Extreme Environment Events and Physical Protection Systems

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Abstract:

Extreme Environmental Events (E^3s) such as forest fires, hurricanes, drastic temperature increases, floods, droughts and storms have been on the rise.[1] The combination of increasing E^3s and the potential remote deployment for small modular and advanced reactors creates a unique situation in which the implementation of physical protection systems and their resiliency to E^3s must be addressed[2]. In this work we examine the impact of E^3s on the physical protection systems at a small modular reactor (SMR) facility. This will include an assessment of all levels of stakeholder responsibility, from State-level requirements, to the competent authority's regulatory framework, to the operator's responsibilities, and the site's implementation. In this effort we attempt to analyze the resiliency of the physical protection system (PPS) technologies to E^3s and address strategies for response force members to adequately secure the site before, during and after an extreme environment event. Facility designers and security personnel must understand the effects of an E^3 on physical security systems and identify unique strategies to secure these facilities before, during and after. The results of this effort may be directly applicable to other critical infrastructure sites.

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Introduction

Extreme environmental events include both those that are extreme environment events and issues such as increasing temperatures that may cause heat waves. The International Panel on Climate Change defines an extreme weather event as:[3]

> *"occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable".*

The International Atomic Energy Agency (IAEA) has deemed the following the most pertinent extreme weather events that the energy sector should consider

- Extremely high and low temperatures and precipitation,
- Extremely high winds,
- Storms including cyclones, hurricanes, typhoons, and tornadoes, as well as the associated storm surges,
- Hail, and
- Lightning.[4]

The deployment of small modular reactors (SMRs) is being considered in remote locations around the world. The deployment of these facilities may result in security systems being operated to secure nuclear material where this has not been done before. For the successful deployment, and secure deployment of SMRs, extreme environmental events should be analyzed to determine their effect on physical security systems and to allow future operators to develop contingency and compensatory measures to secure the nuclear material. This paper will discuss the legal and regulatory framework surrounding E^3, E^3 analysis for a hypothetical SMR, and future conclusions and recommendations for SMR facilities.

Legal and Regulatory Framework

A complex legal and regulatory framework exists within the United States to address an extreme environment event. This framework has input from and is implemented by multiple government agencies.

Pre-Event

Emergency response plans are developed collaboratively by the site operator, the U.S. Nuclear Regulatory Commission (NRC) and the Federal Emergency Management Agency (FEMA). Part of the review of a site's emergency response plan is to ensure there is proper interface between site security operations (both onsite and local law enforcement) and emergency response personnel.[5] Before an event occurs, the operator, NRC, and FEMA establish emergency planning zones. These planning zones include the plume exposure pathway and in the ingestion pathway. The plume exposure pathway is an approximately 10-mile radius area surrounding a plant that may result in public exposure to airborne radioactive contaminants. The ingestion pathway is an approximately 50-mile radius area surrounding a plant that may result in ingestion of radioactive contaminants through eating and drinking.[6] Before an event it is important for the facility to determine responsibilities for onsite and offsite organizations that impact the security of the facility.

Planning for an extreme environment event also plays a major role in the implementation of an effective security system. Planning consists of both planning for the secure operation of the facility, but the continued operation of equipment, and the safety of the personnel operating the plant. Planning for an

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extreme environment event is complex. Some of the items that need to be planned for can be seen in the table below.[7]

Personnel	Equipment
Radiation monitoring	Secure from high winds
Food and water	Secure from wain water
Safety equipment (i.e. hard hats, flashlights)	Ensure adequate power supply
Ensuring staff report onsite	Communication networks are operable

Table 1 Event Planning

During-Event

The NRC implements a temporary suspension of security measures, identified in 10CFR 50.54(x). This suspension of security measure occurs when the site cannot adequately secure the material under the license conditions and technical specifications that provide adequate protection. This temporary suspension of security measures is meant to allow for the individual sites to allocate security personnel in a safe manner that ensures the safety of its personnel. This temporary suspension of security measures may allow the plant to ensure that its personnel remain safe but can also allow for the reallocation of security personnel and assets to provide detection most near the target.[8]

During an extreme environment event the security system may become inoperable due to many issues. Loss of power may impact the security system, flooding or disasters may cause portions of the security system to become inaccessible or inoperable. When an event such as this occurs, site security operators must ensure that there exists contingency plans and compensatory measures are in place. It is important for the plant to ensure that these compensatory measures and contingency plans exist and can be enacted when the event is over.

Post-Event

After an extreme environment event the site may send medical experts to determine if there has been any release of radioactive contaminants to the environment that may impact the site personnel or the environment. Immediately after an event such as this, site security personnel should assess the entire security system to ensure functionality and operability still exists. When the site can determine that the security system has not been affected, the site may lift the temporary suspension of security measures (10CFR 50.54(x)) after contacting NRC officials. This measure allows the site to resume normal operations of the security system, and that the security system can operate in a manner that is sufficiently effective to meet its license obligations and ensure effective security of the nuclear material.

