Risk-informed Consequence-Driven Physical Protection System Optimization for Microreactor Sites

TEXAS A&M ENGINEERING

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Presentation Overview

- Project Goals and Objectives
- Project Motivation and Background
- Technical Approach
- Roles of Each Partnering Organization
- Anticipated Project Outcomes and Impacts
- Progress to Date
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Presentation Overview

- FY21 Consolidated Innovative Nuclear Research Award
- Award No.: DE-NE0009135
- Period of Performance: 10/01/2021 – 09/30/2023
- Technical Work Scope Identification:
  - CT-4
  - ADVANCED AND SMALL MODULAR REACTOR MATERIALS ACCOUNTANCY AND PHYSICAL PROTECTION
  - “New and novel PPS approaches are also needed that can drastically reduce either up-front or operational security costs for the life of the reactor. Proposals should focus on regulatory needs and describe how the proposed work addresses those needs for the advanced reactors.”

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Project Goals and Objectives

- Project goals (and why the project matters to vendors)
  - Enable a more appropriately-sized Physical Protection System (PPS) for advanced reactor designs while maintaining constant or reducing the risk associated with future reactors; and
  - Pursue reduced security costs for the life of the reactor to increase the cost-competitiveness of safe and secure nuclear power generation.
- Anticipated key technological contribution
  - The coupling of consequence modeling with security design in an integrated safety-security framework

Project Goals and Objectives

- Project technical objectives
  - Assess fundamental systems-level correlations between sabotage-based security events and risk-informed severe accident health-based consequences
  - Develop and demonstrate a new risk-informed approach on a reference microreactor site using
    - State-of-the-art severe accident codes (MELCOR)
    - Consequence analysis computer codes (MACCS)
  - Benchmark the new risk-informed approach against the traditional Design and Evaluation Process Outline (DEPO) methodology for the same microreactor site with metrics of
    - Total PPS footprint (equipment and manpower)
    - Cost

Project Motivation and Background

- The hypothesis:
  - The enhanced safety of advanced non-LWR and microreactor designs sufficiently reduces the consequence space of sabotage events such that the PPS footprint (upfront and operational) may be reduced to generate cost savings without sacrificing security or safety.

Project Motivation and Background

- Economics
  - The survivability of the domestic nuclear power industry depends on the cost-competitiveness of safe and secure nuclear power generation.
  - Competitiveness may be inhibited if federal requirements for physical security and other operations are prohibitively expensive.
  - Crediting safety enhancements in PPS design would provide a cost-reducing approach for advanced reactor vendors who adequately demonstrate meeting performance-based criteria.

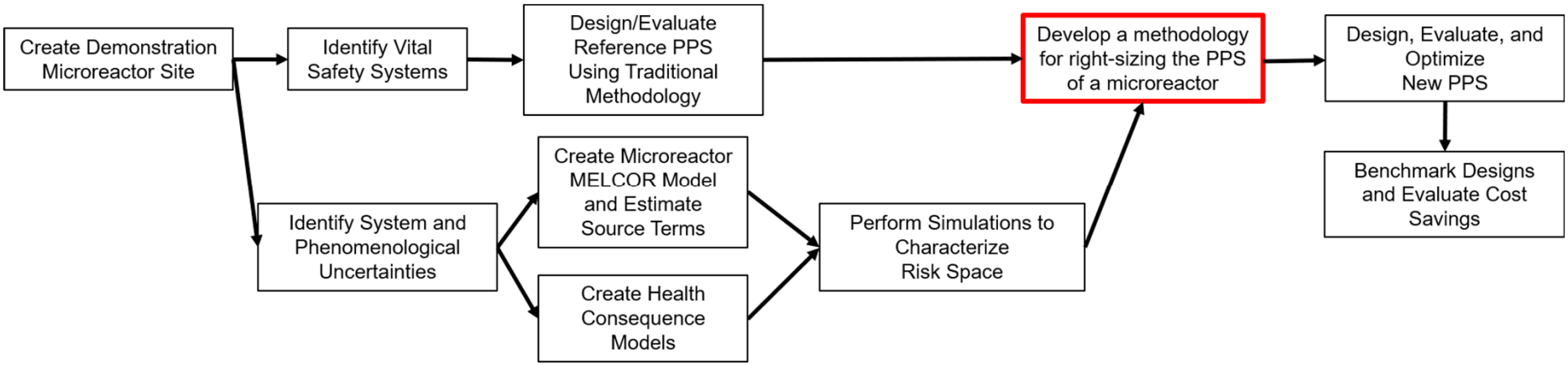
Project Motivation and Background

- One pathway for reducing the cost of nuclear power generation:
  - Minimize the upfront and operational costs of the PPS.
  - However, PPS reduction can only be justified if the site risk is either maintained or (ideally) reduced.
- This work proposes:
  - Development of a risk-informed PPS methodology that justifies PPS cost reductions by crediting the enhanced and inherent passive safety of advanced reactor designs,
  - Followed by evaluation of a security-by-design paradigm that further assesses consequence-informed risk analysis of a security-induced event.

