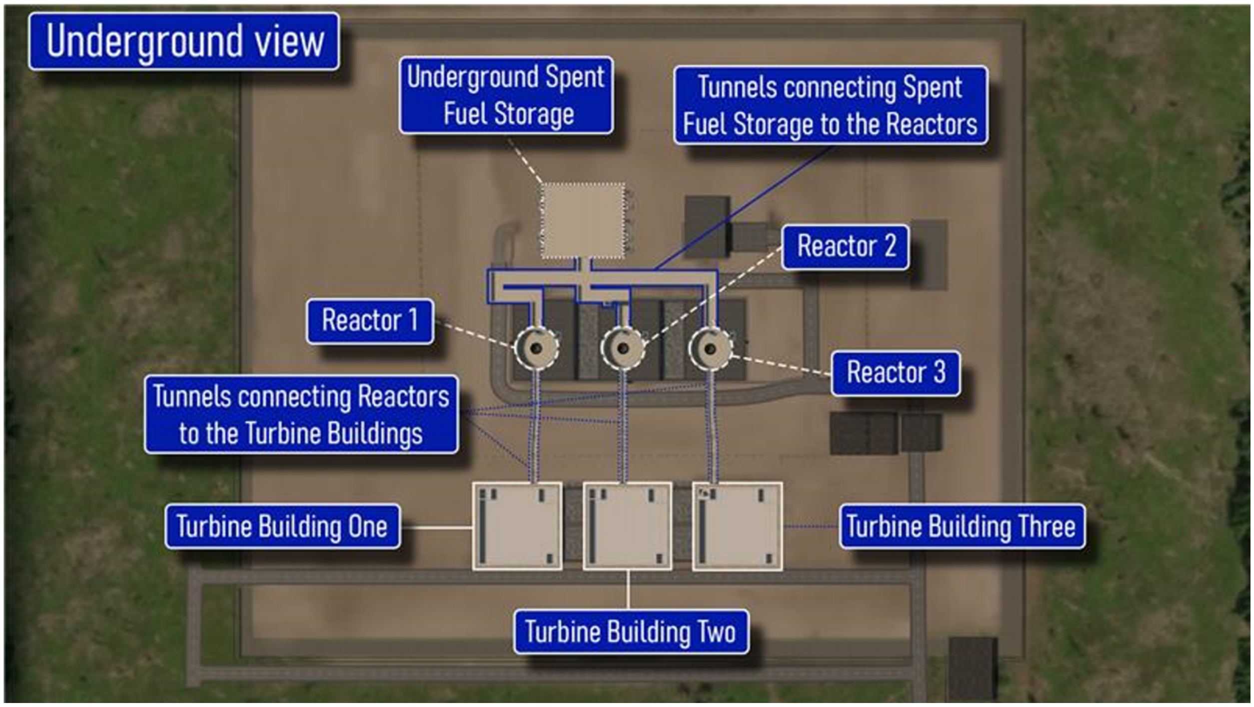

Figure 6. Underground Passageways from Reactor Building to Turbine Building

Figure 5 show the SMRs span multiple below-grade floors. On the right side of each reactor is a ladder and an equipment elevator. Personnel must use the ladder to descend below-grade, as the elevator is too small to fit a person. This feature also helps prevent external adversaries from using the elevator and forces them into using the ladder.

2.1. Design Basis Threat

To conduct the insider analysis for impact of acute theft, protracted theft, and sabotage, a hypothetical design basis threat (DBT) was developed to bound the evaluation and recommendations.

The DBT assumed for this analysis is based on information from the 10 Code of Federal Regulations Part 73.1 (10 CFR 73.1) and an open-source hypothetical DBT. The adversary team members were assumed to have the following characteristics:

- Group size of 4-to-8 individuals
- Ability to conduct a determined, violent external assault
    - Attack by stealth or deceptive actions
    - Operate in groups through a single entry point
    - Have multiple groups attacking through multiple entries
- Military training and skills, willing to kill or be killed, enough knowledge to identify specific equipment or locations necessary for a successful attack
- Information/access from an active or passive insider
- Land or water vehicles, which could be used for transporting personnel and their hand-

carried equipment to the proximity of vital areas

- Land vehicle bomb assault, which may be coordinated with an external assault
- Ability to conduct a cyber-attack
- Ability to perform any of the tasks needed to steal or sabotage critical assets
- Armed with a 7.62-mm rifle and a 9-mm pistol; ammunition; grenades; satchel charges containing bulk high explosives, not to exceed 10 kg total; detonators; bolt cutters; and miscellaneous other tools[1]
- Each able to carry a man-portable total load of 29.5 kg (65 lb)
- Assumed run speed of 3 m/s
- One passive non-violent insider (not included in the adversary group of 4-to-8 individuals)

[1] 10 Code of Federal Regulations Part 73 "Physical Protection of Plants and Materials," https://www.nrc.gov/reading-rm/doc-collections/cfr/part073/full-text.html

3. PPS DESIGN FOR LARGER INITIAL PROTECTED AREA

To conduct this work, the SMR facility was designed to be developed in stages. The first stage of this analysis focused on one operational reactor and a second reactor under construction at the site. The second stage of the analysis focused on two operational reactors and a third reactor under construction. With this approach, the team was able to analyze the various impacts of multi-unit construction on the design and implementation of the PPS. The PPS design and inputs conform to U.S. Nuclear Regulatory Commission (NRC) Draft Guide (DG) 5076, "Guidance for Technology Inclusive Requirements for Physical Protection of Licensed Activities at Commercial Nuclear Power Plants,[2]" and NRC DG-5072, "Guidance for Alternative Physical Security Requirements for Small Modular Reactors and Non-Light-Water Reactors.[3]" Using these two draft guidance documents as a basis for designing and analyzing the PPS in this report provides vendors and utilities an example of a PPS design approach that meets these requirements.

The distance between the reactor buildings is 30 feet, and all reactor buildings are designed to the same height to reduce the overall construction costs and increase the simplicity of the facility design. The above-grade floors of the reactor buildings are 15-feet tall. With the design of these buildings and building separations, there are two options to implement an onsite response force. The first option is to use positioned blast- and bullet-resistant enclosures (BBREs) as blisters on the corners of the buildings. These blister BBREs allow a responder to engage adversaries both externally and internally to a building and provide a defense-in-depth approach to the response strategy. Based on the reactor building and design layouts for this facility, it was decided that the blister BBRE approach would not be the most effective response force strategy. As shown in Figure 7, blisters in the corners of the first reactor building would be blocked visually on the west side of the facility and, therefore, would not provide overlapping fields-of-fire in that area. Additionally, this positioning of blister BBREs would not allow the responders to perform compensatory measures for loss of intrusion detection sensors or camera capabilities around the west side of the perimeter of the facility.

[2] https://www.nrc.gov/docs/ML2328/ML23286A282.pdf
[3] https://www.nrc.gov/docs/ML2326/ML23263A997.pdf

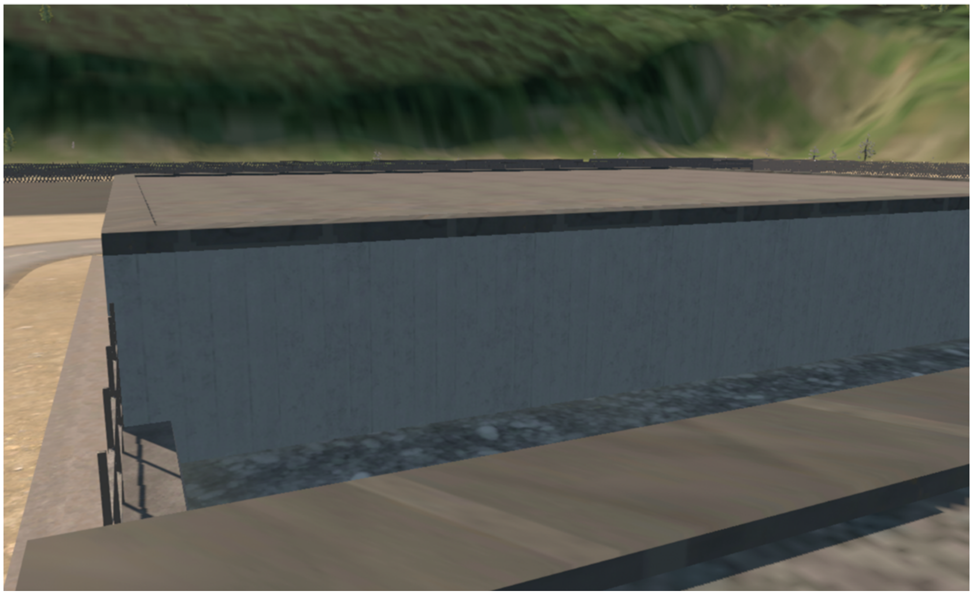

Figure 7. Response Force View from Blister BBREs

Another option is to place BBRE towers around the outside of the reactor buildings in adequate locations to provide effective response to a nuclear security event. With this in mind, the team decided to design the PPS with a once-built perimeter intrusion detection and assessment system (PIDAS) and have the response force strategically positioned in BBRE towers that could be used to protect a single operational unit, two operational units, and three operational units.

3.1. Exterior Intrusion Detection System

Based on an approach such that new construction is occurring simultaneously with operating reactors inside the PA, a single exterior intrusion detection system will be utilized for detection of adversaries attempting to breach the facility. According to DG-5076 4.1.1.1.A, "There should be a minimum of two continuous lines for detecting intrusions at the outermost plant security perimeter boundary defined as the designated boundary for initiating a security response." As this regulatory guide is currently written, this suggests it is acceptable for a vendor to install two redundant, different sensor types around the perimeter of the PA. For this design, dual-stack bistatic microwave (MW) sensors and 6-beam active infrared (IR) sensors were chosen as the two lines of redundant and diverse detection at the PA boundary. These two sensors provide a high probability of detection and have been used in nuclear security applications globally. **It is recommended that all vendors and utilities identify sensors that will perform well in the intended deployment environment and have high probabilities of detection, low nuisance alarm rates, and low false alarm rates.** This will ensure high probabilities of detection that meet DG-5076 4.1.1.1.A guidance for having detection technologies and systems that meet a probability of 90 percent detection with 95 percent confidence.

Vendors and utilities should also consider working with the NRC to determine how compensatory measures may be handled to meet the guidance in DG-5076 to ensure two lines of continuous intrusion detection systems. One option to meet this requirement is by having a third line of intrusion detection sensors always available for use, in the event one of the two required lines of detection fails for an extended period of time. **Another alternative method for compensatory measures may be to use responders who are in position and have the ability to view the**

entire PA perimeter. This may necessitate a facility design that includes pan-tilt-zoom (PTZ) cameras on the response BBREs (Figure 8) and a site requirement for the response force to use them to observe the PA perimeter and identify any intrusions into the facility.

Figure 8. BBRE PTZ

To conduct alarm assessment around the perimeter of the facility, the site can use closed-circuit television (CCTV) cameras capable of assessment in lighted situations and low-light scenarios. DG-5076 4.1.1.2.A. states "…an alarm assessment system that provides increasingly diverse and overlapping closed-circuit television coverage progressing closer to the critical detection point..." In this PIDAS design, the CCTV cameras provide overlapping fields-of-view around the entire PA so that if one camera goes offline, assessment of alarm causes may still occur (i.e., skip sectoring method). The PA perimeter will also have adequate lighting to support camera assessment and facilitate response to security events. However, the CCTV cameras used in this design will not rely on adequate lighting at the PA. Figure 9 highlights the intrusion detection system used in this hypothetical design.

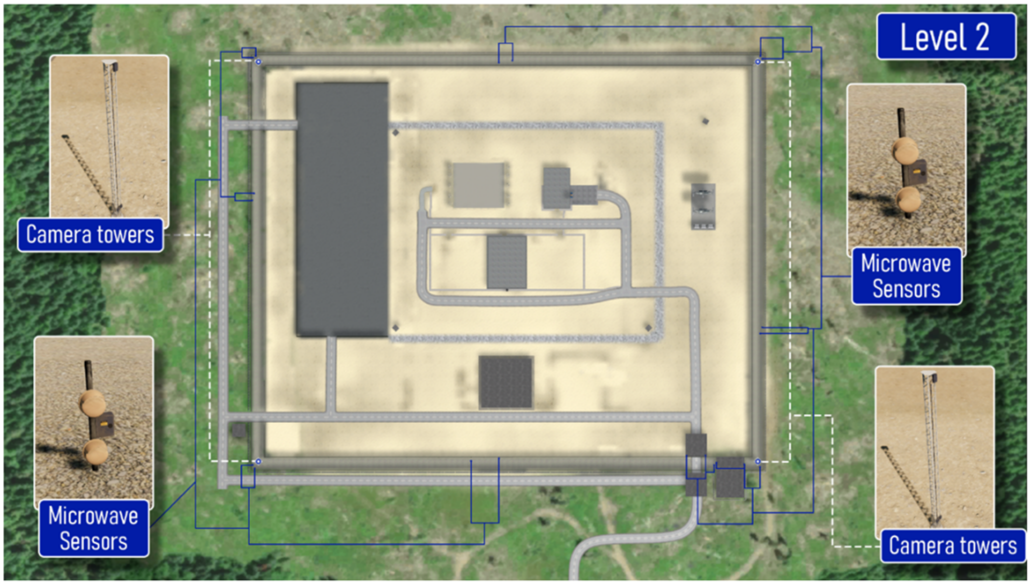

Figure 9. Exterior Intrusion Detection System

3.2. Interior Intrusion Detection Systems

The interior intrusion detection system for this facility includes an ECP into the PA, the reactor buildings, and the fresh fuel receipt building.

3.2.1. Protected Area Entry Control Point

The PA ECP is meant to facilitate vehicle and personnel entry into the PA during both construction and normal operations. All personnel and vehicles must enter through this location and be properly searched for contraband items.

DG-5076 4.1.1.6.B states:

> *Such controls should ensure that two unlikely, independent, and concurrent failure conditions of three entry control features (e.g., coded credential photo identification, personal identification number, and biometric verification) should occur for an unauthorized entry or exit.*

The design for the PA ECP includes a keypad that requires a proximity card and a personal identification number (PIN) to be used in the entry lane turnstiles; then a facial recognition camera is used after passage through the turnstiles to enable authorized access into the PA. This ensures that three redundant, independent, and diverse access control technologies are used to facilitate access into the PA.

DG-5076 4.1.1.6.B states:

> *Physical barriers and configurations of the portals should separate people who are entering from people who are exiting. The exit portal should not permit exiting people to reenter without verification and searches. The portals should also prevent a person or materials from being able to bypass controlled verification and search areas by going above, below, or around the portal.*

In the design of the PA ECP, the entry lane and the exit lanes are separated by a bullet-resistant glass wall. This prevents individuals who are exiting the PA from mixing with people entering the PA. Additionally, the design considers the use of anti-passback features as individuals pass through the radiation portal monitors exiting the facility. Individuals must first use a proximity badge and enter their PIN before processing through the portal; once the individual has passed through the portal, there is no method for them to reenter the PA through the exit lane. Additionally, all search equipment in the entrance and exit lanes are surrounded by glass walls that would prevent passing of contraband items before the items or person can be searched (see Figure 10).

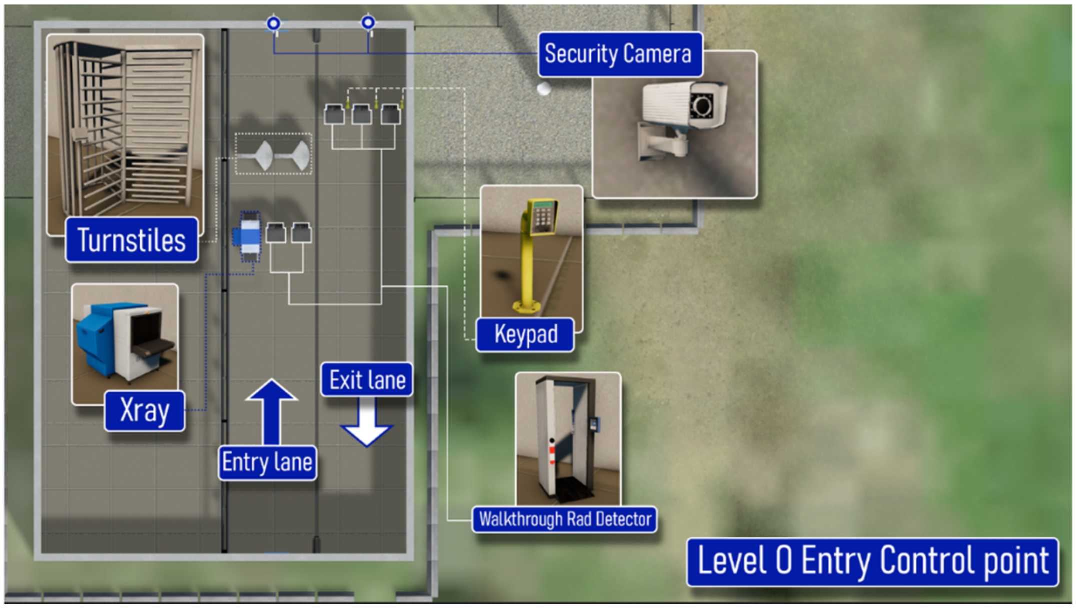

Figure 10. Protected Area Entry Control Point – Personnel

The facility is equipped with an emergency PA exit located northwest of the planned construction laydown yard.

3.2.2. Reactor Buildings

Inside of the reactor building, intrusion detection sensors, access control devices, and assessment technologies are present to ensure adequate interior detection and assessment capabilities exist.

DG-5076 4.1.1.1.B states:

> *The design of physical security SSCs relied on for interior intrusion detection functions should be redundant, independent, and diverse to provide a detection probability of 90 percent with 95 percent confidence for initiating security responses. The design should meet the criteria set forth for exterior intrusion detection systems above and, in addition consider including the following…*

In this design, the reactor buildings have several forms of intrusion detection capabilities that could be used to meet the previously noted requirement. This includes passive infrared (PIR) sensors and balanced magnetic switches (BMS) on the inside of doors. Additionally, CCTV cameras exist to enable the alarm station operator to quickly assess causes for alarms triggered inside the reactor building. Each door entry into the reactor buildings is protected by a BMS, a PIR, and CCTV cameras (Figure 11,Figure 12, andFigure 13). This provides overlapping and multiple layers of intrusion detection technologies that can be used to detect intrusion into the reactor buildings.

Figure 11. Reactor Building Balanced Magnetic Switches

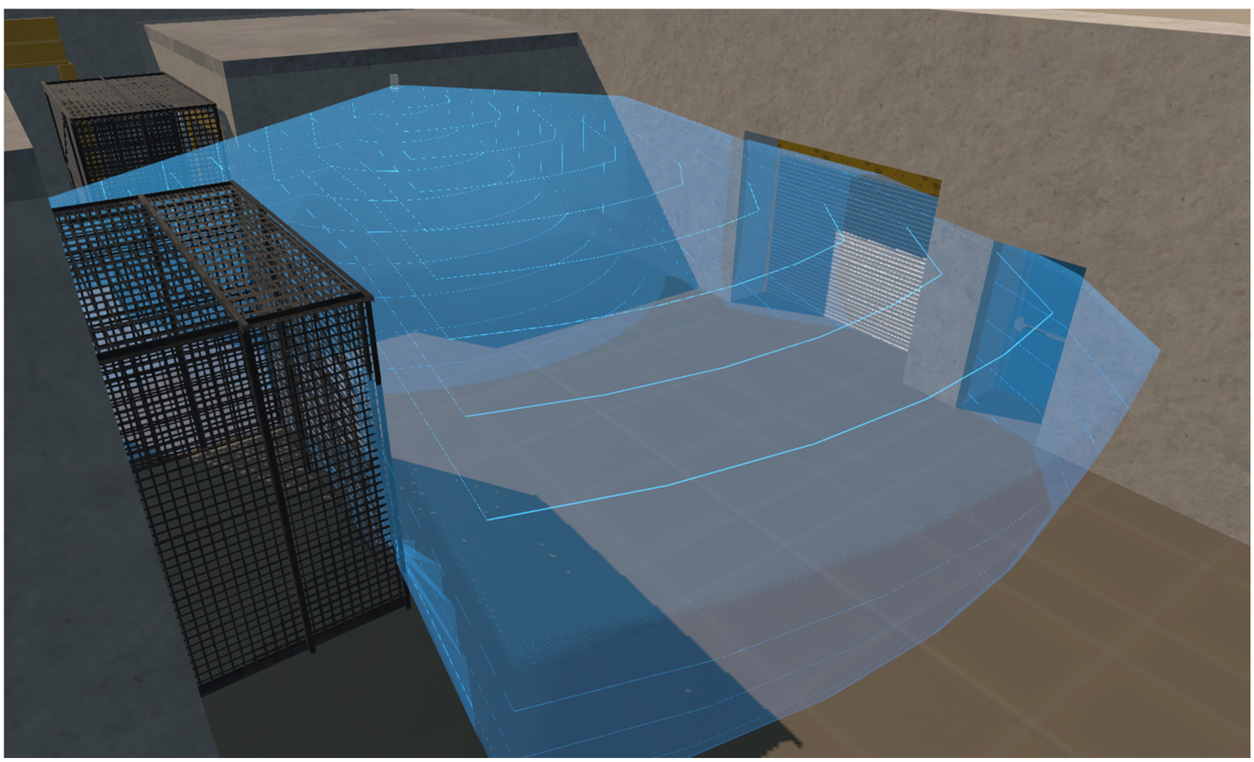

Figure 12. Reactor Building Passive Infrared Sensors

Figure 13. Internal Reactor Building CCTV Assessment Field-of-View

3.2.3. Fresh Fuel Receipt Building

The fresh fuel building (Figure 14) consists of an above-grade floor and a below-grade floor. The above-grade floor has two sides. The right side of the above-grade floor houses fresh fuel to be used in the reactors, and the left side is used to access the CAS and the control room, which are located below-grade.

