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Proceedings of the Workshop on the Integration of Safety, Security, and Safeguards for Advanced Reactor and Fuel Fabrication Facility Design and Operations

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EXECUTIVE SUMMARY

There has been a broad agreement throughout the nuclear industry on considerations encouraging the convergence of safety, security, and safeguards[1] (3S) during design and operations and the use of alternative approaches to meet regulatory requirements. This workshop is aimed at increasing awareness of the development of appropriate methodologies and tools to address future challenges in the interdependencies between the individual 3S domains for advanced reactors, microreactors, and advanced fuel fabrication.

As part of its Integration of 3S During Design and Operations Future-Focused Research Project, the U.S. Nuclear Regulatory Commission (NRC) hosted a two-day virtual workshop, held December 5-6, 2023, to facilitate the exchange of knowledge and gain a better understanding of international perspectives, industry activity, and available modeling and simulation tools related to the integration of 3S. More than 340 domestic and international industry, government, national laboratory, university partners and members of the public registered for the workshop, which featured four sessions—one morning and one afternoon session, on both days—that included 19 expert speakers followed by facilitated panel discussions.

Workshop Objectives

1. Facilitate the exchange of knowledge and best practices for design and operations of advanced reactors and fuel cycle facilities using an integrated 3S approach.
2. Gain a better understanding of industry activities and perspectives with respect to 3S approaches to further inform NRC supporting activities to risk-inform and better equip the agency's readiness and posture to address applicants' and licensees' regulatory needs.
3. Understand developing research capabilities that address the interdependencies and integration between security, safety, and safeguards in both early design and future stages, including construction and operations.
4. Become aware of combined or integrated 3S modeling and simulation tools and applications.

Sessions

- **Day 1, Morning Session** focused on domestic and international government and regulatory perspectives on 3S for advanced reactors and fuel fabrication facilities.
- **Day 1, Afternoon Session** provided information on 3S efforts during the development of U.S. advanced reactors and fuel fabrication facilities.
- **Day 2, Morning Session** discussed wide-ranging 3S considerations for microreactors, molten salt research reactors being development by industry, government, and university partners, and an overview of the history and current understanding of 3S integration.
- **Day 2, Afternoon Session** explored a variety of 3S technology and regulatory research planned or ongoing at government agencies and national laboratories.

[1] In the context of this workshop, safeguards refers to the use of material control and accounting programs to verify that all special nuclear material is properly controlled and accounted for.

Key Workshop Takeaways

- There is significant interest in further exchanges of knowledge between the U.S. and international government agencies, industry, national laboratories, and universities.
- A process of conducting security by design and safeguards by design, along with the current use of safety by design, is approaching consensus among the workshop attendees.
- Incorporating 3S considerations early in the design phase is expected to yield the most benefits.
- There is interest among the nuclear industry in developing standards and best practices in integrated 3S for advanced reactors and fuel fabrication facilities.
- While there are efficiencies that can be achieved in many operational areas, vital area identification and transport security are key areas where safety and security can be integrated.
- There is interest in finding a standardized way to balance the need for information security and the benefits of sharing information and/or expanding "need to know."
- NRC staff and industry would benefit from proactive engagement regarding ongoing 3S integration activities.

Presentation slides are available in Appendix B and via the NRC's Agencywide Documents Access and Management System, under Accession No. ML24059A005.

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1 DAY 1, MORNING SESSION

1.1 Session Overview

Speakers from the International Atomic Energy Agency (IAEA), U.S. National Nuclear Security Administration (NNSA), Canadian Nuclear Safety Commission (CNSC), Département de la Sécurité Nucléaire (France), and the National Nuclear Laboratory (U.K.) shared U.S. and international perspectives on the importance of 3S integration, and the work being done in their respective spaces. The presentations in this session included discussions of international safeguards and their integration into 3S. While each organization had a slightly different approach, a consistent thread through all of the presentations was that discussion between regulators and industry regarding integration of 3S regulation, processes, and technologies needs to happen early in the design phase, frequently during operation, and throughout the fuel and reactor lifecycles in order to fully realize benefits. This session and panel discussion were led by Jim Rubenstone, U.S. NRC Office of Nuclear Material Safety and Safeguards (NMSS) Branch Chief.

1.2 Presentations

1.2.1 The Role of International Safeguards-by-Design (SBD) and 3S in Preparing the U.S. Nuclear Industry for Export Markets

- **Presenter:** Jeremy Whitlock, Senior Technical Advisor (SBD), Division of Concepts and Planning, Department of Safeguards, IAEA
- **Summary:** This presentation stressed the importance of raising general awareness of safeguards as a high priority for novel technology and deployments, the role of the IAEA to assure safeguards compliance, and the challenges faced by facilities and regulators.

1.2.2 Introductory Considerations in 3S for Operations and Design

- **Presenter:** Jeremy Edwards, Head of Nuclear Strategy, National Nuclear Laboratory (U.K.)
- **Summary:** This presentation provided an overview of 3S considerations, highlighting the strong dependency on the safety-security interface and the benefits of and barriers to 3S integration from the U.K. perspective.

1.2.3 A CNSC Perspective of 3S

- **Presenter:** Sanja Simic, Safety Analysis Lead, Directorate of Assessment and Analysis, CNSC.
- **Summary:** This presentation discussed the CNSC regulatory understanding and approach to advanced reactor design, highlighting the need for multi-disciplinary teamwork and collaboration.

1.2.4 DOE/NNSA Perspective on 3S (Safety, Security, Safeguards) for New Nuclear

- **Presenter:** Dr. Anagha Iyengar, Deputy Program Director for Analytics & Innovation, Office of International Nuclear Security, U.S. Department of Energy, NNSA
- **Summary:** This presentation focused on NNSA support for 3S-by-design and reiterated the agency's belief that this process may lead to reduced cost and ease the export licensing process. It also provided information about how and when in the development process industry can engage with NNSA for support.

1.2.5 New Reactors and Fuel Fabrication in France: Thoughts Regarding 3S

- **Presenter:** Thomas Languin, Deputy Head, Office for Regulatory and International affairs, at the Département de la Sécurité Nucléair (France)
- **Summary:** This presentation provided a summary of France's national framework regarding nuclear security, safety, and safeguards in France, small modular reactor projects in France, and lessons learned and thoughts regarding new reactors and fuel facilities.

1.3 <u>Discussion Highlights</u>

One interesting discussion topic from the first panel session was about information security and the need for regulators, consultancies, and vendors to work together to determine their shared boundaries between "need to know" and the desire to share information and lessons learned that could benefit the advanced reactor industry as a whole.

2 DAY 1, AFTERNOON SESSION

2.1 <u>Session Overview</u>

Speakers from Nuclear Energy Institute (NEI), Westinghouse, and General Electric Global Research gave industry perspectives on 3S integration in current and future advanced reactor projects. Presenters stated that U.S. vendors have already heavily invested in 3S considerations from the inception of advanced reactor designs, with vigorous and science-based testing and evaluation planned for plant design validation. Speakers shared plans for various technologies—including remote monitoring, increased standardization, in-situ real-time material monitoring sensors, advanced material management, and the application of blockchain technology—that are hoped to improve design, decrease operational downtime, enhance security, and increase cost savings. This session and panel discussion were led by Jose Cuadrado, U.S. NRC Office of Nuclear Security and Incident Response (NSIR) Branch Chief.

2.2 <u>Presentations</u>

2.2.1 3S Perspectives from the NEI

- No presentation slides were used in this presentation.
- **Presenter:** Florence Knauf, Director of Supplier Relations, NEI

- **Summary:** This presentation discussed trade associations and supply chains within the nuclear industry and how these experiences can be leveraged to facilitate advanced reactor growth.

2.2.2 Westinghouse's 3S Considerations for Advanced Reactor Deployment

2.2.3 Westinghouse's 3S Perspective for an Advanced Reactor Fuel Fabrication Facility

- The above two presentations were provided by the same speaker with combined slides.
- **Presenter:** Amanda Spalding, Fellow Engineer, Advanced Reactor Licensing, Westinghouse
- **Summary:** These presentations included an overview of Westinghouse's eVinci microreactor design, 3S considerations during deployment, and pre-application engagement with NRC during deployment.

2.2.4 Probabilistic Digital Twin and Distributed Ledger Technology-based Safeguards Solution for Aqueous Nuclear Reprocessing Facilities

- **Presenter:** Dr. Scott C. Evans, Principal Scientist Machine Learning, General Electric Global Research
- **Summary:** This presentation discussed the ARPA-E Converting UNF Radioisotopes into Energy (CURIE) program to convert used nuclear fuel into new fuel for advanced reactors using a novel safeguard solution called MAYER (monochromatic assay yielding enhanced reliability).

2.3 Discussion Highlights

Topics that arose during this panel discussion included transportation of fueled microreactors, safety redundancy, remote monitoring vs remote operation, cybersecurity, perspectives on companies incorporating integrated 3S approaches, and how industry plans to interact with regulatory agencies during design phases.

3 DAY 2, MORNING SESSION

3.1 Session Overview

This session opened with interesting presentations on 3S and regulatory considerations for ongoing design work in microreactors, molten salt research reactors, and advanced reactors, led by industry partner Oklo Inc., academic partner Georgia Tech, and industry partner Tennessee Valley Authority (TVA), respectively. Dr. Farshid Shahrohki of Framatome provided an overview of the origins of safety, security, and safeguards standards, and addressed some of the challenges faced today when integrating 3S, including accident avoidance, diversion resistance, physical control, and cybersecurity. This session and panel discussion were led by Steve Lynch, U.S. NRC Office of Nuclear Reactor Regulation (NRR) Branch Chief.

3.2 Presentations

3.2.1 Regulatory Considerations for Microreactor Security

- **Presenter:** Brian Kloiber, Reactor Engineer, Oklo, Inc.
- **Summary:** The presentation described microreactor security considerations, including consequences and threat motivators, and described potential benefits of applying a graded security approach for microreactors that incorporates the wide spectrum of licensed activities and operational sizes, in comparison to the operating fleet.

3.2.2 ACU NEXT Lab’s 3S Perspective for a Molten Salt Research Reactor

- **Presenter:** Dr. Steven Biegalski, Chair of Nuclear and Radiological Engineering and Medical Physics, Georgia Institute of Technology
- **Summary:** This presentation discussed the Molten Salt Research Reactor (MSRR) program led by Abilene Christian University (ACU), MSRR design, timelines, and material control and accounting (MC&A) process.

3.2.3 Integrated Safety, Safeguards, and Security

- **Presenter:** Dr. Farshid Shahrohki, Director of Advanced Reactor Technologies, Framatome, Inc.
- **Summary:** This presentation reviewed the history of national and international safeguard standards and regulations, and the challenges involved in integrating 3S during advanced reactor design.

3.2.4 Aspects of 3S Related to Advanced Reactors – Utility Perspective

- **Presenter:** Greg Boerschig, Vice President, Clinch River Project, TVA
- **Summary:** This presentation discussed TVA’s preparation for its first small modular reactor, including funding, environmental impact, siting, and 3S approach.

3.3 Discussion Highlights

A wide-ranging panel discussion included topics such as research needed to better understand sabotage consequences in non-LWR reactors, using physical barriers in material control, how to prioritize 3S considerations if in conflict, maintaining cross-communication and preventing siloing when integrating 3S, design basis threat considerations for non-LWR reactors, and IAEA/NRC engagement during the design process.

4 DAY 2, AFTERNOON SESSION

4.1 Session Overview

This session began with the NRC discussion of future-focused research currently in progress and the introduction of three case studies that study 3S integration and continued with a presentation on cybersecurity requirements under consideration and their impacts on 3S integration. DOE-NE's Advanced Reactor Safeguards and Security (ARSS) program then presented on its work to address challenges that advanced reactor vendors face in meeting MC&A, physical protection system, and cybersecurity requirements for reactors built in the U.S. Sandia National Labs presented an engineering approach to 3S-by-design, where interactions drive innovation, and on how to measure and analyze the economic benefits and challenges of 3S integration. Oak Ridge National Lab shared its approach to integrating 3S using modeling and simulation, focusing on documenting areas of interface, methodologies, and software between the 3S domains, followed by Idaho National Lab reporting on DOE-NNSA International Nuclear Security Techniques for Advanced Reactors (INSTAR) methodology for evaluating security risks and consequences associated with advanced reactor technology designs, meant to inform designers of inherent security considerations and insights on basic risk/consequences early in the design process. This session and panel discussion were led by U.S. NRC Office of Nuclear Regulatory Research (RES) Division Director John McKirgan.

4.2 Presentations

4.2.1 NRC's 3S Future-Focused Research Project

- **Presenter:** John Matrachisia, Reactor Engineer, Reactor Engineering Branch, Office of Nuclear Regulatory Research, U.S. NRC
- **Summary:** This presentation focused on ongoing research efforts at the NRC and provided details on the development of three case studies, which including scenarios on advanced reactor, microreactor, and fuel fabrication facility 3S.

4.2.2 Cybersecurity Considerations

- **Presenters:** Ismael Garcia, Senior Technical Advisor, Office of Nuclear Security and Incident Response, and Mauricio Gutierrez, Instrumentation and Control Engineer, Office of Nuclear Regulatory Research, U.S. NRC
- **Summary:** This presentation reviewed current cybersecurity requirements for nuclear power plants, new cyber requirements for advanced reactors under consideration, and potential integrated cybersecurity-safety assessments for nuclear power plants.

4.2.3 3S Integration in the DOE-NE ARSS program

- **Presenter:** Dr. Ben Cipiti, Distinguished Member of Technical Staff, Sandia National Laboratories and National Technical Director for the ARSS program funded through the Department of Energy Office of Nuclear Energy
- **Summary:** This presentation addressed ARSS goals and objectives, including the near-term challenges that advanced reactor vendors face in meeting MC&A, physical protection, and cybersecurity requirements for reactors built in the U.S. This presentation included technical considerations between onsite and offsite response forces.

4.2.4 Novel Risk Methods for Integrated 3S

- **Presenter:** Dr. Adam Williams, Principal R&D Systems Engineer Center for Global Security and Cooperation, Sandia National Laboratories
  Summary: This presentation reviewed 3S examples in advanced reactors, provided engineering basis for 3S-by-design, and ended with opportunities for successful 3S implementation.

4.2.5 An Approach to Integrating 3S Modeling and Simulation

- **Presenter:** Steve Reed, Engineer, Oak Ridge National Laboratory
- **Summary:** This presentation discussed benefits and key aspects for successful 3S integration and how modeling and simulation can be used in this effort.

4.2.6 NNSA INSTAR Multi-Lab FY23 Integrated Advanced Reactor Security Project Summary

- **Presenters:** Christopher Chwasz, Senior Regulatory Development and Licensing Engineer, and Scott Ferrara, Regulatory Development Engineer, Idaho National Laboratory
- **Summary:** This presentation provided an overview of the INSTAR scope and objective to provide a logical framework to qualitatively characterize and risk-qualify advanced reactor security vulnerabilities early in the design and licensing process, and key outcomes of this effort.

4.2.7 Economic Reasons for 3S-by-design

- **Presenter:** Dr. Bobby Middleton, Distinguished Member of Technical Staff, Sandia National Laboratories
- **Summary:** This presentation discussed current nuclear power plant construction costs, the economic benefits of advanced reactors, and economic modeling that can guide decision making.

4.3 Discussion Highlights

The final panel discussion, which included robust side-conversations in Zoom chat, ranged from decreasing security costs during the advanced reactor design stage, to thoughts on the complementary nature of security and safety technologies and classification, to incorporation of the different domestic and international definitions of safeguards (per IAEA and NRC), to the rules of engagement with armed intruders, to the impacts of new technologies on fuel types.

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APPENDIX B PRESENTATION SLIDES

The role of international safeguards-by-design (SBD) and 3S in preparing the U.S. nuclear industry for export markets

Safeguards

NRC 3S Workshop (virtual) – December 5, 2023

Jeremy Whitlock

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Safeguards awareness: a new priority

Safeguards

SMRs, advanced reactors:

- **Novel technology and deployment models:** need for new safeguards approaches, measures and equipment

Back-end management:

- **Novel processes, large volumes:** preparation needed for safeguards measures and termination on waste

2

Role of IAEA safeguards

IAEA Safeguards

Credible assurance that countries are honouring their international obligations (under the NPT) not to divert nuclear material from peaceful use to a nuclear weapon (or other nuclear explosive device).

- ➢ In safeguards planning scenarios, the State is the prime 'actor'.
- ➢ Nuclear facilities support the State in meeting its international obligations.

3

The challenge:

IAEA Safeguards

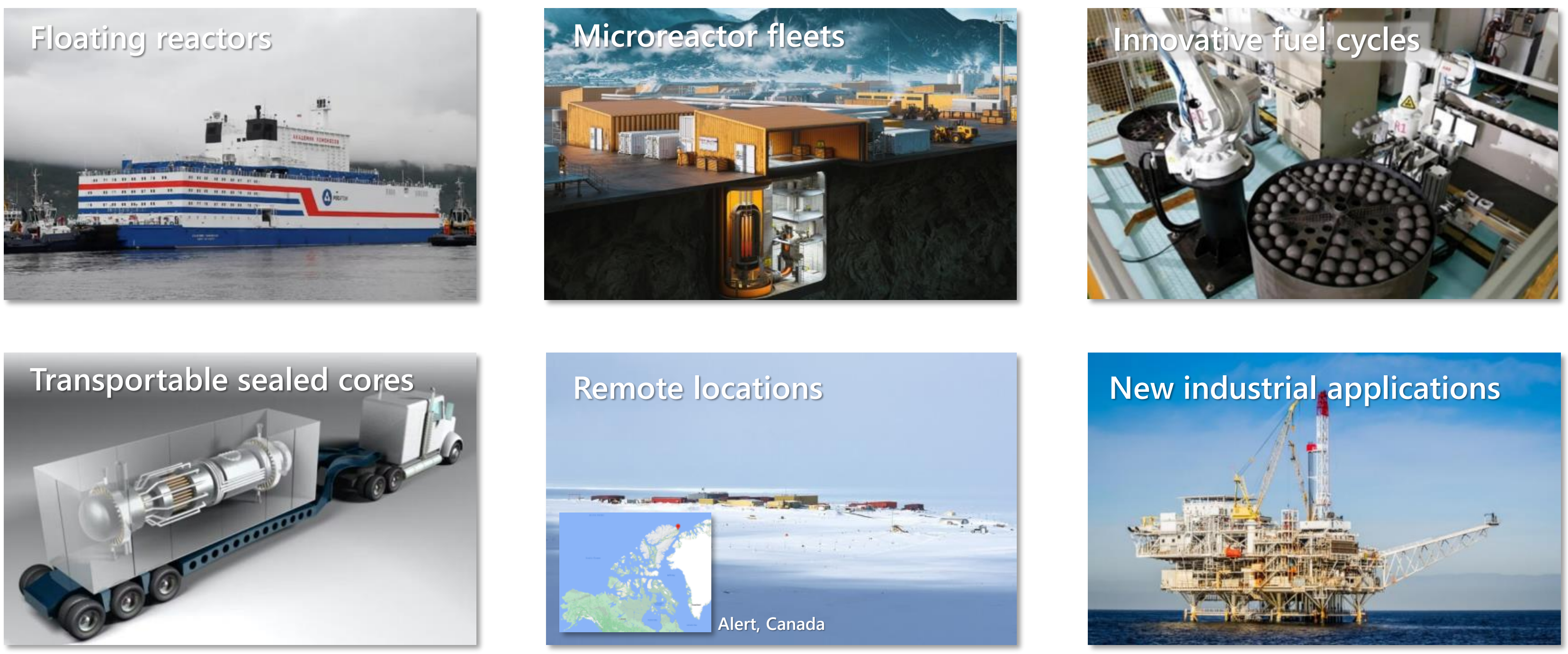
- A new nuclear facility in a non-nuclear-weapon State (NNWS) will need to be safeguarded **when deployed**
  - ➢ *regardless of the size, complexity, accessibility, owner/operator or supplier of the technology*
- Many vendors are not aware of the significance of this **customer requirement**
  - ➢ *lack of awareness of international safeguards, or perception that it doesn't impact design*
- Advanced reactors may require **advanced safeguards** (which requires R&D)
  - ➢ *new core/fuel designs, plant layouts, SF management, fuel cycle facilities, IAEA equipment*

- Enhanced security and 'inherent' PR **do not necessarily mean simpler safeguards**
  - ➢ *'safeguardability': often overlooked external component of PR*

4

We need to be ready to safeguard these:

IAEA | Safeguards



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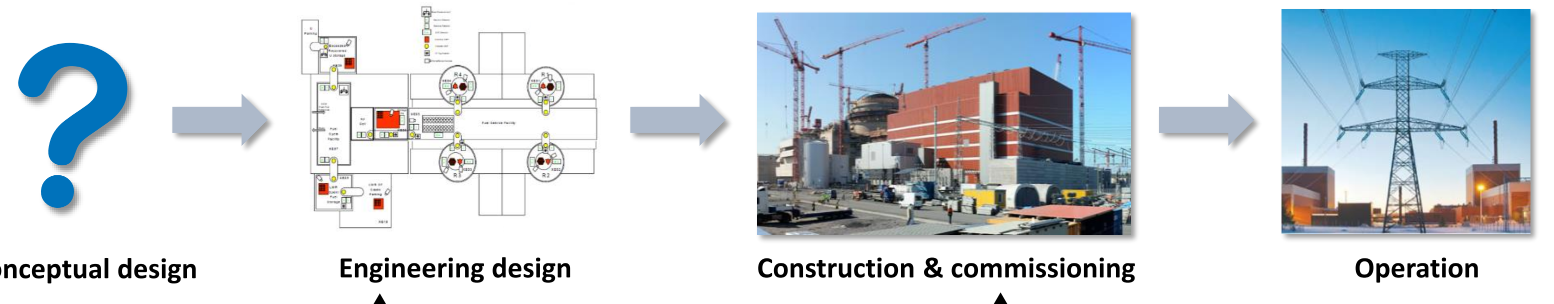
WANTED: Efficient, effective safeguards

IAEA | Safeguards



Safeguards by Design

National safety requirements

National security requirements

Other national design codes and standards

Operational goals

International safeguards obligations:
Provision of design information
Nuclear material accountancy

"3S"

- ✓ **Integration** of safeguards needs into the design process
- ✓ **Awareness** by all stakeholders of safeguards obligations
- ✓ **Voluntary** best practice: not an enhanced obligation
- ✓ **Life-cycle & fuel-cycle tool:** any design process

How can design make safeguards easier?

IAEA | Safeguards

Verification of Nuclear Material Accountancy

- To verify State's declaration of nuclear material **inventory and flow** (e.g. item counting, weighing, non-destructive assay)
- Can involve **inspections** or **remote monitoring of unattended equipment**

Containment and Surveillance

- To maintain **continuity-of-knowledge** (e.g. cameras, seals, measurements) between inspections
- Can involve **remote monitoring of unattended equipment**

Design Information Verification

- To verify State's **declared facility design** (construction, operation, modification or decommissioning)

SAFEGUARDS-RELATED DESIGN CONSIDERATIONS:

Physical access around facility, fuel storage configuration, complexity of fuel movement, health & safety, accommodating IAEA equipment, use of unattended equipment

Ease of installation of IAEA seals, cameras, instruments (brackets, electricity, lighting, conduits, penetrations, HVAC), number and size of hatches, environmental conditions

Physical access around facility, complexity of layout, health & safety

SAFEGUARDS BY DESIGN

7

Suggestions to US industry and R&D community

IAEA | Safeguards

- **Raise awareness** of international safeguards in design community, engage with IAEA
- Consider the value of having **one design that is applicable to all customers**
- Consider possibility of **VOA acceptance of innovative facilities** by the IAEA
- Consider **impact of IAEA safeguards needs** in near-term designs (e.g., conventional C/S equipment installation, accommodation for IAEA seals on containers)
- Consider **impact of evolutionary 'concepts of operations'** on safeguards implementation (e.g., multiple modules, smaller footprints, remote monitoring)
- Support development of **advanced NDA equipment** and other measures for bulk and on-line fuelled designs (~10 year lead time)

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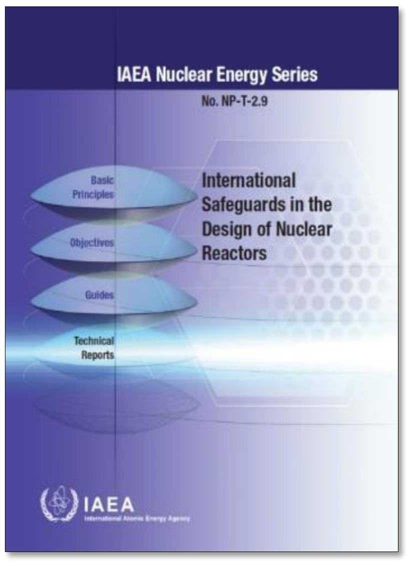
IAEA safeguards-by-design (SBD) guidance

IAEA Safeguards



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IAEA Safeguards

IAEA
International Atomic Energy Agency

Thank you for your attention!

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10

Safeguards

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Dr. Whitlock lives in Vienna, Austria, and feels that canoes are the closest humans have come to inventing a perfect machine.

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Safeguards

Additional slides

SBD: IAEA activities

IAEA Safeguards

- **SMR Member State support program tasks:**
  - *Russia, South Korea, US, Canada, Finland, France, China*
  - Technologies include FNPP, integral PWR, MSR, PB-HTR
  - Goal is to work with Member States to:
    - evaluate design aspects that impact safeguards
    - investigate safeguards implementation strategies

- **Internal IAEA collaborations:**
  - IAEA SMR Platform (single point of contact for Member States)
  - Dept. of SG SBD Working Group (Safeguards, Nuclear Energy, Nuclear Safety and Security)
  - Other internal collaborations with NE and NS (e.g., 3S interfaces in Design Safety Reviews)
- **External engagements:**
  - Raising awareness with stakeholders through third-party interactions and collaborations

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Introductory Considerations in 3S for Operations and Design

5th Dec 2023

NATIONAL NUCLEAR LABORATORY

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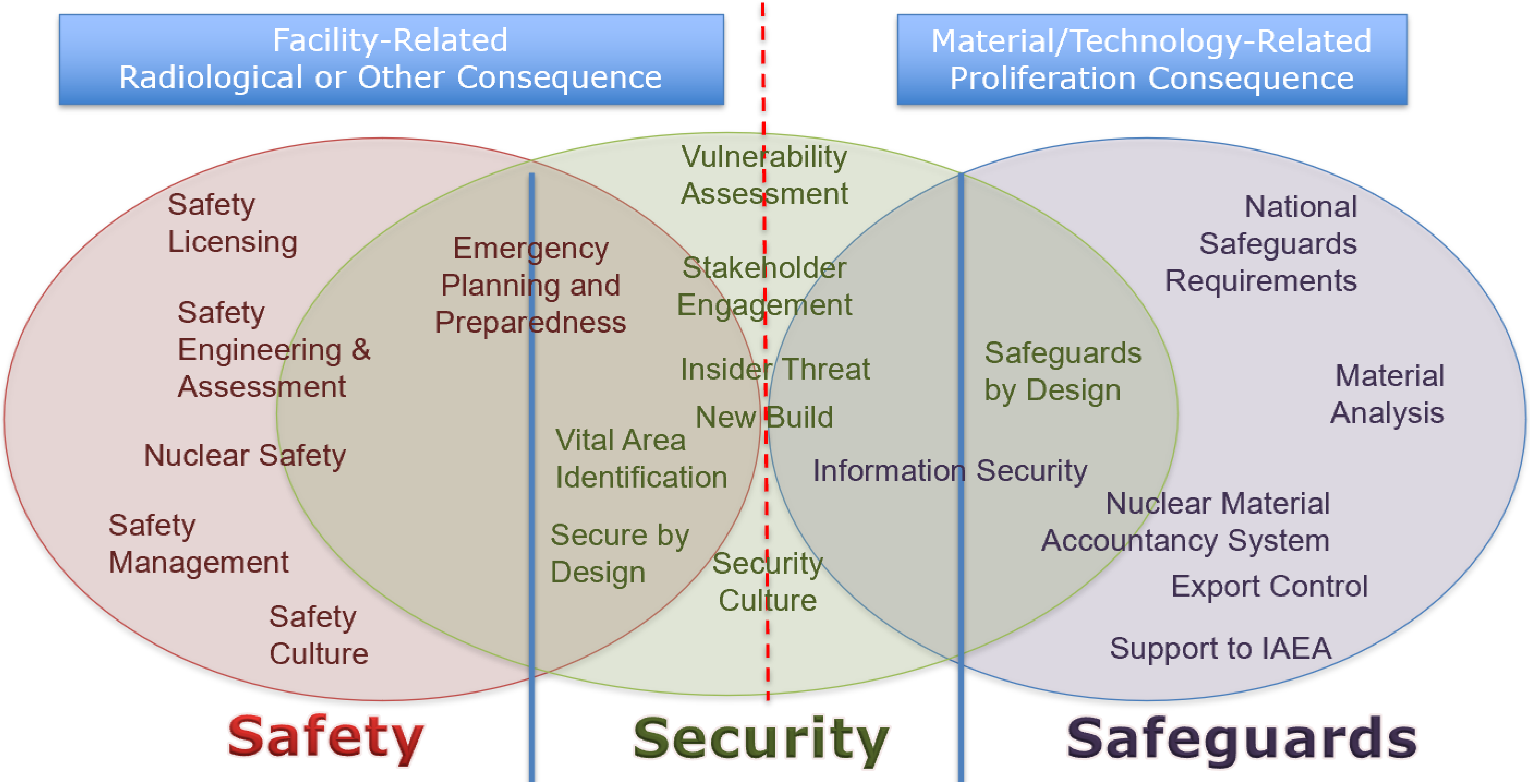
Summary

To provide an overview of 3S considerations

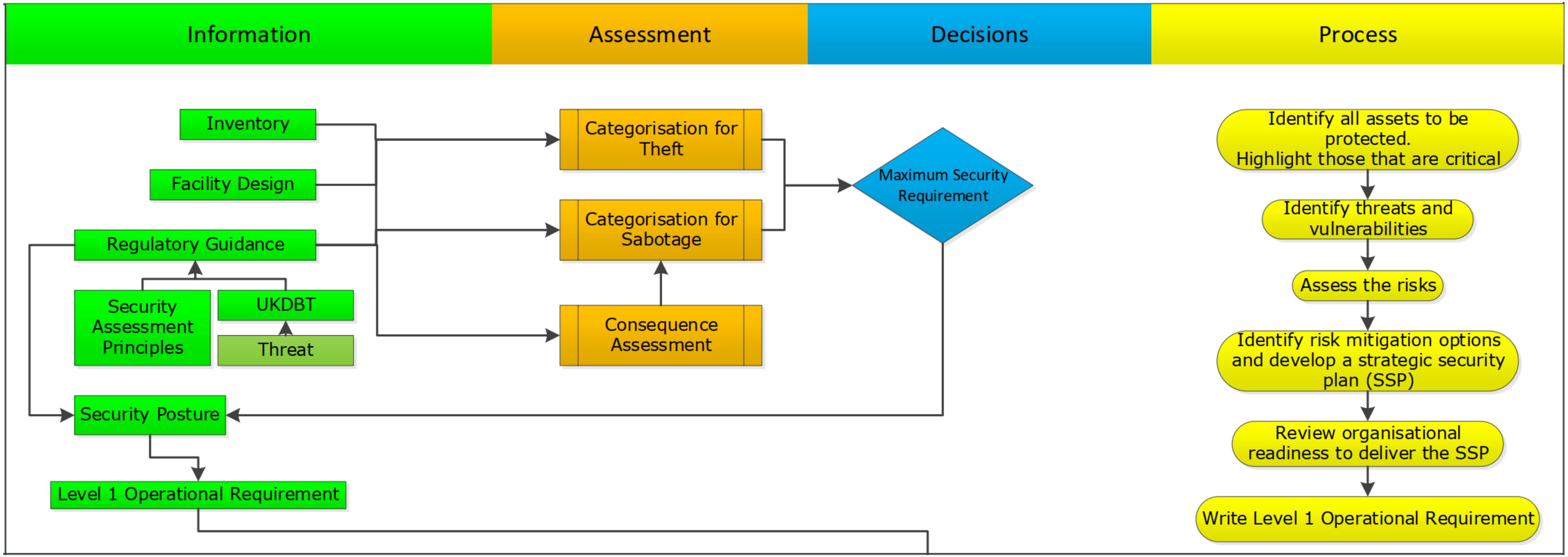
Highlight strong dependency on safety-security interface

Benefits and barriers

3S interactions



Safety - Security Critical Interfaces



Some key considerations – benefits and barriers

- Engineering design / operation
- Failure scenarios
- Passive and active features – their importance, and failure-mode
- Opportunities for 3S efficiencies
- Understanding inventory – throughout lifetime operation
- Fuel cycle / Process modelling
- Aggregation of materials (NSS 27-G Implementing Guide)
- Radiological consequence assessment – identification of key / dominant nuclides
- Safety case provides operating envelope and formal change management
- Capability and information integration – effective multi-disciplinary project delivery

Thank you

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Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

Canada

NRC 3S Workshop:

CNSC expectations for 3S

Dec. 5, 2023

Sanja Simic, Lead, Safety Analysis

Directorate of Assessment and Analysis

Canadian Nuclear Safety Commission

CNSC Regulatory Approach

- The Canadian Nuclear Safety Commission regulates the use of nuclear energy and materials to protect health, safety, security and the environment; to implement Canada's international commitments on the peaceful use of nuclear energy; and to disseminate objective scientific, technical and regulatory information to the public
- Canada has extensive experience in operating and regulating CANDU reactors:
  - All reactors are regulated as Class 1A nuclear facilities; and,
  - "Small Modular Reactor (SMR)/ Advanced Nuclear Reactor (ANR)" has no legal meaning or regulatory distinction
- Over the last few years, CNSC staff have been developing their understanding of how SMRs/ANRs might be different from traditional reactors and what those differences will mean for safety, security and safeguards (the 3S's)

Concept By Design

- Expectation that SMR/ANR technologies must be safe, secure and proliferation-resistant given their potential standalone nature, international deployment and deployment in remote locations
- Adoption of the 3S concept early in the design phase (3S-by-Design):
  - Safety-by-design: passive systems and inherent safety characteristics
  - Security-by-design (SeBD): security is fully integrated into the design process of a nuclear facility from the very beginning
  - Safeguards-by-design (SBD): international safeguards requirements are fully integrated into the design process of a nuclear facility from an early stage and throughout its life cycle
- Risk-informed approach that requires multi-disciplinary teamwork

Safeguards-by-design in Canada

- Requires engagement between the IAEA, the regulator and/or safeguards authority, and the vendor
- Canada has a decades long history of successfully considering safeguards aspects in new facilities and designs:
    - On-load reactors of CANDU type require installed IAEA safeguards equipment to monitor the continual flow of nuclear material
    - Dry storage containers for irradiated CANDU fuel and waste management, storage and packaging facilities
- Now new fuel, advanced reactor and novel fuel-cycle facility designs are being proposed by vendors
- At the CNSC, lessons learned from the past have been incorporated into the organization's SMR pre-licensing vendor design reviews

Safeguards-by-design in Canada, cont.