After assessing the state of the security system, if the system is deemed ineffective the site may stay in the temporary suspension of security measures until the security system can return to its license obligations to secure the nuclear material. A damaged security system may require the replacement of components, reconfiguration of subsystems, and testing components and subsystems. Replacing components may be required after an extreme environment event damages component of the security system. The replacement of components may take long periods of time, depending whether the components that were damaged are stored onsite or if the components must be brought in. This timeline may be extended if a private firm must be brought in to install the components. Once the components are installed each component must be operationally tested and performance tested. After these tests occur the subsystem should be operationally tested and configured to ensure that the subsystem operates as intended. These steps must be taken to lift

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the temporary suspension of security measures. It is for this reason that the temporary suspension of security measures may not be lifted from a site for a long period of time following an extreme environment event.

While the security system is being maintained or components are being installed, the site will be operating under compensatory measures and contingency plans. These compensatory measures and contingency plans must be tested and evaluated to ensure that they are effective. These plans and measures must also be trained on by security and safety staff in conjunction so that when implemented the site may ensure effective nuclear security.

The following section will describe how this framework when applied to a hypothetical SMR facility was designed and assessed. This analysis identified many applications that can be made to securing SMR facilities when faced with an extreme environment event.

Hypothetical Facility Analysis

For this analysis a hypothetical SMR facility was developed and placed in a costal region. This hypothetical facility was an integral Pressurized Water Reactor (iPWR) SMR facility. This facility contained four reactor cores, four turbine buildings for each reactor, a spent fuel pool, and a nuclear material receiving building. This hypothetical design was based on input from many international iPWR facility designs[10] (figure 1). This section will discuss the analysis that was conducted for this hypothetical SMR facility.