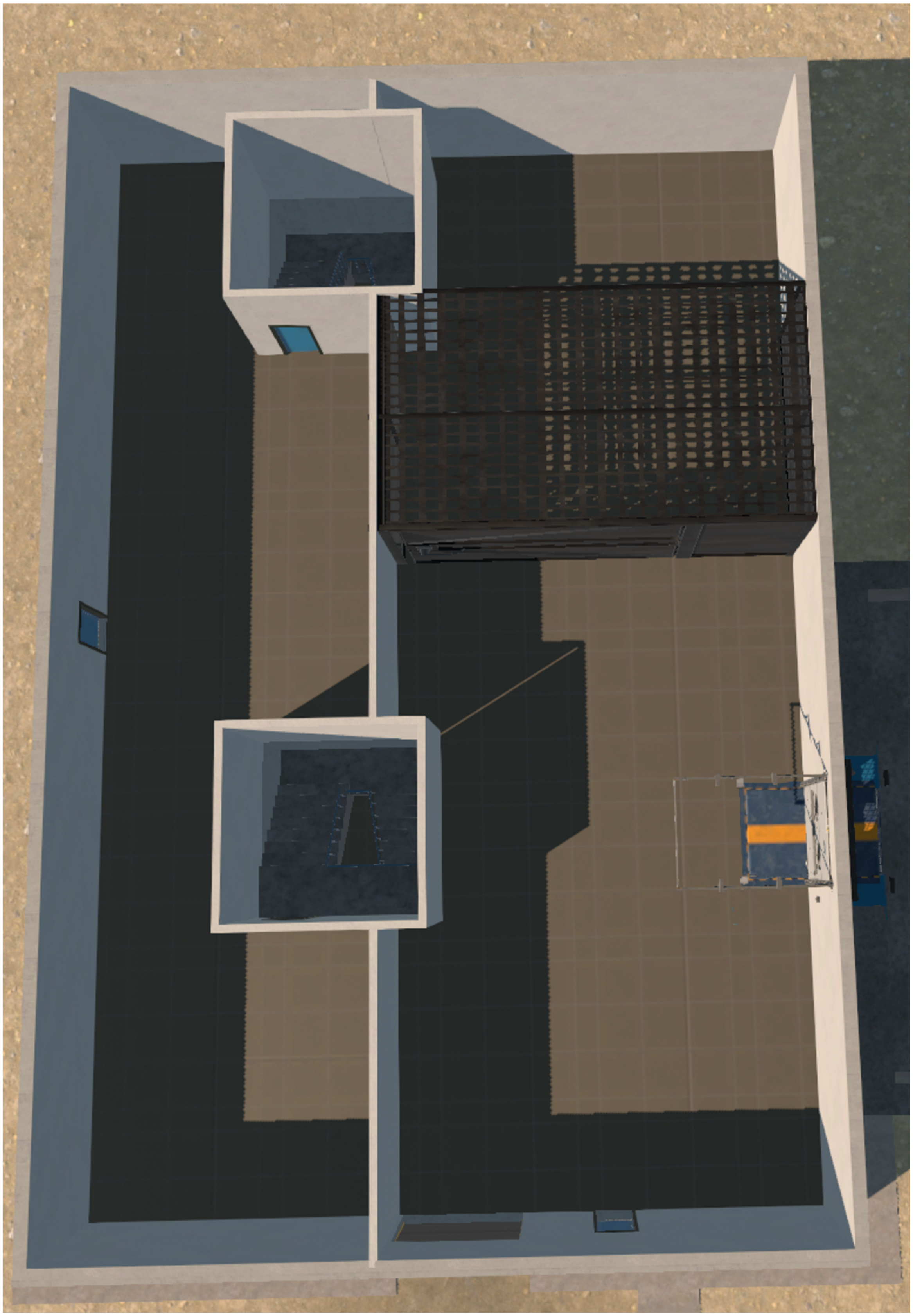

Figure 14. Fresh Fuel Receipt Building

The fresh fuel receipt building is designed like the reactor buildings. Each door entrance into the above-grade floor is equipped with a BMS and overlapping fields of coverage provided by PIRs (Figure 15 andFigure 16). These door entrances can also be seen through CCTV cameras in the CAS, once an alarm is generated.

Figure 15. BMS on Doors

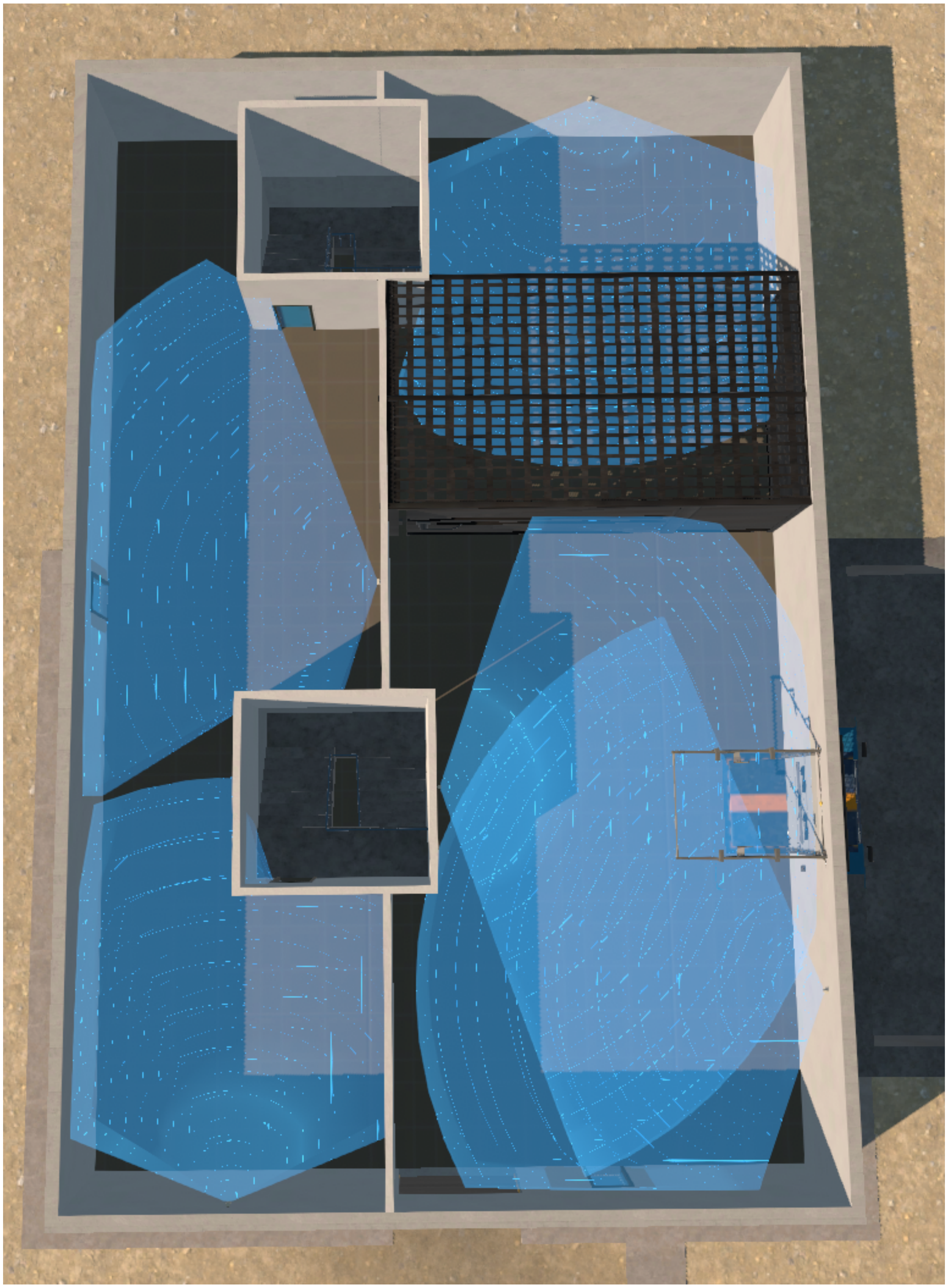

Figure 16. Above-Grade PIR Placement

3.3. Delay Features

The goal of the delay barriers and technologies in this hypothetical reactor facility is to increase overall response force effectiveness at interrupting and neutralizing the adversary force. During the facility design process, delay features were identified based on the most likely and credible adversary attack pathways. One of the key factors in the design of the delay features was channeling the adversaries into locations that are more advantageous for the response force. By doing so, the overall number of responders needed to neutralize a DBT adversary force can be minimized and the overall effectiveness of the PPS is increased. Three unique delay features were considered in the overall design of the delay system and strategy:

- Ankle-breaker rocks
- Turbine grating
- Shark cages

These delay features provide robust protection in the plant design, ensure adequate channeling of adversaries, and are applied such that the overall cost for implementation and maintenance of the PPS is reduced. Vendors and utilities should be aware that according to DG-5076 A.4.1.1.4.C, security delay:

- Can only be credited for occurring after detection;
- Must use the most conservative (least time to defeat) delay times for physical barriers; and
- Delay time can only be accounted for after detection, assessment, and communication to the response force.

3.3.1. Ankle-Breaker Rocks

Ankle breakers are large rocks used to decrease adversaries' stability when walking or running, thereby increasing the difficulty for traversal. Ankle-breaker rocks are used along strategic locations to delay the adversary or channel them into specific locations that are more advantageous for the response force. In this design, ankle breakers are placed between the turbine buildings, between the reactor buildings, and in a square fashion around the PA. The rocks delay the adversaries as they move from the perimeter to the reactor buildings, particularly when the adversaries are weighed down with attack gear used for penetrating and sabotaging the facility. Cutouts in the ankle-breaker rock placement exist to allow vehicle and pedestrian access to the facility. However, these cutouts are strategically located near BBRE towers to enable multiple responders to engage. Ankle breakers are a cost-effective fixed delay barrier that requires no maintenance or upkeep and forces the adversaries to spend time identifying alternative paths and attack strategies. This provides the facility with an extra delay barrier that increases adversary task time and adversary exposure time to fire from responders in BBRE towers. Figure 17 highlights the placement of ankle breakers in red.

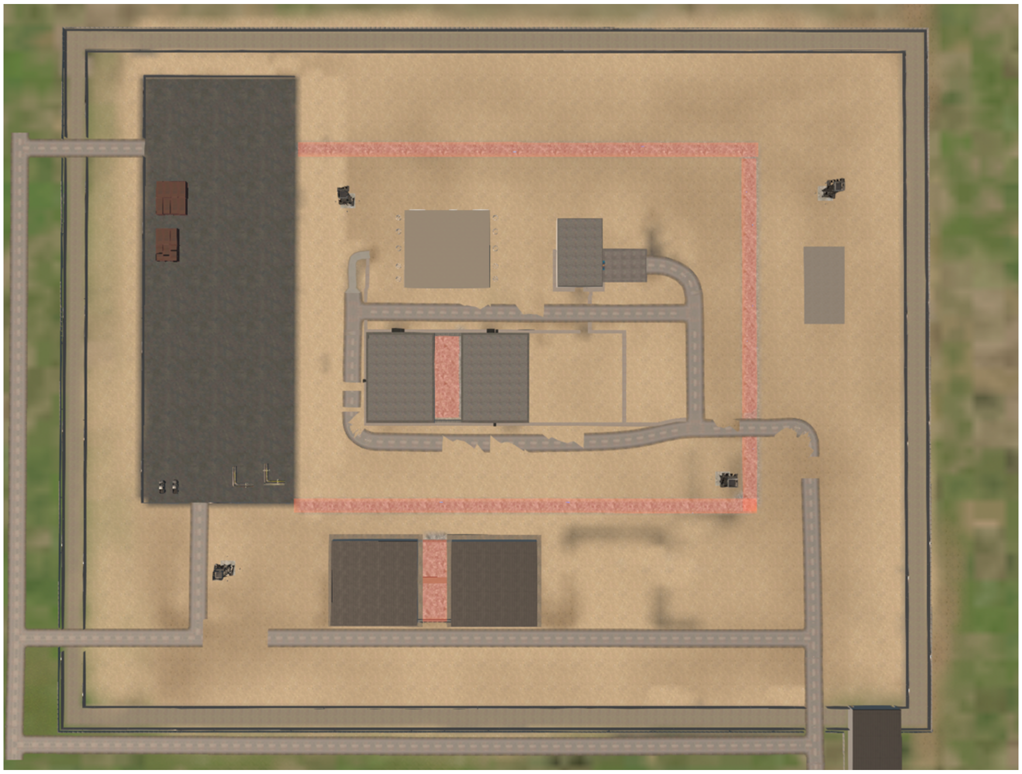

Figure 17. Ankle Breaker Locations

3.3.2. Turbine Grating

In this facility design, the turbine buildings create a potential sabotage pathway with both cover and concealment up to the reactor buildings. To address this, turbine grating was placed between each of the reactor and turbine buildings (Figure 18 shows an example of placement), which forces the adversaries to spend resources (time and energy) to bypass it. As an adversary attempts to breach or bypass the turbine grating, it creates an opportunity for the response force to engage the adversary force. The turbine grating near the exterior of the reactor buildings does not significantly improve the PPS design, as the adversaries still have enough space and offset distance that a response force may not be able to effectively engage and neutralize them. However, the turbine grating located closer to the PA boundary does create a formidable obstacle for the adversaries to defeat. **Integrating delay barriers with the response force strategy can lead to increased response force effectiveness at neutralizing an adversary and reduced overall costs for the design and implementation of an effective PPS.**

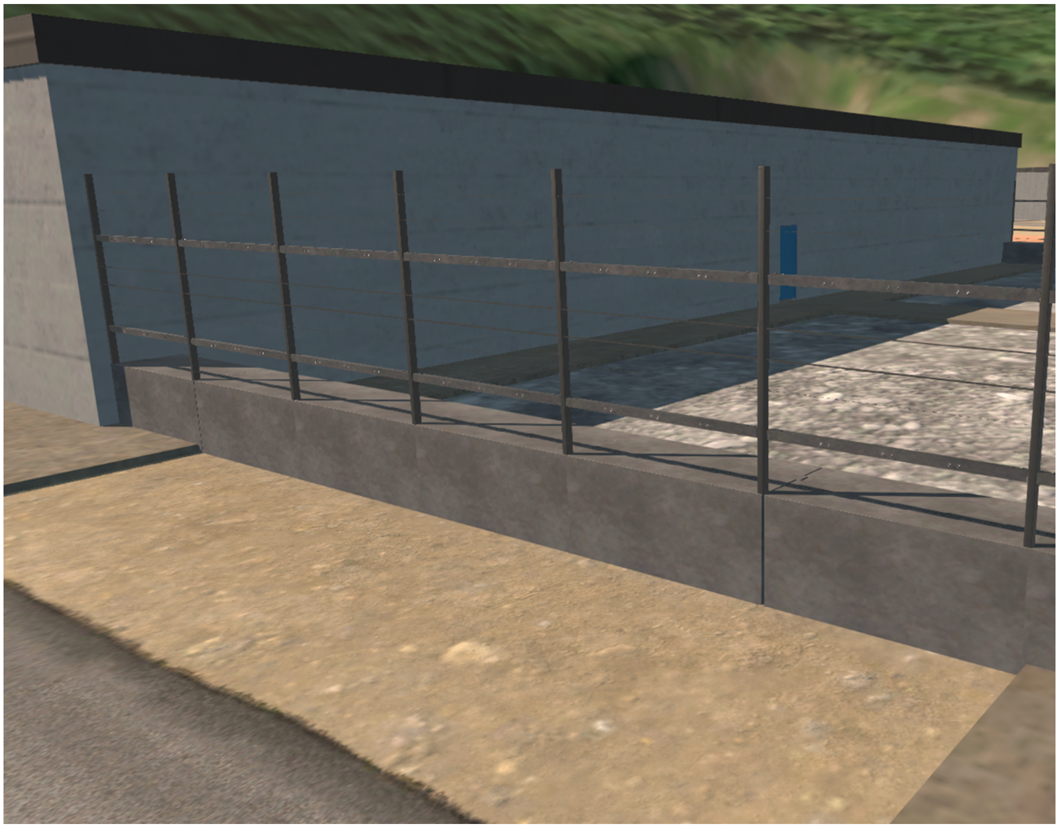

Figure 18. Turbine Grating Between Buildings

3.3.3. Shark Cages

Shark cages are turbine grating structures located at doorway entrances for both high-bay doors and personnel doors. These shark cages present another formidable and cheap delay barrier that can increase the complexity of an adversary attack if installed and implemented correctly. Shark cages act as a personnel trap without the additional reinforced concrete traditionally used in such configurations. A personnel trap enforces proper entry control and approved access authorization to enter an area. The shark cages used in this design are made of turbine grating anchored into the concrete wall with a locking entry door. The door into the shark cage is accessed by a badge and PIN reader. When presented with authorized credentials, the badge and PIN reader will unlock a series of magnetic locks on the inside of the shark cage, allowing access into it. Once the individual enters the shark cage, they must again use their badge and PIN at another reader to enter the door into any reactor building at the facility. Additionally, before entry can be made into the reactor building, the individual in the shark cage must be verified by the CAS operator, using CCTV cameras with facial recognition. This creates three-factor authentication for any individual to gain access into the reactor buildings of the facility. In this design, the shark cages are located exterior to the reactor building, which necessitates weatherproof covering to ensure rain, snow, and other weather events will not disable the shark cages' electronic security measures. The shark cages are also equipped with cypher locks, in the event that power is lost to the facility, which would disable the badge and PIN readers and the magnetic locks. The shark cages are equipped with crash bars, which will allow exit from the area during an emergency event and will automatically send an alarm to the CAS operator. This creates increased security at a potentially reduced cost while ensuring operational safety at the facility. **When considering shark cages in the design of a facility, it is**

important to coordinate the response strategy with the shark cages. Additionally, designers should account for operational and safety concerns, such as facility evacuations.

3.4. Path Analysis

To provide vendors with an understanding of how to use these draft guidance documents to determine adversary task times, the team used open source delay times and PathTrace, a Sandia-developed path analysis software,[4] to conduct a path analysis on this facility. The path analysis considered delay timelines for the theft of fresh fuel, the sabotage of spent fuel, and the sabotage of one of the onsite reactor cores.[5] Two scenarios were analyzed to demonstrate the overall adversary task times associated with a direct sabotage attack on one of the reactor vessels and theft of a fresh fuel canister from the fresh fuel storage area.[6]

3.4.1. Reactor Sabotage

The proposed adversary path for reactor sabotage is as follows: adversaries breach the facility from the east, avoid the ankle-breaker rocks, breach through the shark cage to enter the reactor building, proceed below-grade using the maintenance ladder, and begin to sabotage the reactor. Figure 19 andFigure 20 show this adversary pathway.

[4] https://modsimtools.sandia.gov/pathtrace/

[5] The analysis does not take into consideration the potential radiation dose in the reactor areas or the spent fuel area. For information on this, see "Insider Theft and Sabotage Analysis for Pebble Bed Reactors." SAND2024-12939R.

[6] Open-source probabilities and times can be found in "Modeling and Simulation Probability of Detection and Delay Database." Other sources include: SAND2024-06098O, SAND2011-9366, "Technology Transfer Manual: Access Delay," Volume 1, issued April 2012.