- CNSC recommends vendors integrate safeguards considerations into their early design phase:
  - The safeguards-by-design dialogue builds awareness amongst all stakeholders around both the design and safeguards requirements
- While the process is voluntary, it is an informative and beneficial step before the required ones
- Early engagement can ensure that safeguards requirements are considered before design freezes, thereby reducing costs for retrofitting IAEA safeguards equipment
- Promotes the integration of safeguards with safety and security within the design process

Canadian Safeguards Support Program task

- The CNSC accepted an IAEA Member State Support Programme task on "Safeguards by Design for Small Modular Reactors" in 2019
- The task aims to identify the key technical challenges for safeguards implementation involving SMRs, and the steps that can be taken to support incorporating SBD principles into the designs
- The IAEA's design information questionnaire is used as tool to consolidate the safeguards-relevant information from the design and provide it to the IAEA
- The CNSC has shared preliminary design information from two vendors as part of the project and has started initial discussions with the IAEA on a potential safeguards approach for one of these designs

Modernized Nuclear Security Regulations 1/3

- Canadian regulatory framework for nuclear security is currently being updated, including the *Nuclear Security Regulations* (NSR) and the associated Regulatory Documents for nuclear security (REGDOC-2.12 series)
- The proposed amendments to the NSR will ensure the continuity of Canada's robust nuclear security regime, while affording licensees and proponents greater flexibility in demonstrating how they can meet nuclear security regulatory requirements
- The performance objectives of Canada's nuclear security regulatory requirements are to prevent the theft of nuclear material and prevent the sabotage of nuclear material and nuclear facilities
- Must be achieved by defeating the adversary (effective intervention)

CNSC

Modernized Nuclear Security Regulations 2/3

- For high-security sites (facilities that use, produce, process and/or store Category I or II nuclear material) the requirement to defeat the adversary characterized by the DBT (for high-security sites) will remain
- Prescriptive requirements on how the performance objectives are to be achieved will be removed (e.g., requirement for an on-site armed response)
- Maximize the flexibility in range of interventions that can be used by an operator in terms of the use of various techniques, tactics and procedures and/or engineered systems and civil structures for deterrence, delay, detection, denial and/or response, or any combination thereof
- Expanded requirements for cyber security considerations for the protection of sensitive and prescribed information

CNSC

Modernized Nuclear Security Regulations 3/3

- Licensees/applicants will be able to propose methods that employ novel technologies and concepts of operations; safety and security-by-design; the use of on-site armed response forces; and/or arrangements with off-site armed response forces
- Proposed modifications maintain clear performance objectives while providing the operator maximum flexibility in how they are met
- Align with Canada's domestic laws and regulations, and its international commitments
- Afford existing operators and new operators (green field) the flexibility to modify their nuclear security programs

Safety-by-Design, 1/3

- SMRs/ANRs rely on passive systems and inherent safety characteristics of the reactor
- Examples of Safety-by-Design:
  - Reactors that use natural convection for cooling
    - No pumps, claim no need for emergency generators
  - Seismically robust SMRs
    - Modules submerged in a pool of water below ground in a robust building
    - Reactor pool attenuates ground motion and dissipates energy
- Vendor's claims about the increased safety margins and potential for practical elimination of the severe damage to the reactor core
  - Consequently, reduced reliance on robust containment and emergency response

Safety-by-Design, 2/3

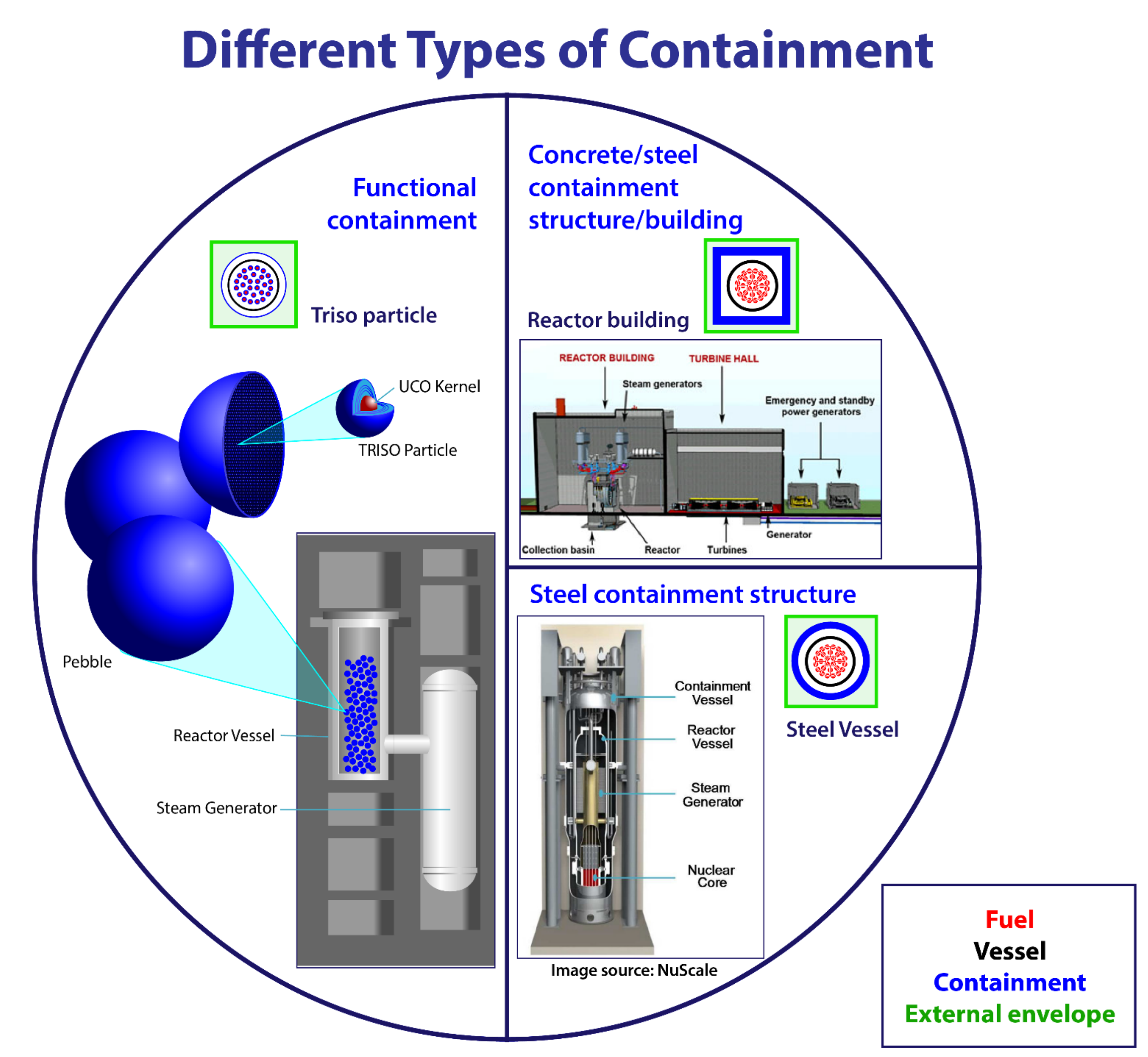
- Novel designs, new reactor types/technologies and deployment of SMRs pose challenges to the existing regulatory framework:
  - Can existing requirements, for example for containment, be applied to all SMR/ANR designs?
  - Can traditional criteria for containment systems be complemented by design and performance criteria suitable for specific reactor designs (for example, HTGR reactor designs with the allegedly highly robust fuel)?
    - This could result in a simplified containment design with a smaller plant footprint while meeting dose limits and safety goals, *functional containment*

Safety-by-Design, 3/3

- How can we deal with a vendor proposing a functional containment under our current regulatory regimes?

- Complex question, because the impact of such proposal is multi-fold, on:
  - Safety (e.g. reduced capacity for radionuclide retention)
  - Security (e.g. aircraft crash, possibly DBT)
  - Safeguards (e.g.: TRISO fuel)

- Need for an integrated approach to assessing risk to Safety, Security, and Safeguards (3S)



Interfaces of safety with nuclear security and safeguards

- IAEA GSR Part 1, Requirement 12:

Interfaces of safety with nuclear security and with the State system of accounting for, and control of, nuclear material

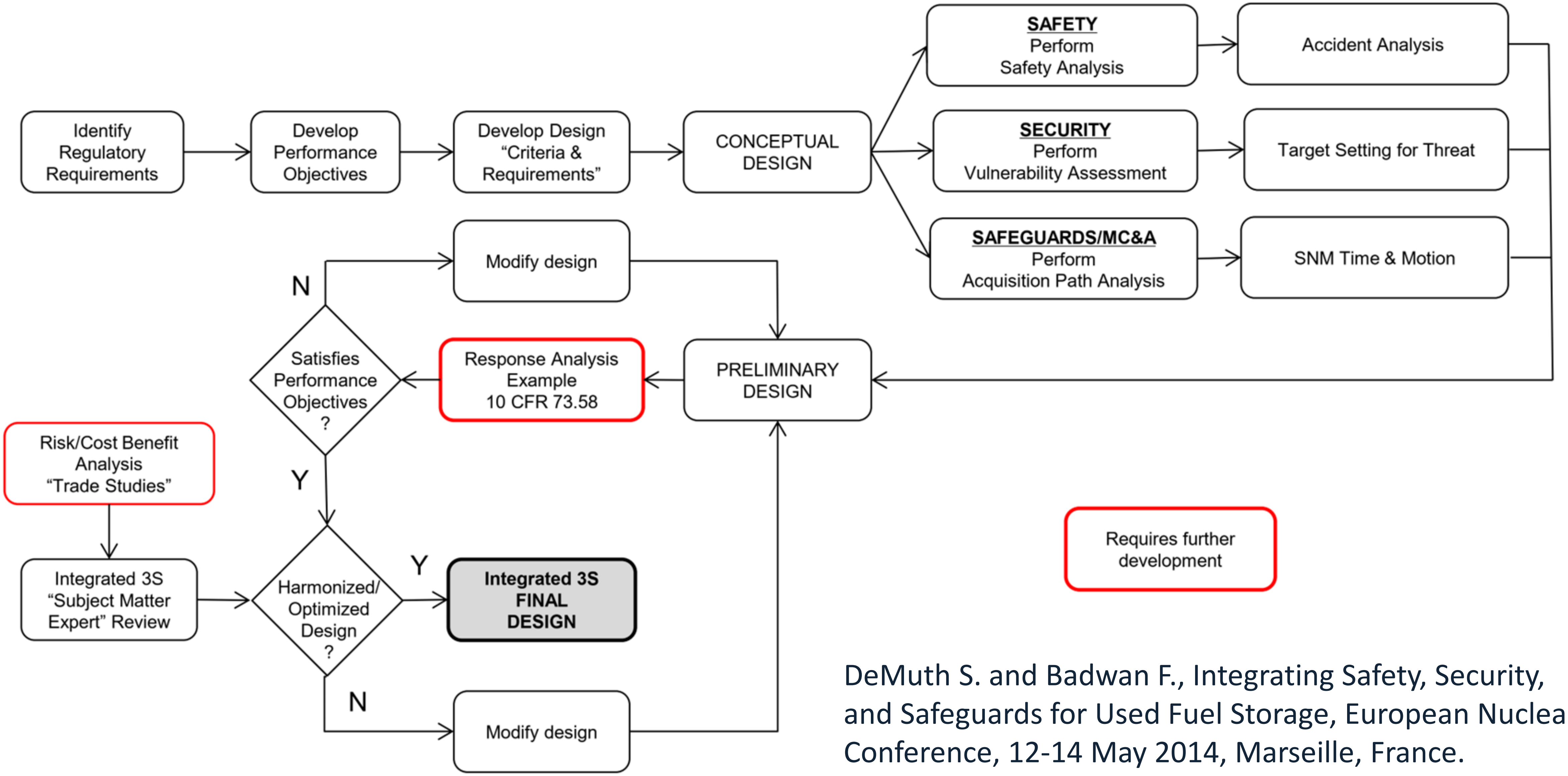
The government shall ensure that, within the governmental and legal framework, adequate infrastructural arrangements are established for interfaces of safety with arrangements for nuclear security and with the State system of accounting for, and control of, nuclear material

Integrated approach to assessing risk to Safety, Security, and Safeguards (3S)

- Various SMR designs encompassing advanced and innovative technology solutions are currently being developed
- Many are still in the design stage:
  - Opportunity to pursue an integrated approach to assessing risk to 3S
    - Different from the past, when for example, security was an afterthought for nuclear facilities
    - Some degree of integration exists, but needs to be improved
  - Opportunity to design out certain risks not only by designing for safety but also for security (security-by-design) and safeguards (safeguards-by-design)

CNSC Regulatory perspective on 3S

- REGDOC-2.5.2 “Design of Reactor Facilities: Nuclear Power Plants”, Section 4.3.4 *Interface of safety with security and safeguards*:
    - *Safety measures, nuclear security measures and arrangements for the system of accounting for, and control of, nuclear material for an NPP shall be designed and implemented in an integrated manner so that they do not compromise one another*
- Use existing good regulatory practices for SMR reviews:
    - Understand the design
    - Verify that the licensee can meet regulatory requirements/expectations
    - While reviewing the design, work jointly among disciplines
    - If modifications are needed, ask the licensee to implement them
        - Iterative process from preliminary design to final design



DeMuth S. and Badwan F., Integrating Safety, Security, and Safeguards for Used Fuel Storage, European Nuclear Conference, 12-14 May 2014, Marseille, France.

CNSC Regulatory perspective on 3S, cont.

- Example of collaboration among disciplines – Cyber Security:
  - Vendors should satisfy the cyber security requirements of REGDOC-2.5.2 and CSA N290.7-14
  - Implementation of cyber security features (e.g., intrusion detection software, virus protection software, access control software) shall not adversely impact the performance, effectiveness, reliability or operation of safety and safeguard functions
- Recommendations to:
  - Vendors: incorporate "by design"
  - Other regulators:
    - look at the culture and encourage collaboration – organizational structure
    - proactively think of 3 S' overlaps and integration
    - engage early with the vendor

Thank you

Stay connected!

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nuclearsafety.gc.ca

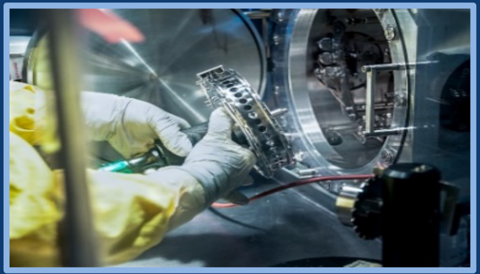
U.S. DEPARTMENT OF ENERGY
NATIONAL NUCLEAR SECURITY ADMINISTRATION
OFFICE OF DEFENSE NUCLEAR NONPROLIFERATION

Office of Defense Nuclear Nonproliferation

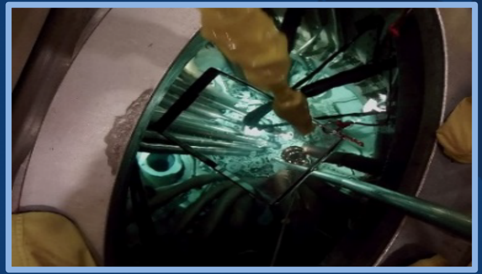
Perspectives on 3S (Safety, Security, Safeguards) for New Nuclear

Dr. Anagha Iyengar, Office of International Nuclear Security

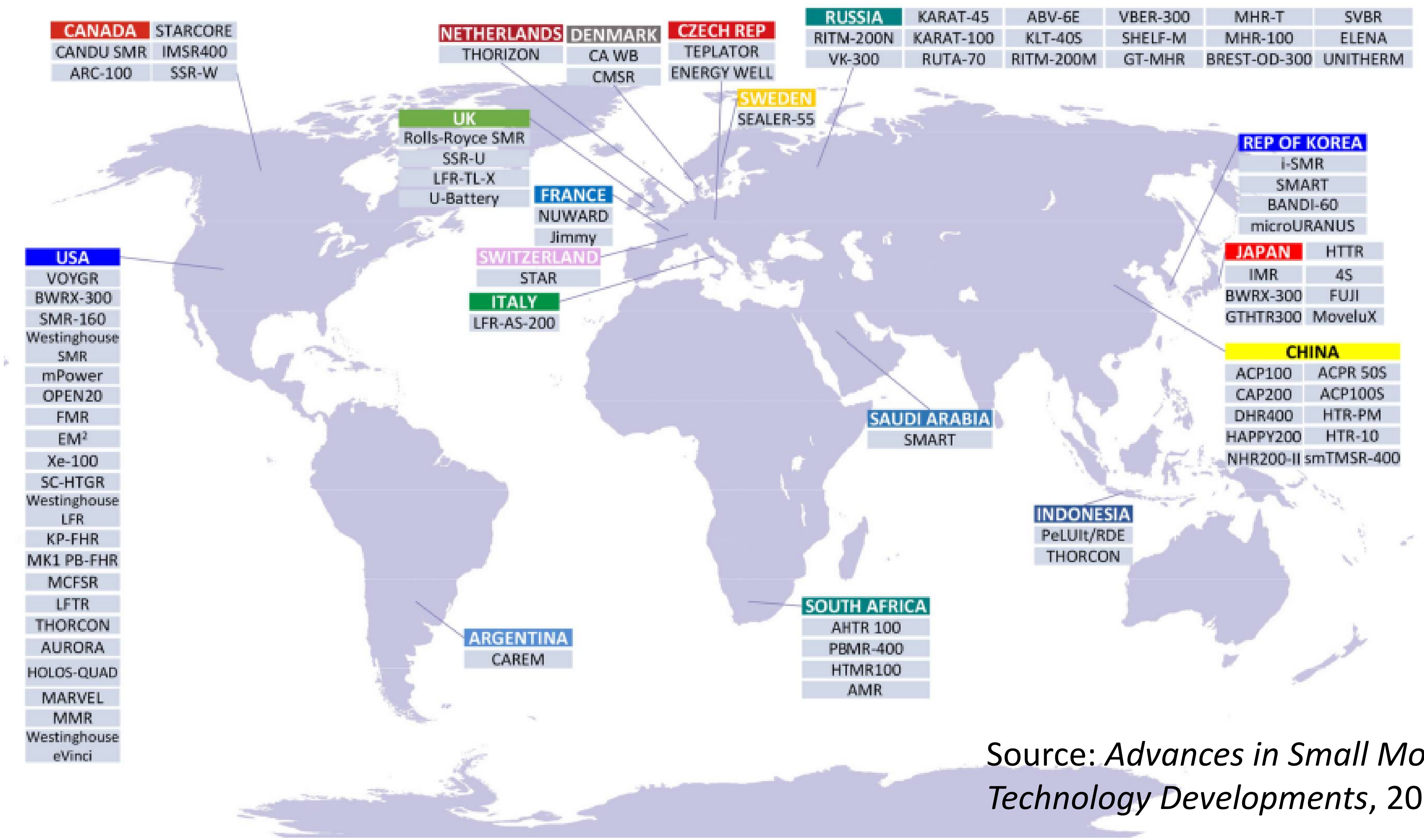
December 5, 2023







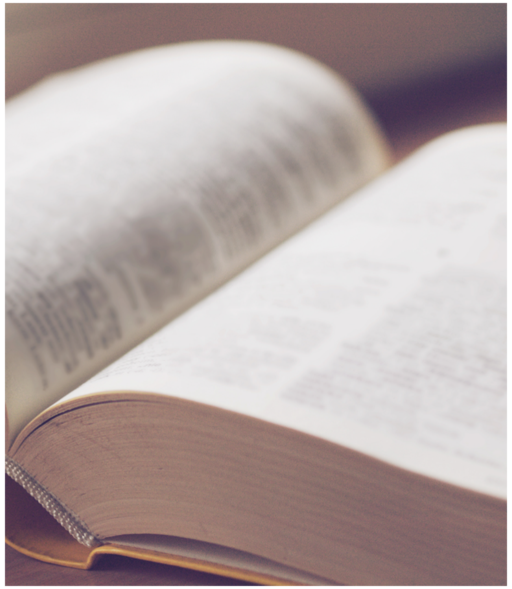
ADVANCED REACTOR AND FUEL CYCLE LANDSCAPE



Source: *Advances in Small Modular Reactor Technology Developments*, 2022 edition, IAEA

NEW NUCLEAR TECHNOLOGIES CHALLENGE TRADITIONAL APPROACHES

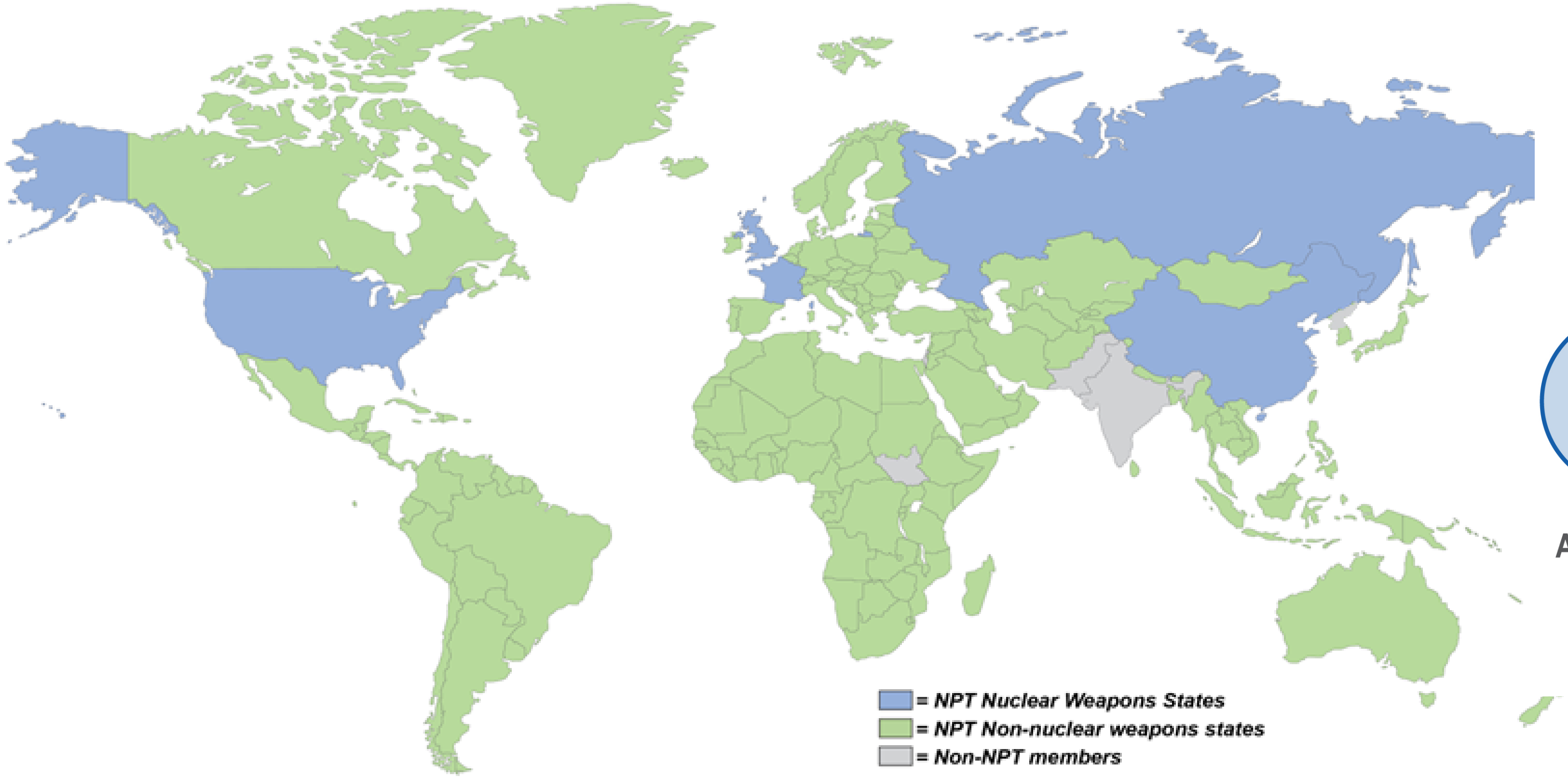
Existing Fleet	Advanced Reactors
Large / fixed footprint	Smaller and transportable
Site specific design	Factory fabricated / mass produced
Large upfront investment; high staffing levels	More easily accessible to developing countries – less upfront capital; limited staffing
Standardized fuel design and supply chain	Exotic fuel materials, forms, higher enrichment
Power applications	Varied industrial applications and increased siting options



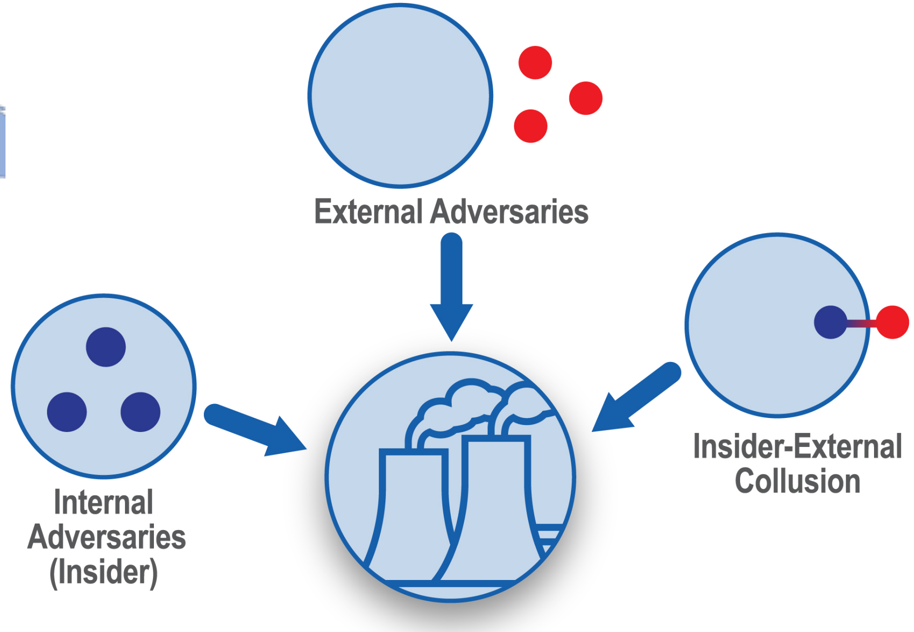
- **National**
  - International Agreements
  - National Frameworks / Regulations
- **Site**
  - Facility
  - Site
  - Operational Models

WHAT ARE THE RELEVANT S'?