Technical Approach

- Incorporate risk-informed techniques into security design
  - Deterministic techniques, such as conservative analysis by system-level reactor safety codes, do not capture the entire risk spectrum of a given reactor site.
  - This work is novel in that it will use a risk-informed approach.
    - Risk-informed approaches use the known uncertainties of a system to characterize the risk space such that decision makers can make decisions to meet regulatory objectives based on system performance.
    - For PPS design, a risk-informed approach should be considered over a deterministic approach.
    - The risk-informed approach provides a holistic overview of system performance under an encompassing range of conditions.

Technical Approach – Task Flow



Roles of Each Partnering Organization

- Texas A&M University
  - direct the team and promote project integration
  - co-lead in development of the notional reactor site
  - develop the microreactor model and perform source term calculations
- Georgia Institute of Technology
  - direct the tasks of health consequence model development and simulations
- Sandia National Laboratories
  - co-lead in development of the notional reactor site
  - lead the tasks of identification of vital safety systems
  - design the PPS using traditional methods
- All will collaborate in the following tasks:
  - development of the new PPS design methodology and optimization
  - development of the new risk-informed consequence-driven PPS design methodology
  - benchmarking of the new design methodology
  - generation of cost estimates

Project Outcomes and Impacts

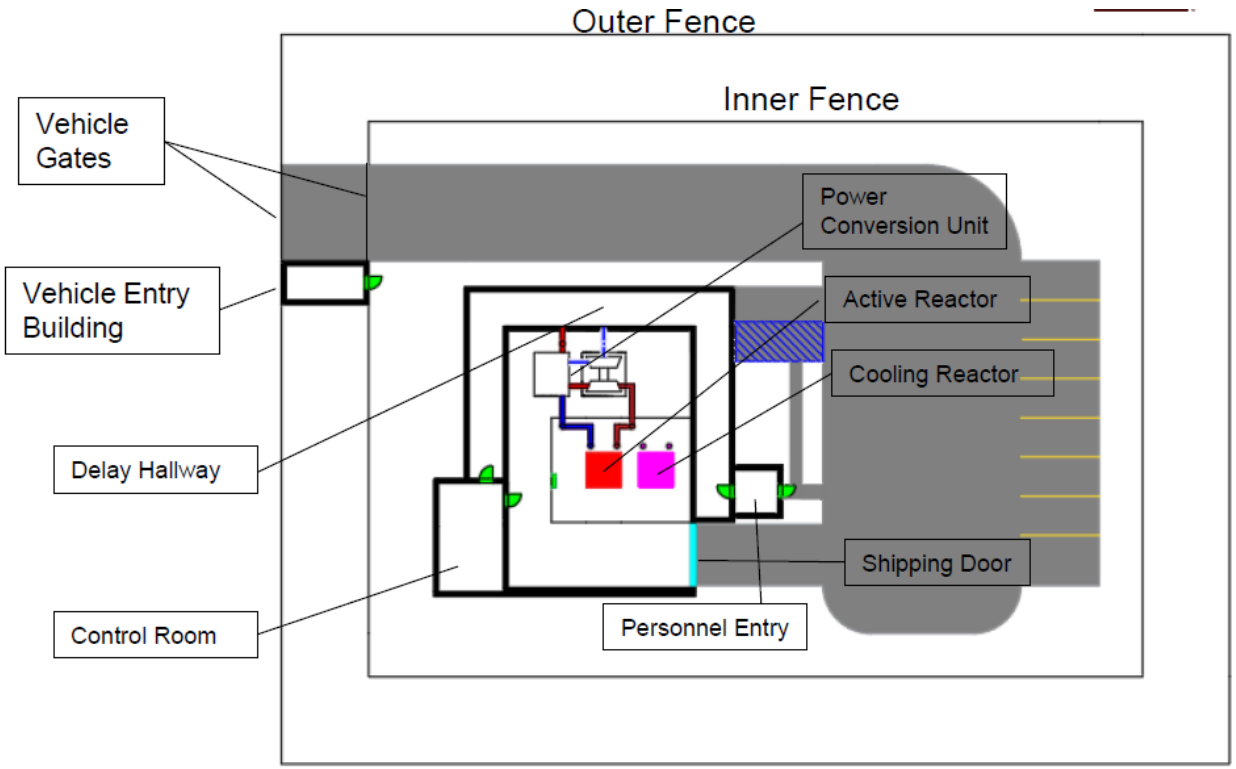
- Outcomes
  - A flexible methodology for PPS design optimization that will reduce upfront and operational security costs
  - Potentially, justification for incorporating consequence analysis into physical security regulations
  - A means to define the level of risk for microreactors which is based on an integrated analysis of security and safety effects
- Impact (and why the project matters to vendors)
  - If successful, this new methodology will
    - provide a means for cost-reductions of future builds,
    - maintain or possibly increase the security of reactors and
    - promote the NRC's efforts to credit safety features of advanced reactors through proposed amendments to current physical security regulations.