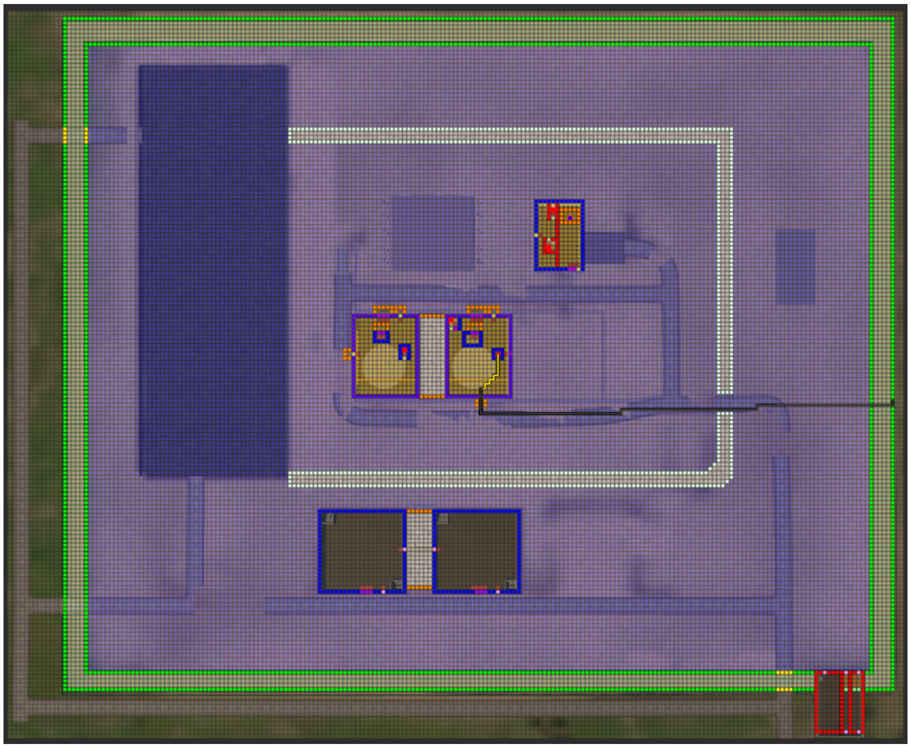

Figure 19. Above-Grade Reactor Sabotage Attack Pathway

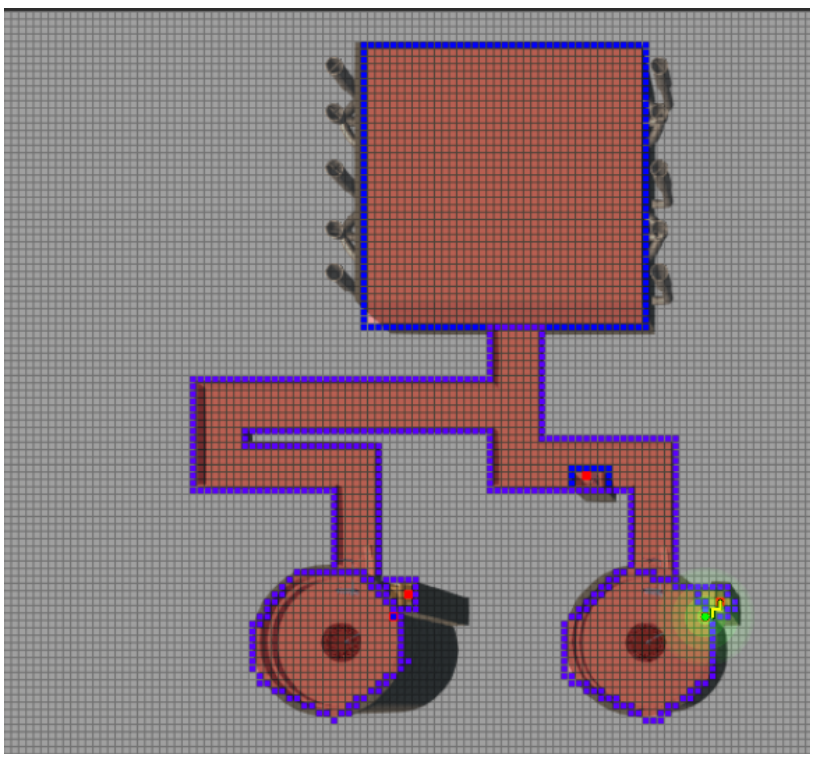

Figure 20. Below-Grade Reactor Sabotage Attack Pathway

Table 3 summarizes the results and total adversary task time to complete this act. The table shows both an overall adversary task time and an adjusted adversary task time based on assumed response force communication times and the maximum assessment time listed in DG-5076 A.4.1.1.2. It is assumed that response force communications will take 30 seconds to complete after assessment. This results in a total reduction in adversary task time of 75 seconds.

Table 3. Reactor Sabotage Adversary Task Time

Probability of Detection	Overall Adversary Task Time (s)	Adjustments for Alarm Assessment (s)	Adjustments for Alarm Communication (s)
99%	1,320	1,275	1,245

3.4.2. *Fresh Fuel Canister Theft*

For a fresh fuel canister theft, the proposed adversary attack path takes the quickest way into the facility and the easiest path to exit the facility. The adversaries enter the facility from the north, cross the PA boundary, cross the ankle-breaker section, proceed to the fresh fuel storage building, enter the storage building, enter the cage enclosing the fresh fuel, steal the fuel canister, and proceed to leave the facility by avoiding the ankle-breaker rock section. This adversary attack path can be seen in Figure 21.

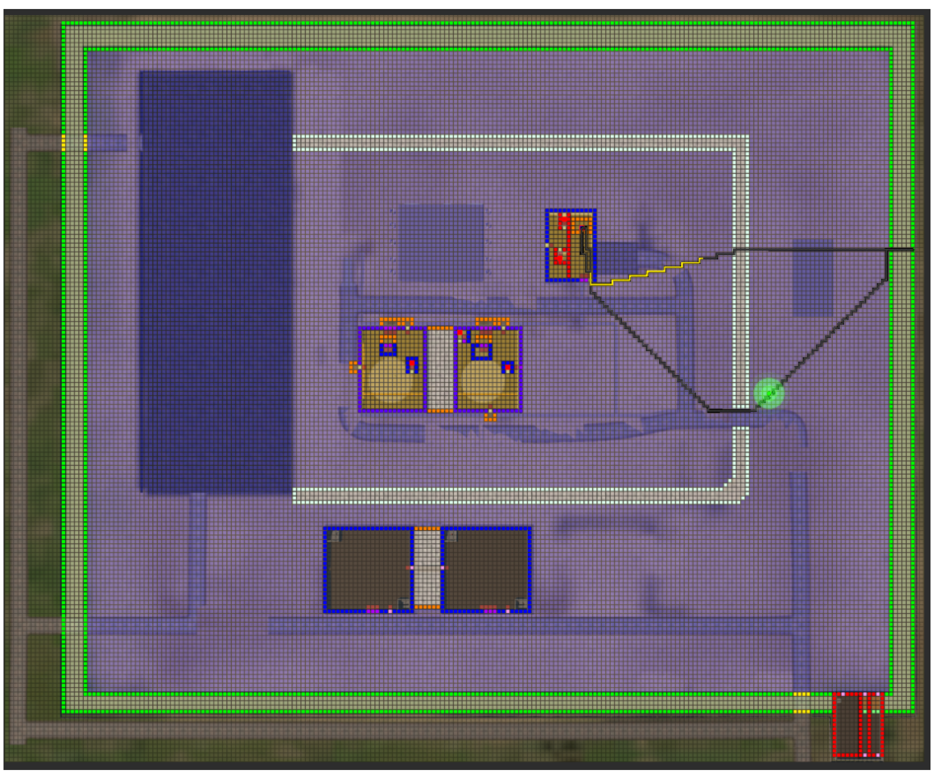

Figure 21. Fresh Fuel Canister Theft Attack Path

Table 4 summarizes the results and total adversary task time to complete this act. The table shows both an overall adversary task time and an adjusted adversary task time based on assumed response force communication times and the maximum assessment time listed in DG-5076 A.4.1.1.2. It is assumed that response force communications will take 30 seconds to complete after assessment. This results in a total reduction in adversary task time of 105 seconds.

Table 4. Fresh Fuel Theft Adversary Task Time

Probability of Detection	Overall Adversary Task Time (s)	Adjustments for Alarm Assessment (s)	Adjustments for Alarm Communication (s)
99%	793	718	688

As shown in the previously highlighted figures, this hypothetical facility is designed with robust delay features that are used to delay an adversary team and channel adversaries into advantageous positions where the response force can effectively interrupt and neutralize them.

It is important for SMR vendors to consider the overall potential risk of theft and sabotage at an SMR facility. With regard to theft, SMR fresh fuel canisters assumed to be packed in a Versa-Pac (VP55) canister can be filled up to a maximum of 750 pounds.[7] With the combined weight of the canister and its contents in mind, **designers should consider the ability of the adversary to steal a canister of fresh fuel at a site.** Adversaries must first be able to gain access to one canister of material, then be able to remove that canister from the perimeter of the facility. **If the detection, delay, and response capabilities are designed appropriately, the likelihood of successful adversary theft of a fuel canister may be reduced.** By using shark cages and a well-designed onsite response force, an SMR facility may be able to reduce the risk for both theft and sabotage.

3.5. Response Features

The initial response force design and configuration for this facility utilized four armed responders in BBRE towers. These towers are meant to both provide response and act as compensatory measures if detection and assessment capabilities are lost at the facility (either due to loss of power or adversary attack). These towers provide responders the ability to have larger fields-of-view and, therefore, greater lines-of-sight to potentially engage and neutralize an adversary force attempting an act of sabotage at the SMR facility. In addition, **the design and location of the BBRE towers combined with the delay barriers designed into the facility can lead to increased system effectiveness without a large increase in PPS implementation cost, both up-front and long-term.** The initial location of these BBRE towers can be seen in Figure 22.

[7] "Insider Theft and Sabotage Analysis for Pebble Bed Reactors," Sandia National Laboratories, September 2024, SAND2024-12939R.

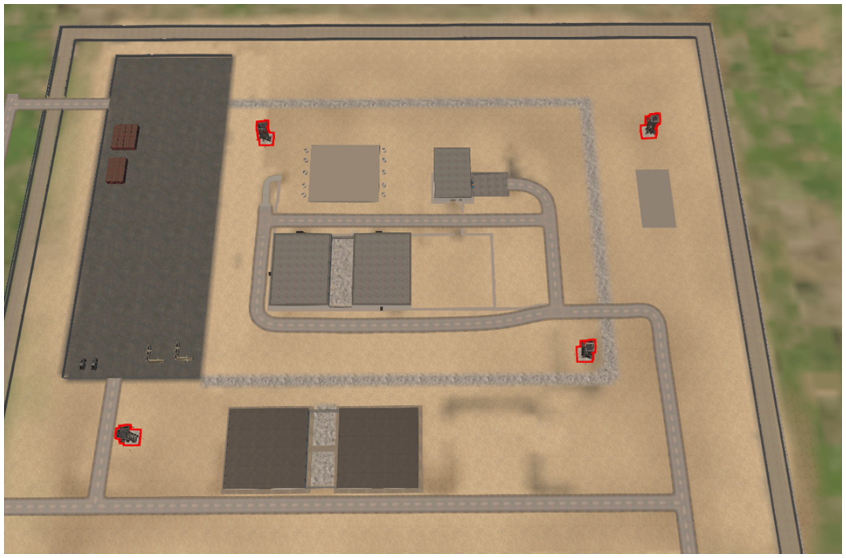

Figure 22. BBRE Tower Locations

These tower locations were based on the modular construction of the facility, the necessary material and equipment movement to facilitate construction, and the current location of operational reactors at the facility that must be protected from acts of sabotage. These response locations may change when all three units of the facility are completed; to support this, these BBRE towers are designed such that they could be moved to a final location once the site is fully operational. The BBRE tower located to the southwest is currently in a position that enables visual observation of both the construction laydown yard and the west entrance into reactor building one, and it sits at an elevation where the responder can see over the turbine buildings and to the southern edge of the PA boundary. This provides a large area of observation and large fields-of-fire for the responder located in this tower. Additionally, the responder in the southeast BBRE tower has overlapping fields-of-fire with the responder in the southwest BBRE tower.

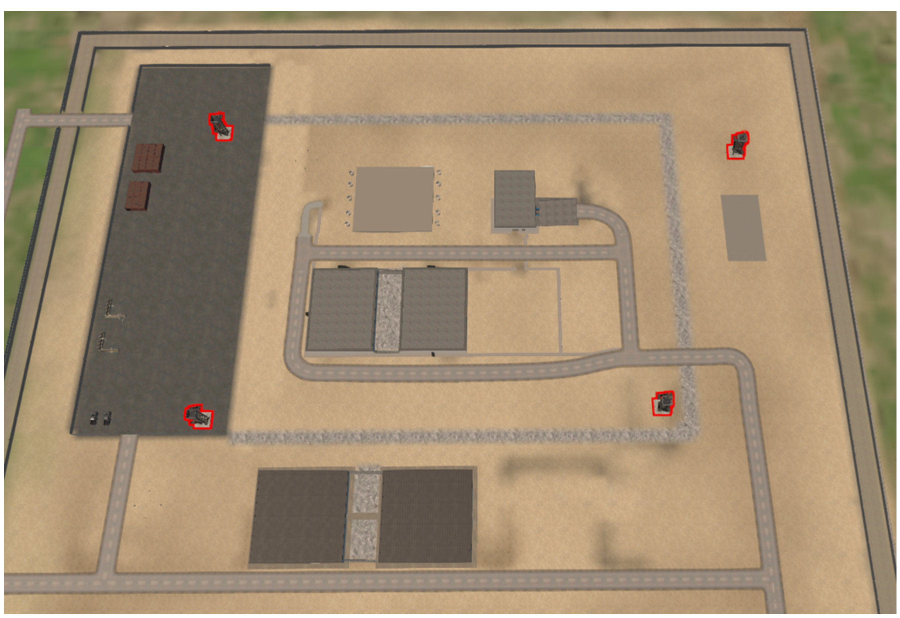

Figure 23. Final BBRE Locations

3.6. Single Operating Unit and Second Unit Under Construction

The first scenario analysis considered one operational reactor and a second reactor under construction at the site. As discussed previously, there are various benefits and drawbacks to the method of implementing an operational PPS around a single unit with a second unit under construction. Figure 24 highlights the PPS and response force locations for the first unit operating while the second unit is under construction; this figure also indicates that the first reactor to be constructed is the middle of the three planned units.

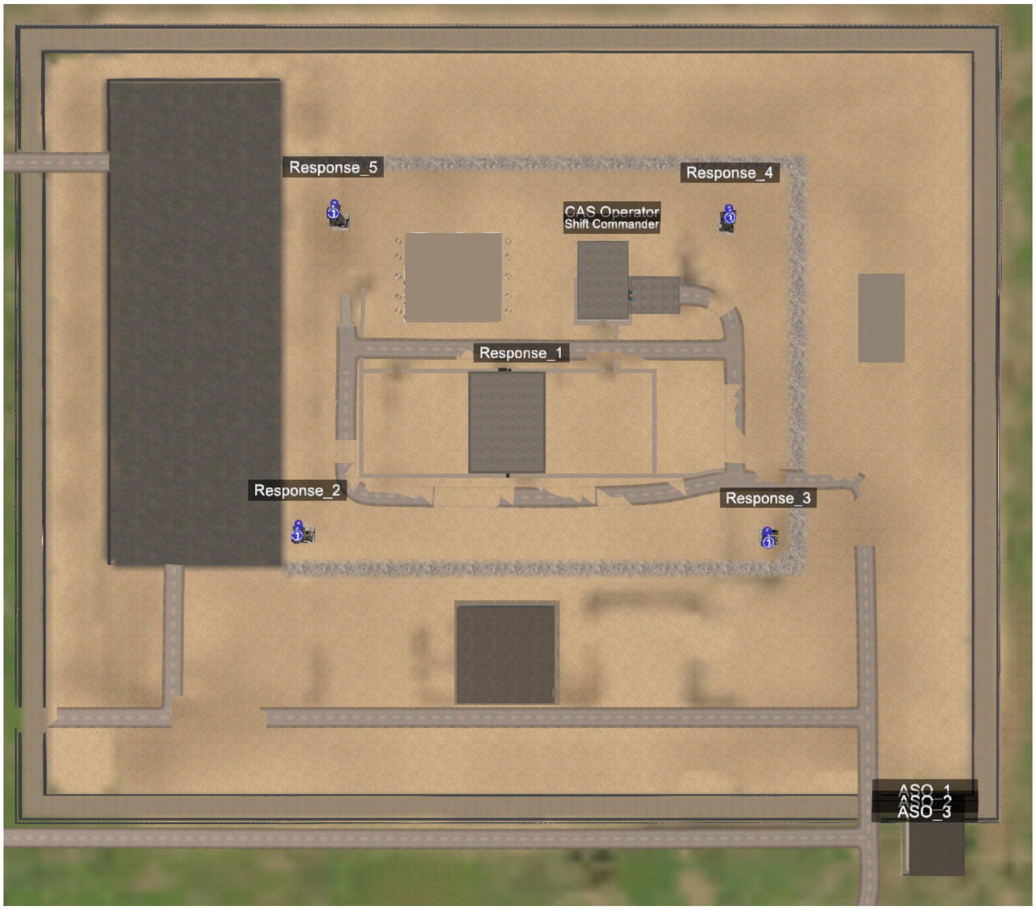

Figure 24. Single Unit PPS and Response Locations

The response force BBRE towers are located closer to reactor building one compared to the figures in Section 3.5. This setup better facilitates response to an adversary incursion to reactor building one. By placing the responders closer to the reactor building, it provides better oversight of the laydown yard, the ECPs, and the exit points from the laydown yard.

3.6.1. Adversary Attack Scenario

The first adversary attack scenario considers a group of adversaries attacking the facility from the south. At the beginning of scenario one, an adversary team member moves a box truck with a VBED up to the PA ECP. Once the driver reaches the PA ECP, the VBED is detonated. This VBED detonation either neutralizes the armed security officers (ASOs) in the ECP or renders them combat ineffective (Figure 25).

Figure 25. VBED Detonation at ECP

Immediately after VBED detonation at the PA ECP, the remaining group of adversaries approaches the PA fence on the south side of the facility and begins suppressing three of the four response towers (Figure 26).

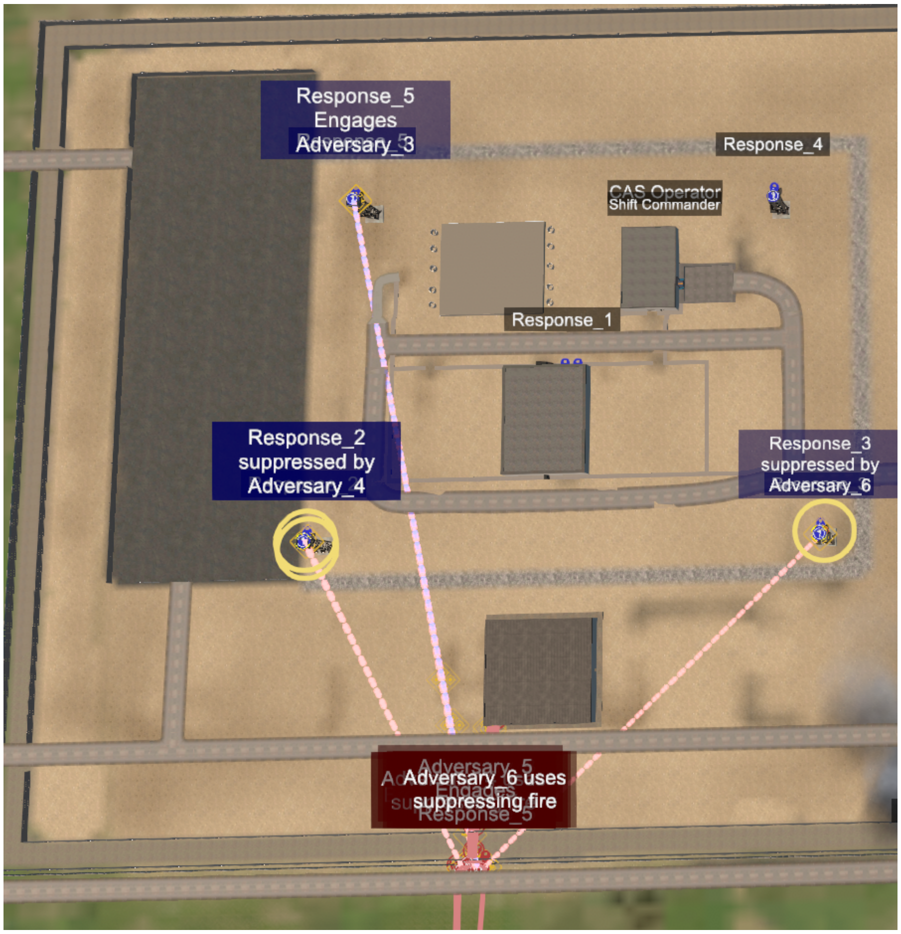

Figure 26. Adversaries Begin Suppression

While the adversary team completes the breach of the PA barrier, responder 5 and responder 2 neutralize two adversaries as they attempt to cross through the PA barrier.[8] Two adversaries ultimately reach the southwest corner of the turbine building and suppress responder 2 and responder 3. Once the adversaries leave the cover of the turbine building and move toward the southern entrance door to the reactor building, responder 2 and responder 3 neutralize the two remaining adversaries.

The design of the PPS leads to an effective system that can neutralize the adversary before they can reach the entrance to the reactor building. Due to the response force locations and the ability for multiple responders to engage adversaries as they cross open space leading up to the reactor building, the adversary team is unsuccessful in attacking the facility in this configuration. One other factor that leads to this effective PPS design is the entry door locations into the reactor building. Because the door locations for this reactor building are only on the north and south sides, this significantly limits the number of potentially successful attack pathways for an adversary.

[8] It should be noted that in any engagement where an adversary or responder is neutralized, the engagement was simulated 1,000 times using probability of hit and probability of kill data.

3.7. Two Operating Units and Third Unit Under Construction

The PPS design and configuration for two operational units at the site and a third unit under construction required modifying the response force locations to better protect all three reactor buildings. Responder 2 was moved further to the southeast along the road to the laydown area, compared to the initial location for one unit being operational. Responder 4 was also moved to the northeast, north of the switchyard, compared to the initial position when only one unit was operational. By shifting responder 2 to the southwest, they can more effectively engage adversaries attempting to breach the west-facing door into reactor building two. This placement also enables effective engagement in the laydown yard and the south entrance door into reactor building one. Shifting responder 4 to the northeast increases their visibility to the north-facing door for reactor building one and creates a greater field-of-view along the southern portion of the facility. These changes can be seen in Figure 27.

