DOE ARS – SMR Security by Design and Analysis

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Motivation

- Reduction of cost for Small Modular Reactor (SMR) deployment and operations
- Increase security measures inherent to SMR facility designs
- Security systems designs based on limited or no onsite response
- Understand the regulatory changes for SMR facilities
- Develop security strategies for various SMR types (iPWR, PBR, Microreactor)
Introduction

- Hypothetical integral Pressurized Water Reactor (iPWR) facility was designed
- Design incorporated safety, security, and operations
- Design focused on developing a security system and facility design that created adequate detection and delay to allow for an offsite response force
  - Incorporated understanding of site safety and operations
- The hypothetical facility was designed with a denial strategy in place
- Offsite response force teams were considered
  - 30-Minute Response Time
  - 60-Minute Response Time
  - 2 Manned Hardened Fighting Positions
Security Regulation Changes for SMRs

• “Alternative Physical Security Requirements for Advanced Reactors,” A Proposed Rule by the Nuclear Regulatory Commission, Docket No. NRC-2017-0227

• Keep the requirements of 73.55 to protect against sabotage but set out additional guidance in 73.55(s) for advanced reactors which can establish a performance-based approach
  • Relieved of 73.55(k)(5)(ii) minimum number of armed responders
  • Relieved of 73.55(e)(9)(v) and 73.55(i)(4)(iii) requiring that the secondary alarm station, including if offsite, be designated and protected as a vital area
  • Sites must still have two onsite alarm stations per 73.55(i)(2), but a designated secondary alarm station may be offsite. It is not required to be a vital area, nor is its associated secondary power supply required to be.

• One of the most significant NRC comments is the allowance for the use of local law enforcement rather than licensee security personnel to interdict and neutralize the DBT

• Nuclear Energy Institute developing guidance to demonstrate an applicant meets eligibility criteria: NEI 20-05, “Methodological Approach and Considerations for a Technical Analysis to Demonstrate Compliance with the Performance Criteria of 10 CFR 73.55(a)(7)”
The NRC is proposing to amend security requirements based on three *eligibility criteria* specified in a new 73.55(a)(7). If any individual criterion is met the revised requirements the licensee would be *eligible* to able to follow the performance-based alternative approach in 73.55(s): (The following are paraphrased. Please see NRC-2017-0227-0023 for entire language)

- Dose limits in 10 CFR 50.34 and 52.79 are not met after a radiological event involving loss of engineered safety features and physical structures.
  - i.e., there are no target sets which would result in exceeding dose limits
- The DBT cannot compromise plant features necessary to mitigate an event, which prevents the release from reaching values in the CFR sections.
  - i.e., the DBT is not capable of compromising a target set which would result in exceeding limits
- The reactor and facility includes inherent safety features which would maintain the dose below consequences above if a target set is successfully sabotaged.
  - i.e., mitigation measures prevent the sabotage of the target set from exceeding dose limits
SMR Security-by-Design

- Security-by-Design utilizes many factors to increase design performance and cost-effectiveness of facility designs and physical protection systems
- SBD utilizes the following methods:
  - Implementing security into the design phase of the SMR facility
  - Facility designs that increase the effectiveness of the physical protection system
    - Minimize entry points (where allowable)
    - Minimize access points to target locations
    - Utilize building materials to increase delay time
    - Identify locations where active delay features can be used to multiply adversary task time
- SBD allows the facility to:
  - Decrease long-term facility costs
  - Increase resiliency to adversary attacks
Development of a Domestic SMR

- Review of U.S.-based SMR designs in advanced design and licensing stages
- Collection of characteristics
- Integral PWR design
- Internals include two once-through steam generators and 10 coolant pumps
- 4.9%-enriched LEU
- Below-grade containment and spent fuel pool
- Four units per plant
- Passive Residual Decay Heat Removal System (PRDHRs)
- 72 hours of cooling after power loss
### Sabotage Targets

<table>
<thead>
<tr>
<th>Location</th>
<th>Form of Material</th>
<th>Amount of Material On-site (wt% enrichment)</th>
<th>Total Isotope Amounts</th>
<th>Level of Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Core</td>
<td>UO₂ pellets in rods</td>
<td>13,478 kg U (4.9% U-235)</td>
<td>660 kg U-235</td>
<td>High</td>
</tr>
<tr>
<td>Spent Fuel Pool</td>
<td>UO₂ pellets in rods</td>
<td>53,192 kg U (4.9% U-235)</td>
<td>2,606 kg U-235</td>
<td>High</td>
</tr>
</tbody>
</table>