Safeguards

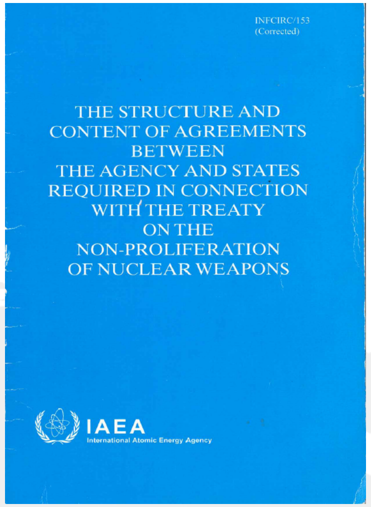


Security



Nuclear Infrastructure Issues Associated with Nuclear Security & Safeguards

IAEA Milestones Approach to Nuclear Infrastructure for Nuclear Power
(IAEA Nuclear Energy Series NG-G-3.1 Rev.1)

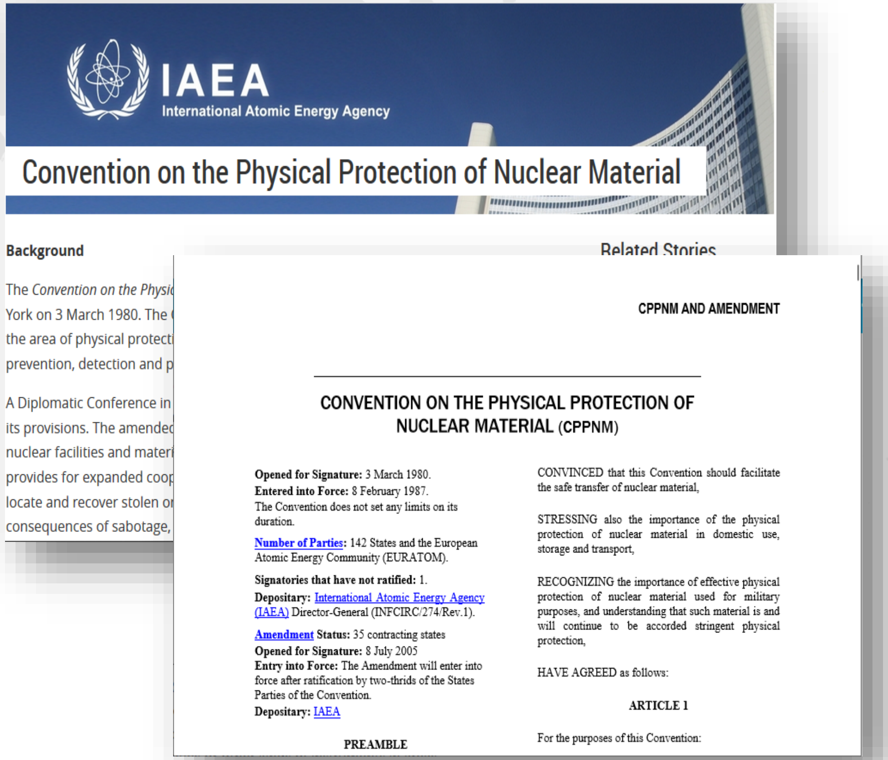


INFCIRC/153 (Corrected)

THE STRUCTURE AND CONTENT OF AGREEMENTS BETWEEN THE AGENCY AND STATES REQUIRED IN CONNECTION WITH THE TREATY ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS

IAEA
International Atomic Energy Agency

Comprehensive Safeguards Agreement
(INFCIRC/153)



IAEA
International Atomic Energy Agency

Convention on the Physical Protection of Nuclear Material

Background

The *Convention on the Physi*
York on 3 March 1980. The
the area of physical protect
prevention, detection and p

A Diplomatic Conference in
its provisions. The amended
nuclear facilities and materi
provides for expanded coop
locate and recover stolen or
consequences of sabotage,

Related Stories

CPPNM AND AMENDMENT

CONVENTION ON THE PHYSICAL PROTECTION OF NUCLEAR MATERIAL (CPPNM)

Opened for Signature: 3 March 1980.
Entered into Force: 8 February 1987.
The Convention does not set any limits on its duration.

Number of Parties: 142 States and the European Atomic Energy Community (EURATOM).

Signatories that have not ratified: 1.
Depositary: International Atomic Energy Agency (IAEA) Director-General (INFCIRC/274/Rev.1).

Amendment Status: 35 contracting states
Opened for Signature: 8 July 2005
Entry into Force: The Amendment will enter into force after ratification by two-thirds of the States Parties of the Convention.
Depositary: IAEA

PREAMBLE

CONVINCED that this Convention should facilitate the safe transfer of nuclear material,

STRESSING also the importance of the physical protection of nuclear material in domestic use, storage and transport,

RECOGNIZING the importance of effective physical protection of nuclear material used for military purposes, and understanding that such material is and will continue to be accorded stringent physical protection,

HAVE AGREED as follows:

ARTICLE 1

For the purposes of this Convention:

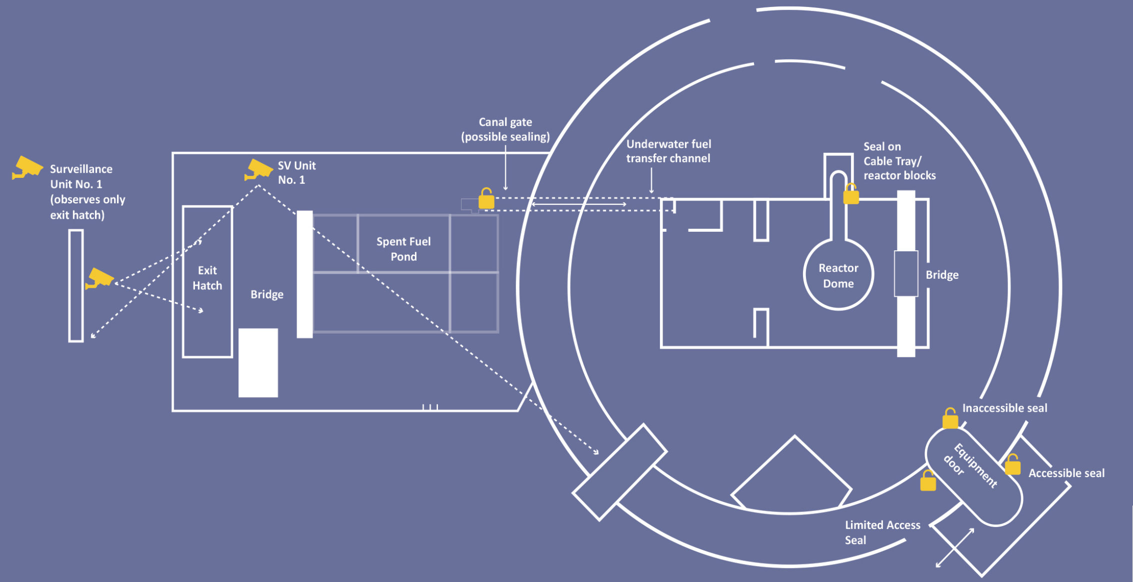
SAFEGUARDS AND SECURITY BY DESIGN

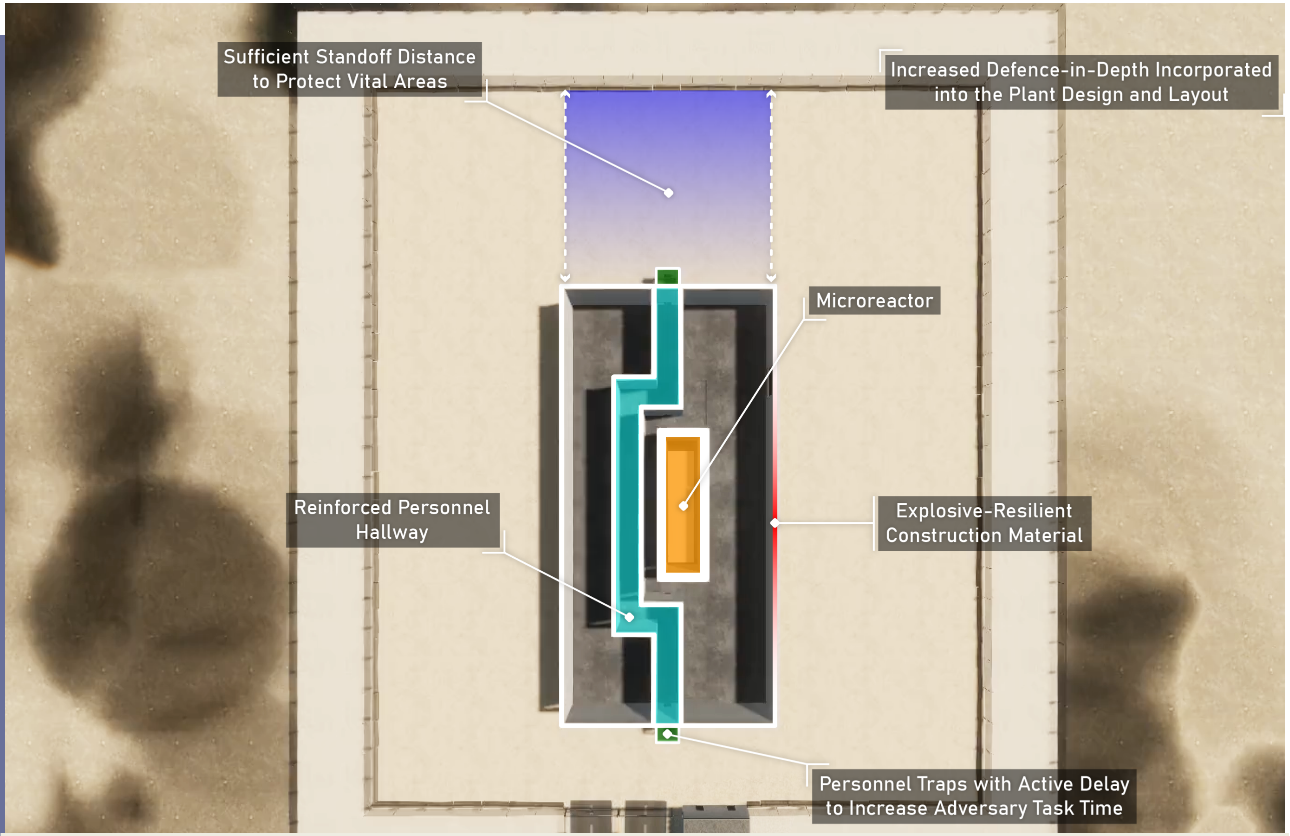
What is Safeguards-by-Design?

The early integration of IAEA safeguards considerations into the design process of a new or modified nuclear facility, such as IAEA safeguards surveillance, containment and monitoring equipment.

Diagram Key

- IAEA surveillance system
- IAEA seal/tamper-indicating device

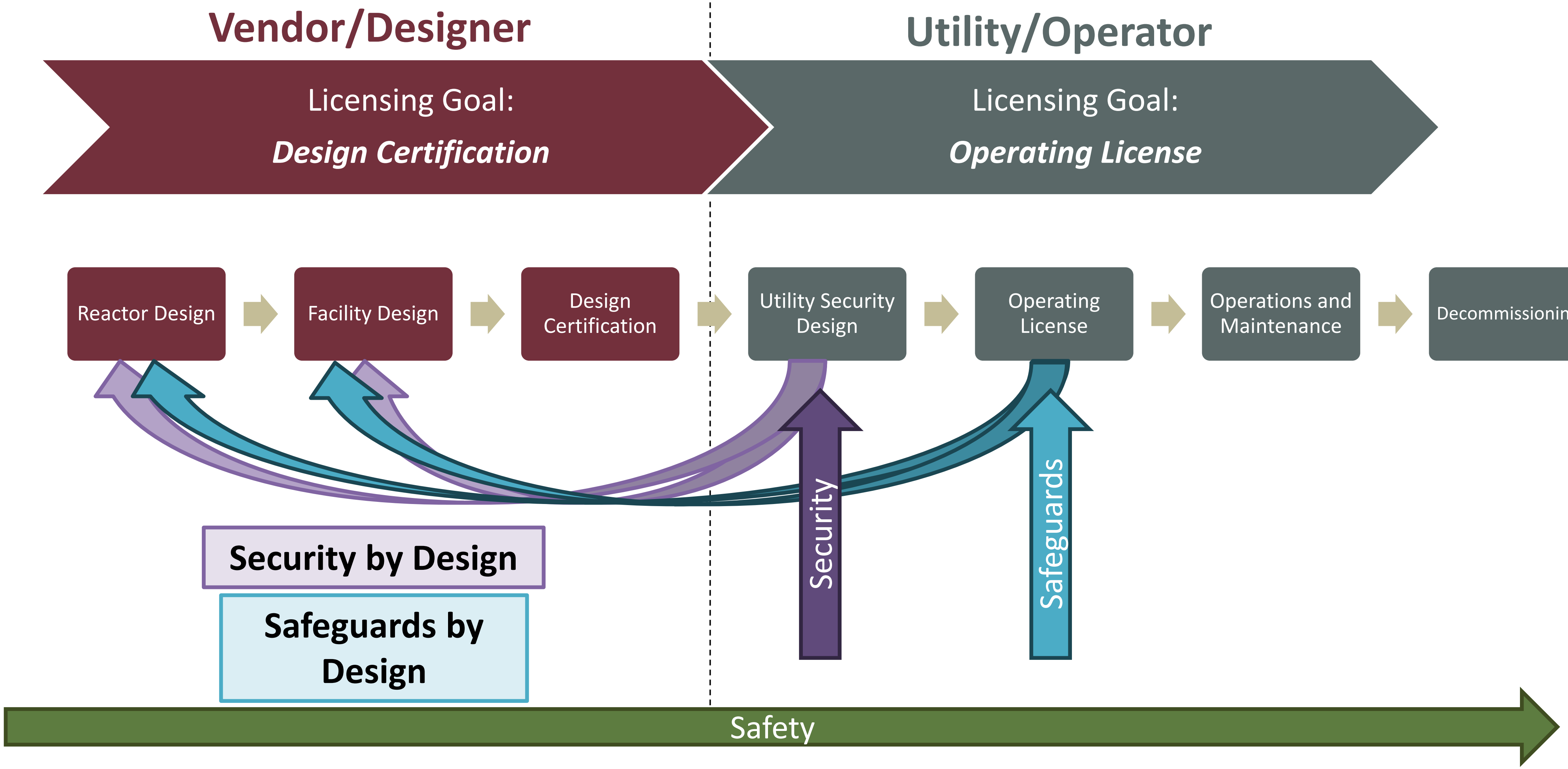


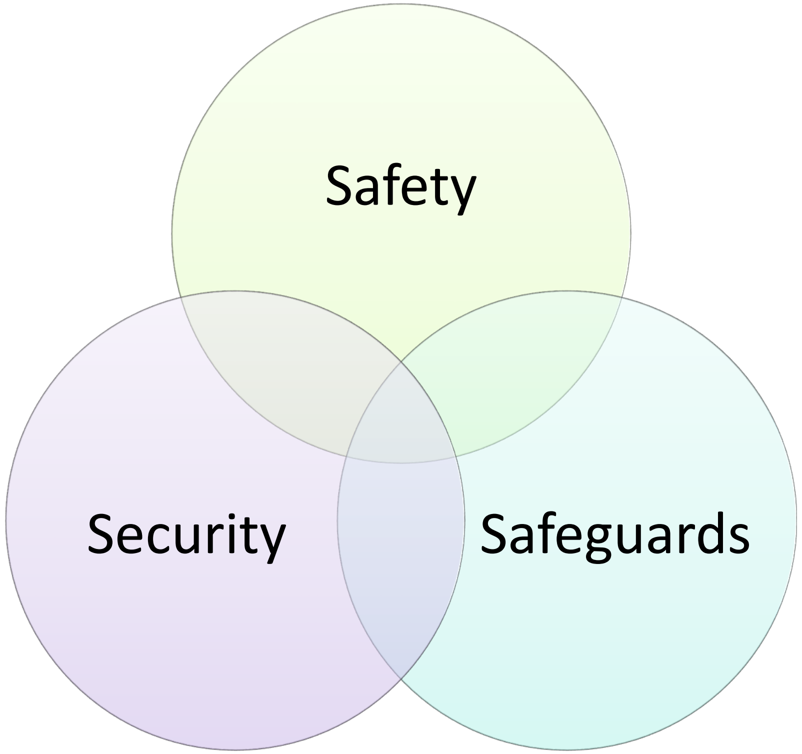


What is Security by Design?

Risk-based approach to nuclear security that seeks to eliminate vulnerabilities to theft, sabotage, or other malicious acts by integrating security features early in the design process and throughout the facility life cycle.

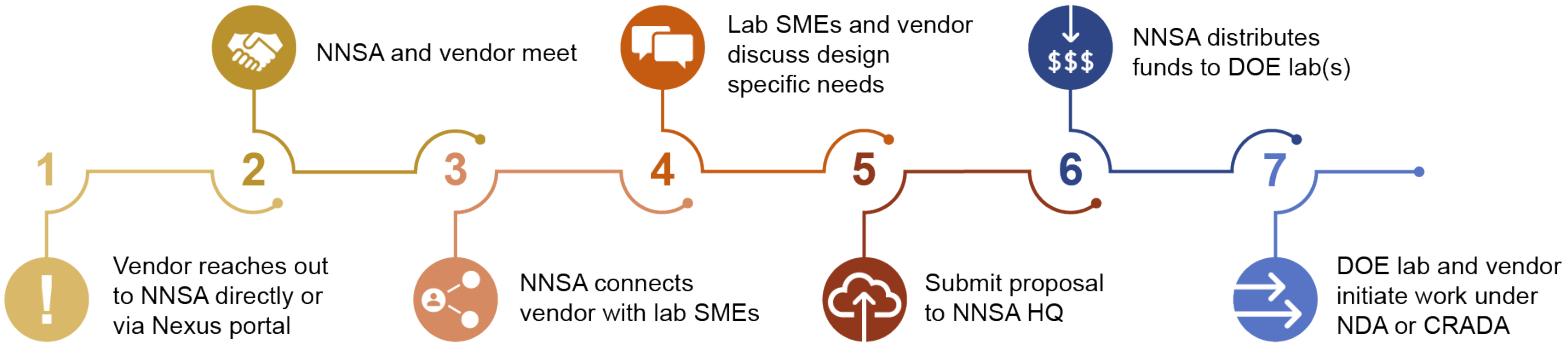
WHERE DO THE 3S' COME INTO PLAY VS. WHERE SHOULD THEY BE CONSIDERED?





- "3S by Design" should focus on addressing as many requirements in "design" stages as possible
- Security systems can and should be designed before the facility is constructed with other 2 S' in mind
  - Passive safety ≠ Passive security
- Safeguards approaches should be developed in coordination with IAEA with other 2 S' in mind
- Early 3S effectiveness evaluation may lead to reduced costs
- Improve marketability of designs and may ease export licensing review process

HOW DOES NNSA ENGAGE WITH INDUSTRY?



To engage industry, the DOE National Labs can enter:

- *Nondisclosure Agreements* (NDAs) to have detailed discussions of technologies that can include proprietary information
- *Cooperative Research and Development Agreements* (CRADAs) to expand a company's proprietary capabilities or knowledge-set

Additional information regarding **NNSA** support for international deployment can be found at the Nuclear Nexus website:

https://nuclear-nexus.anl.gov/

CONTACT US

Learn More About Us:

https://nuclear-nexus.anl.gov/

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NRC 3S WORSHOP
5 – 6 DECEMBER 2023

PERSPECTIVES FROM THE FRENCH NUCLEAR SECURITY AUTHORITY

Summary

- ❑ National framework regarding nuclear security, safety and safeguards in France
- ❑ SMR projects in France
- ❑ Lessons learnt and thoughts regarding new reactors and fuel facilities

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NATIONAL FRAMEWORK REGARDING NUCLEAR SECURITY, SAFETY AND SAFEGUARDS IN FRANCE

French regulatory framework overview

- **3 different sets of laws, regulations and regulatory bodies**:
  - Security: code of defence - Minister of energy
  - Safety: code of environment - Minister of safety (regulations, site authorisation) and Autorité de sûreté nucléaire (independent regulatory body – licensing, control, enforcement)
  - Safeguards: Prime minister (Comité Technique Euratom) – laws and decrees codified

French regulatory framework overview

	Laws	Regulatory body	Control body	Inspections
Safety	Environment Code	Ministry of Energy	ASN	Safety inspections by ASN
Security	Defence Code	Ministry of Energy	Ministry of Energy / Nuclear Security Department (DSN)	Security inspections by DSN
Safeguards	Euratom Treaty + IAEA commitments + international agreements	Ministries involved	CTE	Safeguards inspections by Euratom and the IAEA

French regulatory framework overview

- **Close cooperation between the 3 competent authorities** and importance of interface management between security, safety and safeguards is recognised by the State and by the French operators

- **Periodic meetings** between 3 regulatory bodies

French regulatory framework overview

- **Cooperation not "limited" to 3S**: Other regulations/competent authorities need also close interface management with nuclear security: intelligence services, law enforcement, critical infrastructures, protection of information, cybersecurity, ministry of defence…

French regulatory framework overview

- Nevertheless, **close cooperation between the 3 competent authorities** and **importance of interface management** between security, safety and safeguards **is recognised by the State and by the French operators**

- Periodic meetings between 3 regulatory bodies

Regulatory interfaces between 3S

- Safety → Security:
  - Art R1593-18 of the code of environment and ministerial order of 7th February 2012 require that **accidents from a malicious origin must be described in the safety case**, with justification that safety measures and emergency plans are adapted to address such accidents
  - ministerial order of 7th February 2012 require that **safety measures must be compatible with security regulation**

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Regulatory interfaces between 3S

- ❑ Security → Safety:
  - ❑ ministerial order of 13th April 2023 require that **security measures must be compatible with safety regulation** and that **synergies must be sought** with safety (and radiation protection, health and safety of employees, environment protection and regulations regarding security of critical infrastructures)
  - ❑ ministerial order of 13th April 2023 require that **security case must be consistent with the safety case**

Regulatory interfaces between 3S

- ❑ Security → Safeguards:
  - ❑ **NMAC regulations are part of security regulations** (code of defense and ministerial order of 13th April 2023 – when interface with security)
  - ❑ Centralized accounting (IRSN), updated daily, used both for security and safeguards

SMR PROJECTS IN FRANCE

SMR Projects

- NUWARD (PWR): 1st reactor 2030 (2 x 170 MWe)
- NAAREA (MSR): 1st prototype 2028 (XAMR)
- NEWCLEO (LFR UK/Italy): 1st prototype 2028 (30 MWth)
- JIMMY (HTGR): 1st reactor 2028 (HALEU, triso – 10 MWth)
- CALOGENA
- ARCHEOS: PWR 10 to 200 MWe
- OTRERA: RNR-Na, 110 MWe
- HEXANA : RNR-Na, 400 MWth
- Blue Capsule : HTR/RNR-Na 150 MWth, triso
- Thorizon (NRG – Netherlands national research laboratory): Thorium

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Authorization process

Pre - authorization

Prior opinion (optional)

Authorization

HEXANA
OTRERA
ARCHEOS
CALOGENA

NUWARD
JIMMY
NAAREA
NEWCELO

NUWARD (beginning in 2024)

JIMMY (beginning in 2024)

Informal technical dialogue

Authorization process

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LESSONS LEARNT AND THOUGHTS REGARDING NEW REACTORS AND FUEL FACILITIES

3S by design

- The 3 competent authorities push designers to take into consideration security, safety and safeguards from the beginning of the project

- They have periodic meetings to exchange information on the projects

- The DSN (security authority) issued guidance to raise the awareness and the understanding of nuclear security issues

Challenges of new reactors and fuels

- **Variety of technologies**: **low knowledge** regarding security concerns:
  - **Effective proliferation risks for new fuel**: triso HALEU, PuCl…
  - → "practicably irrecoverable" notion
  - → assessment of the risk to have together with safeguards experts
  - How to **assess radiological consequences in case of malicious act**?

Challenges of new reactors and fuels

→ Differing from existing reactors, **nuclear security measures could be more costly than nuclear safety**

- Consequences of non-malicious accidents lowered thanks to intrinsic safety
- Consequences of malicious accidents lowered by limited radioactive source term / but reactors could be installed closer to dense populated areas

→ unacceptable radiological consequences?

→ nuclear security measures could be similar to those necessary for “normal” nuclear facilities

Challenges of new reactors and fuels

- **Lower potential for synergy with safety measures?** (in a smaller reactor, the malicious act could more easily destroy both the target and safety measures)

→ **Hope of progress regarding nuclear safety** (passive and inherent safety…) **could be** very **disappointing from the point of view of nuclear security** (no significative added value for nuclear security, or new opportunities for malicious actors to create accidental situations that are not considered in the safety case)

Challenges of new reactors and fuels

- Possible divergence of regulatory approaches between security and safety?
  - For safety, with 100 or 1000 more reactors, risk for a given reactor could be required to be reduced by 100 or 1000 to maintain similar overall nuclear risk

Challenges of new reactors and fuels

- ❑ Possible divergence of regulatory approaches between security and safety?
  - ❑ For security, the number of reactors don't increase the risk, that is mainly driven by the number of potential terrorist cells that could access the national territory.
  - ❑ Securing so many reactors at the same time could be very challenging for the State / increase vulnerability against terrorist attacks.

Challenges of new reactors and fuels

- ❑ Waste management

- ❑ Reactors without permanent on-site staff: management of nuclear accidents and of terrorist attacks?

- ❑ Synergies security / safety:
  - ❑ Cybersecurity
  - ❑ Insider threat

eVinci™ Microreactor

3S Considerations for Microreactor Deployment

December 5, 2023

Westinghouse

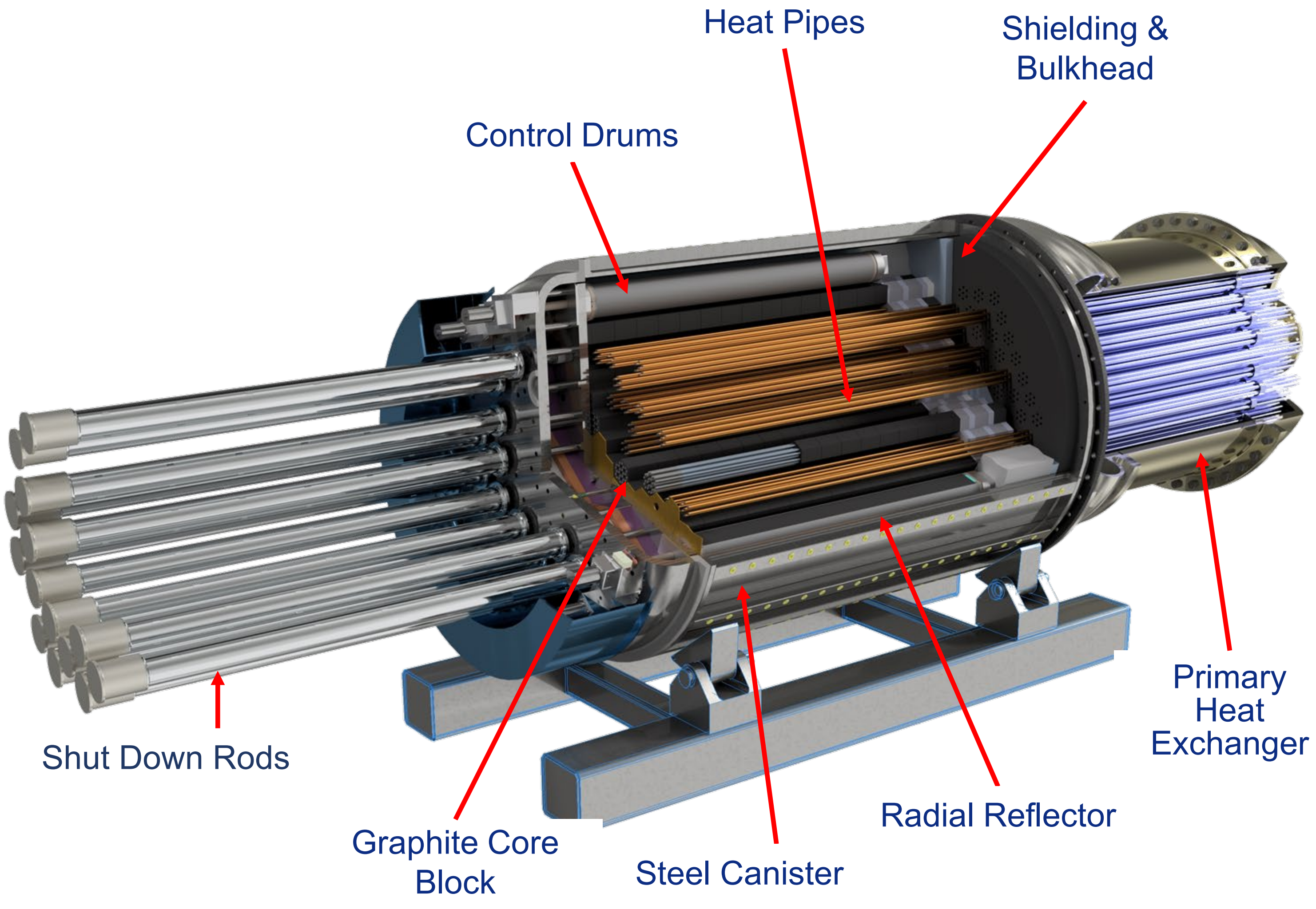
Agenda

- eVinci Microreactor Design Overview
- eVinci Microreactor Deployment Model Overview
- 3S Considerations for eVinci Microreactor Deployment
- eVinci Microreactor NRC Pre-application Engagement
- Questions

The eVinci Microreactor

Safety through passive heat pipe technology, enabling a very low-pressure reactor

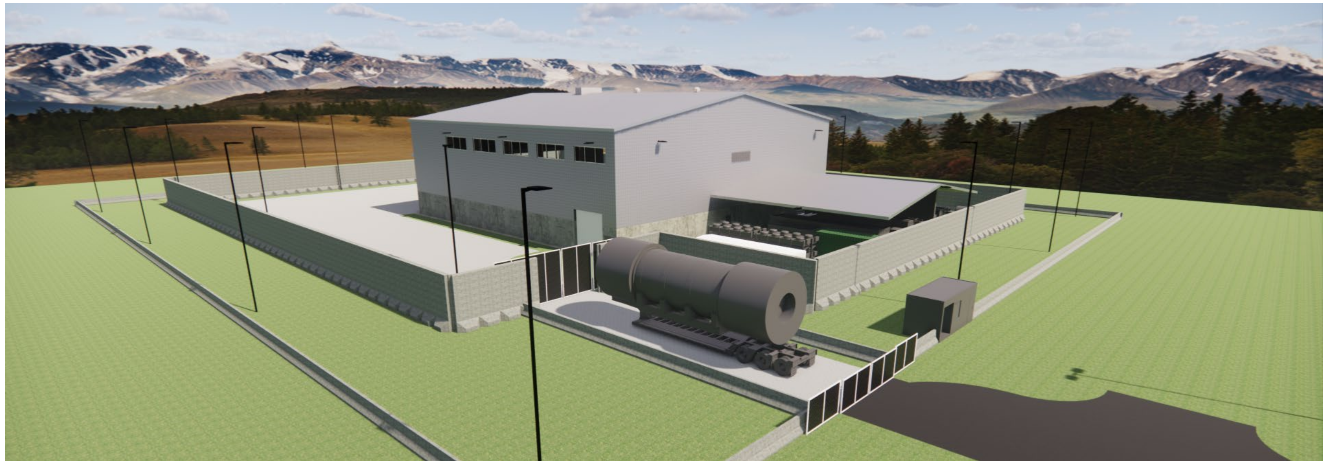
Parameter	eVinci
Power	15 MWt
Fuel Cycle	8 years
Fuel (Enrichment)	TRISO (19.75%)
Coolant	Heat Pipes
Reactor Pressure	~1 atm
Moderator	Graphite
Power Conversion	Open-Air Brayton
Efficiency	34%
Decay Heat Removal	Radial Conduction