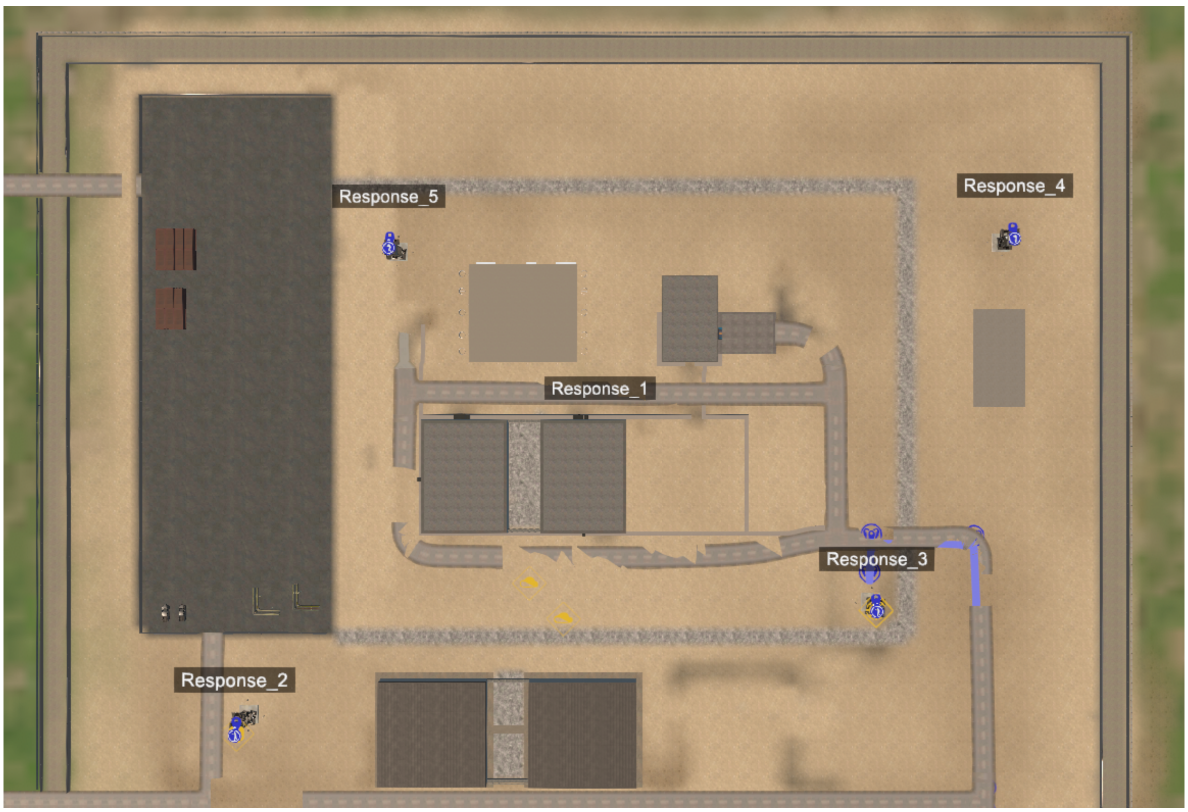

Figure 27. Modified Response Locations

Based on the increased number of targets and the overall number of entry points into the reactor buildings, two adversary attack scenarios were developed and analyzed.

3.7.1. Adversary Attack Scenario One

The first adversary attack scenario considered the adversary team attacking the facility from the west, using material that may be present in the laydown yard for cover and concealment as they attempt to breach into reactor building two. This scenario can be seen in Figure 28.

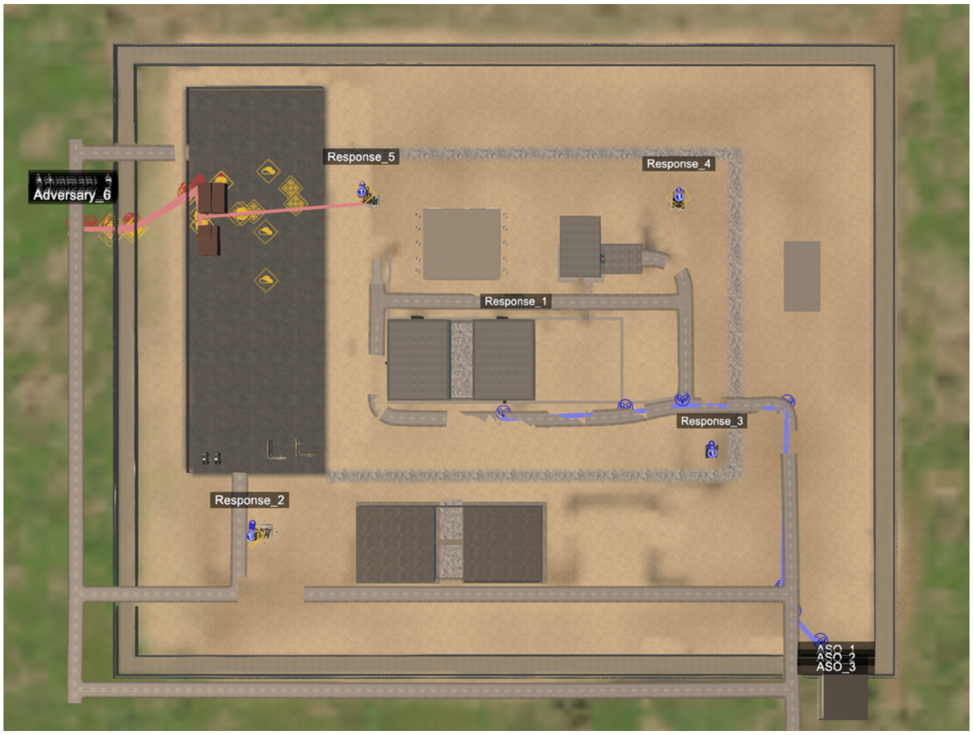

Figure 28. Adversary Attack Scenario One for Two Operating Units

The adversary group first attempts to breach into the PA from the west side of the facility. As the adversary team begins to breach the PA barrier, they begin to suppress responders 2, 4, and 5.

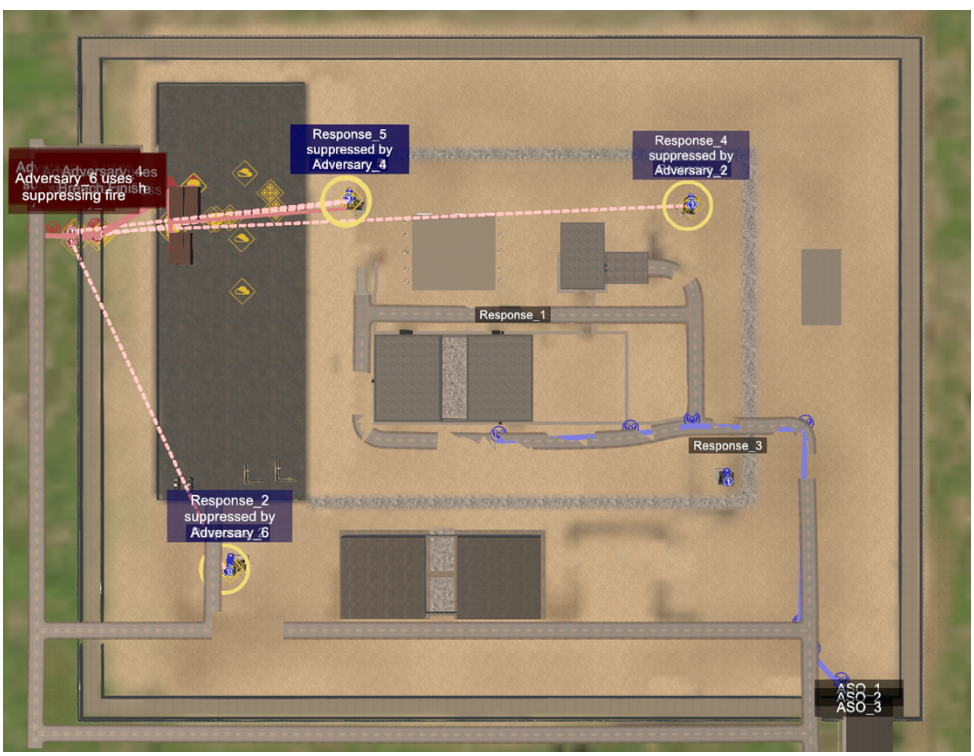

Figure 29. Adversary Suppression of BBRE Towers

As the adversary team begins to cross the PA toward the laydown yard, responder 2 begins to engage the adversary team and neutralizes two of the adversaries. Once the adversary team has entered the laydown yard, they deploys smoke grenades to conceal their movements to the second reactor building. Upon deployment of the smoke grenades, two of the adversaries begin to provide suppressing fire on responders 5 and 4. At this time, the response team lead (RTL) dispatches two of the ASOs from the PA ECP to move into reactor building one and protect it. One ASO stays in the PA ECP to ensure the ECP is locked down. This is shown in Figure 30.

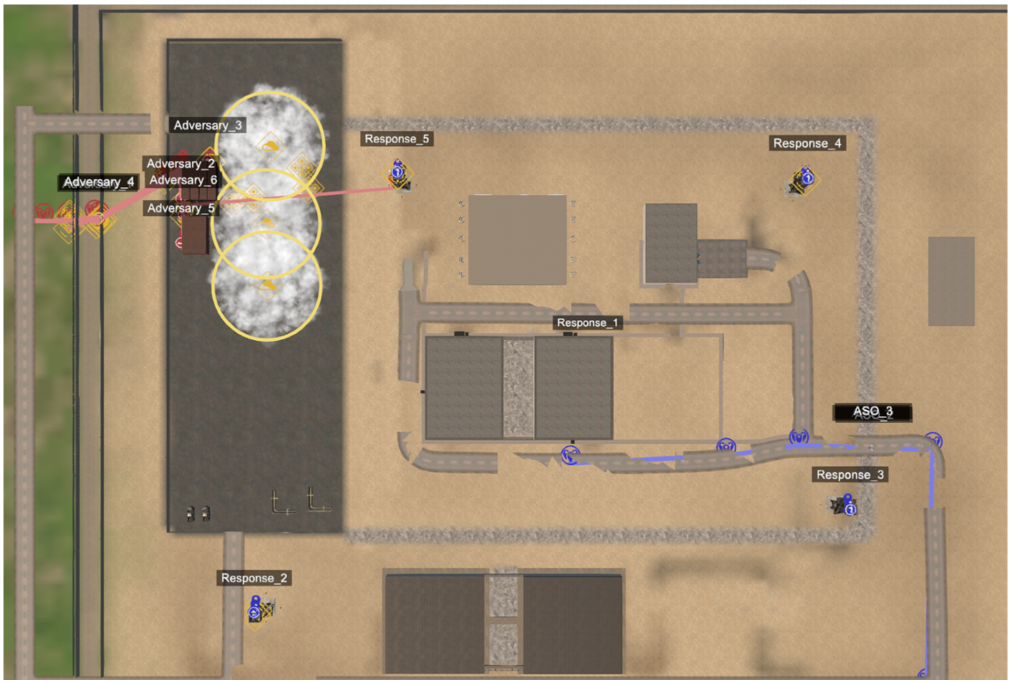

Figure 30. Adversaries Using Smoke and ASOs Moving

Once the adversaries begins using suppressing fire, the remaining adversary team members begin moving through the smoke toward reactor building two; responders 2 and 4 can use their thermal-optic scopes and engage and neutralize two of the adversaries moving toward reactor building two. After these two adversaries are neutralized, the remaining adversaries attempt to cross the open space from the laydown yard to the reactor buildings. These two adversaries are neutralized by responder 5 and responder 2 before they reach the shark cage at the western entrance into reactor building two.

Moving responder 2 to the southwest enabled earlier engagement along the western fence line, before adversaries were able to enter the laydown yard. This effectively minimized the number of adversaries able to enter the laydown yard and suppress other towers at the facility. Additionally, providing the responders with thermal-optic weapon platforms allows them to neutralize the adversaries after they deploy smoke grenades.

3.7.2. Adversary Attack Scenario Two

The second adversary attack scenario considered the adversary team attacking the facility as one group from the south. In this scenario, the adversary team begins by breaching the PA barrier while suppressing responder 2 and responder 3. The adversary team neutralizes responder 2, but responder 3 neutralizes one adversary before they begin to cross the open space toward the turbine buildings.

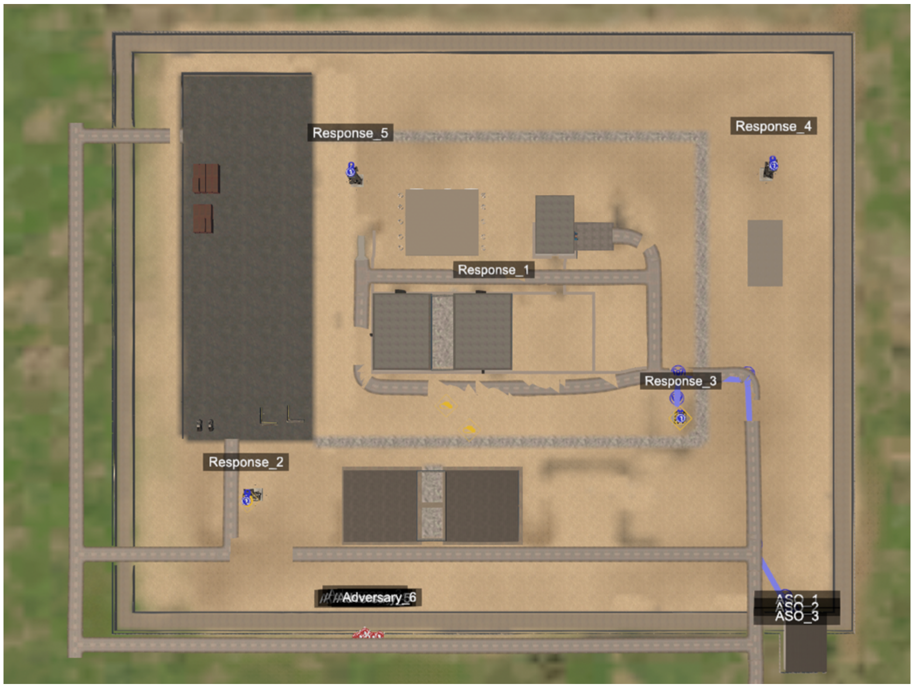

Figure 31. Attack Scenario Two for Two Operating Units

As the adversaries move toward the turbine buildings, two ASOs leave the PA ECP and attempt to make their way to the base of the BBRE tower for responder 3.

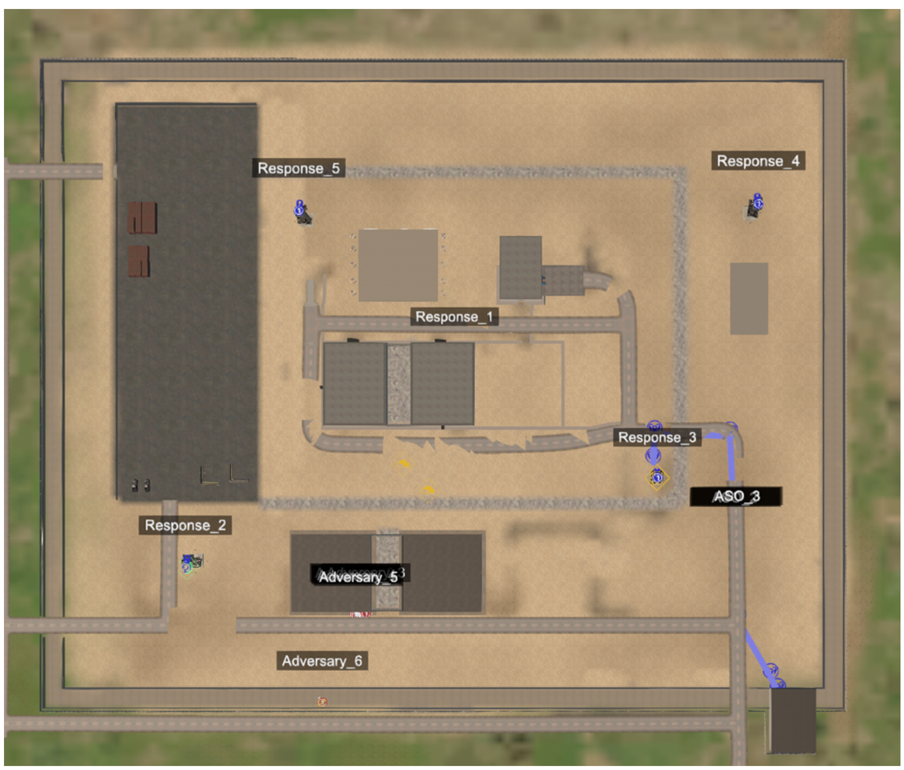

Figure 32. ASOs Moving to Responder 3

The adversary team attempts to use the space between the turbine buildings as a location for cover and concealment before trying to cross open space as they move toward the south entrance door of reactor building one. As the adversaries reach the northern turbine grating between the turbine buildings, they deploy smoke grenades in front of the shark cage while they attempt to begin breaching it. As the adversaries begin their breach, responder 3 engages and neutralizes the adversary breacher. As the adversary team continues to attempt to breach the turbine grating, responder 3 and responder 4 neutralize the remaining adversaries.

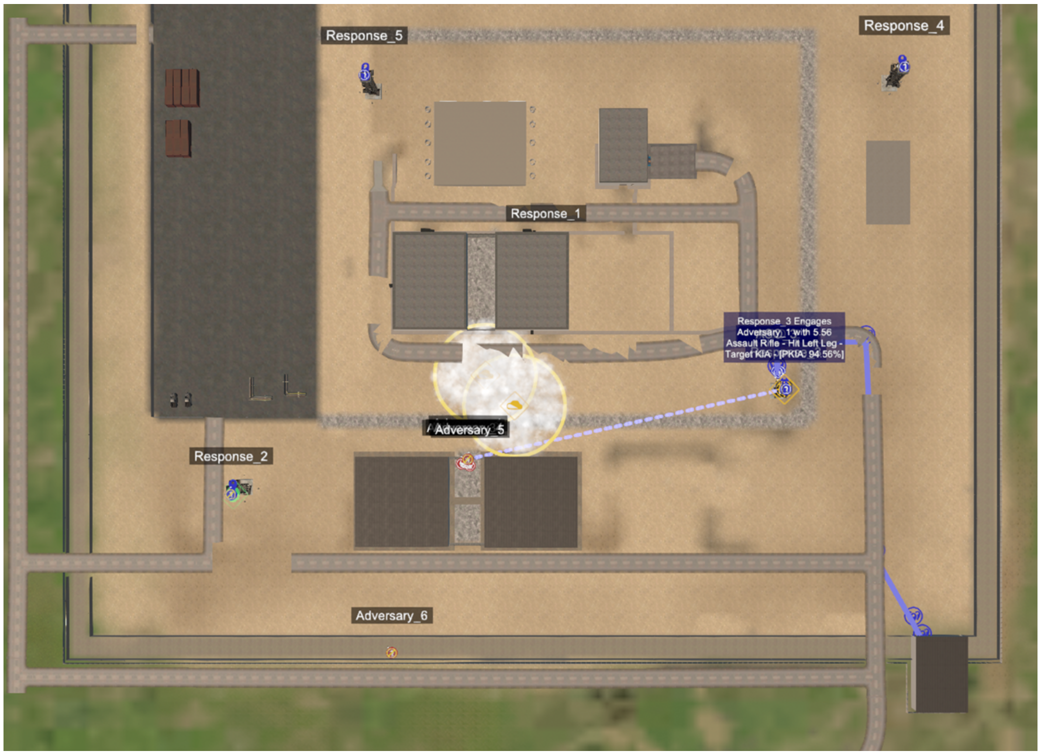

Figure 33. Responder 3 Neutralizing Turbine Grating Breacher

This design proved to be robust against the chosen adversary attack scenario. The contributing factors to the success of the PPS are the turbine grating between the turbine buildings, the thermal-optic weapon platforms for the response force, and the open space between the turbine buildings and the reactor buildings. The turbine grating between the turbine buildings presents an obstacle that the adversary team must breach or climb over. If the adversary team chooses to explosively breach the turbine grating, they must retreat to a safe standoff distance and leave the area between the turbine buildings to survive the breach. This forces the adversary out into open areas where they are exposed. In this scenario, the adversary team breaches the turbine grating with power tools, which forces the breacher to spend extended time in the open where responder 3 has line-of-sight and can easily engage and neutralize them. The thermal-optic weapon platforms provided to the response force allow them to effectively engage the adversary despite the smoke dissipated by the smoke grenade (which was used by the adversary for concealment during the breach). The open space between the turbine buildings and the reactor buildings requires the adversary to cross a large distance without cover or concealment, allowing responders 3 and 4 to effectively engage and neutralize them.

3.8. Larger Initial PA Considerations

The above-conducted analysis provides many insights for SMR vendors and utilities that may impact the PPS and the operations of an SMR facility.

The scenario that considered two operational reactors and one under construction had a different BBRE tower configuration than the scenario with three operational reactors. **SMR vendors and operators should consider the desirable end state of the facility and evaluate PPS designs and response configurations that reduce the total number of moves or changes to the response force configuration.** Moving BBRE towers can be expensive and lead to increased costs over time. In this example, the response BBRE configuration for three operational reactors also would have been effective for the scenarios with two operational reactors and one reactor under construction.