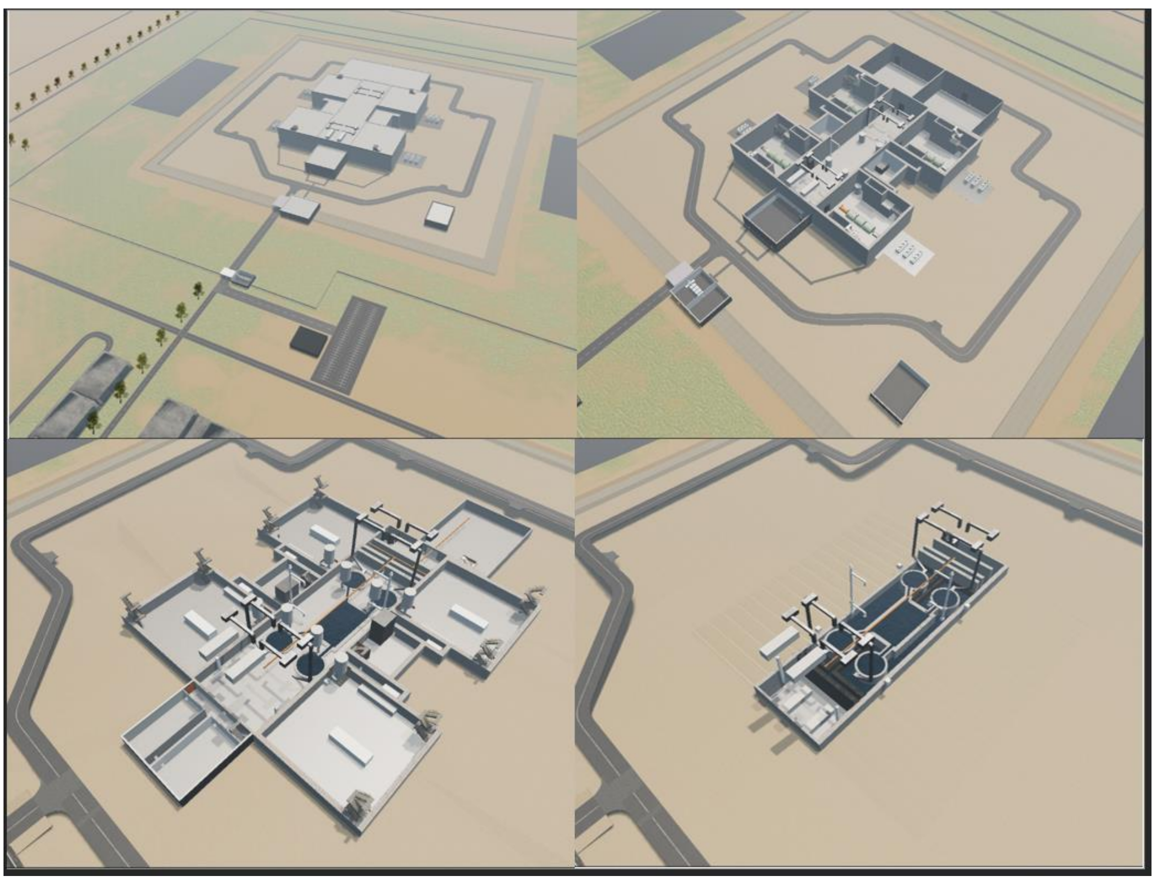

Figure 1 Hypothetical SMR Facility. Above-grade (top left), basement one (top right), basement two (bottom left), basement three (bottom right).

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Subject Matter Expert Interviews

Subject matter expert interviews were conducted from experts in a wide variety of backgrounds. These backgrounds ranged form physical protection, response force operators, site security directors, and regulators. This diverse background in subject matter experts allowed for the creation of realistic contingency plans and compensatory measures for a hypothetical site based on input from personnel who have operated security systems during extreme environment events. These interviews produced key insights such as:

- The site must be aware of what environment events it is susceptible to and have plans in place for them.
- The site must seek input regarding emergency planning from the government, the regulatory authority, state officials and regulators, and local law enforcement.
- Adequate critical personnel should be brought onsite before the event if access to the site is expected to be hindered. The site must assess factors including the length of time personnel need to stay on site for and acquire adequate food and clean water supplies to support these personnel for lengthy times. Generally, the design basis is to be prepared for a week.
- The site should have an effective weather monitoring system and trained personnel to monitor the system.
- A site must have effective emergency backup equipment for security and safety functions.
- Site's will generally deploy response force personnel or guards as compensatory measures, when safe conditions allow, when other forms of sensing and assessment have been lost.
- Generally, a site's perimeter is brought further in during an EWE by placing personnel closer to targets, and this is not viewed as decreasing system effectiveness.
- During an EWE, the CAS must evaluate the sequence of alarms along a path to a target, with special concern given to internal alarms, to determine if there is a high probability of a nuisance alarm due to weather or if assessment is needed.
- Re-establishing communications is essential for security personnel post-event.
- Replacement security equipment should be maintained to replaced damaged equipment, and it should be performance tested after installation as soon as reasonably possible once safety permits.
- NMAC, personnel accountability, and testing of safety equipment should occur as soon as safely possible post-event.
- It is crucial for a site to coordinate and train with local authorities. Agreements should be in place with known procedures for offsite assistance if needed.

The information gathered from these interviews was incorporated into the analysis for physical protection systems at a hypothetical SMR facility after an extreme environment event.

E^3 Event Analysis

For this analysis HAZUS was used to model EWEs. HAZUS is a U.S. Federal Emergency Management Agency (FEMA) software tool that allows for estimating potential losses from earthquakes, floods, hurricanes and tsunamis. HAZUS uses geographical information systems to estimate physical, economic and social impacts of EWEs. This tool will be used to identify regions within the United States to analyze the effects an EWE may have on a sites security system effectiveness.

For this project the hurricane and wind model was used for analysis. The HAZUS software is capable of outputting direct damage results for general buildings, essential facilities (police stations and hospitals) and high potential loss facilities. The HAZUS software also outputs debris generated, costs of repair, income loss, crop damage, casualty losses and potential shelter needs as a result of the EWE. The HAZUS

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software allows for hurricane scenarios that are probabilistic, user-defined scenarios or historic events. Probabilistic events use a 100,000 year database of peak gust wind speeds in each census tract. Single-user defined events allow for the user to create a hurricane with a specified track, speed and hurricane intensity. Historic events allow for simulations using hurricane data starting from 1900 of Category 3-5 hurricanes. This allows for analysis of historic storms and their potential impact to locations within the United States.

The HAZUS software was used to locate a Small Modular Reactor facility for tabletop analysis and force-on-force simulations. The location siting is important in conducting the tabletop exercises and force-on-force simulations. The location effects areas such as response force planning, adversary attack planning, and ultimately the effect that a simulated hurricane event will have on this facility. Simulations were conducted based on historical hurricane events and probabilistic events in Texas, Louisiana, Mississippi, and Florida. The analysis focused on these states for potential facility siting based on documented hurricane destruction in the last 100 years.

Using both the probabilistic and historical event analysis tools of HAZUS the largest damage prediction occurred in Florida, specifically the Miami-Dade country. This analysis allowed for the prediction of damage to a nuclear power plant located in the Miami-Dade County. This location also lends itself to locations of nuclear power plants on low-lying levels near coasts or bodies of water.