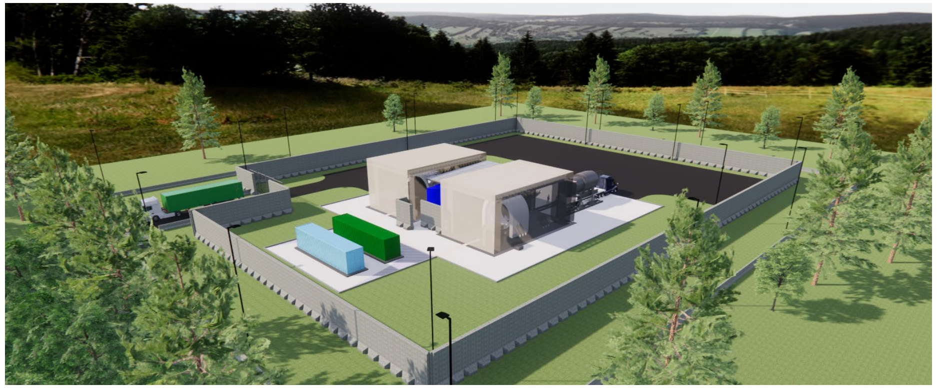


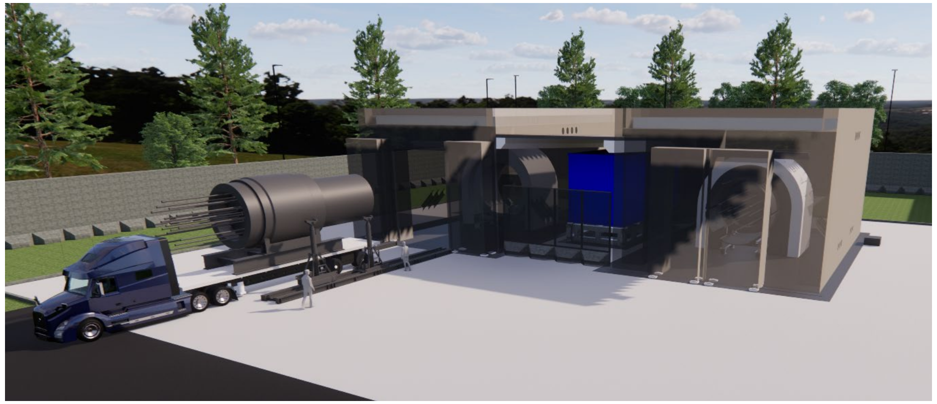
eVinci Microreactor Site Layout

Site and Facility shown for single unit

- All buildings & systems **above ground**
- Reactor site footprint: **~2 acres**
- Building footprint: <**0.5 acres**







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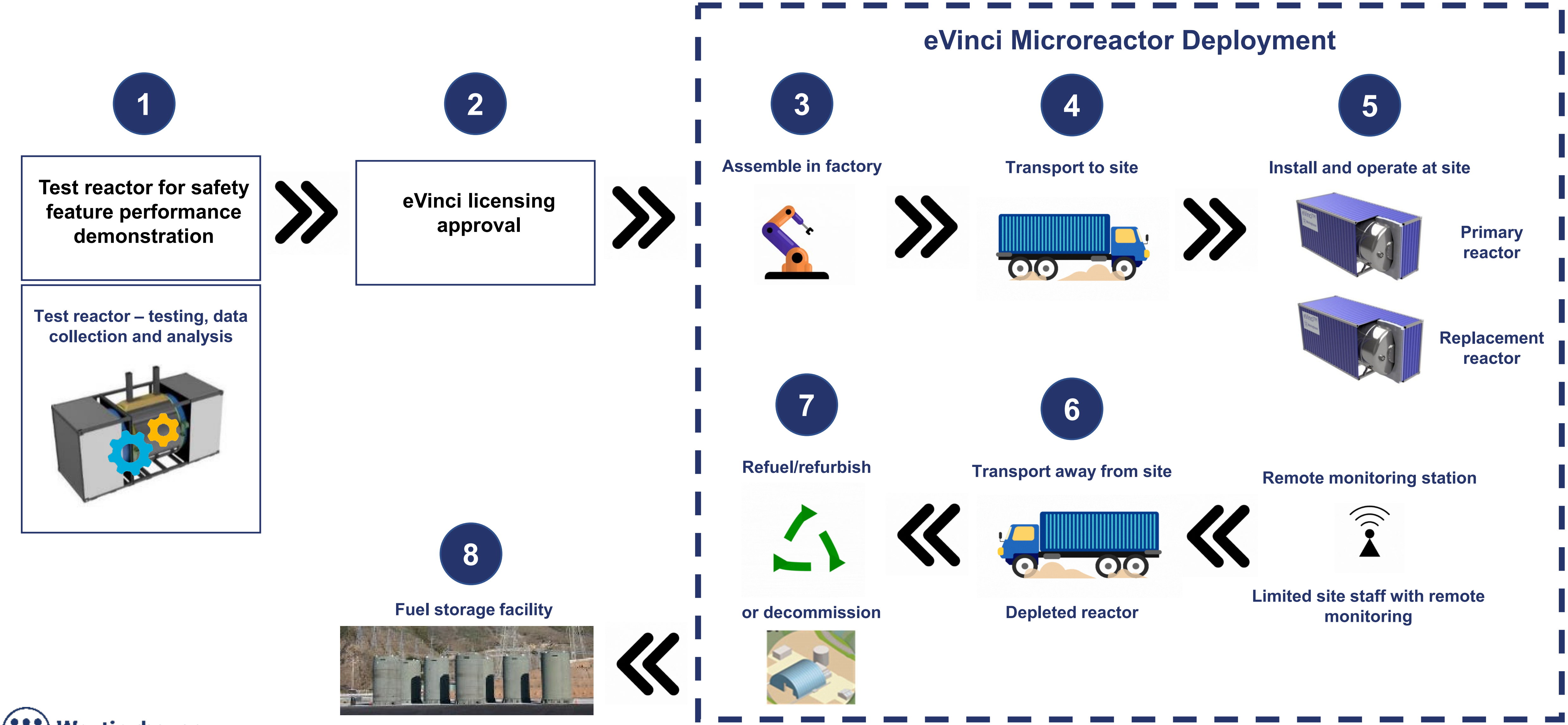
A New Deployment Model Within Current Regulations



Westinghouse

3S Considerations for eVinci Microreactor Deployment

- Consideration of U.S. and Canadian regulatory requirements in design
  - Submittal of reports for joint NRC-CNSC review
- Use of LMP methodology for safety case development and TICAP/ARCAP guidance for content of application places focus on items of highest safety significance
- Increased standardization due to less complex design
  - Standard approval of operational programs through Topical Reports, Standard Design Certification
  - Minimize needs for site-specific solutions/site-specific regulatory approvals
- Considerations of security in design from initial development
  - Ensuring regulations are met
  - Working with national labs on optimizing security for a small site
- Safeguards by Design strategy implemented throughout deployment (starting when fuel is first introduced)
  - Future engagement with IAEA

Pre-Application Engagement – White Papers

Current Status:
https://www.nrc.gov/reactors/new-reactors/advanced/licensing-activities/pre-application-activities/evinci.html

#	Topic	Submittal Wave	#	Topic	Submittal Wave	#	Topic	Submittal Wave
1	Facility Level Design Description	Submitted - 1	13	Advanced Logic System®(ALS) v2	Submitted - 3	25	Inservice Inspection Program/Inservice Testing Program	Submitted – 5
2	Principal Design Criteria	Submitted - 1	14	Component Qualification	Submitted- 3	26	Post-Accident Monitoring System	Submitted – 5
3	Safety and Accident Analysis Methodologies	Submitted - 1	15	Emergency Plan Zone Sizing Methodology	Submitted - 3	27	Equipment Qualification	Submitted – 5
4	Licensing Modernization Project Implementation	Submitted - 1	16	Physical Security	Submitted - 3	28	Probabilistic Risk Assessment and Transportation Risk Assessment	Submitted – 5
5	Regulatory Analysis	Submitted - 2	17	Heat Pipe Design, Qualification, and Testing	Submitted - 3	29	Fire Protection	Submitted – 5
6	Deployment Model	Submitted - 2	18	Nuclear Design	Submitted - 3	30	Cyber Security	Submitted – 5
7	Safeguards Information Plan	Submitted - 2	19	U.S Transportation Strategy	Submitted - 3	31	Radiation Protection and Contamination Methodology	Submitted - 6
8	Test and Analysis Process	Submitted - 2	20	Phenomena Identification and Ranking Table (PIRT)	Submitted - 4			
9	Functional Containment and Mechanistic Source Term	Submitted - 2	21	Integral Effects and Transient Testing	Submitted - 4			
10	Composite Material Qualification and Testing	Submitted - 2	22	Refueling and Decommissioning	Submitted - 4			
11	Fuel Qualification and Testing	Submitted - 3	23	Seismic Methodology	Submitted - 4			
12	Code Qualification	Submitted - 3	24	Operations and Remote Monitoring	Submitted - 4			

Topical Reports

#	Report Title	Submittal Date
1	ALS v2 Platform	Submitted
2	ALS v2 Development Process	Submitted
3	Principal Design Criteria	Submitted
4	ALS v2 Technical Specification Surveillance Requirement Elimination	
5	Nuclear Design Methodology	
6	Fuel Design Methodology	
7	Composite Materials	
8	Functional Containment and Mechanistic Source Term	
9	Inservice Inspection	
10	Graphite Materials	
11	Metallic Materials	
12	Inservice Testing	
13	Physical Security Design	
14	Heat Pipe Qualification Criteria	
15	Testing Program	
16	Component Qualification Methodology	
17	Safety Analysis Methodology	

Questions?

Thank You!

www.westinghousenuclear.com

See our Navigator for more information on the eVinci microreactor and all Westinghouse technology

https://navigator-voyantstudios.com/

Probabilistic Digital Twin and Distributed Ledger Technology Based Safeguards Solution for Aqueous Nuclear Reprocessing Facilities

Scott Evans on behalf of GE Led MAYER Team, (evans@ge.com)

GE Vernova Advanced Research Center, Niskayuna, NY, USA

Acknowledgement

The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001688. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

General Electric Company (GE) recognizes the contribution of the following former GE employees: Bogdan Neculaes and Andrew Hoffman

GE Research LUMITRON TECHNOLOGIES Sandia National Laboratories orano HITACHI

Converting UNF Radioisotopes Into Energy (CURIE)

CURIE

MAYER

Program Team

GE Research
Digital twin, distributed ledger, and non-destructive interrogation/imaging

LUMITRON TECHNOLOGIES
Advanced compact laser Compton scattering light source & photonics simulations

Sandia National Laboratories
Safeguards and security of nuclear facilities, SSPM model

orano
Operator of reprocessing and fuel fabrication facilities, Tech to market

HITACHI
Fuel Fabrication Expertise Industry advisor

Program Description:

The U.S. has accumulated approximately 86,000 metric tons of used nuclear fuel (UNF) from light-water reactors (LWRs), a value that increases by approximately 2,000 tons per year. This UNF is destined for permanent disposal even though more than 90% of its energy remains. Reprocessing UNF to recover reusable actinides and recycling them into new fuel for advanced reactors (ARs) would improve fuel utilization and drastically reduce the volume of waste requiring permanent disposal. CURIE seeks to develop innovative separations technologies, material accountancy, and online monitoring technologies, as well as designs for a reprocessing facility that will enable group recovery of actinides for AR feedstocks, incorporate *in situ* process monitoring, minimize waste volumes, enable a 1¢/kilowatt-hour (kWh) fuel cost for AR fuels, and maintain disposal costs in the range of 0.1¢/kWh.

Innovation Need:

Innovative technologies that enable the secure, economical reprocessing of the nation's LWR UNF could substantially reduce the volume, heat load, and radiotoxicity of waste requiring permanent disposal while providing a valuable and sustainable fuel feedstock for advanced fast reactors. Technical categories identified as the most likely to enable secure, economical reprocessing of UNF to meet these goals include:

Reprocessing technologies: improvements in preparing UNF assemblies for chemical separations; treatment of gaseous process streams; and separations technologies, such as aqueous separations, pyroprocessing, and fluoride volatility, that significantly reduce waste volumes, improve intrinsic proliferation resistance, and provide AR feedstocks; Integrated monitoring and materials accountancy: improvements in sensor and data fusion technologies that enable accurate and timely accounting of nuclear materials; Facility design and systems analysis: technoeconomic and systems analyses of novel approaches to designing, constructing, and operating reprocessing facilities (e.g., modularization, safeguards-by-design, process intensification), to improve safeguardability, reduce costs, and facilitate siting and licensing of reprocessing facilities.

https://arpa-e.energy.gov/technologies/programs/curie

GE Vernova Research Program: MONOCHROMATIC ASSAY YIELDING ENHANCED RELIABILITY (MAYER)

- Novel In-Situ Sensors
- Digital Twin Safeguards
- Distributed Digital Ledger

MONOCHROMATIC ASSAY YIELDING ENHANCED RELIABILITY (MAYER)

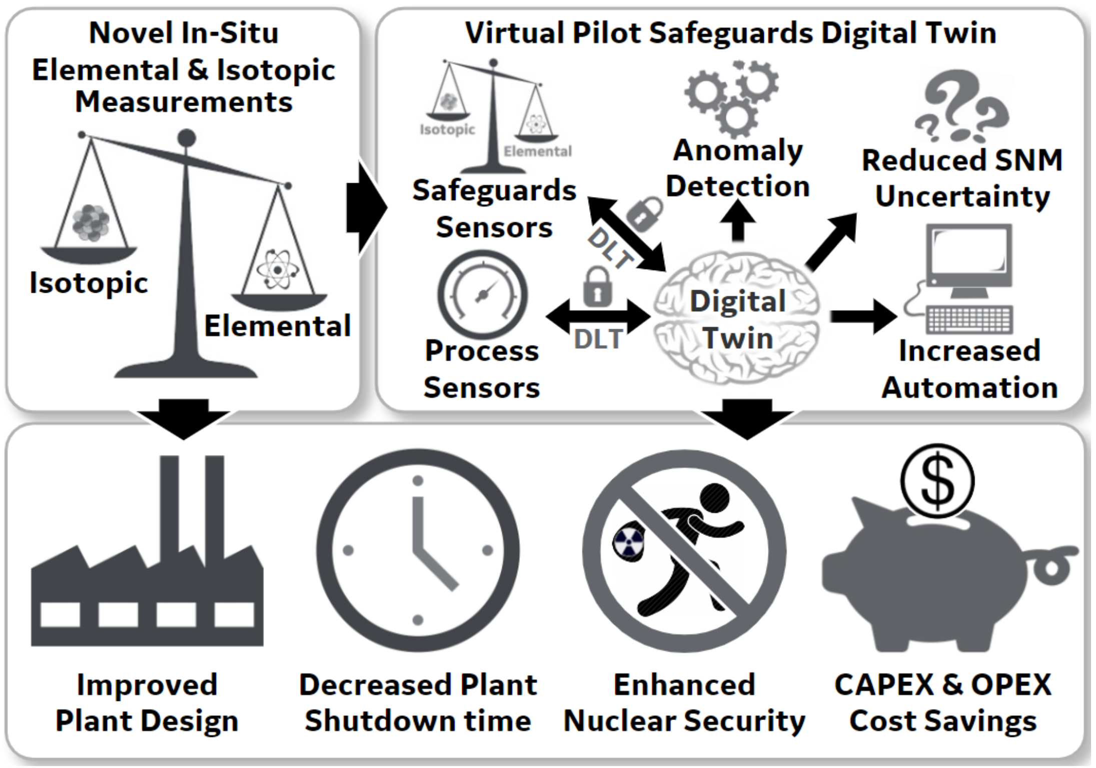
Technology Summary

- *Leverage first of its kind compact, high flux, low bandwidth laser Compton scattering (LCS) photon source for ultra-fast, high-precision IN SITU fissile elemental and isotopic measurements*
- *Development of the first ever aqueous reprocessing facility safeguards digital twin capable of data fusion, real-time probabilistic risk assessment, and anomaly detection*
- *Deliver a distributed ledger approach for ensuring safeguards sensor data security, transparency and integrity for regulatory auditing and feeding to the digital twin*

Technology Impact

- *Reduce required annual plant accountancy shutdown time, resulting in added revenue*
- *Ensure enhanced risk management, preventing unnecessary plant shutdowns due to potential materials diversion, criticality risks, or increases in standard error of fissile inventory*
- *Potentially reduce construction cost for new aqueous reprocessing facility*

MAYER Program Summary



MAYER will deliver a revolutionary safeguards solution for aqueous reprocessing facilities

MAYER novel sensors for in situ measurements – LUMITRON Technologies

- MAYER proposes novel sensors for isotopic and elemental analysis using groundbreaking Laser Compton scattering (LCS) radiation sources
- An accelerated electron beam collides head on with a laser beam producing tunable, monochromatic, high flux X-rays and Gamma rays
- LCS source development partially funded by current DARPA program
- The monochromatic nature of the radiation output is key to interrogate nuclear resonance fluorescence (NRF) physics for isotopic analysis and k-edge physics for elemental analysis. State of the art bremsstrahlung radiation sources are broadband – measurements take much longer and signal to noise is far from optimum

LUMITRON TECHNOLOGIES

DARPA Selects Teams for Work on Tunable Gamma Ray Inspection Technology

Program to develop revolutionary nondestructive inspection capability gets underway

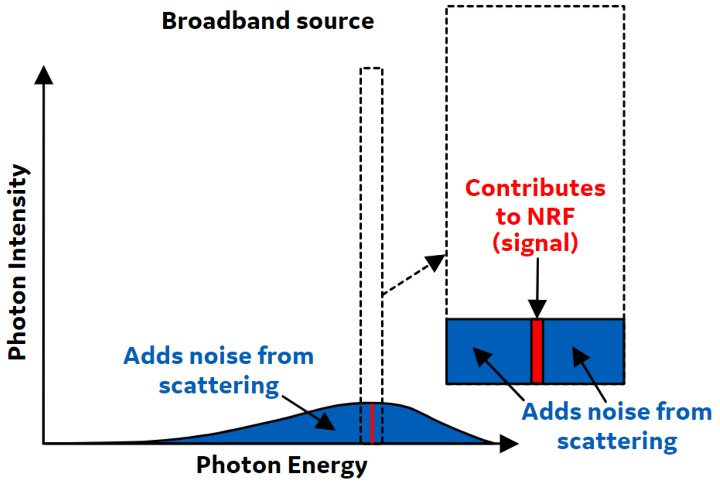
OUTREACH@DARPA.MIL
5/29/2020

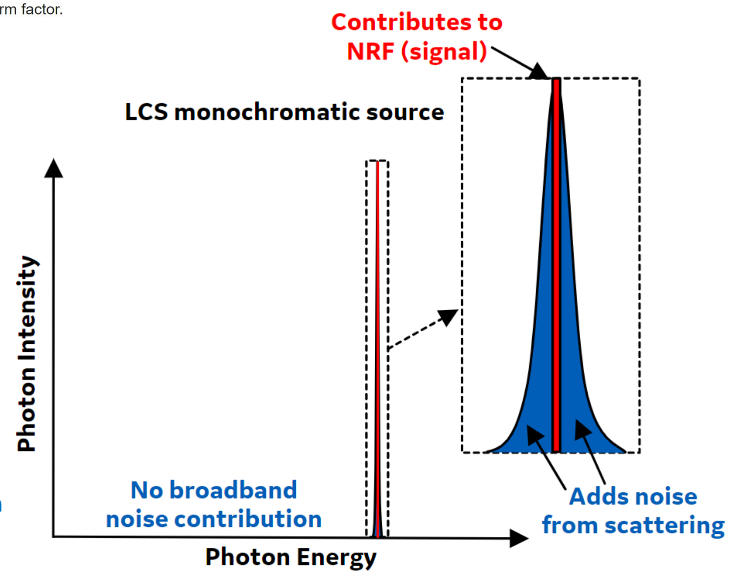
Two California companies were selected for DARPA's Gamma Ray Inspection Technology (GRIT) program and have begun work to develop a transportable, tunable source of gamma rays for a host of national security, industrial, and medical applications.

Lumitron Technologies and RadiaBeam Technologies started work on the GRIT program in April and are exploring novel approaches to achieve high-intensity, tunable, and narrow-bandwidth sources of gamma ray radiation in a compact, transportable form factor.

Prior relevant work

"With GRIT, you could probe and detect specific isotopes of interest by fine-tuning the photon energy to minimize background noise and take advantage of the nuclear resonance fluorescence phenomenon," Wrobel said. "Those isotopes could be found in rare-earth elements of interest or special nuclear materials. To be able to definitively say, 'Yes, there's highly enriched uranium in this object' and be able to characterize how much is present would be a significant leap forward over our current capabilities." (https://www.darpa.mil/news-events/2019-06-14)





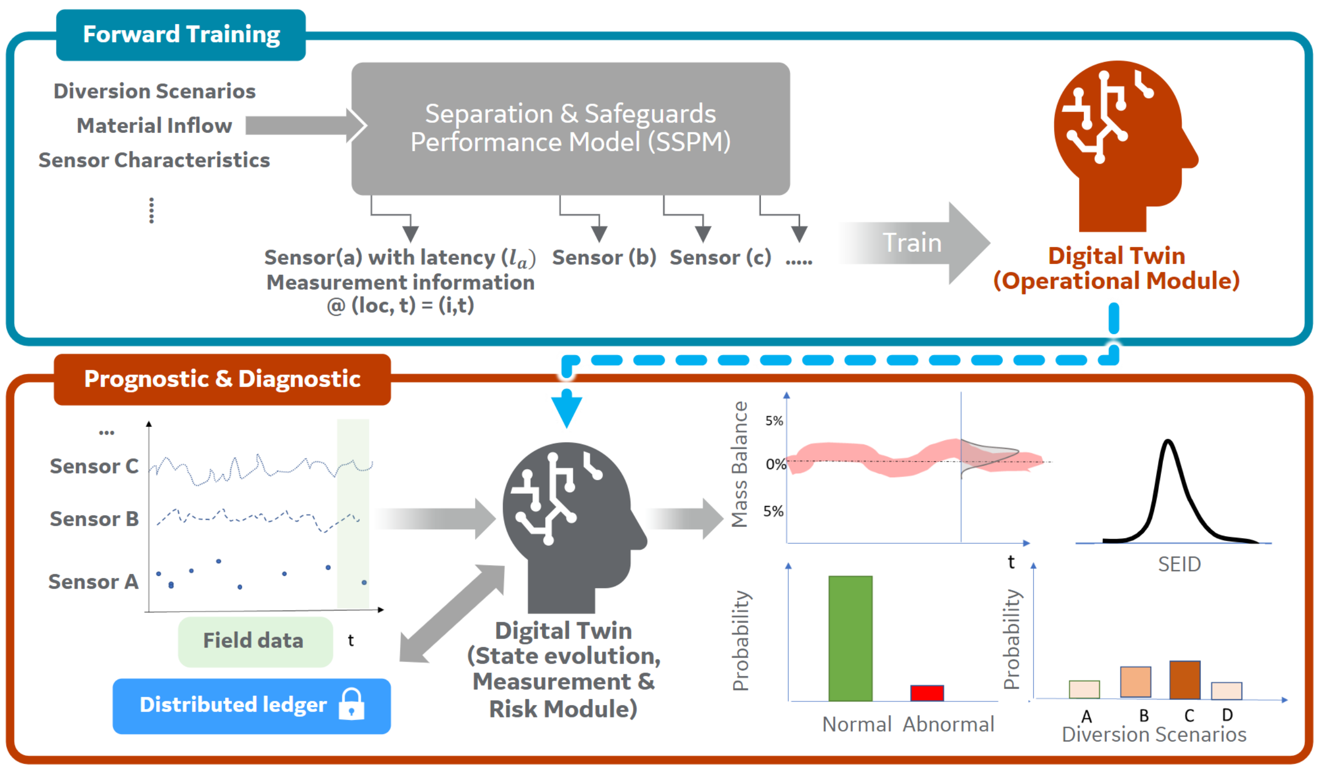
MAYER digital twin

- Digital Twin (DT) lowers overall plant SEID through: **1)** real-time patten recognition to enhance measurement certainty based on historical (training) data, and **2)** data fusion of multi-sensor data available within the plant

- DT provides real-time safeguards risk analysis, which includes instantaneous anomaly detection and identification , and provides real-time quantitative probabilistic risk analysis (i.e., real-time updated SEID)

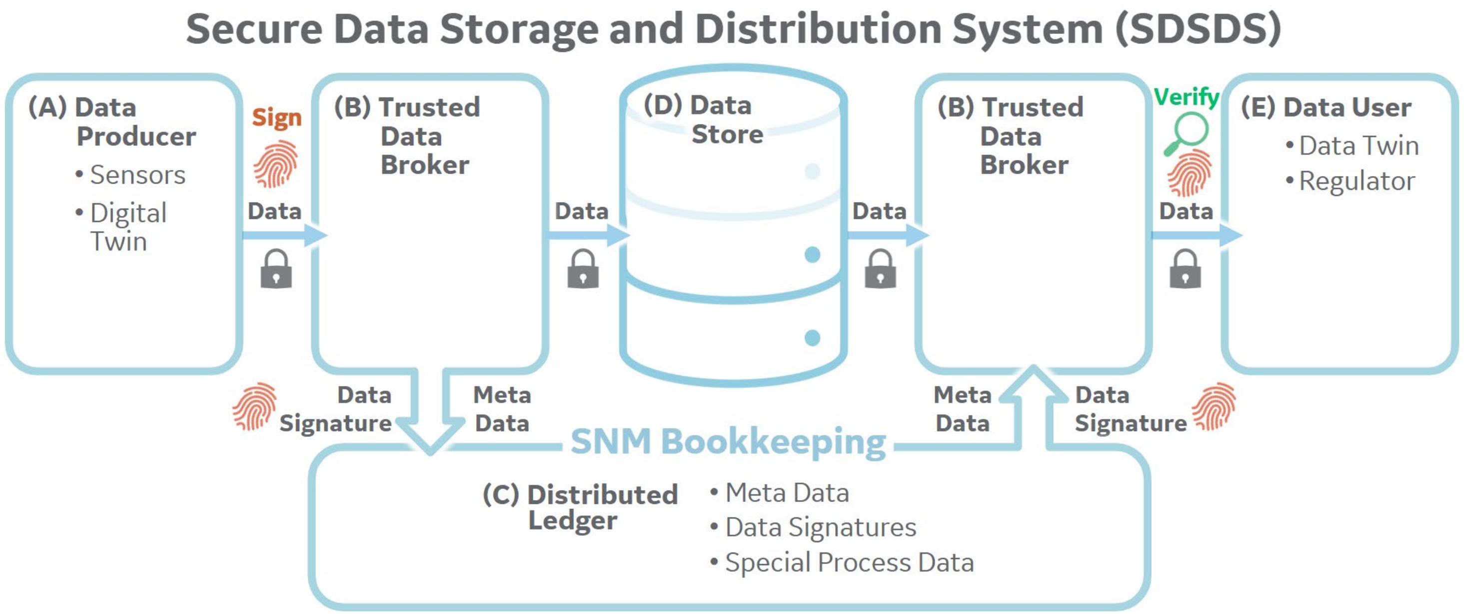
- When combined with MAYER in situ sensors, it enables the plant to rely on dynamic materials sampling rather than high-frequency, costly, scheduled plant shutdowns

- DT enables high-efficiency plant design through robust sensor placement optimization to reduce SEID



MAYER distributed ledger technology

- MAYER will pioneer real-time SNM accountancy bookkeeping through DLT (distributed ledger technology) using the latest Internet of Things Applications (IOTA) platform
- IOTA can process more transactions per second over traditional DLTs— including blockchain. This allows for secure, automated data storage and tracking of high throughput facility sensor data which will decrease labor costs
- DLT provides the digital twin with access to validated high-fidelity secure plant data (real-time and historical)



MONOCHROMATIC ASSAY YIELDING ENHANCED RELIABILITY (MAYER) – PUBLIC SUMMARY AND TEAM

Program Team

GE Research
Digital twin, distributed ledger, and non-destructive interrogation/imaging

LUMITRON TECHNOLOGIES
Advanced compact laser Compton scattering light source & photonics simulations

Sandia National Laboratories
Safeguards and security of nuclear facilities, SSPM model

orano
Operator of reprocessing and fuel fabrication facilities, Tech to market

HITACHI
Fuel Fabrication Expertise Industry advisor

GE Research (GE), in collaboration with Lumitron Technologies (Lumitron), Orano SA and Orano Federal Services (Orano), and Sandia National Laboratory (SNL), will deliver a revolutionary safeguards solution for aqueous reprocessing facilities. This solution, entitled Monochromatic Assays Yielding Enhanced Reliability (MAYER), includes monochromatic *in situ* active interrogation techniques that measure both elemental and isotopic concentrations of fissile isotopes with an uncertainty <1% and a latency <2 min in a high radiation background (~1,000R/hr gammas or $\sim 10^5$ neutrons/sec). This is a disruptive approach, since no other technology currently exists which can take measurements with an uncertainty <1% in a high radiation background facility, to allow for on-line accountancy of special nuclear materials. A reprocessing facility safeguards management virtual pilot digital twin (DT) will be built based on the Separations and Safeguards Performance Model (SSPM) developed by SNL. This probabilistic DT will incorporate both process and safeguards sensors including the novel in situ sensors developed by MAYER. The DT will allow for continuous, on-demand artificial intelligence (AI) training to provide an active defense for lowering standard errors in materials inventory and predicting adverse events, allowing mitigation prior to a required facility shutdown. Data tracking, integrity, and transparency is ensured through distributed ledger technology (DLT); also DLT critically enables trusted data for DT usage. MAYER pays homage to Nobel laureate nuclear physicist Maria Goeppert Mayer.

Regulator Considerations for Microreactor Security

Brian Kloiber - Oklo

Agenda

Microreactor security considerations

- Defining consequences
- Threat motivators

Regulatory gap identification

- Consequence precedent
- Consequence comparison
- Consequence use for threat goals
- Microreactor regulatory gap

Defining consequences

Radiological sabotage – any deliberate act directed against a plant or transport in which an activity licensed pursuant to the regulations in this chapter is conducted, or against a component of such a plant or transport which could directly or indirectly endanger the public health and safety by exposure to radiation

For reactor operations, sabotage is generally tied to fission product release from:

Core damage

Spent fuel sabotage

But why do these things and how is reactor size related?