Progress to Date

- Preliminary training/education items
  - Introductions to security-by-design via SNL PI's recent reports
  - Students have learned codes for:
    - PPS design - SCRIBE3D©, PATHTRACE© and Blender©
    - Severe accident modeling – MELCOR
    - Dose estimates – MACCS
  - Texas A&M participants have undergone Sandia's DEPO training (DEPO = Design and Evaluation Process Outline)

Progress to Date

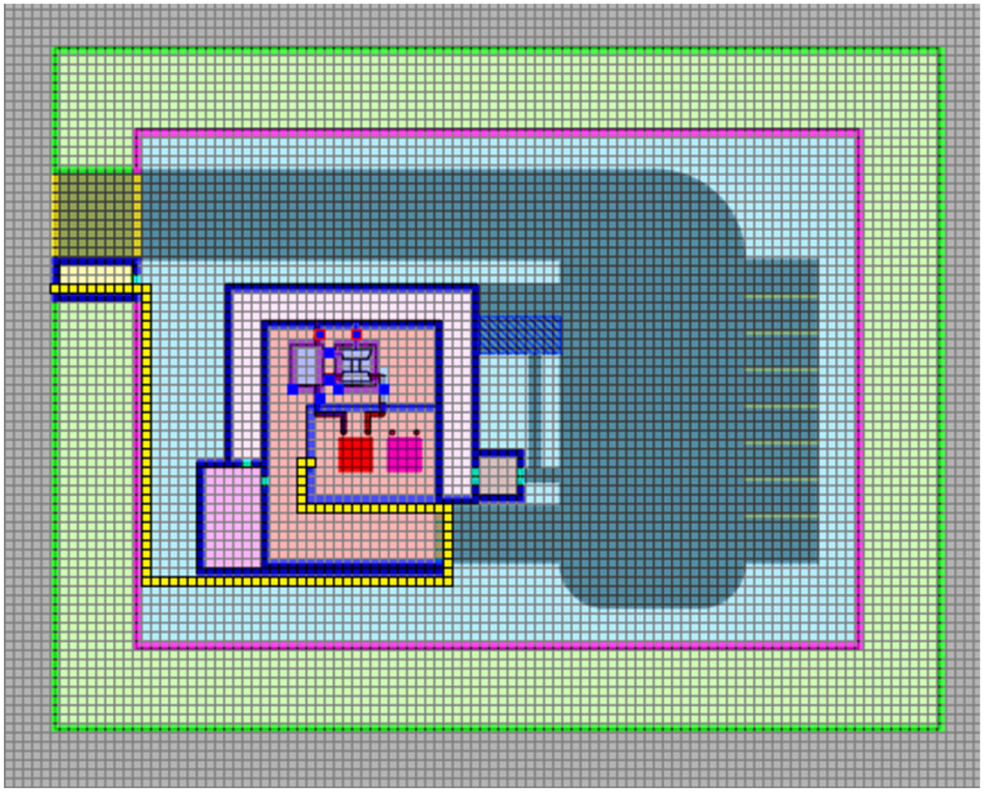
- A PPS has been designed using the DEPO methodology.



Top down view of the initial facility design iteration

Progress to Date

- A PPS has been designed using the DEPO methodology.