The analysis confirmed three possible cases in which could be analyzed in tabletop exercises and force-on-force simulations. These three scenarios are identified below. The analysis did not focus on structural damage to nuclear power plant buildings as this is outside of the capabilities of tools available for this analysis. Instead the analysis focused on the damage that may be brought to systems offsite that would affect the physical protection system at the Small Modular Reactor facility and damage that would occur into the external physical protection systems.

The first scenario concluded no damage to the nuclear power plant or its physical protection system. Offsite power was lost to the facility. However, the facility is designed with above-grade and below-grade backup power for the physical protection system, including camera, intrusion detection systems, and door locks. The second scenario concluded damage to the north side (sea facing side) of the Small Modular Reactor facility external perimeter. The damage assessment in this case includes the loss of all barriers and intrusion detection system in this section of the Small Modular Reactor facility perimeter. The remaining physical protection system remained operable due to the backup power the facility is equipped with for its physical protection system. The third scenario concluded damage to all of the Small Modular Reactor facility perimeter. The damage assessment in this case includes the loss of all barriers and intrusion detection system of the Small Modular Reactor facility perimeter. The remaining physical protection system remained operable due to the backup power the facility is equipped with for its physical protection system.

Tabletop Exercises

Tabletop exercises were conducted with some of the subject matter experts that were interviewed and leveraging the information gathered in the subject matter interview phase. These tabletop exercises were conducted to determine the effectiveness of compensatory measures and contingency plans and to identify methods to adapt contingency plans and compensatory measures for SMR facilities. The results from these tabletop exercises based on scenario can be seen in Table 2.

Scenario Number	Probability of Interruption (%)	Probability of Neutralization (%)	System Effectiveness	Blue Force KIA
1	99	93	92	10
2	99	34	34	14
3	99	99	99	6

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Table 2 System Effectiveness

The results from these exercises show that there is a need to develop contingency plans and compensatory measures specific to SMR facilities to ensure site security after an extreme environment event has impacted the physical protection system. Scenario one shows a relatively high system effectiveness level but results in the loss of many response force personnel. This indicates that improvements could be made to ensure the safety of responders and maintain an effective security system at the site. It is important to consider the effectiveness of the system as well as the safety of the responders during a security event. Scenario 2 shows a degraded system effectiveness and a high loss of responders. This scenario may require new contingency plans and compensatory measures to maintain effective security and reduce the number of responders lost in this scenario.

These scenarios and analysis show that contingency plans and compensatory measures for extreme environment events may need to be evaluated and reconfigured for the specific concerns of SMR facilities. One of the primary concerns is the small footprints of SMR facilities. These small footprints mean the perimeter of the security system is closer to the targets before an extreme environment event and therefore provides less initial delay time to an adversary force. After an extreme environment event has passed and may have caused damage to the security system, the responders may have less time to adjust to an adversary attack and neutralize an adversary attack. The second concern is the use of an offsite response force and how effective an offsite response force may be during and after an extreme environment event. An offsite response force may require additional logistical and operational constraints to allow for an effective response force to be called to the site before an extreme environment event, offsite responders remaining onsite as compensatory measures for disabled technologies, and responders remaining onsite for long periods of time to allow for an effective security system.

Conclusions and Future Work

Based on the results of this study there a few recommendations that can be made for future SMR facilities and providing adequate security before, during, and after extreme environment events. These recommendations can be seen below:

- Sites should have contingency plans, emergency plans, and severe weather plans
  - Contingency plans should consider extreme weather events
  - Severe weather plans should consider the weather events that may impact their site based on long-term historical data
- Sites should consider the impact that extreme weather events in design basis events (DBEs) which may have compensatory measures to the physical protection system
  - Consideration should be given to the effectiveness of the physical protection system before, during and after a weather event
  - Credible beyond DBEs should also be considered as planning exercises
- Sites should consider evaluating contingency, emergency, and severe weather plans through force-on-force exercises/simulations and tabletops
- Sites should conduct regular training on contingency, emergency, and severe weather plans
- If sites rely on offsite response forces, proper coordination and exercises should be considered if an EWE occurs at the site

Based on the work conducted in this analysis work, there are many future projects that would benefit the SMR community regarding security systems during extreme environment events. This study focused

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primarily on the effect a hurricane may have on a security system for an SMR facility, additional analyses should be conducted on additional E^3s. These events may include tsunamis, avalanches, snowstorms, flooding, fires, earthquakes, etc. Studying the effects that these events may allow for an understanding of how security systems may be impacted globally by potential extreme environmental events that may impact security systems. This study should also be expanded to study additional SMR types such as molten salt reactors, pebble bed reactors and microreactors. Studying various types of reactors will allow for an understanding of how changes in reactor designs may require unique contingency plans and compensatory measures based on the target sets and unique features of each reactor type.

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