Threat motivators

Threat goals – variable, but limited to less than threats against the State

- Cause loss of life
- Disrupt power grid
- Cause panic
- Distract

Why would adversaries attempt these things

- Financial gain
- Personal grievance
- Advance an ideology

Radiological sabotage is a potential action to achieve threat goals

- Core damage
- Spent fuel sabotage

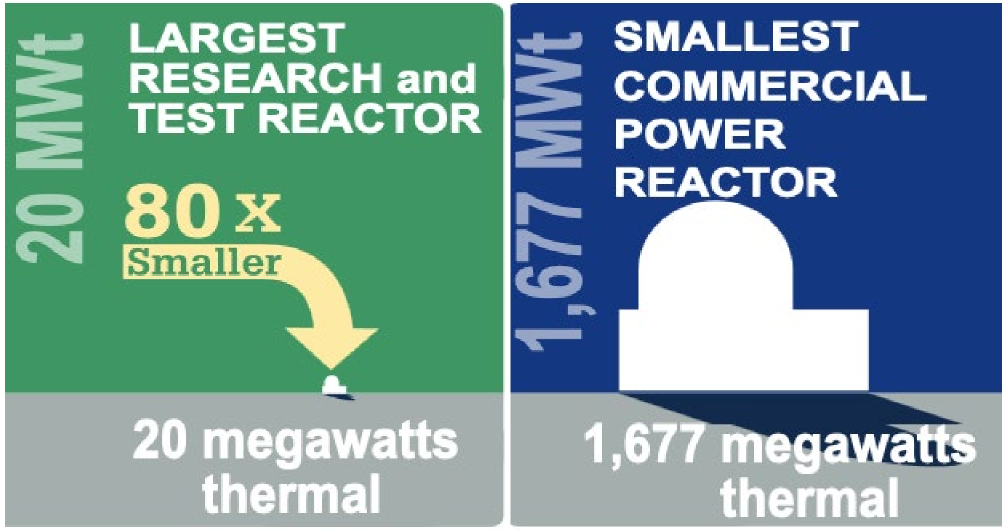
Regulatory gap identification

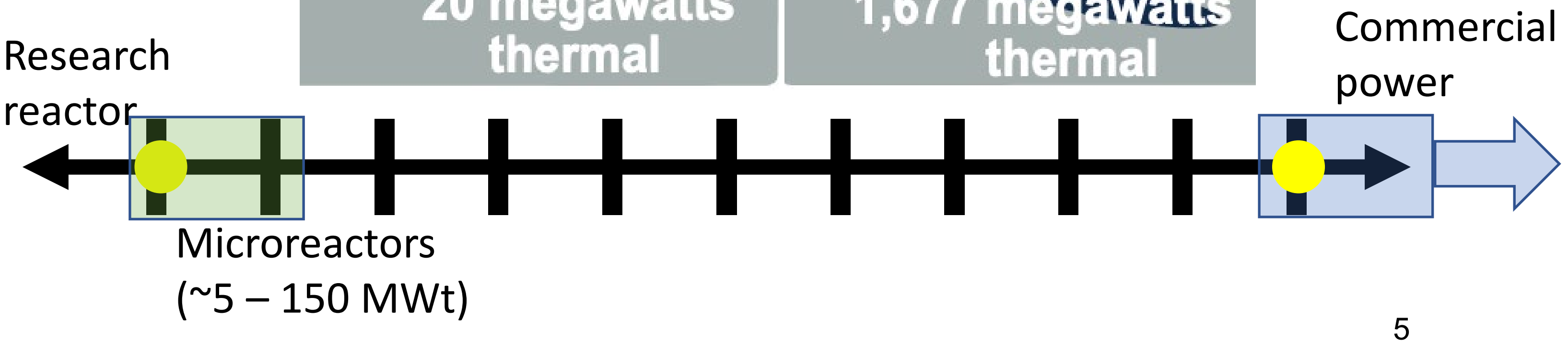
Reactor spectrum of licensed activities

- Commercial power reactors
- Research and test reactors (RTR)
- Microreactors?

Vast gap in operational size

- Overlap or adjacent to RTR
- Power production tied to consequences





Consequence precedent

NUREG/CR-0843 Consequences of Sabotage of Nonpower Reactors

- Dose comparison from fission product release
- Analyzes dose consequences from various authorized nonpower reactors
- Up to 50 MWth reactor size
- Various operating schedules, some operating 20% of the year

Method of release from sabotage

- Fuel melt from heat sink loss
- Compromise boundary, release of fission products

Similar method of release to commercial power reactors

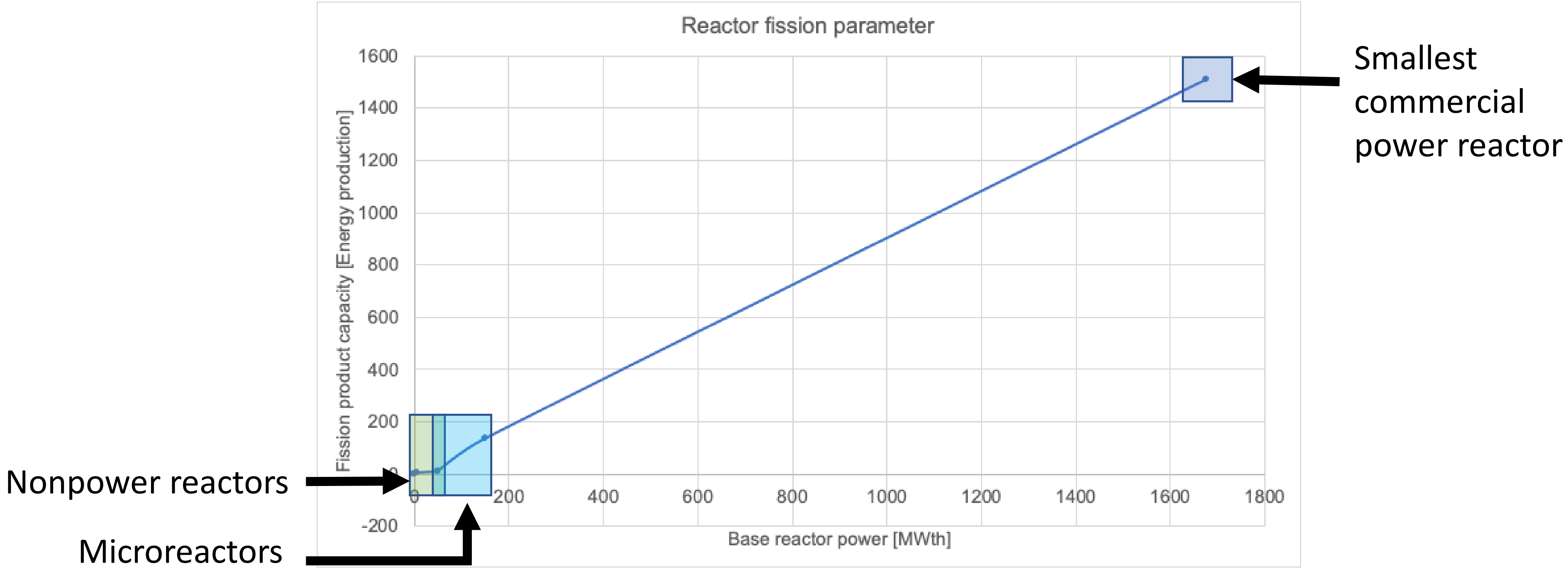
- Atomic Energy Act language mandates minimal regulation for nonpower reactors
- However, the danger must be low enough to warrant different threat

Consequence comparison

Potential fission product release is largely driven by power production

Fission reactions and inventory approximated by rated power and time of operation

Commercial power runs more frequently, but similarity in production is apparent



Consequence use for threat goals

Threat goal	Microreactor and RTR considerations	Large commercial reactor considerations	Higher utility to target
Loss of life	Small workforce population	Very large workforce	Large commercial reactors
Power grid disruption	Contribution to grid or microgrid	Main power source for large areas	Large commercial reactors
Cause panic	Radiological category	Radiological category	Same effect
Distraction	High visibility, but lower resource response	Response resource intensive and complex	Large commercial reactors

Microreactor regulatory gap

In the existing range of threats of radiological sabotage, there are commercial power reactors and non-power reactors; both have different levels of design basis threats.

Microreactors are a unique target for radiological sabotage that combine the operating time of commercial power with the smaller size of nonpower reactors resulting in significantly smaller fission product inventories.

Given the orders of magnitude in size difference from large commercial reactors, microreactors share more in common with fission product inventory with the upper ranges of non-power reactors and are very far from comparison to larger reactors.

Microreactors need a specific design basis threat for their level of potential consequences and utility as a threat target.

Questions

Brian Kloiber - Oklo

NEXT

ACU's NEXT Lab's 3S Perspective for a Molten Salt Research Reactor

by

Steven Biegalski, Ph.D., P.E.

Georgia Institute of Technology

December 6, 2023

Natura Resources SUSTAINABLE ENERGY

ABILENE CHRISTIAN UNIVERSITY

TEXAS The University of Texas at Austin

TEXAS A&M UNIVERSITY

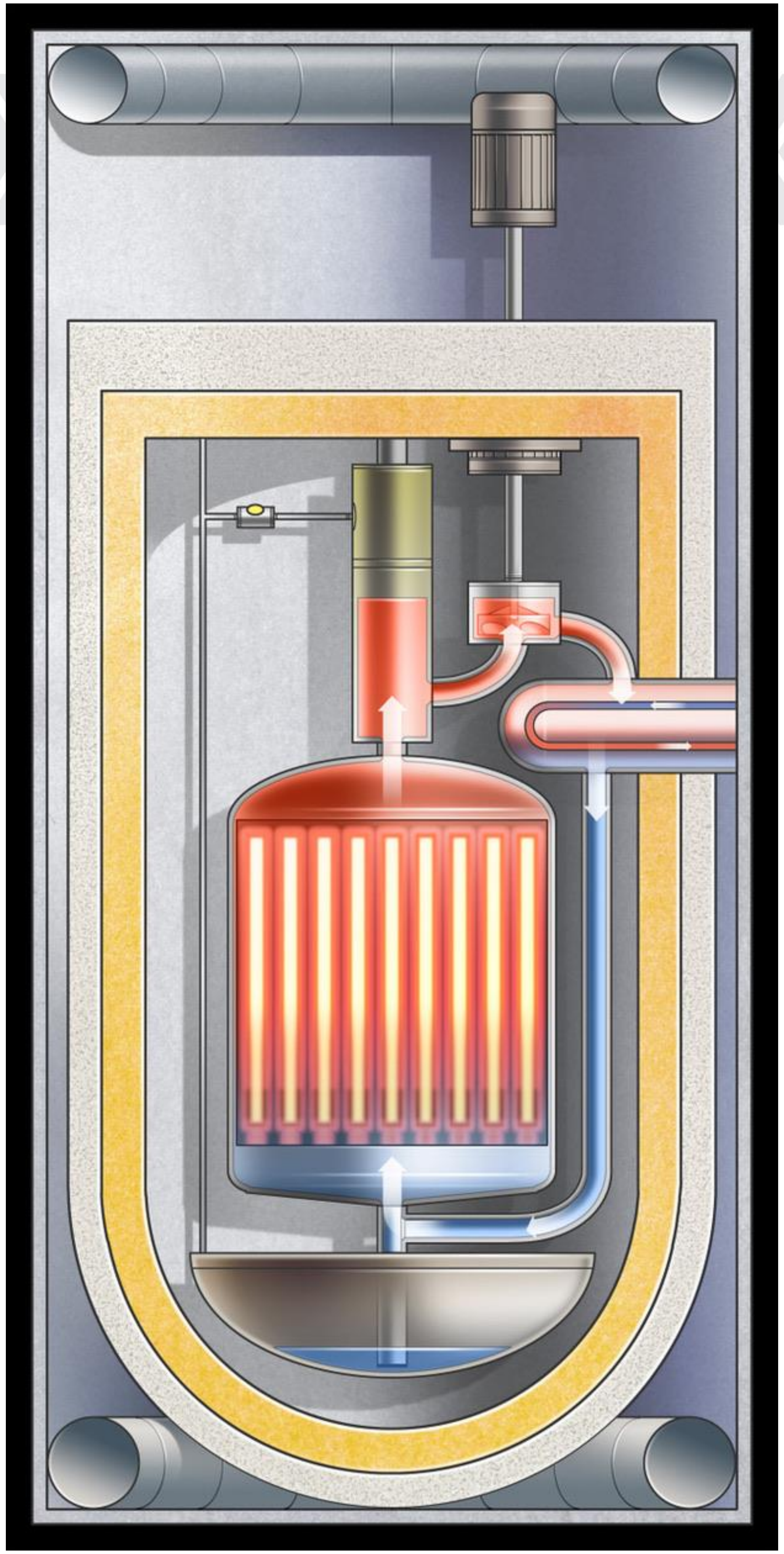
Georgia Tech

Outline

- Molten Salt Research Reactor (MSRR)
- MSRR Timeline
- Material Control and Accounting

Molten Salt Research Reactor (MSRR)

Thermal Output:	1 MW_{th}
Electric Output:	n/a
Fuel:	19.5% enriched HALEU
Moderator:	Graphite
Coolant Salt:	LiF-BeF_2-UF_4 (FLiBe)
Const. Material:	SS 316H
Deployment:	2026
Features:	Passive shut down & cooling Off-site, modular construction
Commercial Benefits:	Demonstrates licensure with NRC Produces experimental data, models & codes



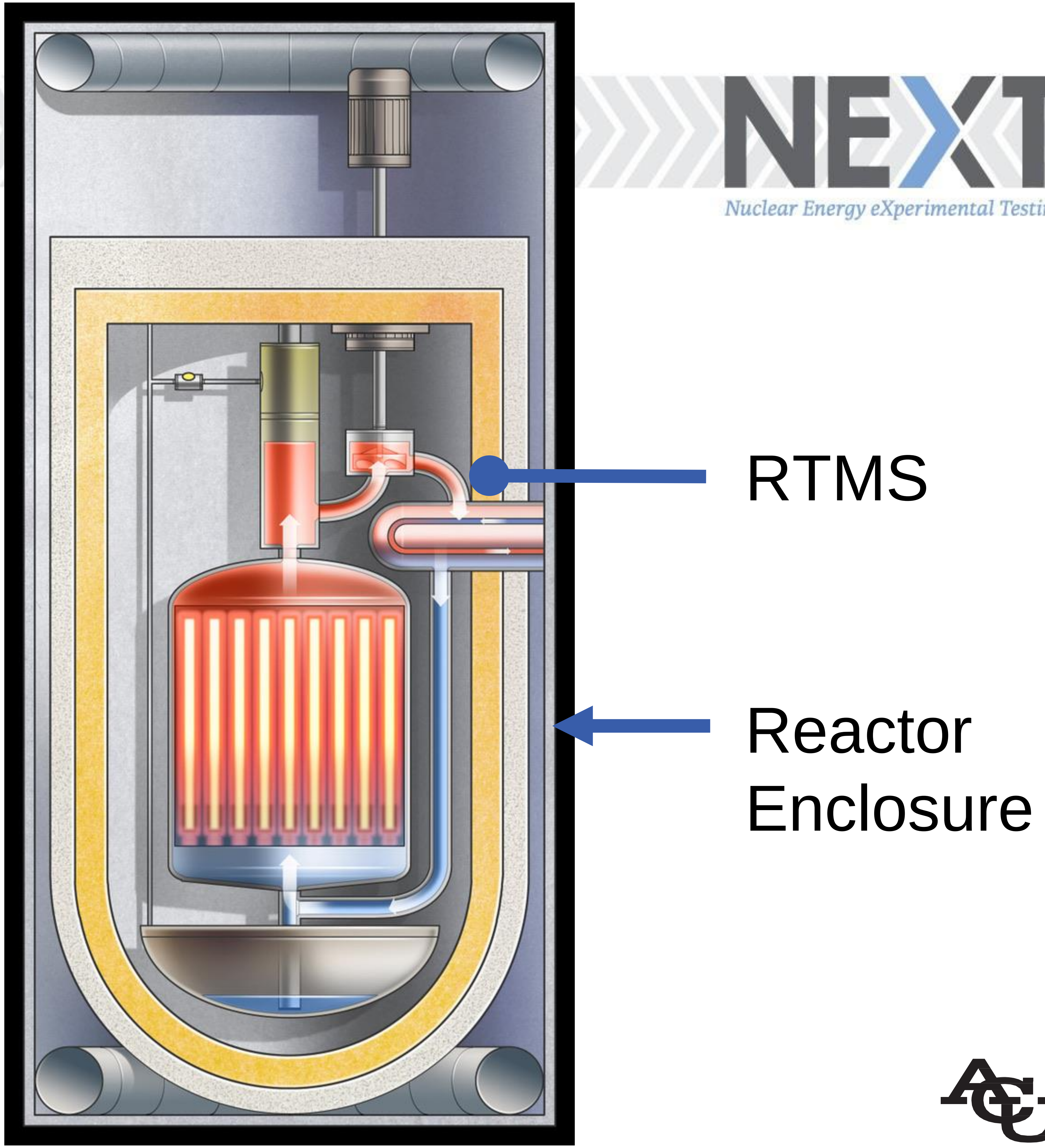
MSRR Layout

NEXT
Nuclear Energy eXperimental Testing

MSRR Safety Features

NEXT
Nuclear Energy eXperimental Testing

- Multiple barriers:
  - Salt
  - Primary fueled salt loop
  - Reactor Thermal Management System (RTMS)
  - Reactor Enclosure
  - Reactor Cell
- Low pressure system
- Shutdown via core drain
- Passive heat removal during shutdown



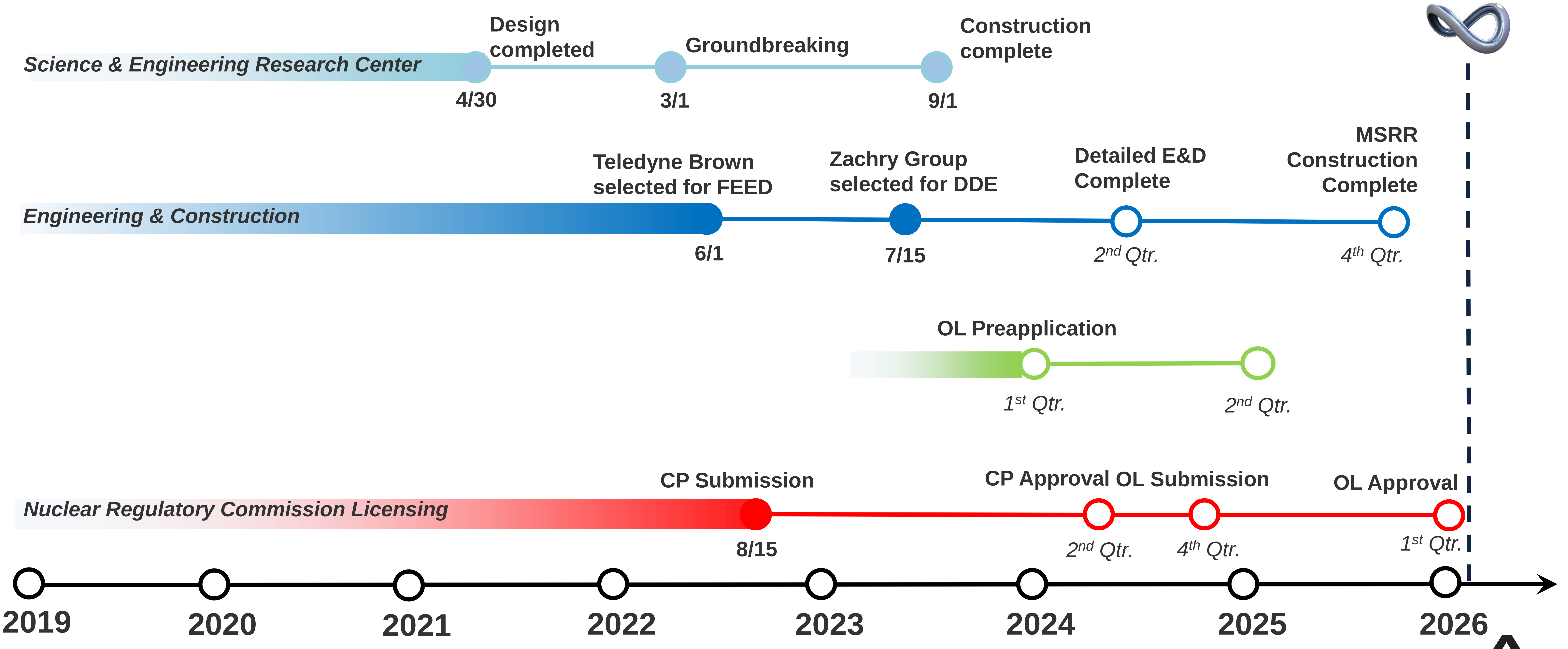
Gayle and Max Dillard
Science and Engineering Research Center

Abilene Christian University – September 2023


NEXT
Molten Salt Research Reactor
ABILENE CHRISTIAN UNIVERSITY
Natura Resources
Sponsor of ACU's NEXT Lab
NEXT

MSRR Timeline

Nuclear Energy eXperimental Testing



MSRR Project Status

NEXT
Nuclear Energy eXperimental Testing

The Natura Resources Research Alliance is leading the way in MSR development and deployment.

1. ACU is licensing the first advanced university research reactor with the NRC.
2. ACU has completed the SERC to house the Molten Salt Research Reactor (MSRR).
3. We are on a path to be the first operating molten salt reactor in the nation since the MSRE.

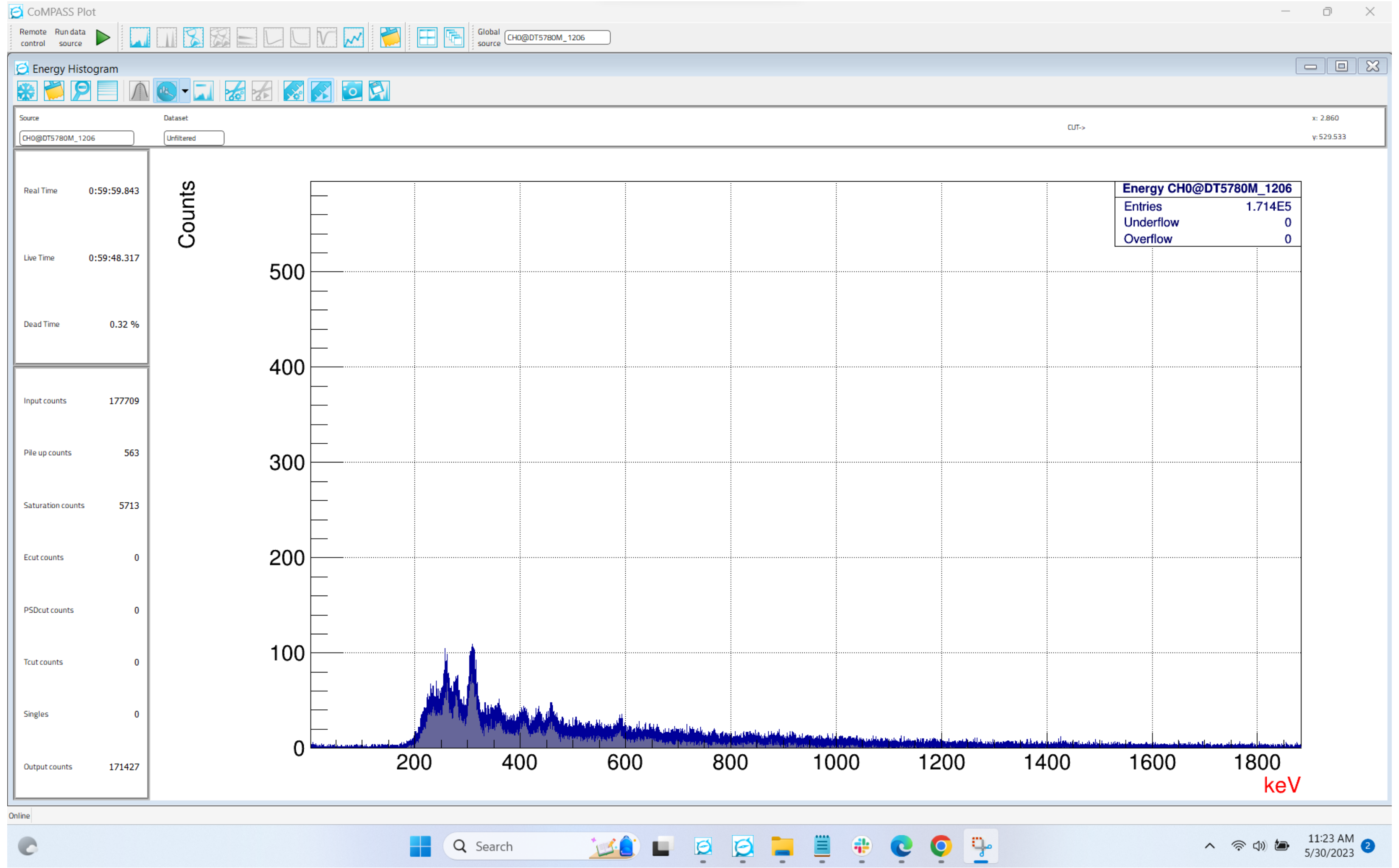
Material Control and Accounting

- Material Control and Accounting program is currently under development.
- General plan is to take a material balance approach.
- Quantify material inputs and outputs.
  - Goal is to have redundant measurement methods.
  - Replicates
  - Need to be able to address uncertainty.
  - Refueling procedures under development.
  - Output measurements supported by computation.
- Robust control and surveillance within material control areas.

Process Monitoring

Nuclear Energy eXperimental Testing

- Process monitoring is not currently planned.
- Initial measurements show that this is not practical and reliable with current commercially available technology.
- Challenges with:
  - High temperatures
  - Radiation levels
  - Complexity of signal



CZT spectra of short-lived fission products

Burn-up Modeling

Nuclear Energy eXperimental Testing

- Burn-up modeling will predict ^{235}U depletion and the production of ^{239}Pu.
- These models will be periodically validated throughout the operation of the reactor.
- Material outputs may be compared to predicted compositions.
- Uncertainty from these models may be too high for adequate application to a Material Control and Accounting plan.
- Information gained may lead to a better understanding on how to implement computational models for future reactors.

MSRR Benefits from 3S Perspective

NEXT
Nuclear Energy eXperimental Testing

- There are many aspects of a molten salt reactor that provide benefits from a 3S perspective:

1) Multitude of physical barriers.
2) Difficulty to remove material from reactor system.
3) Relative homogeneity of fuel-salt makes quantification of composition easier.
4) Any breach of reactor system is easily detected once the fuel salt has been irradiated.
5) Many safety benefits (e.g., strong negative temperature coefficients of reactivity, low operating pressure, low excess reactivity, etc.).
6) High burn of transuranic fuel elements within the fuel.

Testbed Opportunity

Nuclear Energy eXperimental Testing

- The MSRR may provide an opportunity to examine the utility of different Material Control and Accounting technologies.
- Temperatures and radiation levels may affect suitability of equipment and methods for implementation.
- Measurement method accuracy and detection limits may be assessed.
- Data may be utilized to support development of a digital twin.

THANK YOU

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naturaresources.org

framatome

Integrated Safety, Safeguards, and Security

Farshid Shahrokhi

Director of Advanced Reactor Technologies

NRC 3S Workshop

Dec 5 & 6 2023

Content

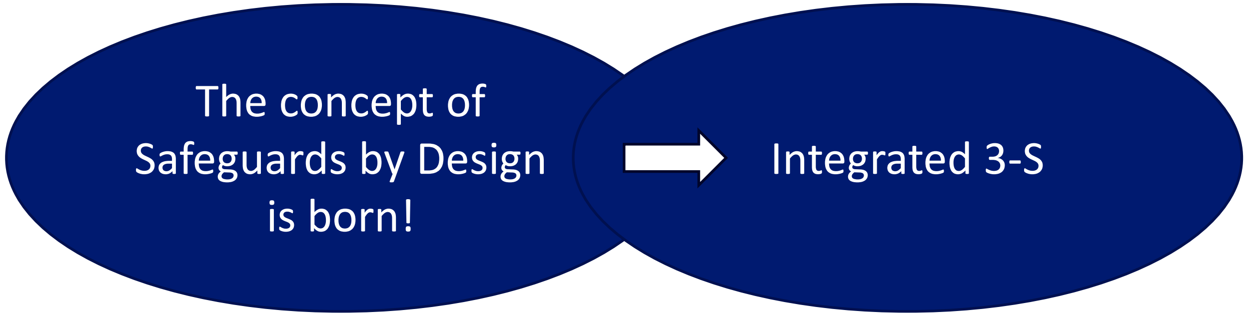
1. National - International Standards & Regulations
2. Challenges of Safety, Safeguards, and Security
3. Integration of Safety, Safeguards, and Security
4. Concluding Remarks

1

National - International Standards & Regulations

History of International Standards Development

- 1945 - The first international expression of the concept of nuclear safeguards - Agreed Declaration Relating to Atomic Energy issued by the leaders of the United States, United Kingdom, and Canada.
- 1946 - The United Nations first met, the first issues it considered was how to ensure the effective control of nuclear energy.
- 1953 - U.S. President Dwight Eisenhower's "Atoms for Peace" speech to the United Nations General Assembly calling for promotion of peaceful uses of atomic energy and the creation of an international atomic energy agency to oversee such uses.
- 1957 IAEA was established.
  - ✓ IAEA was given a dual mission: to promote and to control the atom.
- 1965 - Adopting IAEA Safeguards as the NPT Verification Mechanism Negotiations began.
- 1968 – The Non-Proliferation Treaty (NPT) negotiation was concluded and entered into force in 1970.
- Two GIF Working Groups have been formed with following scopes of work:
  - PR - Proliferation Resistance scope of work:
    - Concealed diversion of declared materials
    - Concealed misuse of declared facilities
    - Overt misuse of facilities or diversion of declared materials
    - Clandestine dedicated facilities.
  - PP- Physical Protections scope of work:
    - Radiological sabotage
    - Material theft
    - Information theft.



IAEA Safeguards By Design

Objective and basic principals

- The objective of IAEA safeguards is the timely detection of diversion of nuclear material from peaceful activities, and the deterrence of such diversion by the risk of early detection.
- A basic SBD principle regarding the operation of facilities is the expectation that process operations can be designed to facilitate the effective and efficient application of safeguards with little or no impact on operational function or performance.
  - ✓ Simplifying path of nuclear material through the facility and the number of locations where it is stored;
  - ✓ Understanding the safeguards use of containment, authentication of data, and continuity of knowledge;
  - ✓ Installing robust and automated accounting system that provides all necessary reports electronically.
- IAEA Agreement with USA:

  "Article 1 (a) The United States undertakes to permit the Agency to apply safeguards, in accordance with the terms of this Agreement, on all source or special fissionable material in all facilities within the United States, excluding only those facilities associated with activities with direct national security significance to the United States, with a view to enabling the Agency to verify that such material is not withdrawn, except as provided for in this Agreement, from activities in facilities while such material is being safeguarded under this Agreement."