Adversary Quickest Path (gold line) from first iteration of PPS Design

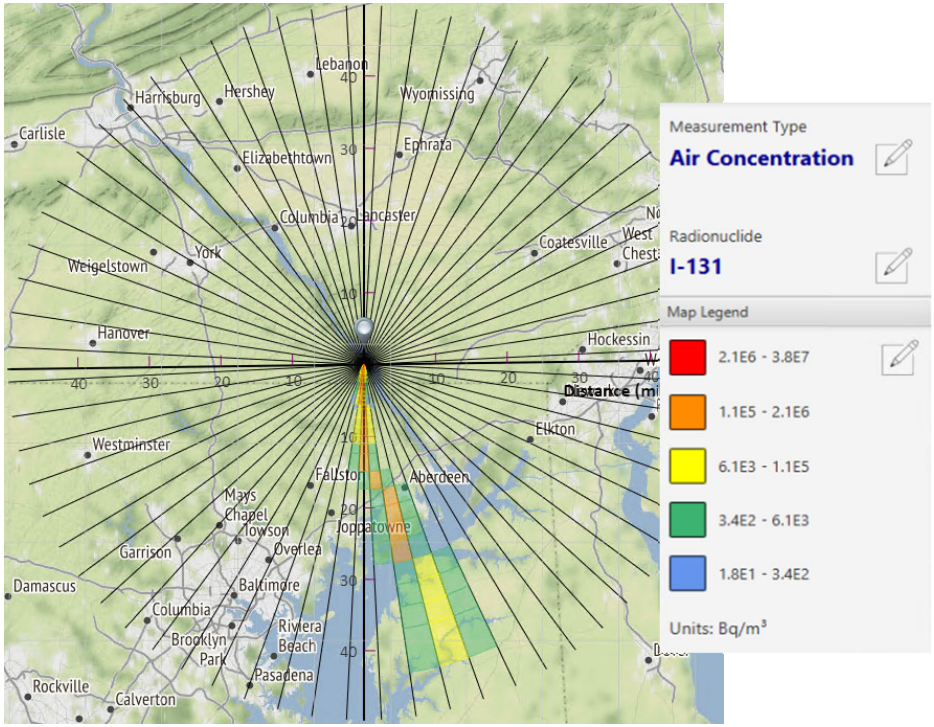
Progress to Date

- MELCOR simulations of the source term.
  - Using an NRC-Sandia developed input model for a heat pipe reactor.
  - Found that the core inventory is so small that it is difficult to produce a source term.
  - We will assume a fractional source term.

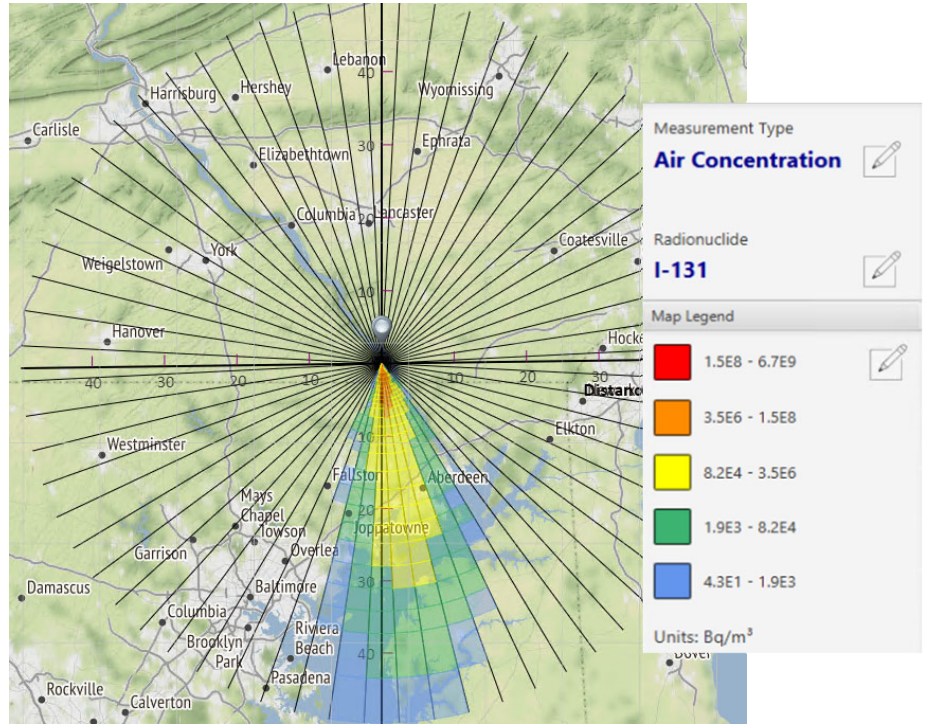
Progress to Date

- MACCS is producing dose estimates using Lagrangian transport and Gaussian plume distributions