During the analysis of the PPS, it was determined that the ankle breaker rocks initially designed into the system did not have an impact on the overall effectiveness of the PPS. Therefore, the team decided the final PPS design did not need to include the ankle breakers, as this would be an unnecessary cost with no appreciable benefit to system effectiveness. **Vendors and operators should consider that throughout the design process there may be PPS measures that are not needed after initial configuration. This should be determined by evaluating the PPS measure against both its impact on system effectiveness and its cost.**

Based on analysis of this PPS, the team agreed the site could benefit from a secondary entrance point into the PA to support construction vehicles and personnel throughput. One significant economic benefit that SMRs may have is a smaller workforce needed to operate the facility. However, during construction, if there is only one entrance point into the PA that must accommodate both operational personnel and construction vehicles and personnel, this could severely increase facility throughput time for personnel access. As a result, there could be delays to the construction of the facility and impacts to operational rhythms that may lead to increased operational costs. To mitigate this, one option is a temporary secondary entrance point for construction vehicles and personnel to enter the PA, which would minimize impacts on site access times.

With each new operational reactor at the facility, additional sensors, cameras, and access control devices will be installed. This will require configuration changes to the intrusion detection system, the access control system, the video management system, and therefore, the facility's overall AC&D system.

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4. PPS DESIGN FOR EXPANDING PROTECTED AREA

A design and analysis of this hypothetical SMR facility considered the use of an expanding PA as more units are brought online, with under-construction units located in the OCA. This design option is such that all construction and related vehicle equipment will be housed in the laydown yard to the west of the operating reactor units. In this configuration, none of the construction vehicles and personnel would need to be searched (nor would any additional security requirements be necessary), as they will not enter the PA. With all construction material and activity occurring in the OCA and not inside the PA, initial security system costs may be lower (as compared to the previously analyzed larger PA approach) because fewer individuals have access to the PA so there is less cost associated with searches/contraband detection. However, this approach does require unique security configurations, as the underground portions of the facility connect the operational units to the unit under construction. Personnel access to the underground passageways from the operational units to the spent fuel building may not be possible because of the high radiation in this area. **With this in mind, vendors/operators should consider constructing the underground passageways that lead from the reactor buildings to the spent fuel building before the reactor buildings are finished.** This may limit the overall security requirements necessary as the facility is being constructed. For example, when an additional unit is under construction, the site can either post an ASO or install intrusion detection technologies at the passageway entrance points to ensure that access into the PA cannot be achieved. It should also be noted that this access point was not considered a credible adversary pathway, as there are multiple reinforced concrete walls below grade that the connections pass through. This would require the adversaries to access the passageway and breach through the walls with enough equipment to create an act of sabotage that could cause a radiological release. Based on the DBT capabilities used in this analysis, this was deemed not credible. **Vendors and operators may have to consider these types of potential access points if facility operations occur below-grade.**

Expanding the PA for each subsequent reactor unit will require configuration changes to the PIDAS and the response force BBRE locations. These additions and reconfigurations could increase costs, and would include changes to the video management system, access control system, and intrusion detection system, as well as the AC&D system to integrate all of these areas after each expansion. As the PA is expanded for each reactor unit, the site will also have to consider BBRE towers that can be moved to within the PA with adequate fields-of-view for engaging and neutralizing adversaries attempting to attack the facility.

4.1. One Unit Operating and One Unit Under Construction

The first expanding PA scenario focused on one reactor under operation and a second reactor under construction. This approach follows the previously described progression of reactor buildings, where the middle reactor building is constructed first. Figure 34 shows the PA design and layout for this configuration, with the middle reactor operating and the western reactor building under construction.

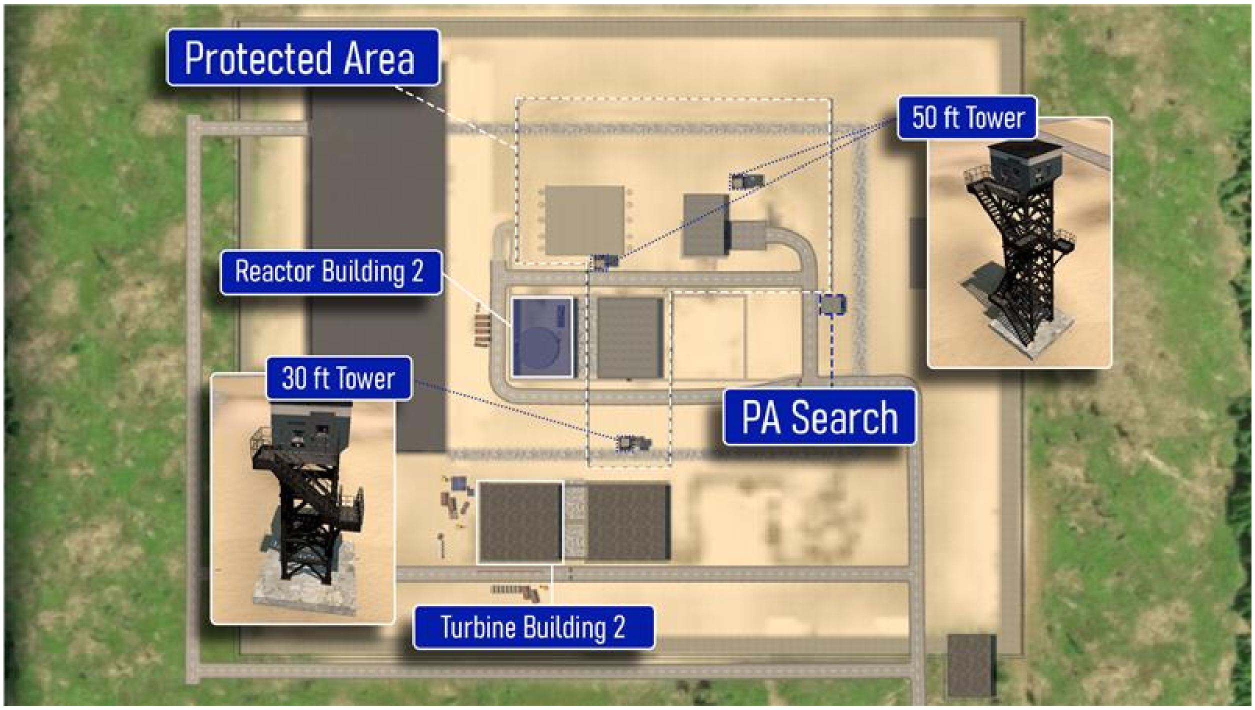

Figure 34. Expanding PA – One Unit Operating and One Under Construction

Figure 34 shows the PA surrounding the operating reactor, the spent fuel storage building, and the fresh fuel storage building. This presents some unique challenges to protecting the facility and creates unique adversary attack pathways to attack the facility, both of which must be considered in the overall security system protective strategy.

As seen in Figure 35 andFigure 36, the PIDAS consists of microwave sensors, active infrared sensors, and CCTV cameras. This design configuration does create unique angles and shorter sectors for intrusion detection systems. For example, there are several corners and directional changes of the perimeter that require an increased number of microwave and active IR sensors to be used to achieve effective coverage. Additionally, shark cages are applied at the entrances to the operational reactor building and the fresh fuel storage building. These shark cages create an additional barrier that adversaries must breach to gain access to target locations, which leaves the adversaries exposed to responder fields-of-view for longer periods of time. This design feature may improve response force ability to neutralize the adversary force.

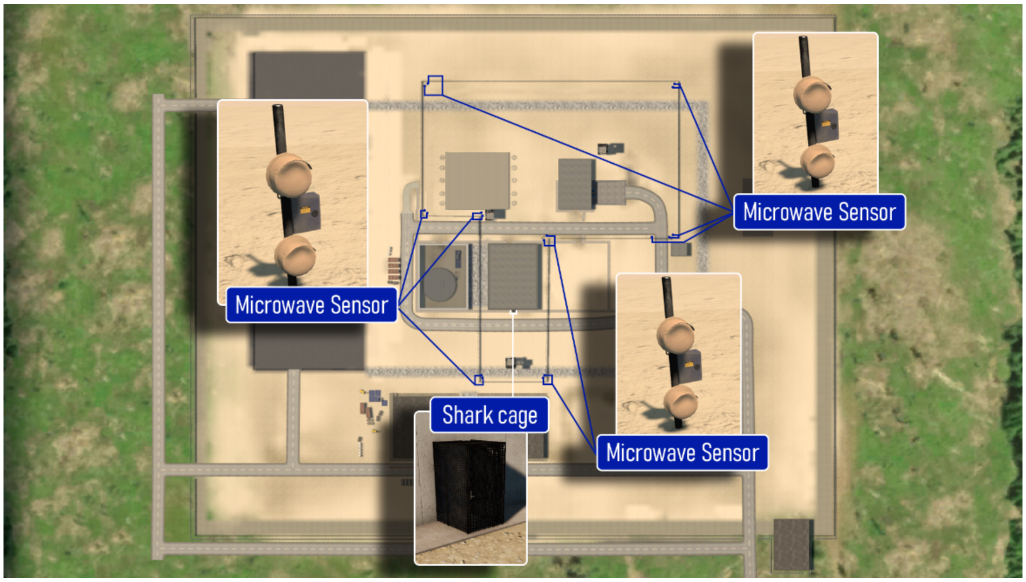

Figure 35. Expanding PA – One Reactor, Microwaves

Figure 36 shows the locations of active IR towers and the entrance locations into the facility for vehicles using the gates. The gate on the eastern side of the facility near the PA entrance point is the primary vehicle entry control point into the PA. One overall facility configuration change is shifting the entrance process for vehicles and personnel to the OCA. In this design configuration, the OCA boundary is located where the start of the PA was in the previous design iteration. All vehicles and personnel must process through the ECP at the OCA. Vehicles will be stopped at the OCA for a preliminary search prior to entry. This search process will ensure that vehicles, including construction vehicles, cannot transport large vehicle explosives into the facility. The vehicle barrier system is located at the OCA boundary and is comprised of modular block walls and hydraulic wedge barriers at the vehicle ECP. Additionally, all individuals will use a proximity badge at this location to enter the facility. This is primarily because the turbine halls are now located outside of the PA boundary, so this process facilitates access control for personnel needing to enter the turbine halls to perform their job duties. In contrast, one benefit of the previous design iteration is that all balance of plant (BOP) equipment (like the turbine and generator) is located inside the PA, which provides additional security layers.

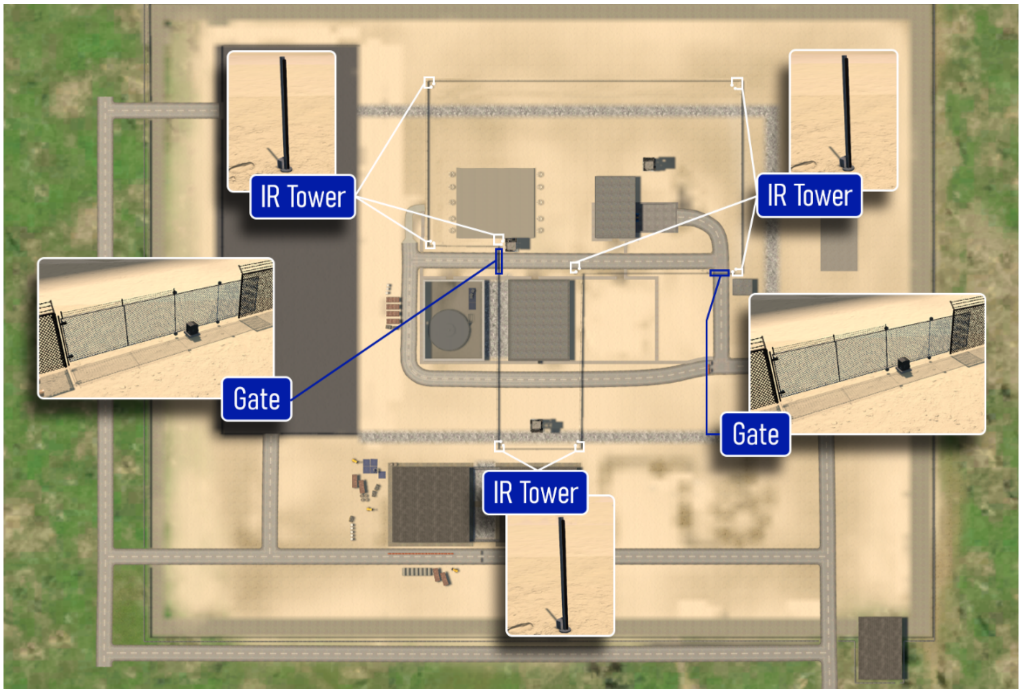

Figure 36. Expanding PA – One Reactor, Active IR and Gates

A challenge at this stage of plant operations is ensuring that all responders have adequate fields-of-view and a minimum of two overlapping fields-of-fire along pathways to access target locations. DG 5076 4.1.1.4.A states,

> *Defense in depth should be provided for neutralization functions with an exterior protection layer of at least two overlapping fields of fire covering each sector of the outermost perimeter physical barriers. The actual number of overlapping fields of fire should be dictated by the amount of time the adversary is exposed between the time of detection and the first delay element or opportunity for the adversary to obtain cover, or concealment.*

Responder one has fields-of-view that include the east and west sides of the operating reactor unit, the entrance into the fresh fuel storage building, and the PA ECP. Responder two has a field-of-view of the western side of the operating reactor unit, the northern entrance into the operating reactor building, the PA ECP, and adversary pathways to the fresh fuel storage building. Responder three has a field-of-view of the eastern side of the reactor building, the northern entrance into the operating reactor building, the PA ECP, and the entrance into the fresh fuel storage building. These fields-of-view can be seen in Figure 37 and Figure 38.

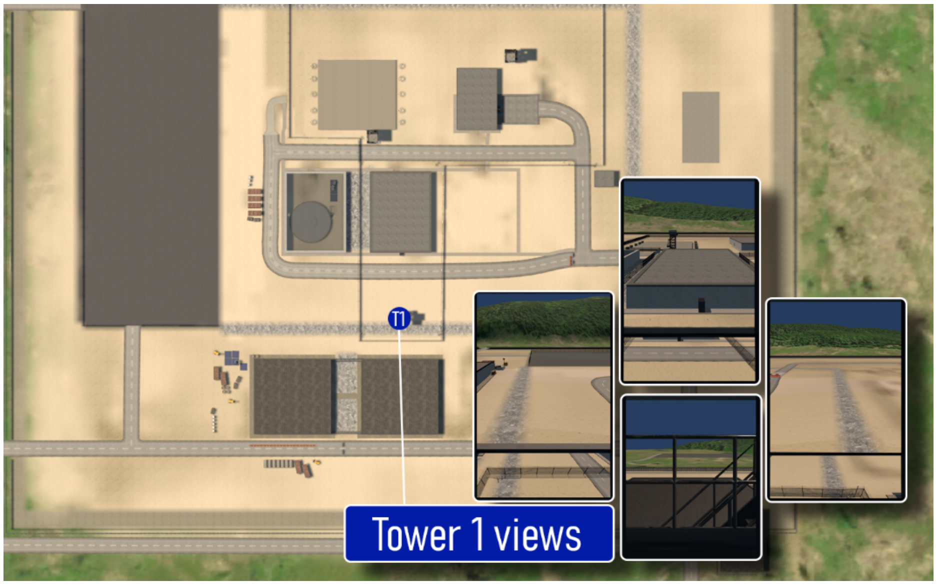

Figure 37. Expanding PA – One Reactor Tower, One Field-of-View

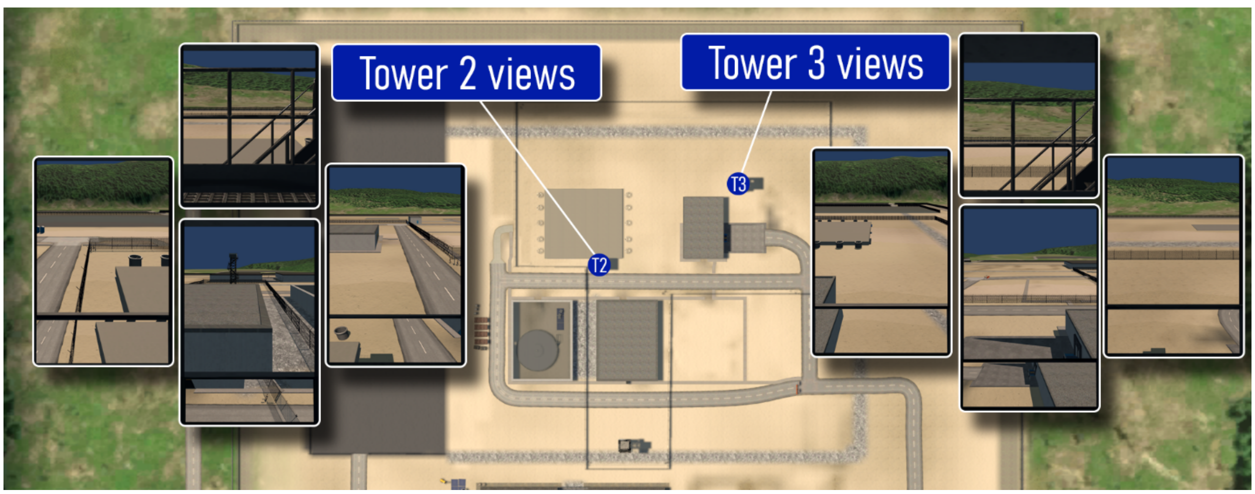

Figure 38. Expanding PA – One Reactor, Tower Two and Three Fields-of-View

4.1.1. Adversary Attack Scenario

The adversary attack scenario developed to evaluate this PPS design considered the adversaries attacking the facility from the west at night and using the construction laydown yard as cover until they reached the under-construction western reactor. Because there is no detection equipment at the OCA boundary and the adversaries are attacking under the cover of darkness, the team determined the scenario start occurred when the adversaries were near the under-construction western reactor building. The start of this adversary attack scenario is shown in Figure 39.

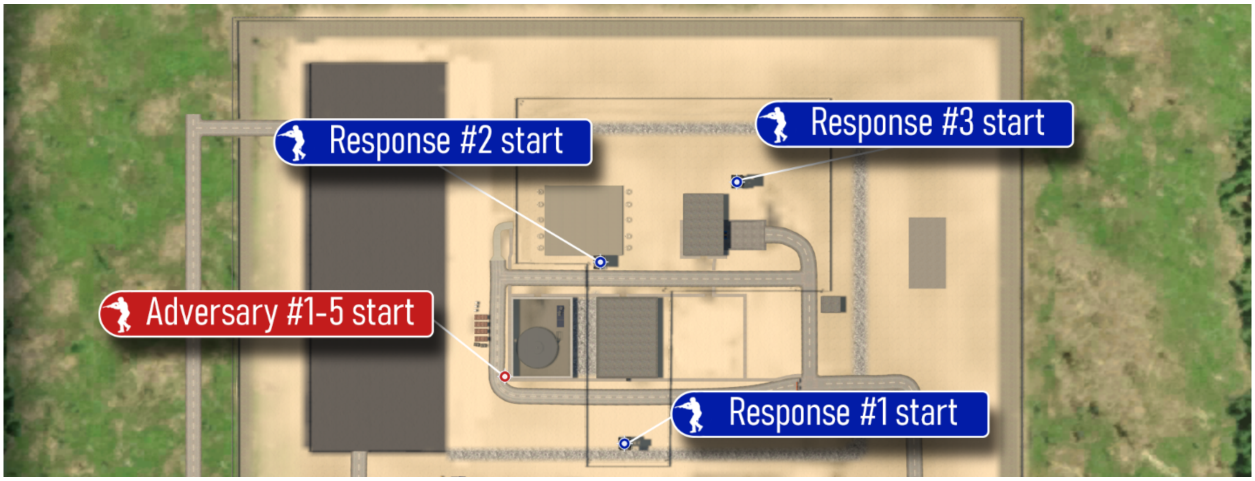

Figure 39. Expanding PA – One Unit Attack Scenario Start

Once the adversary team reaches the southwest corner of the under-construction reactor building, one adversary begins suppressing the western facing gunport for responder one. This allows the rest of the adversary team to move up to the southeast corner of the under-construction reactor building. This adversary motion can be seen in Figure 40.