International Safeguards

Nuclear Materials Management and Safeguards System (NMMSS)

- As the **State System of Accounting for and Control of Nuclear Material**, NMMSS fulfills the U.S. nuclear material reporting commitments to the international community including the **International Atomic Energy Agency**(IAEA) under voluntary safeguards agreements, the **Treaty on the Non-Proliferation of Nuclear Weapons**, Nuclear Cooperation Agreements, and other bilateral and multilateral agreements.
- NMMSS is co-sponsored by the **U.S. Nuclear Regulatory Commission** (NRC) and managed by the NNSA Office of Nuclear Materials Integration.

Physical Protection of Plants and Materials (10 CFR Part 73)

Material Control and Accountability (10 CFR Part 74)

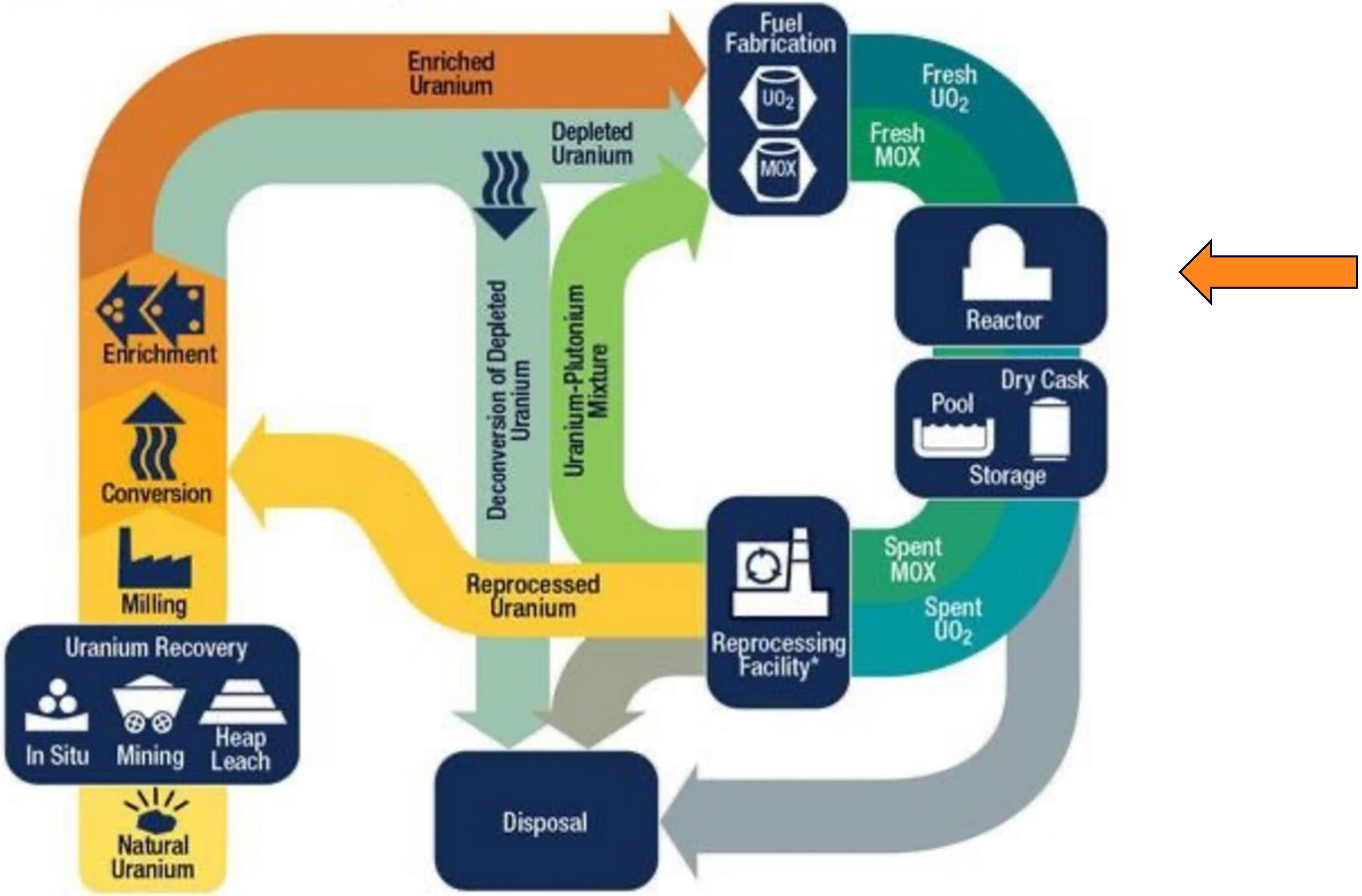
International Safeguards (10 CFR Part 75)

Export and Import of Nuclear Equipment and Materials (Part 110)

2

Challenges of Safety, Safeguards, and Security

The Nuclear Fuel Cycle



Challenges of Safety, Safeguards, and Security

Theft – Diversion – Malicious Acts

• **Challenges**	**Tools and Methods**
✓ **Accidents Avoidance**	Design feature, operating procedures, Training
✓ **Diversion Resistance**	Design feature, Vulnerability assessment, Instrumentation
✓ **Accountability**	Tagging, Assay, Alarms, Physical controls, Inspection
✓ **Theft Prevention**	Tamper resistant locks and seals, Cameras, Access control
✓ **Physical Control**	Limit access, Personnel - Fitness for Duty (Physical / Mental),Training
✓ **Cyber Security**	Control Access, Intruder prevention, Secure networks

Defense in Depth Strategies

3

Integration of Safety, Safeguards, and Security

- In the design –

- In construction -

- In operation -

- In decommissioning -

Integration of Safety, Safeguards, & Security into the Design

Objectives and basic principals

- **During initial design process**
  - ✓ **keep the principals of <u>Safety Safeguards and Security</u> in mind**
  - ✓ **Utilize & Implement 3-S tools within the design**
  - ✓ **Document and protect 3-S design features**
- **The best Safety, Safeguards and Security design features are those that are <u>passive and tamper resistant</u>**
- **Use active 3-S features as necessary**
- **During operations**
  - ✓ **Perform frequent vulnerability assessments and meticulous record keeping**
  - ✓ **Use of dedicated tamper resistant instrumentation**
  - ✓ **Physical and cyber security measure**
  - ✓ **Drill, training and human performance observation**
- **Finally – Defense-in-Depth!**

- Accident Avoidance
- Diversion Resistance
- Accountability
- Theft Prevention
- Physical Control
- Cyber Security

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4

Concluding Remarks

Concluding Remarks

Objective and basic principals

- To own and operate a commercial nuclear facility in the United States or any Agreement State; the State must comply with the IAEA rules and regulations and the owner operator must comply with the reporting requirements associated with position, use, and control of nuclear material.
- IAEA and Agreement States have negotiated standards for use by entities intending to possess, use, transport, or handle special nuclear materials.
- Designers and developers of nuclear facilities "should" implement Safety, Safeguards, and Security features into their design to meet the IAEA, National, and State Regulations and Standards for owning and operating a nuclear facility or material.
- 3-S implementations
  - ✓ Most effectively implemented during the design phase of the facility.
  - ✓ Backfit is possible and must be carefully integrated into the original design.

framatome

Thank you

Aspects of 3S Related to Advanced Reactors - Utility Perspective

Greg Boerschig
Vice President, CRN Engineering & Quality Assurance
TVA Clinch River Project

TENNESSEE VALLEY AUTHORITY

Disclaimer

TVA is currently developing content for a potential future license application(s) to the NRC for an advanced reactor design. TVA has not yet decided to deploy an SMR. Any decisions will be subject to support, risk sharing, required internal and external approvals, and completion of all necessary environmental and permitting reviews.

TVA & New Nuclear Technology

February 2022 TVA BOARD DIRECTION

Approved funding up to $200 million for a program to:

1. Perform design engineering, scoping, estimating, and planning associated with potential future deployment of an advanced reactor at Clinch River
2. Develop new nuclear license applications
3. Continue to study potential, future advanced reactor technologies
4. Study potential for advanced nuclear deployments at other sites

CLINCH RIVER NUCLEAR PROJECT INFORMS POTENTIAL FLEET DEPLOYMENTS

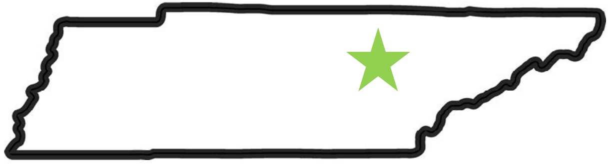
NEW NUCLEAR PROGRAM PLANNING FOR POTENTIAL FLEET DEPLOYMENT

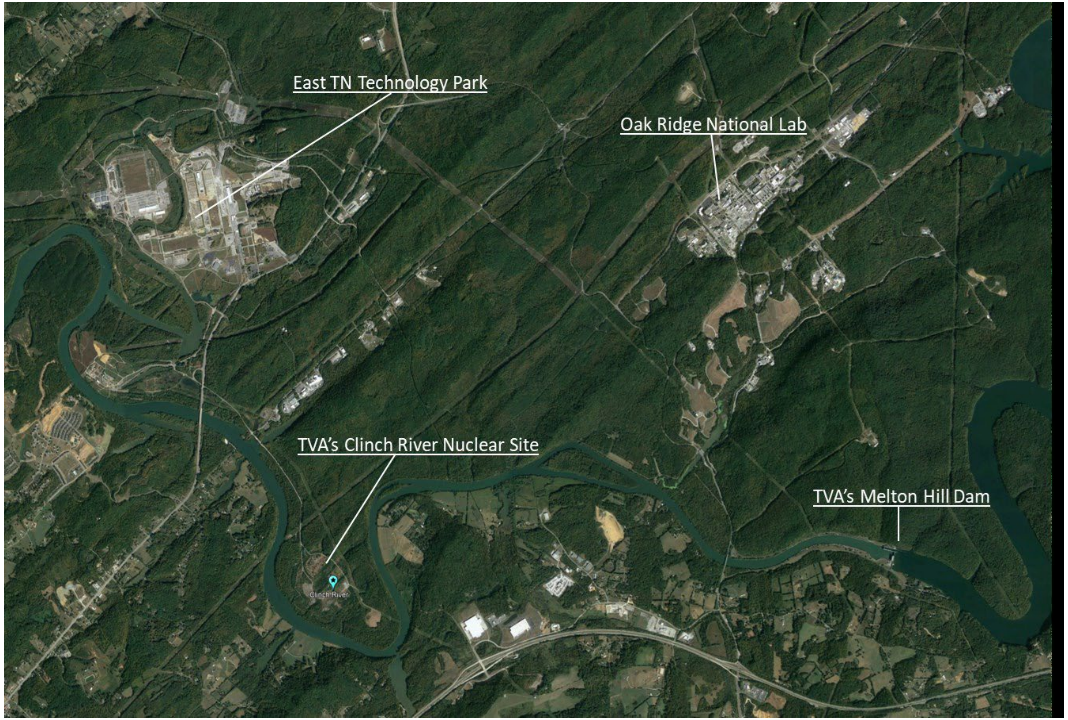
TVA’s Early Preparation for a First Small Modular Reactor

EARLY SITE PERMIT & PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

- NRC Early Site Permit for small modular reactors received in 2019

- Programmatic Environmental Impact Statement for an advanced nuclear reactor technology park completed in Fall 2022





TVA TENNESSEE VALLEY AUTHORITY

Security-by-Design Approach

- Physical and Cyber security principles are considered during all phases of an advanced reactor design
- Security Subject Matter Experts are included as part of the design team
- Physical and Cyber security features are considered/evaluated and "built in" the design
- Tools and methods are identified and used to support the Physical and Cyber Security Programs based on the passive design and nuclear safety of advanced reactor designs

3S Tool Opportunities

- Integration of Modeling and Simulation (M&S) tools with input from 3-D modeling tools

- Use of M&S tools to:
  - Maximize the passive design features of advanced reactors
  - Efficiently move from a “design-standard” security plan to develop a “site-specific” plan
  - Demonstrate and defend a site-specific security strategy such as minimum number of armed responders and defensive strategy

TENNESSEE
VALLEY
AUTHORITY

Integrated Safety, Security, and Safeguards Future-Focused Research Project

John Matrachisia, Office of Nuclear Regulatory Research

Jim Rubenstone, Office of Nuclear Material Safety & Safeguards

Al Tardiff, Office of Nuclear Security & Incident Response

Raj Iyengar, Office of Nuclear Regulatory Research

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Acknowledgements

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Beth Reed	Al Tardiff	Jim Rubenstone	Mauricio Gutierrez
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Steve Lynch	Lou Cubellis	Bernie White	Brian Cohn
Duke Kennedy			Francheska Colon-Gonzalez

Sandia National Laboratories

Los Alamos NATIONAL LABORATORY

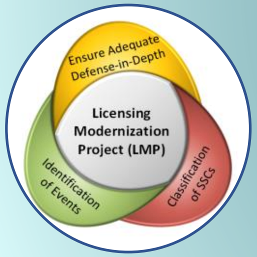
Safety Security Safeguards

Future-Focused Research Program

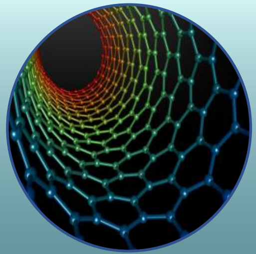
- Supports the NRC vision of becoming a modern, risk-informed regulator by funding research activities:
  - Intended to help the NRC prepare for upcoming challenges
  - Having longer-term (>3 years) horizons and greater risk opportunities than considered in typical activities addressing program office needs

Key Attributes for Remote Operation of NPPs

High Entropy Alloys



Licensing Modernization Project - Operating Reactors



Nuclear Nano Technology – Advanced Fuel Applications

Digital Twins – Regulatory Viability

Motivation/Drivers

- Nuclear industry stakeholders have expressed an interest in 3S-by-design approaches
- Potential advantages of integrated 3S-by-design
  - Mitigating complexity risk
  - Sharing key inventory and operational data across subsystems
  - Reducing economic and regulatory costs

Safety
Security
Safeguards

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Strategy

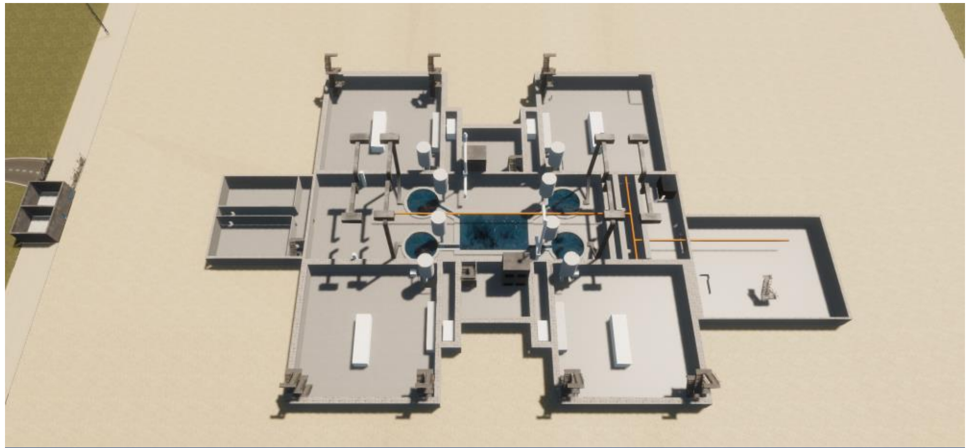
- Identify analysis and modeling & simulation methods for integration and assessment of 3S interdependencies
- Build NRC knowledge base
- Identification of regulatory considerations and tool identification-limitations-abilities
- Internal Coordination
- External coordination with the Department of Energy and international entities

Case Studies: Purpose

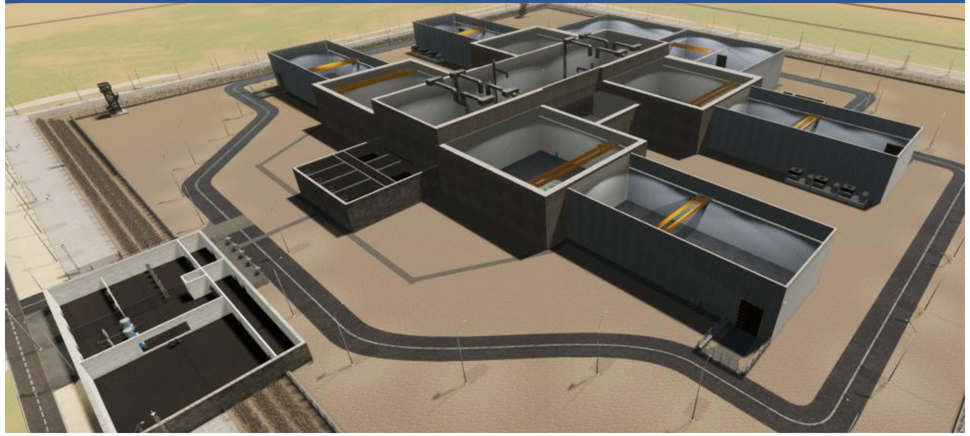
- Develop case studies to consider the integration of 3S (safety, security, and domestic safeguards [MC&A]). These case studies will be used in an NRC-RES report being developed for release in 2024 to provide a technical discussion on the current practices and gaps associated with 3S applications for advanced reactors.
- Case study scenarios being considered:
  - Molten salt reactor in a rural area
  - Microreactor in transit to site and operating in an urban area (two parts)
  - Fuel fabrication facility
- Scenarios to be developed using Scribe3D modeling and simulation visualization software.
- Goal is to publish releasable data.

Molten Salt Reactor in a Rural Setting

- **Facility/Terrain**
  - Four reactors using liquid fuel
  - Small response team onsite
- **Examples of 3S Considerations**
  - Upgrades to physical protection system, including perimeter fencing, vehicle/pedestrian checkpoint, and others
  - Refueling; moving fuel, poisons build-up, storage vat, movement through secure areas, hot cannister movement release issue, unirradiated material theft concern
  - ROWS, offsite response

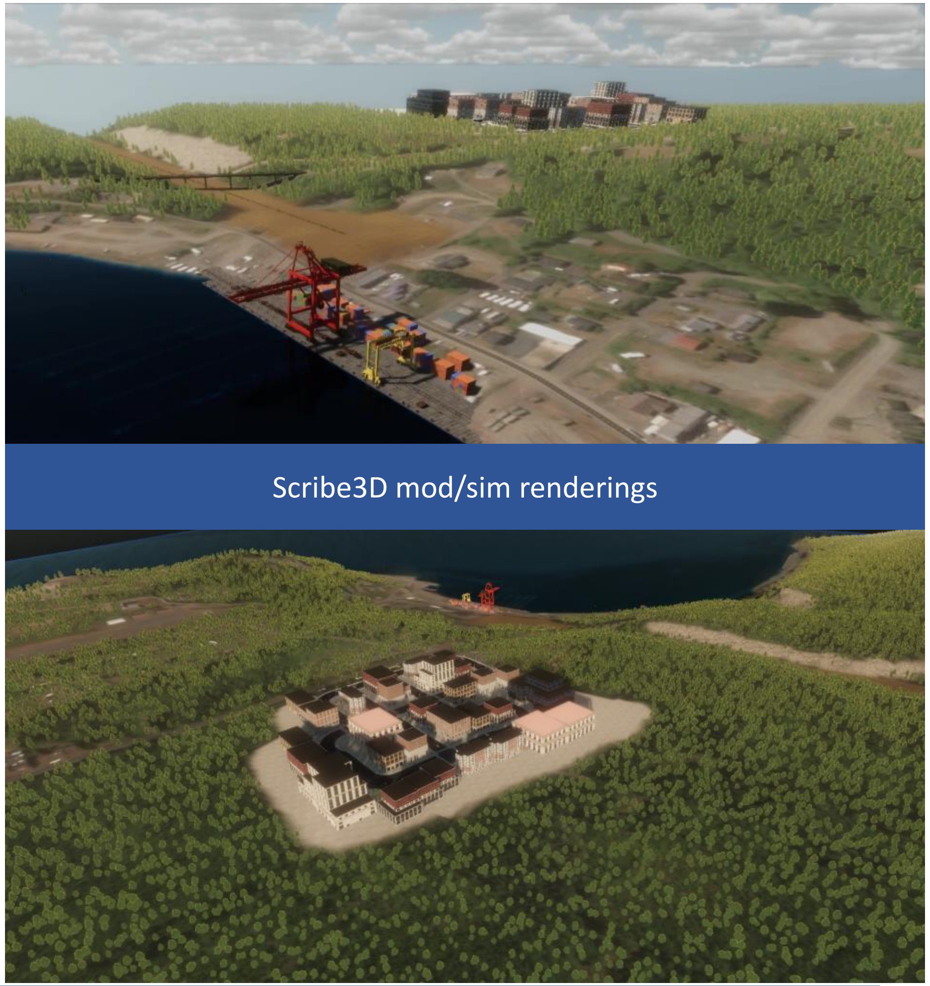


Scribe3D mod/sim renderings



Microreactor in Transit (Part 1 of 2-part scenario)

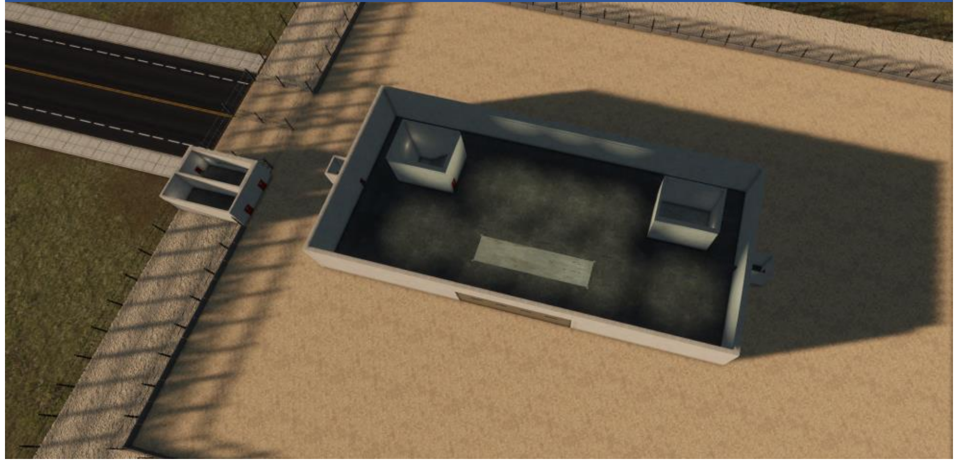
- **Facility/Terrain**
  - Microreactor being moved to an urban area
  - Arrival at port, transport on public roadways, sited close to small city
- **Examples of 3S Considerations**
  - Multiple attack vectors (sea, land, air)
  - Transport container
  - Old reactor/new reactor onsite simultaneously
  - Urban growth around site


Scribe3D mod/sim renderings

Microreactor in an Urban Setting (Part 2 of 2-part scenario)

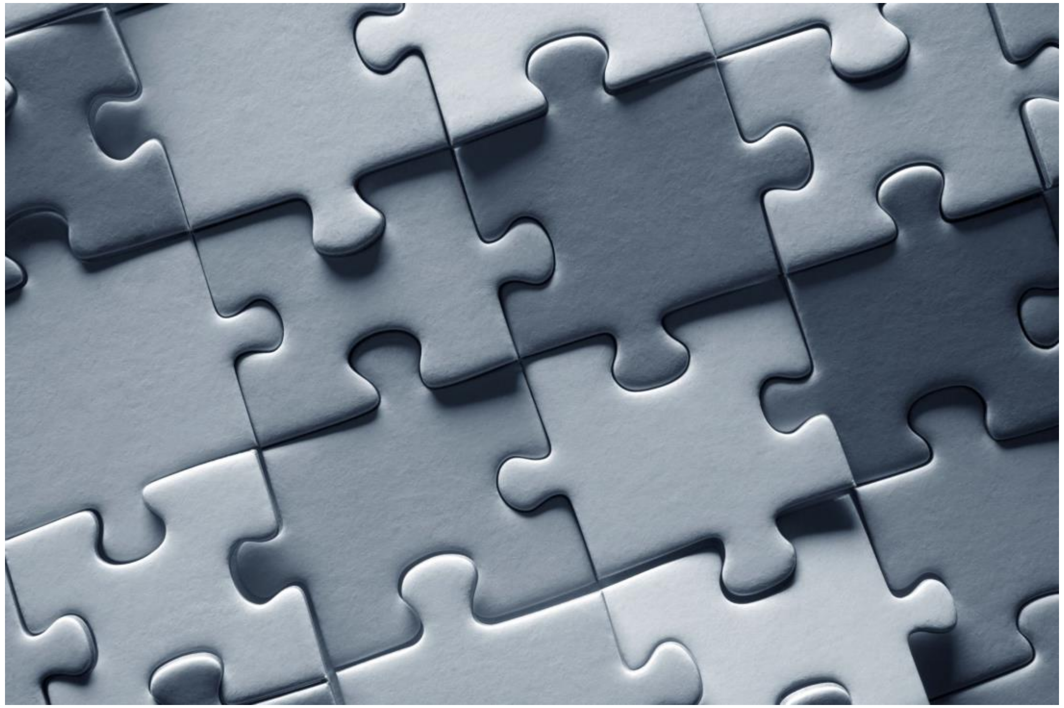
- **Facility/Terrain**
  - Microreactor (LANL Snowflake) operating in an urban area
  - Run autonomously; no main control room, no onsite staff
  - PPS includes vehicle entry/exit, 2 fences, and an unfenced, grassy area surrounding the facility
- **Example of 3S Considerations**
  - Cybersecurity
  - Underground core location (containment/confinement)
  - Offsite security
  - Urban evacuation plans in case of release

Scribe3D mod/sim renderings



Expected Outcomes

- Key interfaces identified
- Synergies/conflicts identified
- Regulatory challenges identified
- M&S tool capabilities and limitations
- Be ready for future reviews
- Broad applicability beyond fixed-site reactors (e.g., microreactors, FNPP)
- Areas requiring further research identified



Thank you

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Safety Security Safeguards

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NRC 3S Workshop: Advanced Reactors and Fuel Fabrication
December 5-6, 2023

Cybersecurity Considerations

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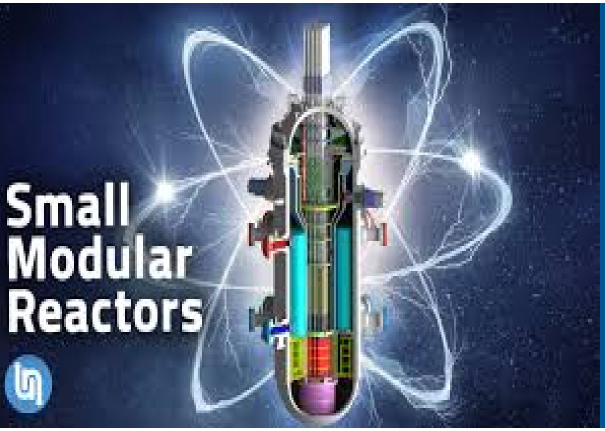

Cybersecurity Requirements for Nuclear Power Plants

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Nuclear Power Plants Cyber Requirements – 10 CFR 73.54

Digital Computer and Communication Systems

SAFETY

SECURITY

EMERGENCY PREPAREDNESS

SUPPORT SYSTEMS

CYBER ATTACKS impacting:

- Integrity / Confidentiality of data and software
- Denial of access to systems, services or data
- Operation of systems, networks and associated equipment

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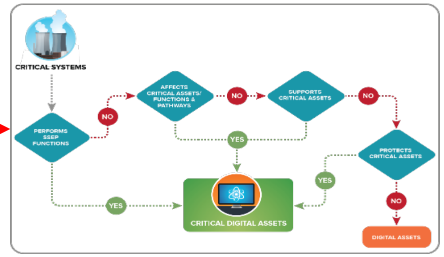
Definitions:
CFR: Code of Federal Regulations

Note: 10 CFR 73.54 rule text can be found at: https://www.nrc.gov/reading-rm/doc-collections/cfr/part073/part073-0054.html

Regulatory Guide 5.71

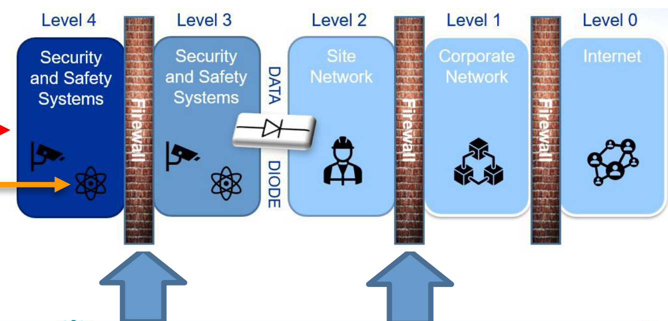
1. Cyber Security Assessment Team

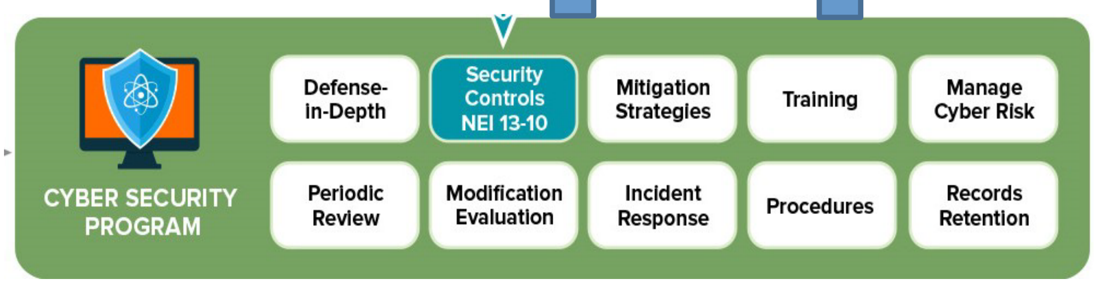
2. Identify Critical Digital Assets (CDAs)



3. Implement Defensive Architecture

4. Apply Security Controls





Definitions:
NEI: Nuclear Energy Institute
RG: Regulatory Guide

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Note: RG 5.71 can be found at: https://www.nrc.gov/docs/ML2225/ML22258A204.pdf

Draft Cybersecurity Requirements for Advanced Reactors

Preparing for a Wide Variety of Advanced Nuclear Technologies

EVOLVING LANDSCAPE

- Research and Test Reactors
- Molten Salt Reactors
- Small Modular Reactors
- High-Temperature Gas-Cooled Reactors
- Liquid Metal Cooled Fast Reactors
- Micro-Reactors

13+ Current and potential applications by 2027

6+ Potential operating licenses by 2027

- Many different reactor technologies
- Range of sizes from < 10 MWt to 600 MWt
- Multiple reactors on a single site
- Hazards vary with power level and radionuclide inventory

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Proposed New Cyber Requirements