Progress to Date



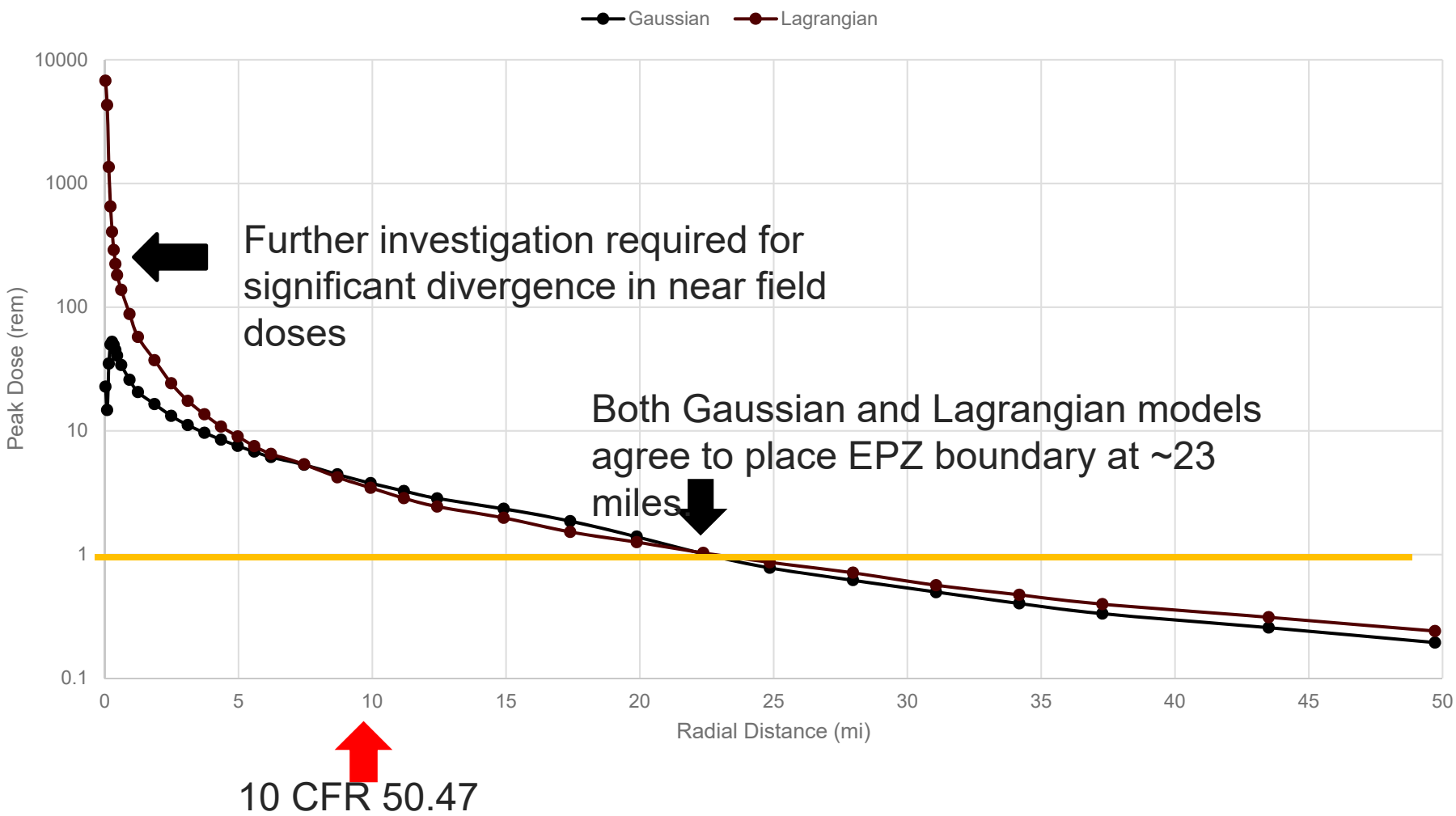
Gaussian at +24H



Lagrangian at +24H

Visual Representation of Gaussian and Lagrangian Distributions

Progress to Date



Combined Mean Peak Dose Distribution

Conclusions

- Methodology is functioning
  - Currently performing demonstration analyses with a heat pipe reactor design.
  - The team is adding in regulatory considerations, including 10 CFR 53.
  - Methodology is designed to be technology neutral.
- Lessons Learned
  - Microreactors have such small source terms that there is difficulty in providing meaningful source term for dose analysis.
  - The team will apply the methodology to a reactor design with a larger core inventory.

Physical Protection System (PPS)

- First of all, what is a Physical Protection System (PPS)?
  - "Physical protection (also called physical security) consists of a variety of measures to protect nuclear facilities and material against sabotage, theft, diversion, and other malicious acts."
  - https://www.nrc.gov/security/domestic/phys-protect.html
- The PPS can include:
  - Threat assessment
  - Physical protection areas
  - Intrusion detection
  - Intrusion alarm system
  - Armed response

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