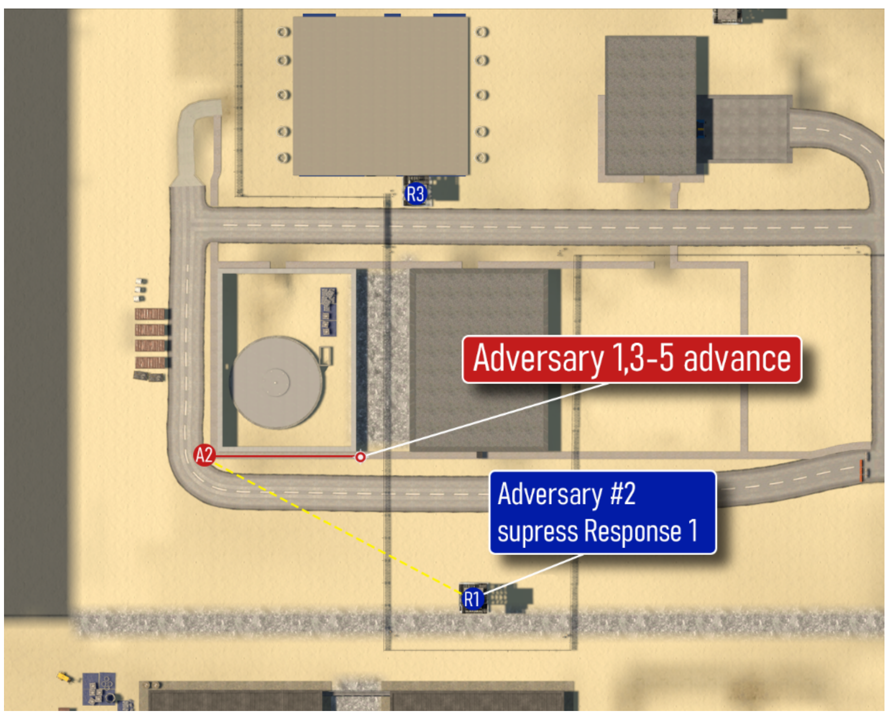

Figure 40. Expanding PA – One Unit Adversary Initial Movement

The remaining adversary team members move up toward the southeast corner of the under-construction reactor building. Once the team reaches the southeast corner, one adversary member begins to suppress responder two and one additional adversary begins to suppress the north facing gunport of responder one's BBRE tower. This is meant to disable the responder's ability to engage the adversary team members as they attempt to breach into the operating reactor building. It is important to note in this scenario, detection by exterior sensors has not occurred yet, and the response team would be communicating with the RTL about the unfolding situation. This adversary movement can be seen Figure 41.

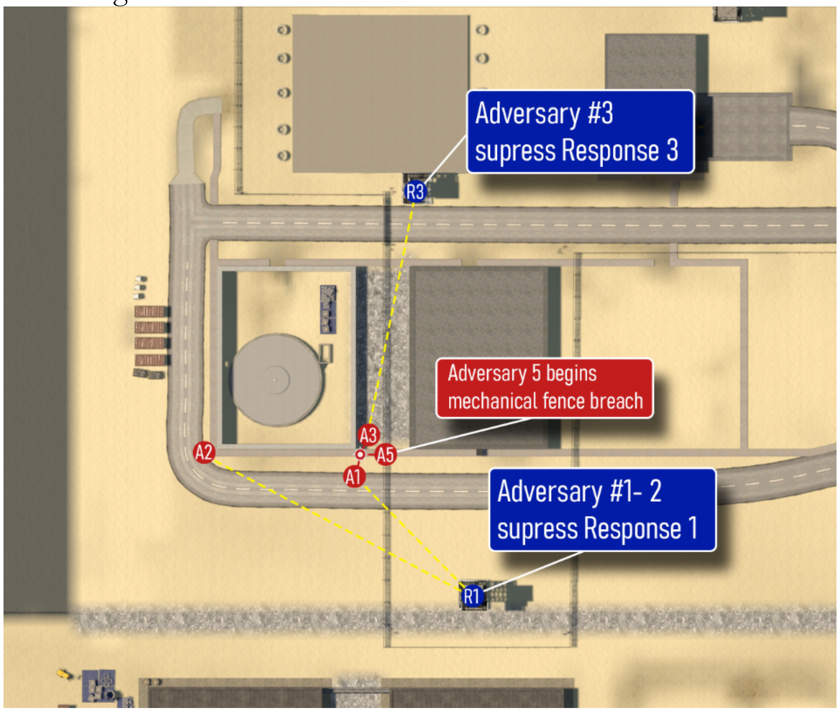

Figure 41. Expanding PA – One Unit Adversary Engagement

The response strategy developed for this facility is aimed at preventing the adversary team members from penetrating into the reactor building. This response strategy allows responder one to not engage the adversaries until they reach the shark cage they must breach to enter the facility. As the adversary team moves forward after breaching the PA fence line, responder one engages the adversaries during their attempt to breach the shark cage. This additional exposed breach allows responder one to initially engage and neutralize two adversaries. Once these two adversaries have been neutralized, a third adversary moves up and all suppressive fire shifts to responder one's BBRE tower. As the adversary moves up to the shark cage, the responder engages and neutralizes this third adversary[9] (see Figure 42).

[9] All engagements between responders and adversaries were simulated in Scribe3D© with subject matter expert input. All engagements were simulated 100 times.

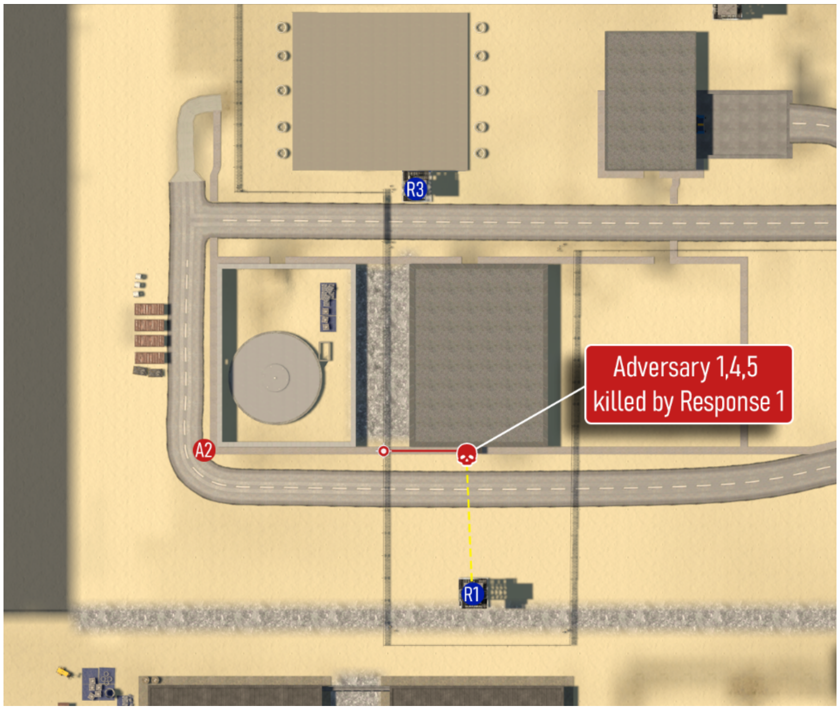

Figure 42. Expanding PA – Responder One Neutralization of Adversaries

Once three of the adversaries have been neutralized, both remaining adversaries move to the shark cage entrance of the reactor building. One adversary is closer to the shark cage, and responder one waits until they reach it and then neutralizes them. Adversary two, who was behind the final remaining adversary, is neutralized by responder two as they cross the opening space between the under-construction reactor building and the operating reactor building.

The PPS was able to defend against the identified adversary attack scenario due to the overlapping fields-of-fire for responder one and responder two, the shark cage on the reactor building door, and the orientation of the BBRE towers. In this adversary attack scenario, the adversary team decided to use the construction areas to block their path of entrance and to obstruct responder three's ability to engage them as they attempt to breach into the facility. This adversary attack angle negates their ability to suppress the northern facing gunport of responder one. In addition to the response force strategy, this allows responder one to be highly effective at engaging and neutralizing the attacking adversary force.

4.2. Two Units Operating and One Unit Under Construction

The next iteration of this facility approach and analysis is two operational units and a third under construction. As seen in Figure 43, this design option considers the PA expanding around each unit as it is completed and fuel is brought into each reactor core. Figure 43 highlights the location of response BBRE towers and shows the outline for the PA boundary (dashed lines around the facility).

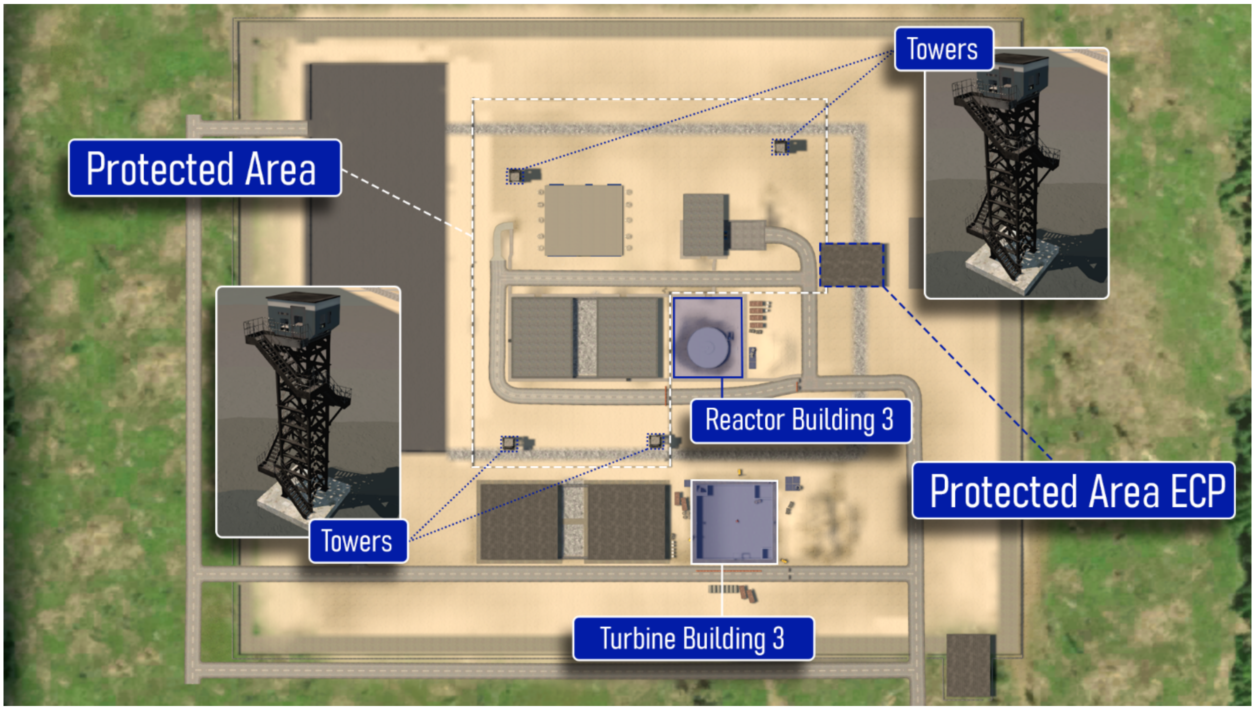

Figure 43. Expanding PA – Two Units Operating

The facility has a much smaller PA boundary, with the two operating reactor units, the spent fuel storage building, and the CAS and fresh fuel storage building located inside of the PA. The PA ECP is also moved closer to the reactor buildings then it was in the design where one large PA is used for the facility, though the ECP size and configuration is identical to that used for one larger PA (see Figure 10). **It should be noted that there is also a configuration change to the vehicle gate locations and changes to the overall exterior intrusion detection system. This change will require the intrusion detection system and the assessment systems to be reconfigured in the CAS and the secondary alarm station, leading to potential increased costs.** Figure 44 highlights the locations of the PA gates and active infrared towers.

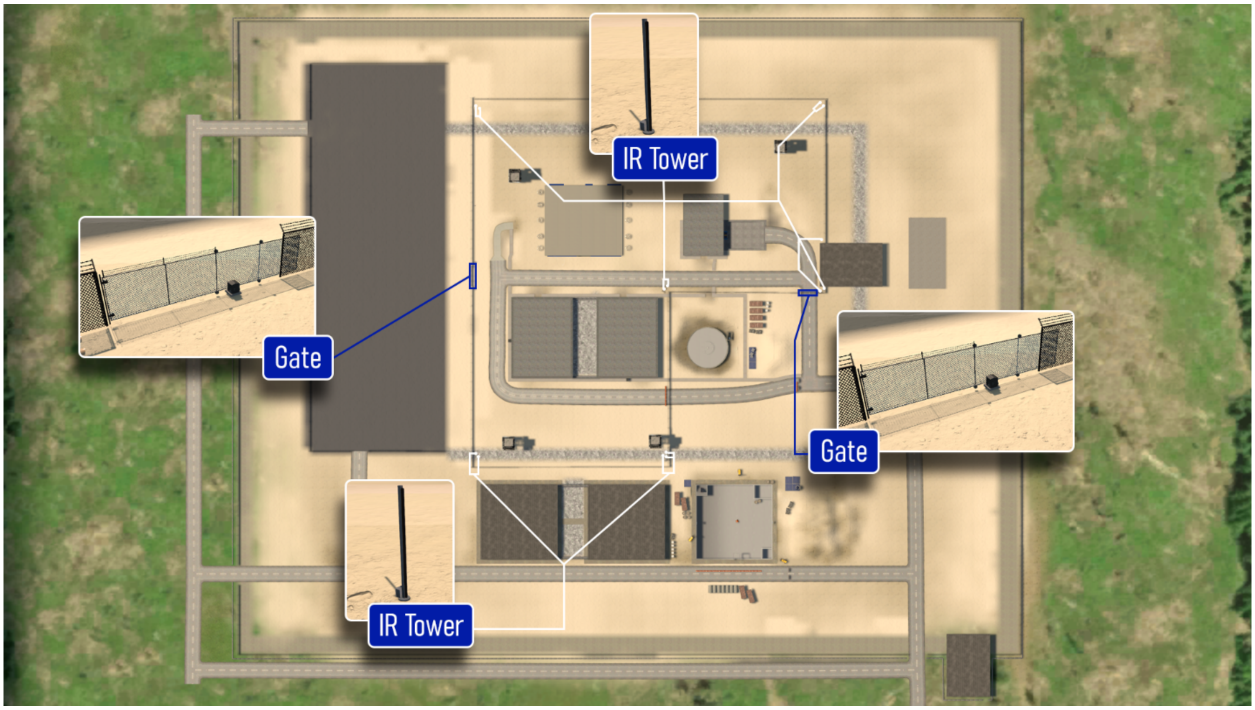

Figure 44. Expanding PA – Two Units Operating Gates and Infrared

Figure 45 highlights the microwave sensors and shark cages located around the facility.

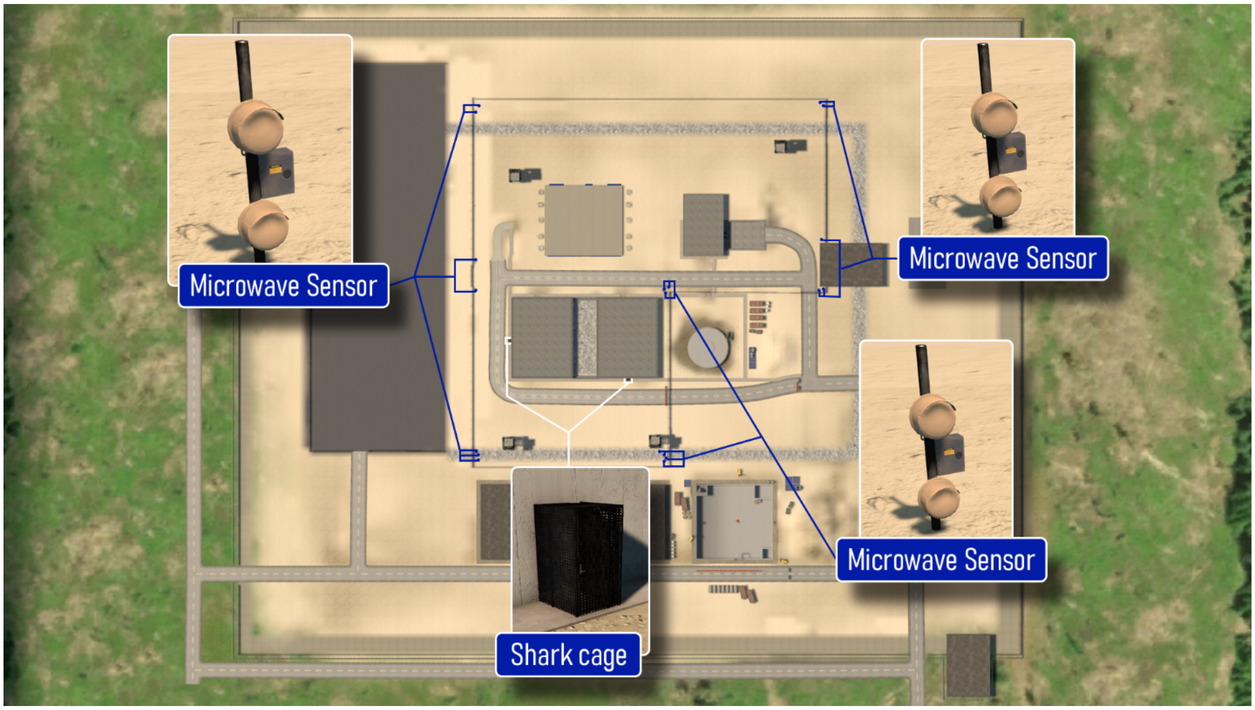

Figure 45. Expanding PA – Two Units Operating Microwaves

When considering expanding the PA around additional operating reactors, it is important to determine the proper response force BBRE tower locations that enable an effective response strategy to mitigate adversary attack scenarios. With two units operating and a third unit under construction, the BBRE towers are placed to protect vital areas and important structures, systems, and components at the facility as well as provide oversight to construction locations outside of the PA. The BBRE towers shown below are 40-foot BBRE towers that enable larger fields-of-view and improve line-of-sight for the responders to engage and neutralize adversaries. The scenario where one unit was operating and the west unit was under construction used two 50-foot BBRE towers and a 30-foot BBRE tower. Changing the towers out for expansion of the PA could lead to increased costs to replace towers as needed. **If the expanding PA model is chosen by a vendor, they should ensure the tower configuration and layout are considered for every phase of the overall design process.** The responder in tower 1 has fields-of-view to the construction laydown yard, the third unit under construction, and the doorways into each reactor building. The responder in tower 2 has fields-of-view to the construction laydown yard and the northern entrances into the reactor buildings that are operational. The responder in tower 3 has fields-of-view to the northern entrance into the operating reactor buildings, the vehicle entrance into the fresh fuel storage building, and the reactor under construction. The responder in tower 4 has fields-of-view to the reactor under construction, the personnel entrance into the fresh fuel storage building, the southern entrance into the reactor building, and a portion of the construction laydown yard. Figure 46 shows the response BBRE tower locations and their respective fields-of-view.

Figure 46. Expanding PA – Two Units Operating Responder Fields-of-View

One additional benefit to the tower locations and the tower heights is that there are overlapping fields-of view for response towers. For example, tower 1 has a field-of-view to the base of tower 2 and to the base of tower 4. All towers are covered by at least two other towers, ensuring that adversaries attempting to approach the base of a tower can be engaged and neutralized by a responder.

Similar to the PPS design mentioned above, this design will also include turbine grating and ankle breaker rocks between the completed reactor buildings. This offers a delay barrier that can be used to channel the adversaries around reactor buildings and minimize the amount of cover and concealment that is provided to the adversary force attacking the facility. This turbine grating can be seen in Figure 18.

4.2.1. Adversary Attack Scenario

The adversary attack scenario chosen for this design configuration focuses on a group of adversaries attacking the facility from the south of the plant with the initial goal to suppress response towers on the southern portion of the facility. The adversary attempts to place a breaching charge on tower 2 to disable it and neutralize the responder in the tower. The adversary team's objective in this scenario is to breach into the middle reactor building and complete an act of sabotage once inside the reactor building. The start of this adversary attack scenario can be seen in Figure 47.

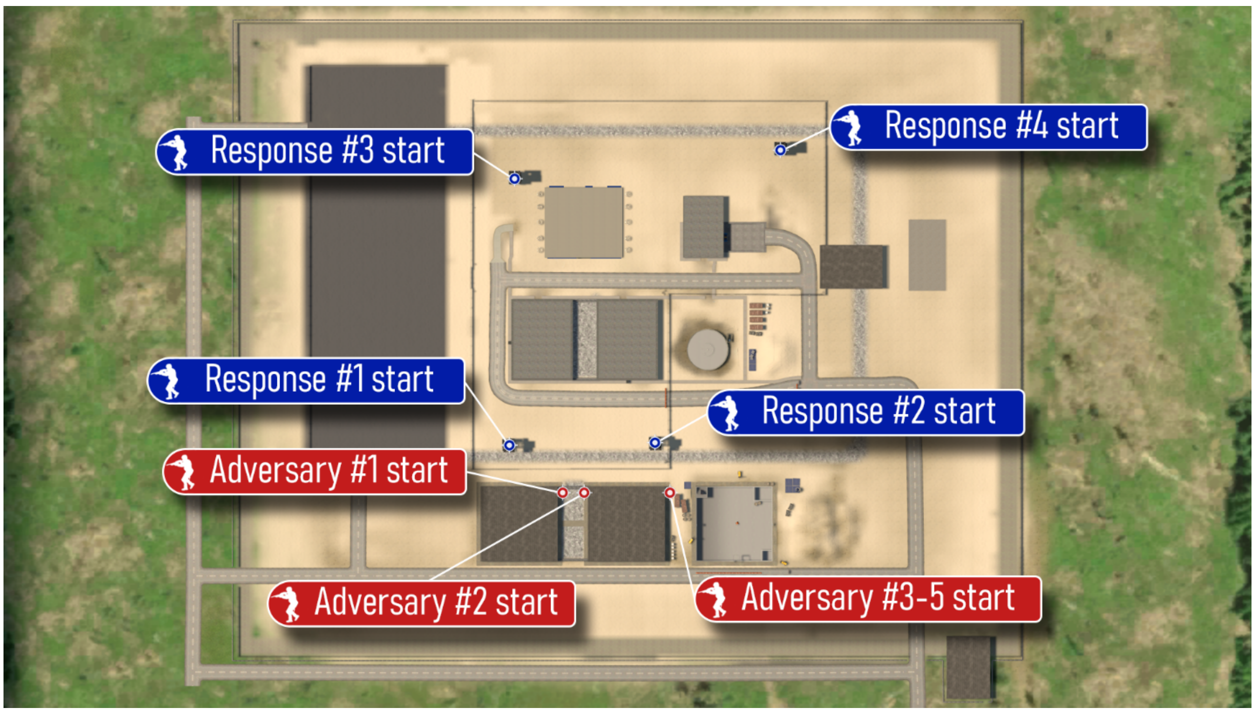

Figure 47. Beginning of Adversary Attack Scenario

As shown in Figure 48, adversaries one and two start the scenario by suppressing the responders in the two southern towers. Additionally, one adversary begins to suppress the gunport on the southern face of the southeast BBRE tower to enable one of the adversaries to move up to the southeastern BBRE tower and place enough explosives to make the tower and responder combat ineffective.