10 CFR Part 53 development for Advanced Reactors

Preliminary Proposed Rule Language Publicly Available

New Cyber Requirements in Proposed Rule

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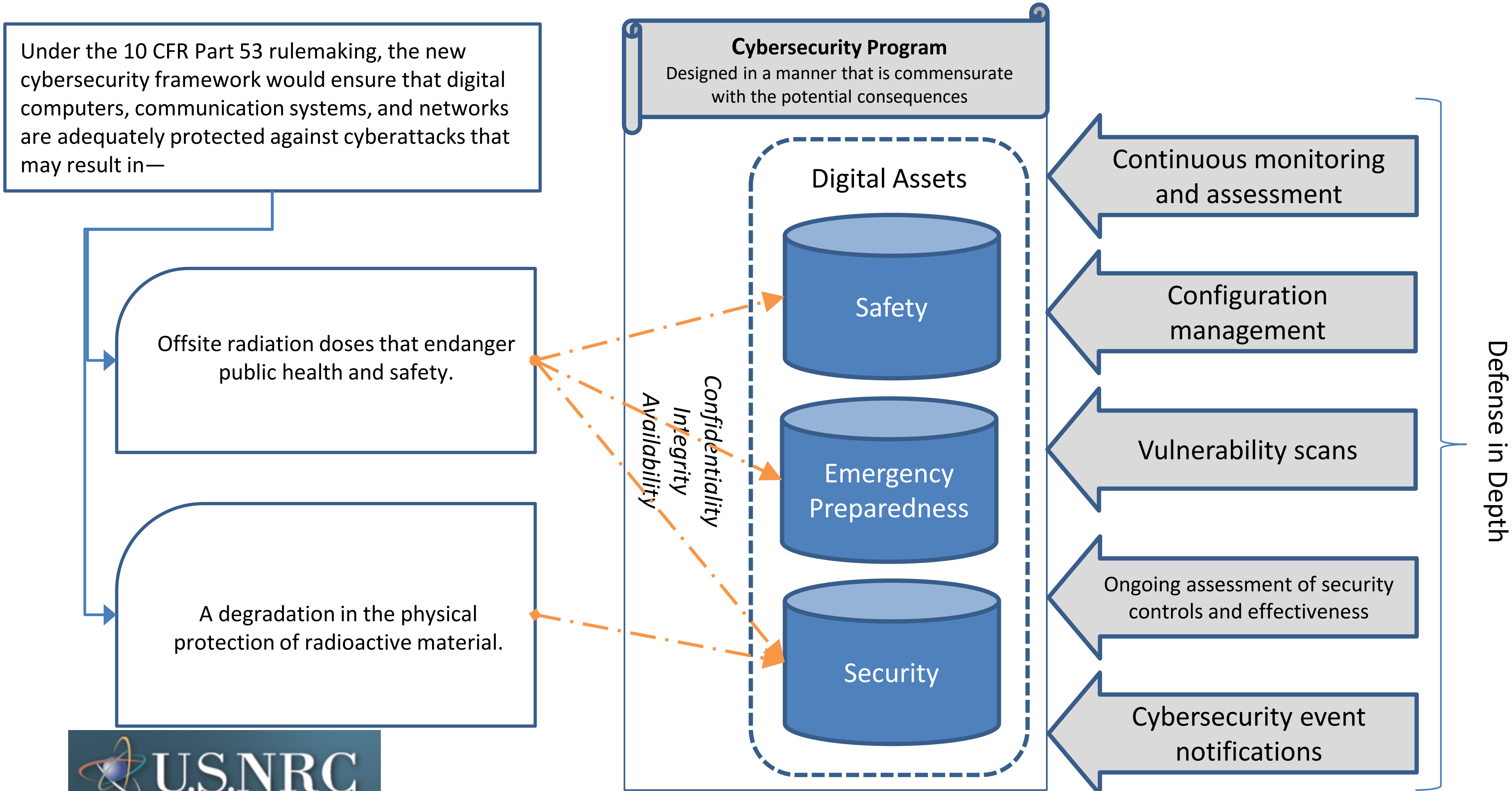
Preliminary Proposed Cyber Requirements



Reference: Part 73.110, "Technology-inclusive requirements for protection of digital computer and communication systems and networks," ADAMS Accession Number [ML21162A093]

Note: This staff-proposed rulemaking has been documented in SECY 23-0021 and is with the Commission for review. More information on the rulemaking process is available at [https://www.nrc.gov/about-nrc/regulatory/rulemaking/rulemaking-process.html]

Draft Regulatory Guide Development

An acceptable approach for meeting the 10 CFR 73.110 requirements

Effective guidance to support a performance-based regulatory framework

Leverage IAEA and IEC security approaches

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Note: This staff-proposed rulemaking has been documented in SECY 23-0021 and is with the Commission for review. More information on the rulemaking process is available at https://www.nrc.gov/about-nrc/regulatory/rulemaking/rulemaking-process.html.

Potential Integrated Cybersecurity-Safety Assessment Methods for Nuclear Power Plants

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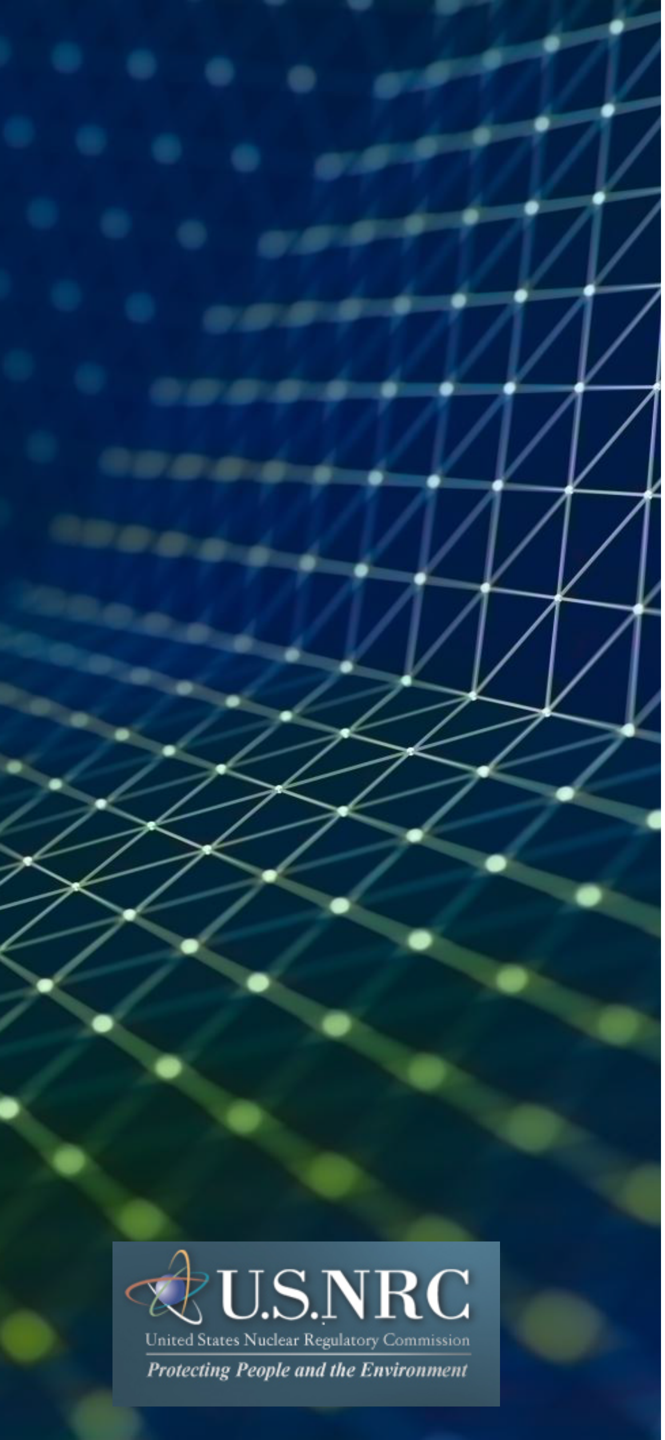


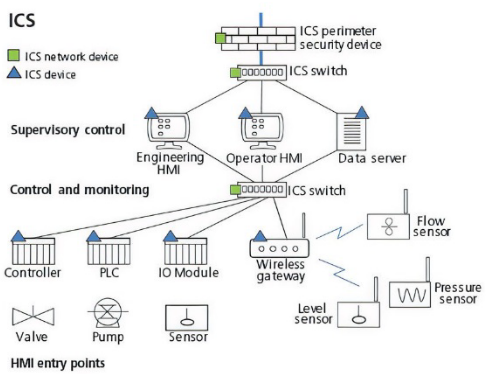
Integrated Cybersecurity-Safety Assessment Methods for Nuclear Power Plants- Potential Regulatory Applications

- **Augment Cyber Risk Assessments performed by licensees via an integrated safety-security assessment**
- **Help licensees ensure security and safety systems proactively address design flaws that could be exploited by a cyber attack**
- **Help licensees ensure that safety functions and cybersecurity features do not adversely affect one another**

Integrated Cybersecurity-Safety Assessment Methods for Nuclear Power Plants - Investigate Potential Use of STAMP

STAMP, CAST, & STPA

Define the system & Gather basic info.



Model the system, and human-machine interactions as a set of control diagrams

STAMP Model

Human | Machine

Controller(s)
Algorithms + Processes

Control Actions

Feedback

Controlled Process(es)

Analyze using CAST or STPA

CAST (Retrospective) — Learn from operating experience

OR

STPA (Prospective) — Identify and address hazards throughout the development process

Definitions:
CAST: Causal Analysis using Systems Theory
STAMP: System-Theoretic Accident Model and Processes
STPA: Systems-Theoretic Process Analysis

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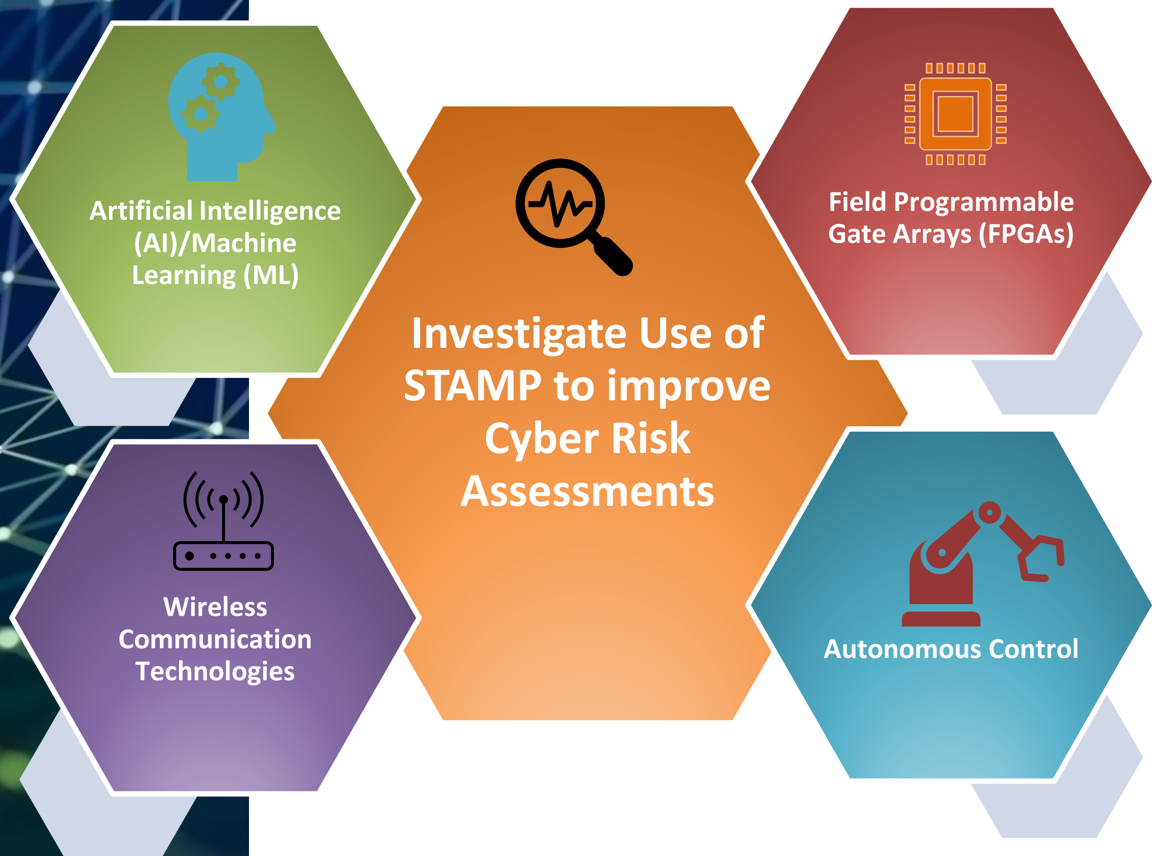
Note: Graphics from isa.org & itgstextbook.com and figure based on material presented by Dr. John Thomas from MIT.

Integrated Cybersecurity Research Approach



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ADVANCED REACTOR SAFEGUARDS & SECURITY

3S Integration in the DOE NE ARSS Program

NRC 3S Workshop

PRESENTED BY

Ben Cipiti Sandia National Laboratories

December 6, 2023

SAND2023-13942PE

ARSS Program Goal and Objectives

The ARSS program is addressing near term challenges that advanced reactor vendors face in meeting material control and accounting (MC&A), physical protection system (PPS), and cybersecurity requirements for reactors built in the U.S.

Material Control & Accounting

Systems Level

PBR MC&A Approach
MSR MC&A Approach
Vendor Engagements
International Coordination

Technology Level

Measurement Technologies
Process Monitoring
Statistical Evaluations

Physical Protection Systems

Systems Level

SMR PPS Design Approach
Microreactor PPS Design Approach
Vendor Engagements

Technology Level

Advanced Intrusion Detection
Advanced Delay Technologies
Advanced Response Tech/Tactics

Cybersecurity

Systems Level

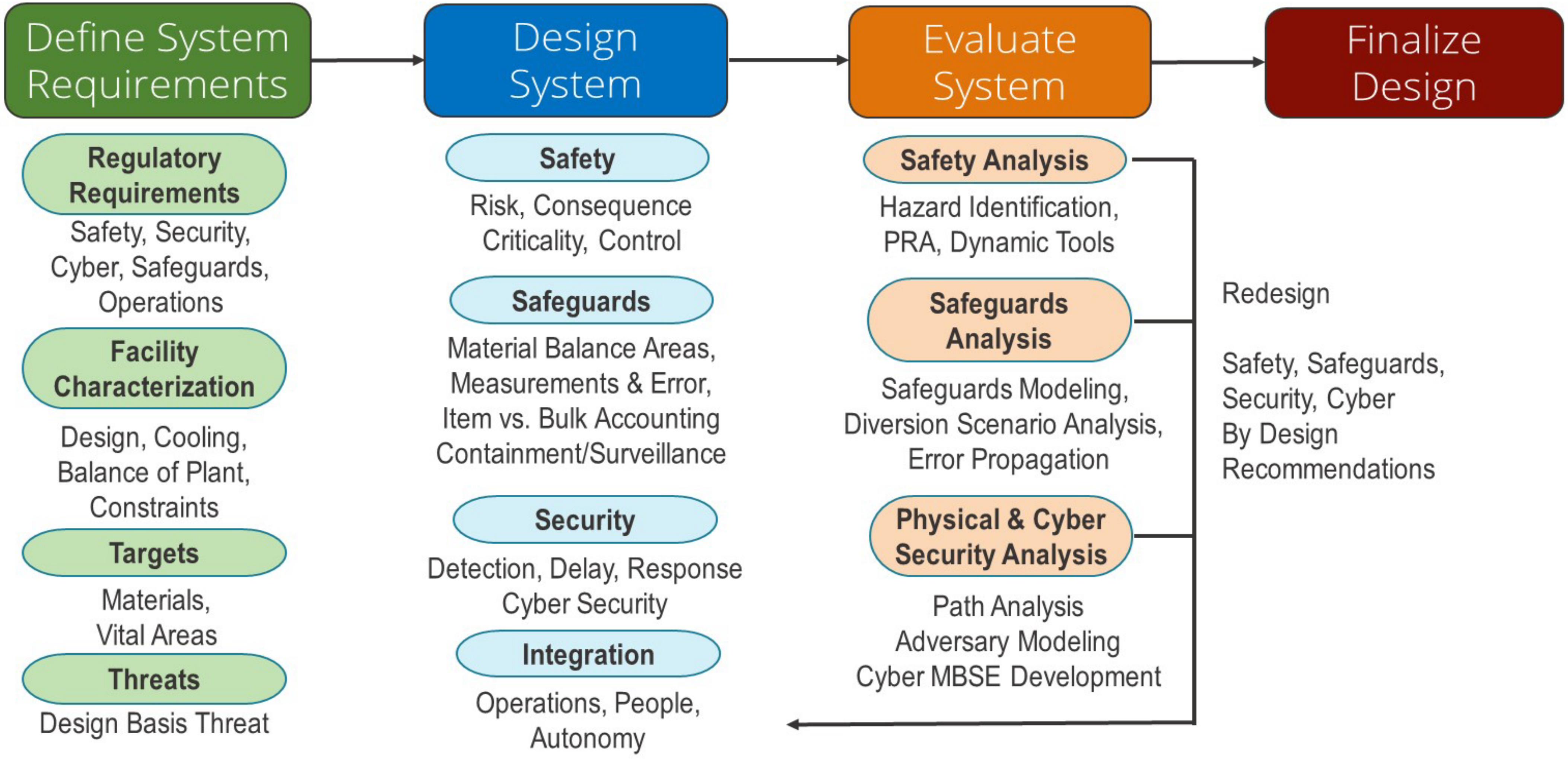
Cyber-Informed Engineering
Defensive Cyber Architecture
Vendor Engagements

Technology Level

Secure Elements/Tokens
Supply Chain
Control System Component Testing

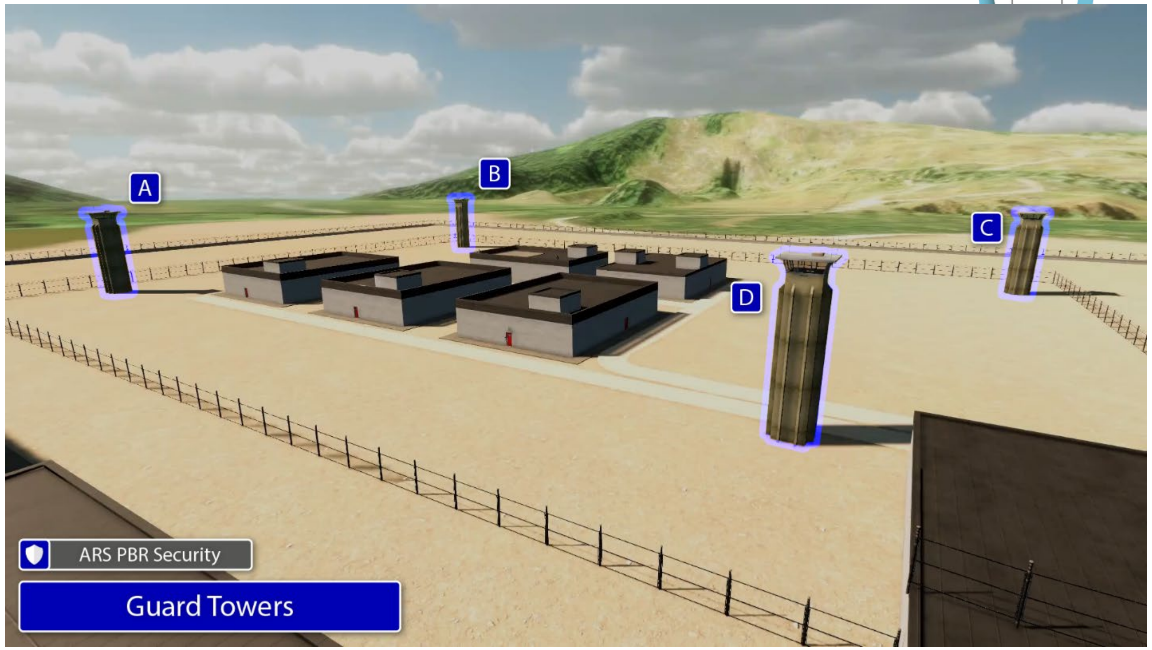
← Interface with Safety →

Overlap in the Design Process



Physical Protection Systems

- The AR vendors would like to reduce the PPS footprint and number of on-site security staff
  - Cost aspect to keep overall plant economics competitive.
  - Marketing aspect to show that these reactors are smaller and safer.
- Systems level work has focused on minimum numbers of staffing required for different reactor types and where those minimum numbers may be reduced through exemptions/alternatives.



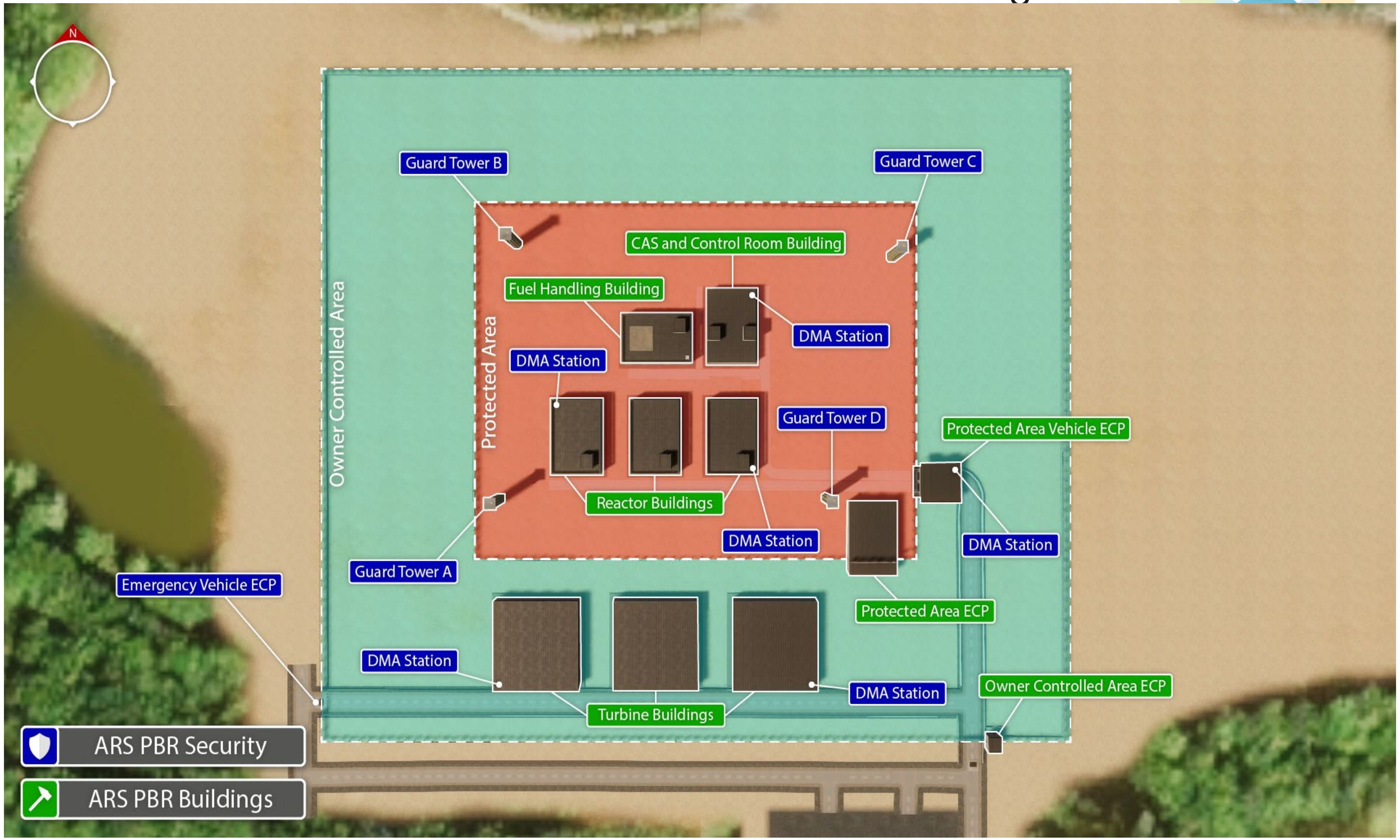
- Vendor engagements are being used to validate PPS design recommendations

Initial Lessons Learned

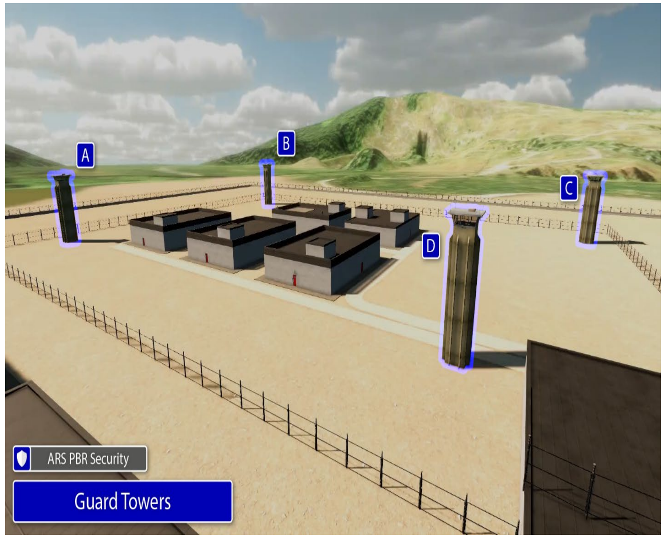
- Initial work examined the use of off-site response but has since moved away from that approach for several reasons:
  - Costs for agreements and training would be the same as on-site responders.
  - Response times lead to the need for significant delay (adding cost)
  - Questions about reliability
- Initial work was also focused on providing R&D to support potential changes in the Part 73 limited scope rulemaking and Part 53.
  - Seeing potential large differences in first-of-a-kind versus n^{th} of a kind.

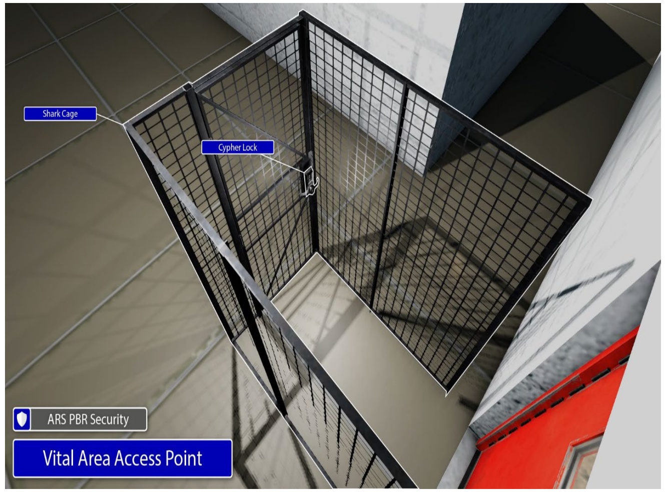
Generic Pebble Bed Reactor PPS Model

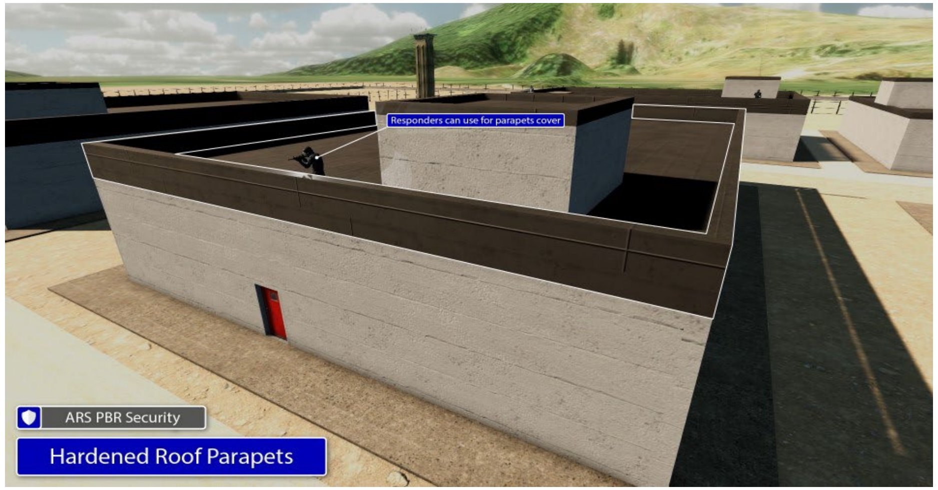
- Deliberate Motion Analytics → External Intrusion Detection
- Owner Controlled Area (OCA) Boundary in Blue
- Protected Area (PA) Boundary in Red
- 4 Response Towers
- 1 Roving Guard with Roof Access
- OCA entry control point for large vehicle searches
- PA entry control point for detailed vehicle inspections
- 6 Vital Areas