**Direct Sabotage Targets**

**Indirect Sabotage Targets**

<table>
<thead>
<tr>
<th>Location</th>
<th>Safety Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Bank/Diesel Generator Rooms</td>
<td>Provide backup power to the site</td>
</tr>
<tr>
<td>Passive Safety Injection Tank</td>
<td>Provide cooling water to the reactor core</td>
</tr>
</tbody>
</table>
Small Modular Reactor Facility Design

- Hardened Mantraps
- Reactor Wall
- Reinforced Roll-up Door
- Active Delay
Scenario Video
# PPS Path Analysis Results

<table>
<thead>
<tr>
<th>Target</th>
<th>Task Time (s)</th>
<th>Probability of Detection (%)</th>
<th>Probability of Interruption (%)</th>
<th>Response Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>5513</td>
<td>99</td>
<td>99</td>
<td>1800</td>
</tr>
<tr>
<td>Spent Fuel Pool</td>
<td>5032</td>
<td>99</td>
<td>99</td>
<td>1800</td>
</tr>
<tr>
<td>Battery Bank</td>
<td>2567</td>
<td>99</td>
<td>100</td>
<td>1800</td>
</tr>
<tr>
<td>Control Room</td>
<td>3043</td>
<td>99</td>
<td>99</td>
<td>1800</td>
</tr>
<tr>
<td>Reactor PSIT</td>
<td>4307</td>
<td>99</td>
<td>99</td>
<td>1800</td>
</tr>
<tr>
<td>CAS</td>
<td>3037</td>
<td>99</td>
<td>99</td>
<td>1800</td>
</tr>
</tbody>
</table>
An offsite response force was considered at this site
- Consisted of 8 members
- SWAT-like response team
- Response time of 30 minutes
- Response time of 60 minutes

An offsite response force with an augmented onsite response force
- 6 offsite members, 2 onsite members
- SWAT-like response team
- 2 onsite members in hardened fighting positions
- Response time of 30 minutes
- Response time of 60 minutes
Sabotage Scenarios

- The force-on-force simulations and probability of neutralization analysis were based on two different scenarios

**Split Attack**
- Adversary team splits into two teams to conduct and complete sabotage at the facility
- Adversary team must successfully sabotage the switchyard, passive safety injection tanks, battery bank and diesel generators, and reactor containment

**Sequential Attack**
- Adversary team attacks the facility in one group to conduct and complete sabotage at the facility
- Adversary team must successfully sabotage the switchyard, passive safety injection tanks, battery bank and diesel generators, and reactor containment
30-Minute Response Force Results

- Use of augmented onsite response force increases system effectiveness
- System effectiveness is greater for split attack scenarios than sequential attack scenarios
60-Minute Response Force Results

- Results show higher system effectiveness for 60-minute response force
  - Increased number of engagements
  - Higher response force-to-adversary ratios in engagements

- Increased system effectiveness against split attack as compared to sequential attack

- Augmented onsite response force in hardened fighting positions increases system effectiveness
Conclusions

• Facility Design Conclusions
  • Decrease access points into the facility
  • Design facility with multiple material types to increase delay
  • Decrease amount of door entrances and access control points
  • Consider facility siting and construction to allow for extended detection
  • Increased safety system redundancy

• Physical Protection System Conclusions
  • Increase extended and early detection
  • Active delay systems
    • Vehicle barriers
    • Obscurants
  • Understanding of potential adversary attack scenarios
    • Split vs Sequential
  • Offsite Response Force
    • Ability to recover the site
    • Design of hardened fighting positions
Future Work

Additional Small Modular Reactor and Advanced Reactor Studies

• Pebble Bed Reactor
  • Advanced physical protection system design
  • Varying response force strategies
  • Remote backup alarm station and control room

• Microreactor
  • Remote deployment
  • Increased response force time
  • Remote central alarm station and control room

Integration and Interface with Safety

• Link sabotage timelines with system accident timelines
• Can an SMR plant be recovered after sabotage occurs?

Full report and analysis on iPWR is available upon request.