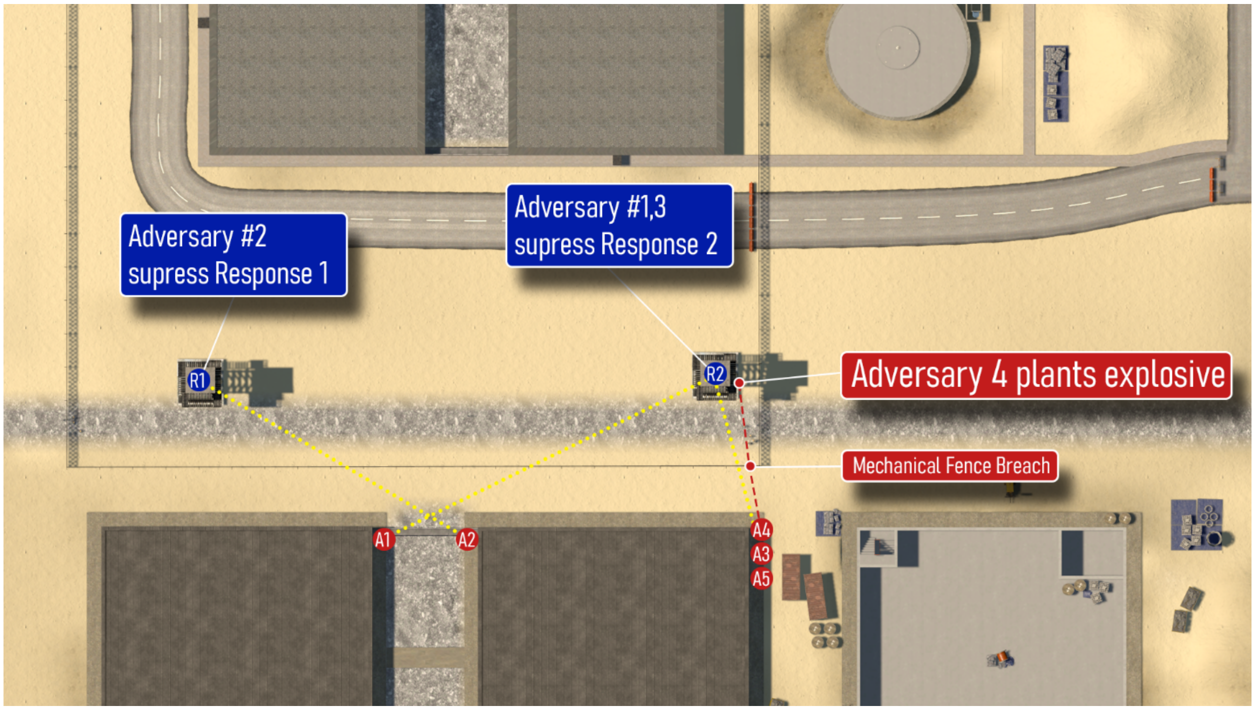

Figure 48. Adversary Suppression of Response Towers

In this adversary attack scenario, responders three and four are not suppressed by any adversary fire, which enables these two responders to engage the adversary force. As suppressive fire begins, the responders in the southeastern BBREs begin to communicate to the CAS operator and RTL about the gunfire they are receiving. The RTL commands responders three and four to find the source of gunfire and, if they can be identified, to engage the adversaries as they attempt to breach into the facility. The responders in these towers engage and neutralize two of the adversaries.[10] Once these adversaries have been neutralized, the responders in the northern BBRE towers engage and neutralize the remaining adversaries. This action occurs before the adversary can place the explosive charges on the southeastern BBRE tower. These engagements can be seen in Figure 49.

[10] All engagements are simulated within Scribe3D 100 times to gain a realistic scenario result.

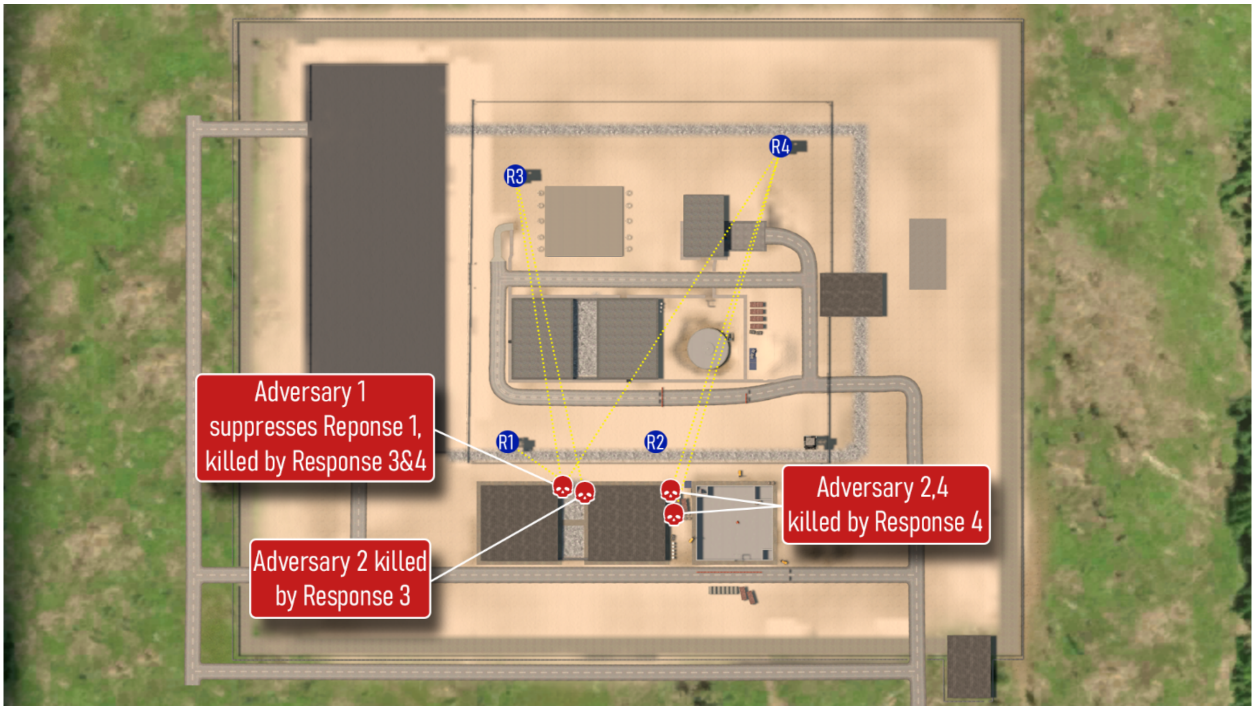

Figure 49. End of Adversary Attack Scenario

This scenario demonstrates the effectiveness of the PPS against this adversary attack. The placement and location of the BBRE towers and the overlapping fields-of-view that are provided to the response force in this configuration are the key elements for system effectiveness in this case.

4.3. Three Operational Reactors

The final design iteration considered the PA expanding outside of all three operational reactors, the spent fuel storage building, the fuel storage building, and the CAS building. Figure 50 shows this expanded PA around these buildings; it also includes the inside of the reactor building and turbine building to better visualize the facility. The PA expands around the third reactor unit to the east of the facility. This change in the facility design does not require the movement of the OCA ECP, the PA ECP, or any other infrastructure. Since the OCA and PA ECPs do not move locations, the overall process for vehicle entry and personnel entry into the facility does not change from the previously described procedures. This means no increased costs or changes to the overall staffing needs of the facility. Additionally, inside of the PA, all reactor building entrances are protected with shark cages and turbine grating between the reactor buildings, as described in the previous section. However, this PA expansion requires the movement of the BBRE towers to improve the effectiveness of the response force against an adversary incursion.

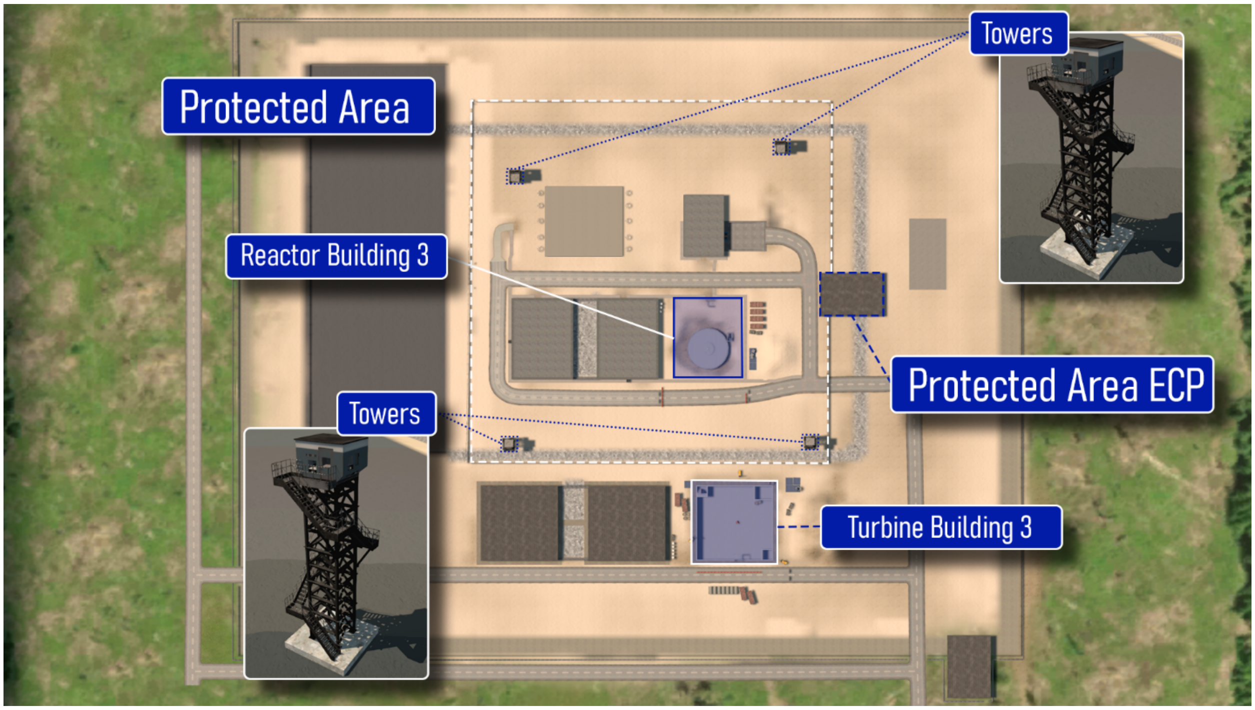

Figure 50. Expanding PA – Three Operational Reactors

Figure 50 shows that two response towers have been moved to facilitate a better response to the PPS. The northeast BBRE tower was moved further northeast, and the southeastern tower was moved further east. Shifting these two towers improves the responders' fields-of-fire for the third reactor building. These towers also have the same design parameters as those throughout this study, where each BBRE tower must be visible by at least one other BBRE tower so there are overlapping fields-of-fire along all adversary pathways into the facility. These fields-of-view for the new BBRE tower locations are shown in Figure 51.

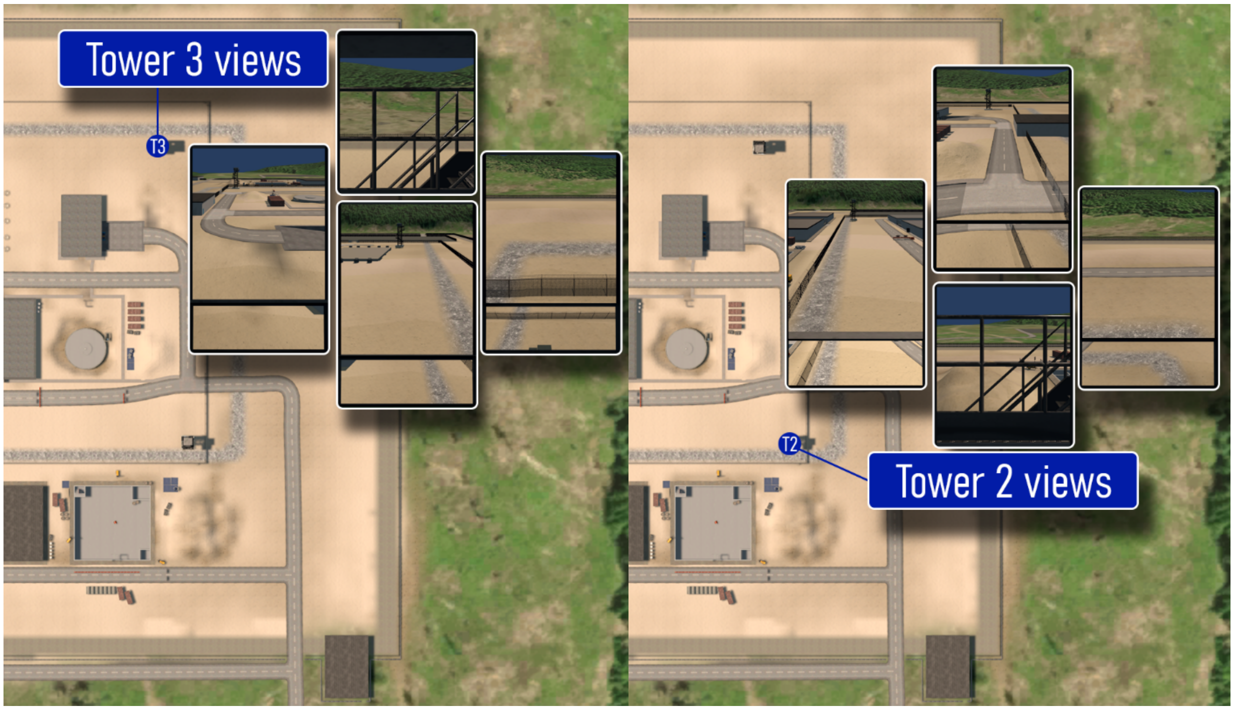

Figure 51. Responder Fields-of-View

4.3.1. Adversary Attack Scenario

The adversary attack scenario considers three adversaries attacking the facility from the southwestern corner of the PA boundary and two adversaries attacking the facility from the southeastern corner of the PA boundary. Ultimately, the adversary team is trying to suppress the BBRE towers long enough so that one member from the adversary team can breach into the reactor building, and from there continue to complete their act of radiological sabotage.

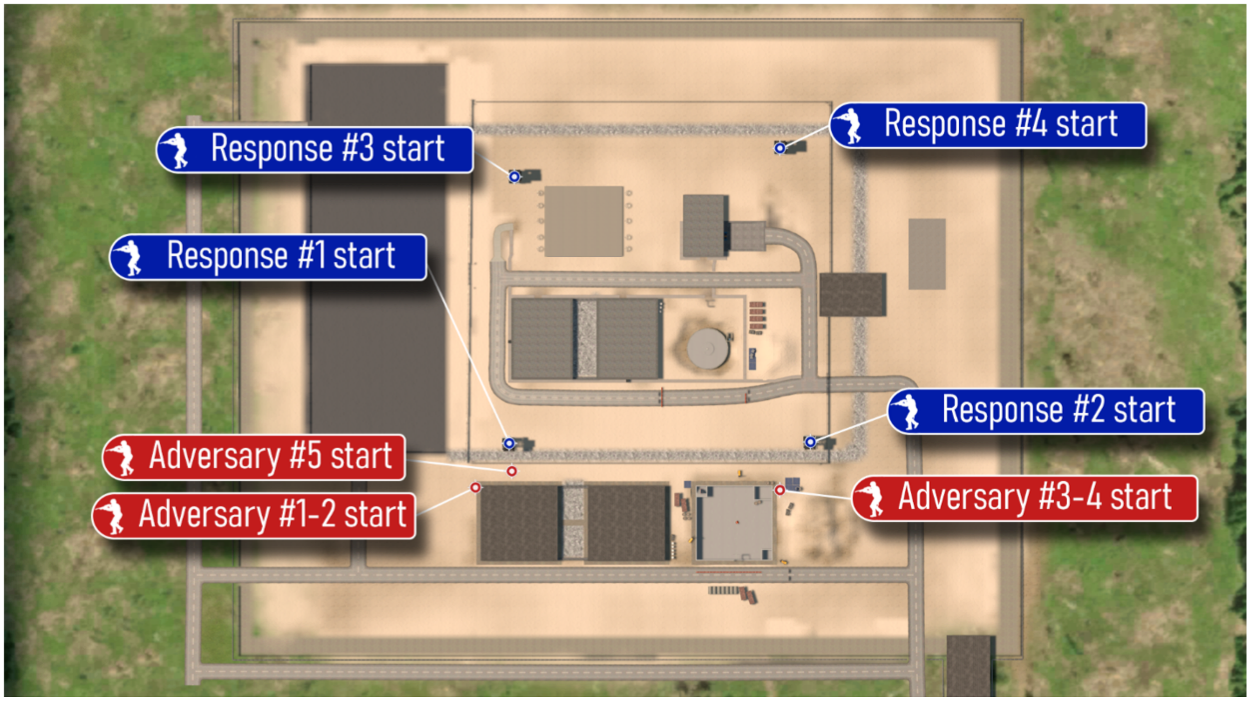

Figure 52. Beginning of Attack Scenario

Once one of the adversary team members breaches the outer fence line in the southwest corner of the facility, the other adversaries begin to suppress the southern BBRE towers to allow the adversary to breach the PA barrier fence. Once the fence line has been breached, the adversary attempts to move to the door of the middle reactor building. This can be seen in Figure 53.

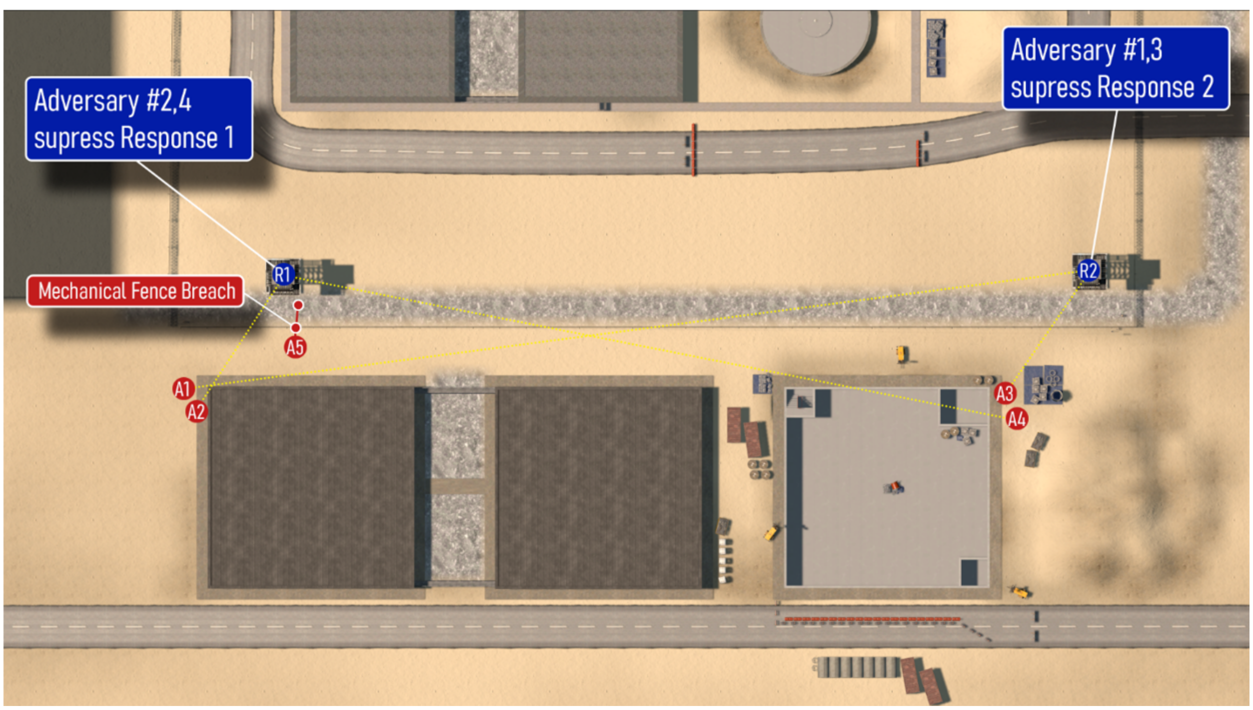

Figure 53. Adversary Suppressing Response BBRE Towers

As the adversaries begin suppressing the southern BBRE towers, the responders in the towers communicate to the CAS and RTL that they are receiving incoming fire. Simultaneously, the CAS receives intrusion alarms from the microwave and active infrared sensors in the PIDAS. Based on these communication times and that the northern response BBRE towers are not being suppressed by an adversary and have unimpeded fields-of-view, they successfully engage and neutralize four adversaries. This occurs while one of the adversaries is moving toward the doorway to enter the middle reactor building. Because the responders in the southwestern and the southeastern BBRE towers are not being suppressed on their northern facing gunport, they are able to engage and neutralize that adversary. The adversary team is unable to reach the shark cage outside of the reactor building door before they are neutralized by the responders.

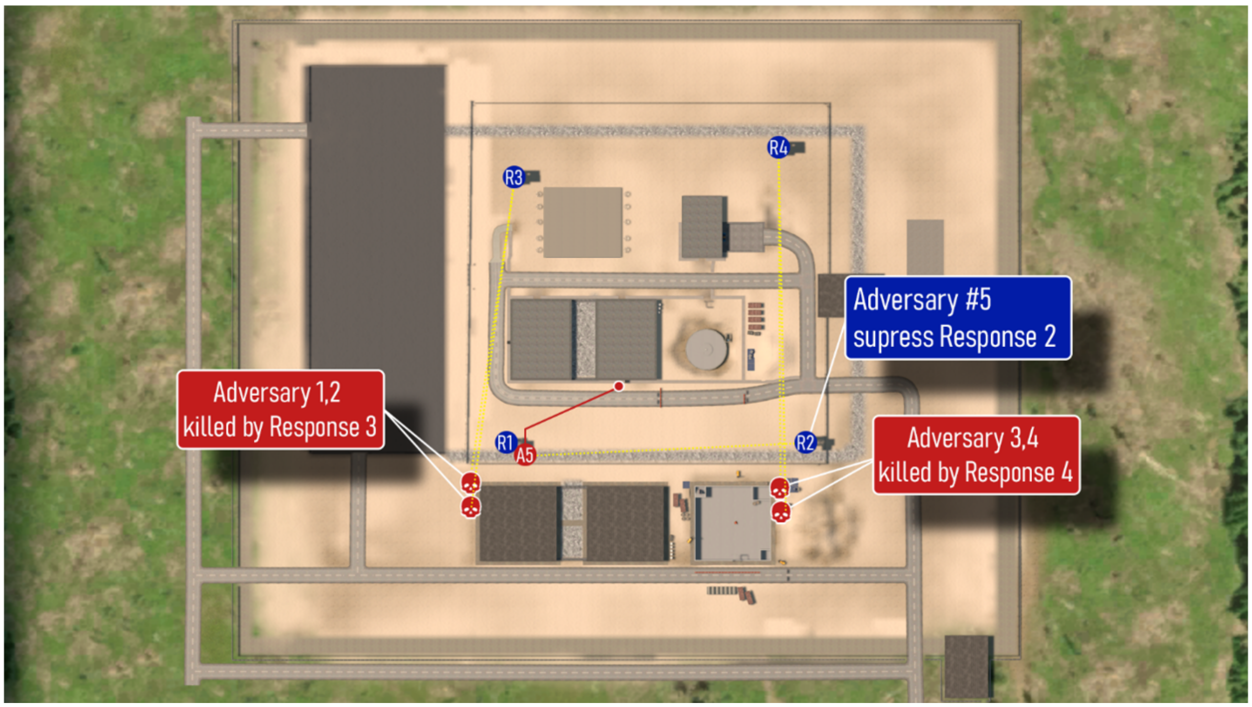

Figure 54. End of Adversary Attack Scenario

This scenario results in the response force being able to engage and neutralize all the adversaries attacking the facility. The primary reason for the success of this adversary attack scenario is the large standoff distance between the PA boundary and the doorways into the reactor buildings. Additionally, the responders' overlapping fields-of-fire allow them to adequately engage and neutralize the attacking adversary force. Another reason for the success of this PPS strategy is the placement of the vehicle barrier system, which ensures that no large VBEDs can be detonated near the facility and neutralize the responders or cause damage to the reactor buildings.

4.4. Expanding PA Considerations

This design process revealed lessons learned that SMR vendors and utilities considering the expanding PA approach should review in order to create an effective security system that reduces upfront and long-term costs associated with moving and expanding the PA around each module.

The first consideration is the fields-of-view presented to responders and the number of responders necessary for protecting the facility as new reactors come online. The first iteration of the facility design considered one operational reactor and required three armed responders in BBRE towers. Additionally, this design utilized two fifty-foot BBRE towers and one thirty-foot BBRE tower. The second phase of this facility considered two operational reactors and required four armed responders in forty-foot BBRE towers. This change in operating parameters and configuration may lead to increased costs as the response towers are changed and reconfigured and an additional response tower and responder are brought in as new reactor modules are brought online. **It is recommended that vendors and potential operators understand what the ideal end state of the facility is and plan for these response force configurations to reduce overall costs to the facility.**

Secondly, vendors and operators should evaluate the layout of the protected area perimeter that is being designed and considered for implementation at each phase of the modularization process. In the above hypothetical facility design, the PA perimeter expands before each module is loaded with fuel and becomes operational. While the final state of the overall PIDAS is smaller to the first design option, there may be some increased costs when considering expansion of the PA for each operational unit. One of these expenses is the need for trenching and running power and communications to new sensors and cameras that are used at the perimeter of the facility. This could potentially be minimized if the power and communication are trenched at one time and are easily accessible for each expansion phase of the PA. However, if the power and communications are trenched before they are needed, there is a risk that those trenched cables could be damaged from construction activities onsite and require replacement.

The next consideration in this design approach is the potential need for AC&D system reconfiguration as each new expansion and building is added to the facility. This is not unique to this scenario, as AC&D system reconfiguration would also occur for each new reactor building that is added inside of the larger PA design. In the expanding PA method, the AC&D system will have to be reconfigured for both the perimeter intrusion detection system and the new buildings added to the facility (as opposed to just for the new buildings in the larger PA configuration). The AC&D system will need to be reconfigured to account for new sensors integrated into the intrusion detection system, new cameras and video being used within the video management system, the increased demand for video recording on the network video recorder, and the addition of new access control devices into the access control system.

5. HYPOTHETICAL PPS COSTS AND STAFFING HEADCOUNTS

One of the many factors that SMR vendors must consider in the overall design process is the cost for physical protection measures at the facility. These costs include both upfront costs to purchase security technologies and long-term operational costs associated with the technologies and the number of personnel needed to operate, maintain, and implement the PPS.

5.1. Larger PA Costs

Table 5 highlights estimated purchase costs for the technologies required to implement the PPS once all three modules are built onsite. It should be noted that these costs are estimates based on a hypothetical facility and do not contain installation, maintenance, and supporting infrastructure costs (i.e., trenching, fiber, ethernet, etc.). These costs may not reflect current costs for security technologies.

Table 5. Hypothetical Security Technology Costs for Larger Initial PA

Security Technology	Estimated Cost ($USD, sorted high to low)
Total Technology Costs	**$15,561,287**
BBREs	$8,800,000
modular block wall	$2,833,000
radio system software	$970,285
hydraulic wedge barriers	$600,000
vehicle radiation detector	$372,151
triaxle camera tower	$275,000
personnel radiation monitor	$259,158
bispectral PTZ camera	$229,600
fencing material & gates[11]	$207,109
radio base station console	$180,000
gravel[12]	$133,500
double stack microwave sensor	$110,187
hand-held explosive detector	$60,000
hand-held radio UHF/VHF	$47,198
access control in/out	$33,628
power over ethernet network switch	$33,000
active IR sensor	$30,668
vehicle explosive detector	$30,000
X-ray machine	$28,000

[11] This is only estimated for PA fence and nuisance fence.
[12] This is only estimated for gravel in the isolation zone between nuisance fence and PA fence.

Security Technology	Estimated Cost ($USD, sorted high to low)
NVR - 40TB storage	$28,000
mag lock	$25,230
shark cage	$22,202
core switch	$22,000
large server rack	$21,840
distribution switch	$20,400
proximity readers	$17,690
field distribution box (FDB)	$13,500
AC&D workstation	$13,500
intercom server	$11,400
intrusion detection system (IDS) server	$10,000
video management system (VMS) server	$10,000
BMS - high security BMS contact	$8,700
badge printer/maker	$8,646
printer	$7,995
metal detector	$7,236
ACS server	$7,000
uninterruptable power supply (UPS) 20 KVA	$6,840
controller	$6,000
media convertor	$5,460
raised floor for server rooms	$5,000
emergency exit push button	$4,845
fiber patch panel	$4,500
hand geometry reader	$4,492
expansion module	$4,400
cooling fan	$4,000
REX motion sensor	$3,800
SFP modules	$3,420
gate intercom	$3,390
cell phone locker	$3,017
power supply	$2,700

Security Technology	Estimated Cost ($USD, sorted high to low)
access control rackmount enclosure w/power supplies	$2,470
router	$2,400
KVM switch	$2,350
AC&D licensing	$990
hand-held radiation detector	$758
access control input/output module	$590
hand-held metal detectors	$450
(12) fuse outputs	$300
guard workstation	$285
fiber optic patch cords	$270
cat-6 patch cords	$180
duress button	$162
patch panels - 48s	$140
tamper switch	$135
battery	$120

The costliest items in this design are the BBRE towers and the modular block wall that functions as a vehicle barrier. The modular block wall is designed to be a K-12 rated vehicle barrier, which is capable of stopping a 15,000-pound vehicle moving at 50 mph. These vehicle barriers are robust and have long operational lifetimes that minimize the potential costs for replacing them. The BBREs are costly due to their blast and bullet resistance. One method to reduce costs for SMR facility designers is to reduce the standoff distance needed to ensure protection of vital areas and vital equipment, as well as responders. A reduced standoff distance means a decrease in the size of the vehicle barrier system and, therefore, a reduction in the cost of the vehicle barrier system.

One element of the design that proves to be very cost-effective is the shark cages for doorways into the facility and buildings. Shark cages are simply turbine grating structures attached to the reinforced concrete building structure. In many of the scenarios in this study, the turbine grating between buildings or the shark cages at door entrances played a critical role in aiding the PPS in effectively mitigating the adversary attack scenario.

It should be noted that the cost for ankle breaker rocks was not considered in the overall costs of the security system, because evaluation of the PPS indicated the ankle breaker rocks did not have an impact on overall system effectiveness

Table 6 shows the hypothetical staffing plan for this facility design. The security shift supervisor oversees all security activities at the facility during a shift, including maintenance and testing. The RTL coordinates the activities and actions of all response force members onsite. The field supervisor manages the security system and all day-to-day activities occurring within the PPS. Four armed responders and four ASOs are considered in the PPS design and for the overall staffing plan.

In the table, each 24/7 position is considered to require four full-time-equivalent (FTE) positions. It should be noted that a 1:4 conversion may not be the correct FTE determination, as the total number of FTEs may be dependent on the facility location; the burden of the job; and policies for leave, vacation, and sick time.

Table 6. Hypothetical Staffing Headcount for Larger Initial PA

Position	24/7 12 hr. Rotating Shift	FTE
Security Shift Supervisor	1	4
Field Supervisor and Response Team Lead	2	8
Alarm Station Operators (CAS/SAS)	2	8
Armed Responders	4	16
Armed Security Officers (ASOs)	4	16
Total	**13**	**52**

Four armed responders are required to always be in the four BBREs. In previous staffing plans developed under Advanced Reactor Safeguards and Security (ARSS) work, five armed responders were considered in the staffing plan, where the fifth responder would provide rotations for the other four armed responders. The same strategy still exists, but instead the team is now considering the rotational responder to be a rotational ASO. This additional ASO can be used to provide support and rotations for the armed responders, conduct vital area checks, and support material movement activities. Having an additional ASO, rather than a fifth armed responder, increases PPS flexibility and response to operational needs such as supporting fuel movement activities, vehicle searches, PA entry control, and personnel searches, while still enabling rotations for the responders.

5.2. Expanding PA Costs

As seen in Table 7, the costs are somewhat different for upfront purchase of security technologies for an expanding PA compared to the costs for an initial larger PA around the operational reactors. Many costs stayed the same for both methods of modularization construction. For example, the costs of BBREs are the same in both design options, because the number and size of BBREs needed to implement the PPS strategy are the same in both cases. The modular block wall costs stay the same between the methods for modularization because the need to defend the facility and the responders from a VBED is the same for both designs. Many of the technical systems, such as radios, radiation detection, and contraband detection items, are also the same, as the search process for contraband items will be required to be the same for both operational sites. The largest changes in costs are seen in the microwave sensors, active IR sensors, and CCTV cameras that are needed for the exterior intrusion detection system.

Table 7. Hypothetical Security Technology Costs for Expanding PA

Security Technology	Estimated Cost ($USD, sorted high to low)
Total Technology Costs	**$15,297,000**
BBREs	$8,800,000
modular block wall	$2,833,000

Security Technology	Estimated Cost ($USD, sorted high to low)
radio system software	$970,285
hydraulic wedge barriers	$600,000
vehicle radiation detector	$372,151
personnel radiation monitor	$259,158
bispectral PTZ camera	$229,600
triaxle camera tower	$220,000
radio base station console	$180,000
fencing material & gates	$107,667
gravel	$95,000
double stack microwave sensor	$60,102
hand-held explosive detector	$60,000
hand-held radio UHF/VHF	$47,198
access control in/out	$33,628
POE network switch	$33,000
vehicle explosive detector	$30,000
X-ray machine	$28,000
NVR - 40TB storage	$28,000
mag lock	$25,230
shark cage	$22,202
core switch	$22,000
large server rack	$21,840
distribution switch	$20,400
proximity readers	$17,690
FDB	$13,500
AC&D workstation	$13,500
intercom server	$11,400
IDS server	$10,000
VMS server	$10,000
active IR sensor	$9,800
BMS - high security BMS contact	$8,700
badge printer/maker	$8,646
printer	$7,995
metal detector	$7,236
ACS server	$7,000

Security Technology	Estimated Cost ($USD, sorted high to low)
UPS 20 KVA	$6,840
controller	$6,000
media convertor	$5,460
raised floor for server rooms	$5,000
emergency exit push button	$4,845
fiber patch panel	$4,500
hand geometry reader	$4,492
expansion module	$4,400
cooling fan	$4,000
REX motion sensor	$3,800
SFP modules	$3,420
gate intercom	$3,390
cell phone locker	$3,017
power supply	$2,700
access control rackmount enclosure w/power supplies	$2,470
router	$2,400
KVM switch	$2,350
AC&D licensing	$990
hand-held radiation detector	$758
access control input/output module	$590
hand-held metal detectors	$450
(12) fuse outputs	$300
guard workstation	$285
fiber optic patch cords	$270
cat-6 patch cords	$180
duress button	$162
patch panels - 48s	$140
tamper switch	$135
battery	$120

Considering that fewer exterior intrusion detection system technologies are needed and the overall size of the PA boundary is smaller in the modular construction method, operation and maintenance costs and costs for the supporting infrastructure needed to operate the exterior intrusion detection system may be lower.

One additional cost difference between the identified methods is the operational costs for, 1) implementing access to the facility, and 2) implementing insider threat mitigation programs for construction personnel. Currently NRC 10 CFR 73.55 requires all individuals entering the PA with unescorted access to be a part of the overall insider threat mitigation program. There is a process and requirements in place to provide escorts to individuals who do not have unescorted access to the PA. Based on this, the method of construction that considers one large PA will require the following:

- All unescorted visitors must be enrolled and managed in the insider threat program
- All individuals entering the PA must be searched for contraband items
- All individuals entering the PA must have a facility-specific badge
- Individuals without unescorted access must be escorted by individuals with unescorted access to the PA

The above requirements may increase the overall operational costs to ensure access as more individuals are enrolled in the insider threat mitigation program, which may lead to more individuals being needed to implement the insider threat mitigation program. The more people who have access to the PA, the longer it takes to facilitate entrance into the PA, which may hamper operations or require a secondary PA ECP for construction activities. Either of these options may lead to increased costs both operationally and to accommodate the increased number of personnel and security technologies. These factors should be determined by each individual facility to identify the potential costs. It may mean that an expanding PA method for construction leads to overall reduced operational costs during construction, which could result in an economically viable way to secure a modular construction facility.

The difference in the overall staffing headcount is the total number of armed security officers present at the facility. This facility design utilizes five ASOs, rather than four, in the larger PA design around the operating reactors. The fifth ASO is meant to facilitate the personnel entrance at the OCA. If a vehicle arrives at the OCA boundary, then an ASO from the PA ECP must shift to the OCA vehicle ECP to help facilitate the search of vehicles.

Table 8. Expanding PA Hypothetical Staffing Headcount

Position	24/7 12 hr. Rotating Shift	FTE
Security Shift Supervisor	1	4
Field Supervisor and RTL	2	8
Alarm Station Operators (CAS/SAS)	2	8
Armed Responders	4	16
ASOs	5	20
Total	**14**	**56**

This hypothetical staffing plan shows an increase in one 24/7 position and a resulting increase of four FTEs. This increase in FTEs will increase the overall operational costs of the facility and the PPS.

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6. RECOMMENDATIONS AND CONCLUSIONS

Modular construction may create economic benefits for the deployment of SMRs in the U.S. These benefits include using the power produced by the first SMR as a funding source to offset the costs associated with building subsequent SMRs. In addition, it provides an opportunity for gaining operational experience with the first SMR build that can be applied to follow-on builds and may lead to reduced operational costs as more units come online. Modularized construction is a newer concept that will impact the design and operation of the PPS.

SMR vendors and operators must consider the overall cost to implement PA access and escort programs based on the modularization method chosen by the facility. As demonstrated in this report, the methods for access to the PA will be different based on the modularization design method. Depending on the approach, access to the PA may impact operations at the facility (particularly if a reactor is operating simultaneously with a unit under construction in the PA) and ultimately lead to increased costs. These factors may offset other costs that would be incurred in a modularization method that uses the expanding PA approach. SMR operators should ensure they identify these costs and evaluate which option is most beneficial to the economic viability of their facility.

Another consideration is the overall cost for continuous expansion of the PA compared to the cost of designing and building a larger PA from the beginning. It is well-documented that traditional PA boundaries consisting of a PIDAS can be costly. The high costs for a PIDAS are primarily based on routing and trenching cables and fiber needed to support communication from the sensors and cameras in the field to the CAS. Due to the costs of a PIDAS, it may be more cost-effective for a facility to design and operate one PIDAS than to design multiple PIDAS configurations. One of the potential cost considerations is the configuration changes that may be required for the AC&D system. As the PIDAS continues to expand with each new reactor module brought online, the AC&D system will also have to grow, and configuration will have to change to support the expanded footprint. This may increase the overall costs for implementing an AC&D system and PIDAS. Vendors and utilities should discuss these potential costs and impacts with various AC&D vendors and operational facilities to understand the ramifications associated with expanding a PIDAS versus designing and implementing one larger PIDAS for the facility from the onset.

Vendors and operators considering modular construction should examine the idea of having two separate personnel and vehicle entrances to the OCA and PA. This configuration may be dependent on the method for modular construction. When considering one larger PA it may be more advantageous to have a construction entrance into the PA and a PA entrance for operations at the facility. During the construction phase, many individuals and vehicles will be entering and exiting the facility. This number of people could increase the time for personnel working the operational portion of the facility to process through the ECPs, which could seriously hamper the operational times and rhythms of the facility. If the facility creates a second entrance point for construction vehicles, this could reduce operational burdens; however, this would increase the number of ASOs in the staffing plan until the construction entrance to the PA is closed, and only the primary PA ECP is used.

DG 5076 4.1.1.4.A states,

> *Defense in depth should be provided for neutralization functions with an exterior protection layer of at least two overlapping fields of fire covering each sector of the outermost perimeter physical barriers. The actual number of overlapping fields of fire should be dictated by the amount of time the*

adversary is exposed between the time of detection and the first delay element or opportunity for the adversary to obtain cover, or concealment.

In the first scenario with a larger PA around all operational reactors, the response force does not have two overlapping fields of fire at the outermost security perimeter. While this may be a potential requirement as a part of 10 CFR 73.100, vendors and operators should consider that this may be an area for future exemptions. In this configuration, the vendor and operator may be able to prove that their response strategy stops the adversaries from accessing target locations and target material, thereby preventing a radiological release.

Vendors and future operators of SMR facilities should consider all costs impacts related to the design and implementation of a PPS based on expected production costs from the plant and each subsequent module. Both methods for modularization will have different areas that impact costs. The expanding PA method will come with larger costs for integration of the intrusion detection and access control systems and moving the PA boundary, and larger security personnel costs. In contrast, the larger PA costs will come with higher long-term operation and maintenance (O&M) costs associated with more protection equipment, and higher O&M costs for implementing the insider threat mitigation program for the facility. Overall, based on the potential configuration changes that would need to be made for the expanding PA design and the long-term costs with the larger staffing headcount it is recommended for vendors to consider using one larger PA for a modularization construction approach.

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