PBR PPS Attributes

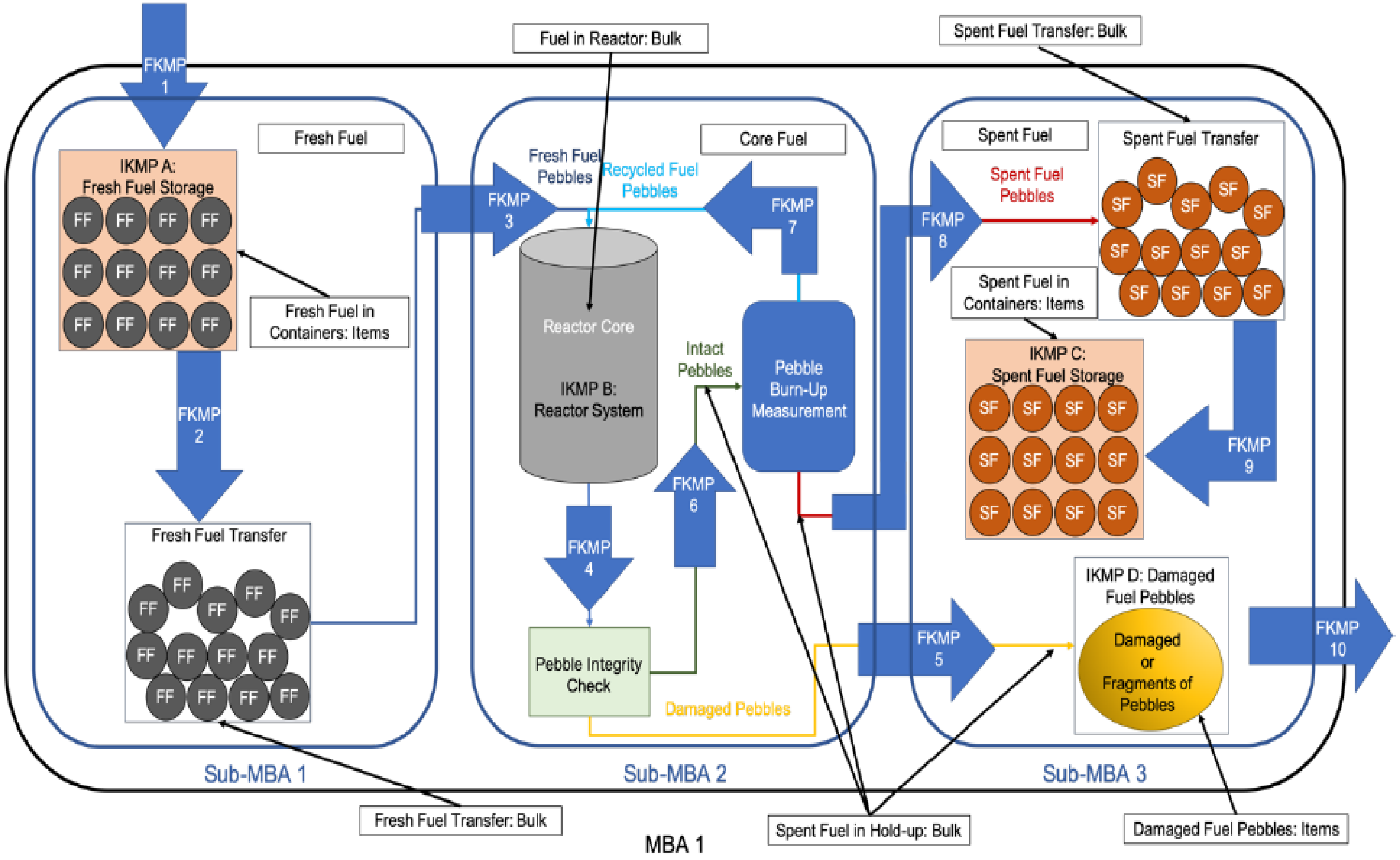




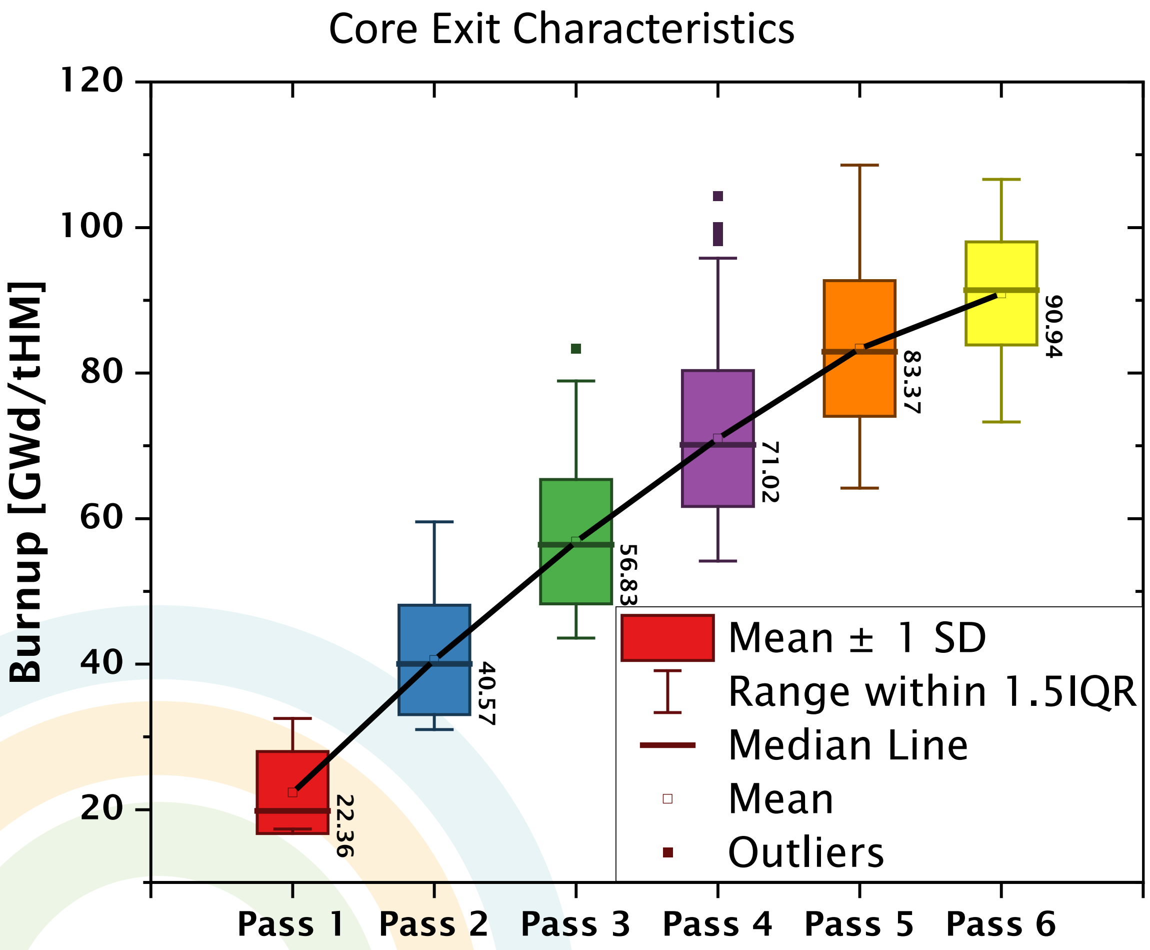


MC&A for Pebble Bed Reactors

- Completed a milestone report on the MC&A approach for PBRs.
- Item accounting on fresh and spent fuel canisters.
- Fuel handling system consists of pebble counters, pebble integrity check, and burnup measurements.
- The burnup measurements can inform actinide content in spent fuel canisters.



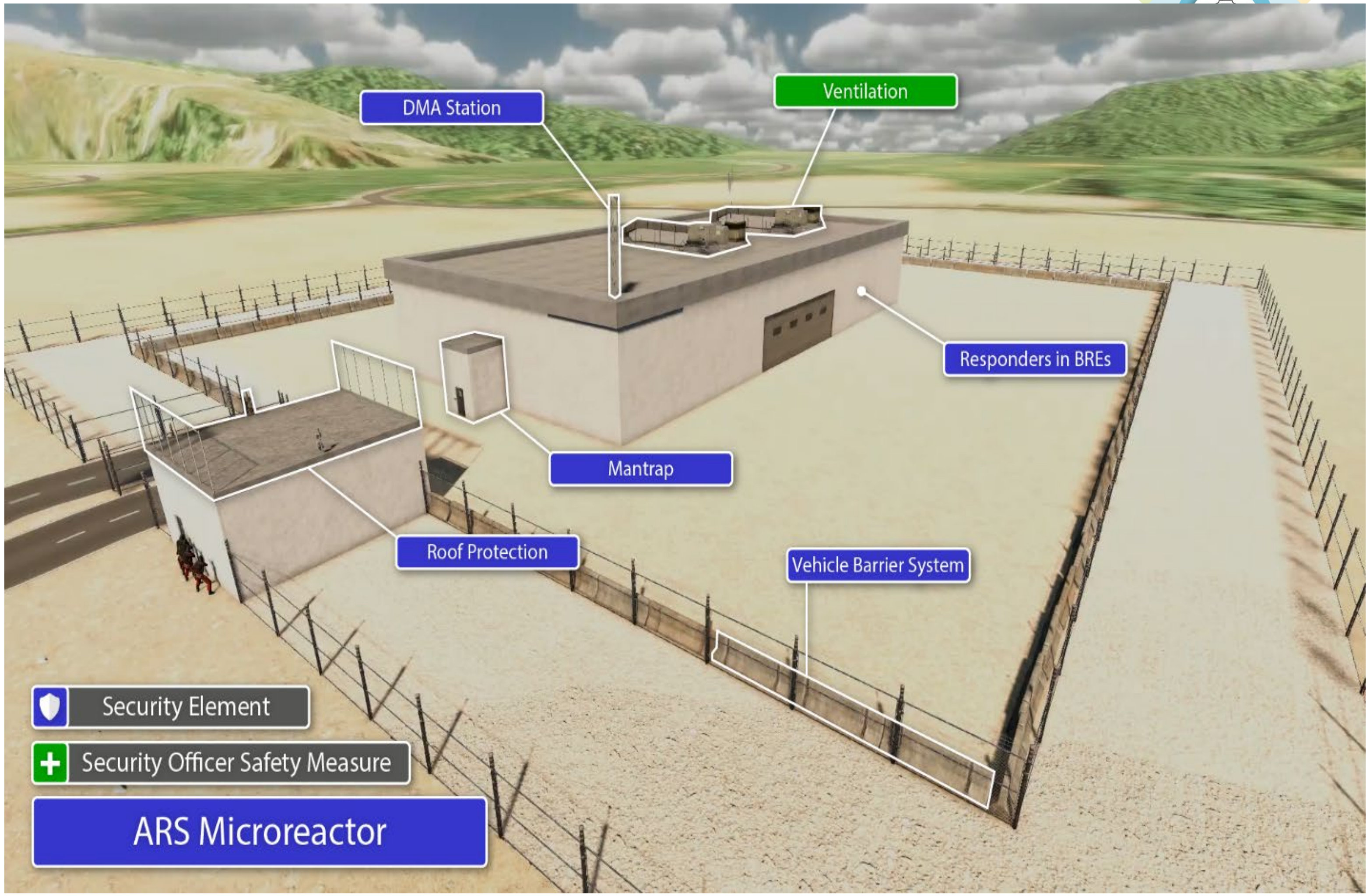
MC&A for Pebble Bed Reactors



- The analysis on the left shows the range of burnup values achieved based on the pass.
- Based on a PBMR-400 model, the largest additional burnup achievable is 16.8 GWD/MT, so if the burnup limit is 100 GWD/MT, pebbles could need to be ejected once greater than 83.2 GWD/MT.
- ARSS is supporting an NDA measurement campaign on spent TRISO fuel and also looking into machine learning algorithms to improve the burnup measurement.

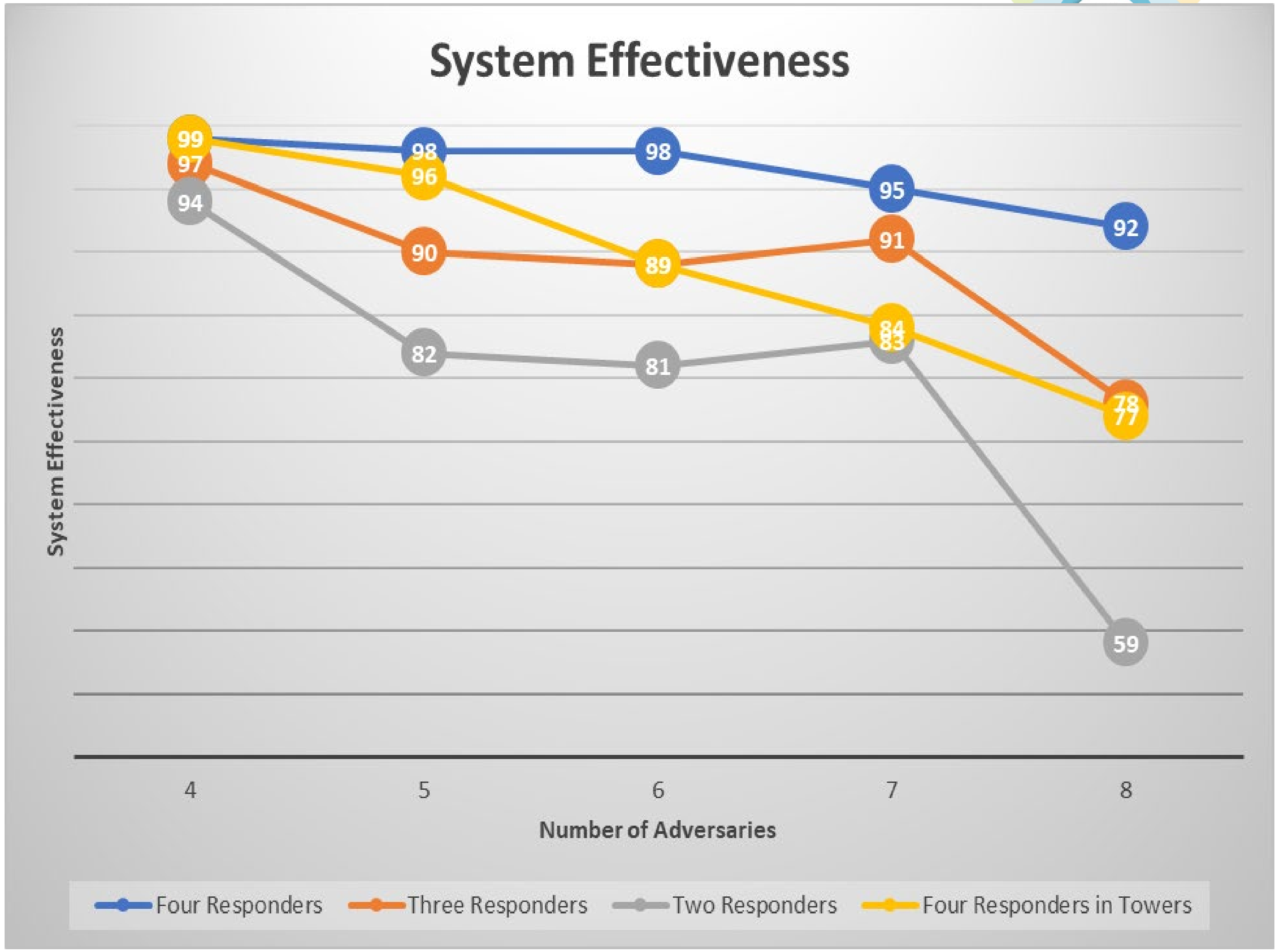
Generic Microreactor PPS Model

- Deliberate Motion Analytics → External Intrusion Detection
- Owner Controlled Area Boundary
- Protected Area Boundary
- 4 different scenarios analyzed
  - 4 internal responders
  - 3 internal responders
  - 2 internal responders
  - 4 responders in towers
- One Entry Control Point
- Two Vital Areas



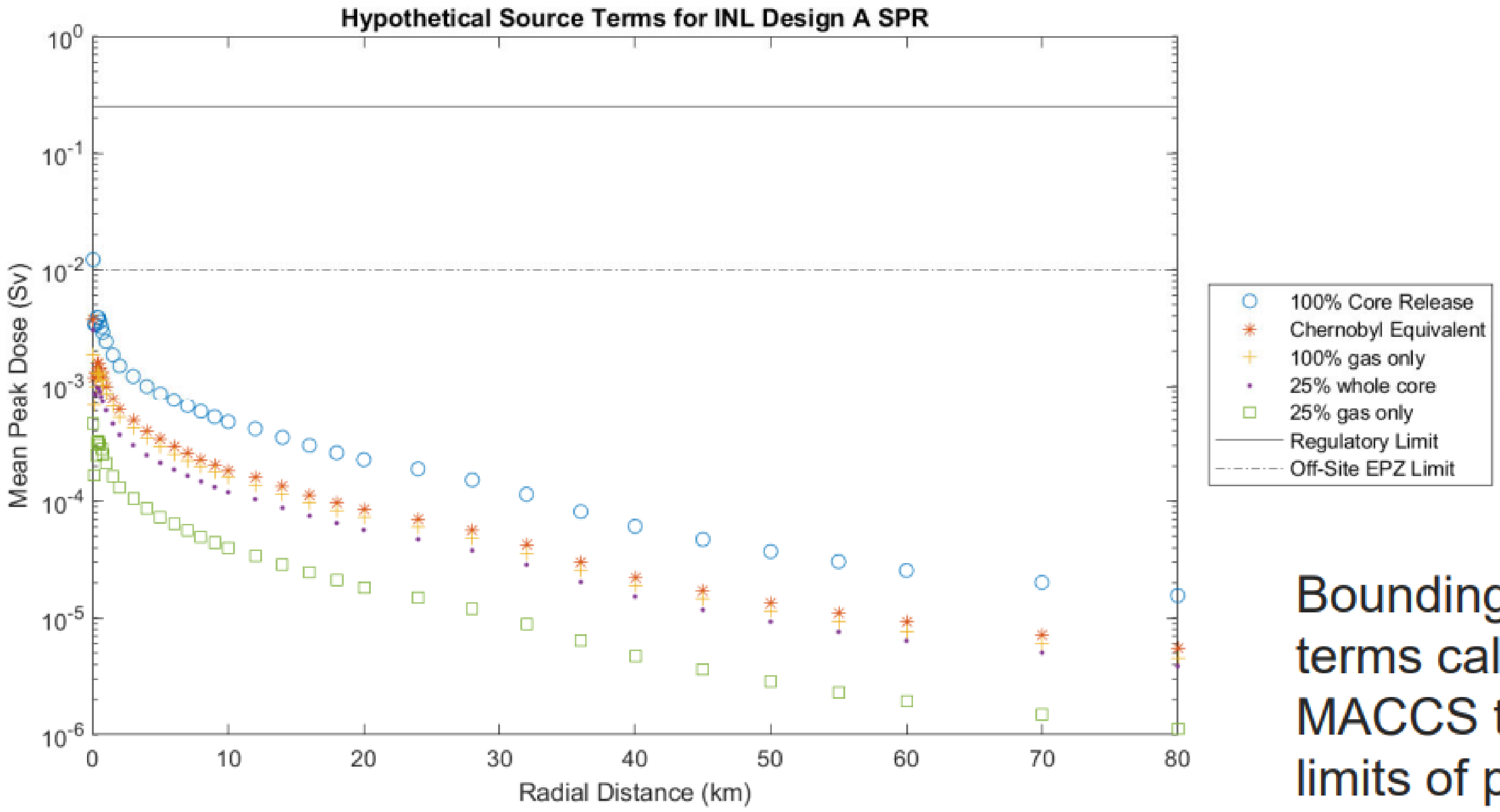
Microreactor System Effectiveness and Staffing Plan

Position	24/7 Rotating Shift	FTE
Security Shift Supervisor	1	4
Response Team Lead	2	8
Alarm Station Operators (CAS/SAS)	3	12
Armed Responders	5	20
Armed Security Officers (Personnel, vehicle, and material processing)	3	12
Total	14	56



Taking Source Term into Account

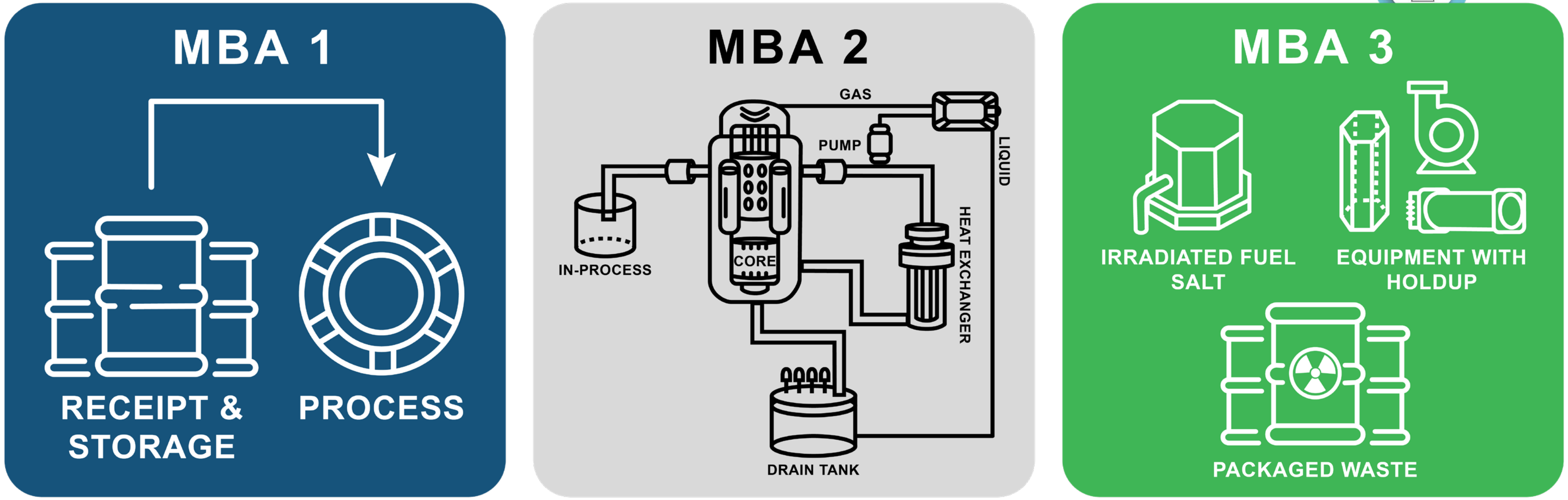
- An NEUP led by Karen Kirkland at TAMU and Shaheen Dewji at Georgia Tech examined source terms from a heat-pipe microreactor.
- Full core release shown to be below the regulatory limit.
- Potential for significant impacts for both physical and cyber.



Bounding case source-terms calculated from MACCS to show upper limits of potential off-site consequence (Wang 2023)

MC&A for Liquid Fueled Molten Salt Reactors

- MSRs are bulk facilities and will very likely need to submit an FNMC plan.
- Item accounting at front end and back end, with diversion monitoring for the reactor loop.



Periodic inventories performed, IDs and SEIDs calculated
(follows Part 74 requirements)

Monitoring performed in specific locations to detect diversion

Periodic inventories performed, IDs and SEIDs calculated
(follows Part 74 requirements)

Cybersecurity R&D

- One program goal is to define a Defensive Cyber Security Architecture for each class of advanced reactor.
- The DCSA is used to develop the network design, system components, and flow of information.
- The goal here is not to design the system for the vendors, but rather provide recommendations and develop the technical basis for components that may be used.

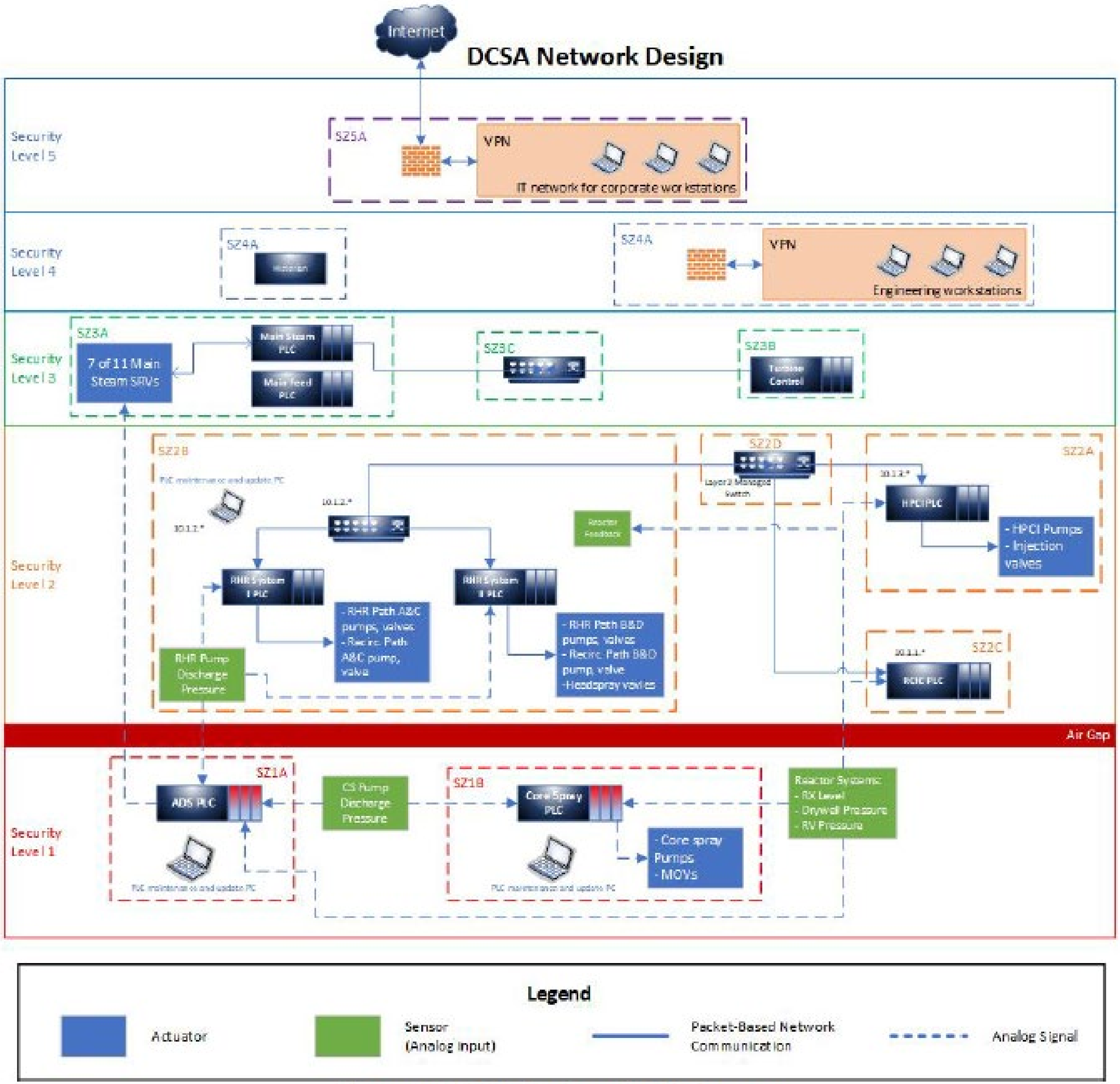


Figure 7. DCSA design of RHR System

Cybersecurity R&D

- Advanced Reactor Cyber Analysis and Development Environment (ARCADE)
  - Modeling environment that connects physical plant models to control system emulations to support cyber security testing and evaluation
- Development and evaluation of security techniques for control systems
  - Identify performance characteristics and requirements for using security techniques (e.g., encryption and authentication) in control systems
  - Secure Elements – Explore use of smart chips in control system components for supply chain security and embedded encryption and authentication
  - Integrity guaranteeing protocols – Evaluate alternatives to encryption to ensure integrity in control systems
- Wireless Cybersecurity
  - Develop requirements for secure wireless applications
  - Develop testing and evaluation protocols to support use of wireless in new applications

Discussion

- New reactors can take full advantage of a 3S by Design approach to develop cost-effective yet robust plant protection systems.
- We see more of a need for integrated 3S as we move toward the more exotic fueled reactors (PBRs and MSRs).
- Existing program work is beginning to evaluation 2S interfaces, but we expect to expand work on integrated 3S approaches as the program matures.
- We plan to develop a series of reports in the 3-5 year time frame on integrated 3S design recommendations for each class of advanced reactor.

Program Contacts

UUR Reports will be posted to the program website:

https://energy.sandia.gov/ars

CUI Reports can be shared with vendors, NEI, and NRC provided certain conditions are met to protect the information.

Ben Cipiti, National Technical Director (SNL) bbcipit@sandia.gov

Katya Le Blanc, Deputy National Technical Director (INL) katya.leblanc@inl.gov

Dan Warner & Savannah Fitzwater, Federal Program Managers (DOE) daniel.warner@nuclear.energy.gov, savannah.fitzwater@nuclear.energy.gov

Safety, Safeguards and Security (3S)-by-Design: An Engineering-Based Approach

Adam D. Williams (Sandia National Laboratories)

NRC 3S Workshop: Advanced Reactors and Fuel Fabrication

December 2023

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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Roadmap

Introduction & Background

Safety-Security-Safeguards (3S) Examples in Advanced & Small Modular Reactors

Engineering Basis for "3S-by-design"

Conclusions, Insights & Implications

Introduction & Background

Safeguards, security, and safety are commonly seen as *separate areas* in nuclear governance. While there are technical and legal reasons to justify this, they *also co-exist and are mutually reinforcing*. Each has a *synergetic effect on the other*, and authorities should carve out avenues for collaboration to contribute to the effectiveness of the nuclear order. For instance, *near real-time nuclear material accountancy and monitoring systems* provide valuable information about the location and status of nuclear material. This in turn is useful for *nuclear security* measures. Similarly, such information enhances *nuclear safety* by contributing as input to critical controls and locations of nuclear materials.

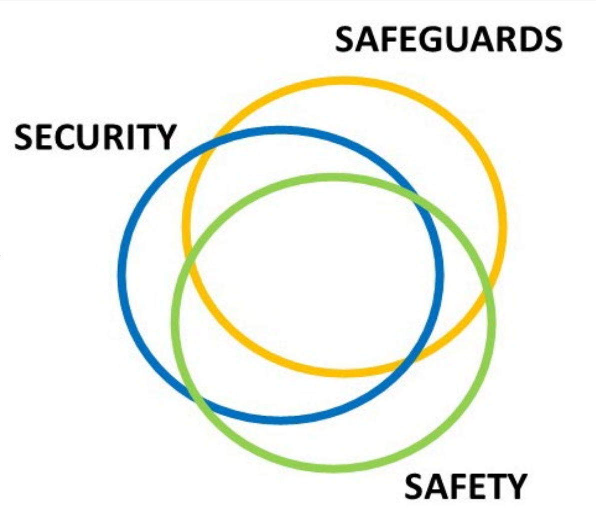
Former Deputy Director-General for Safeguards at the International Atomic Energy Agency Olli Heinonen

Introduction & Background

co-exist and are mutually reinforcing

synergetic effect on the other

OR



Today's State of the art:
3S Alignment

Tomorrow's State of the art:
3S Interaction

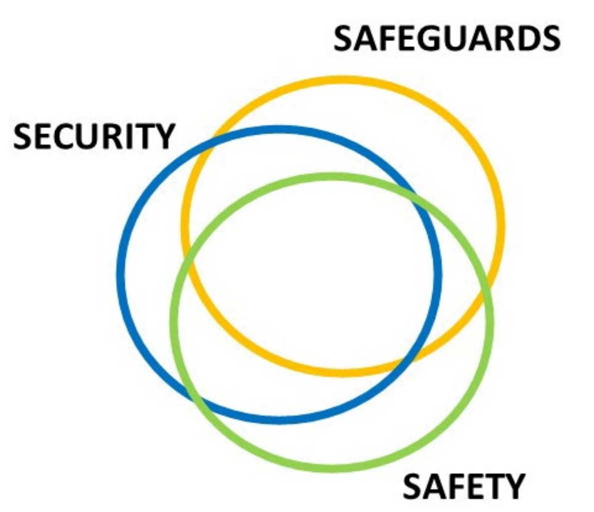
Introduction & Background

co-exist and are mutually reinforcing.

synergetic effect on the other,

How do we ENGINEER for these effects & interactions?

- *Increased overlap* between safety-security-safeguards related to such A/SMR characteristics as:
  - Increased deployment flexibility
  - Novel fuel types (including physical attributes)
  - New fuel flows & handling systems
  - Increased automation in operations
  - Smaller onsite staffing



Tomorrow's State of the art:

3S Interaction

(3S) Examples: Advanced & Small Modular Reactors

Example 1:
Security-Safety Interfaces in SMRs

- *Challenge*: smaller economic margin vs. same DBT
- *Individual 'S' Considerations*:
  - Increased reliance on off-site response
  - Increased efficiency for onsite solutions
  - Implementing advanced technologies
- *Interactions-based Solution(s)*:
  - Additional protection for "less-critical"
  - Decay heat removal can mitigate sabotage

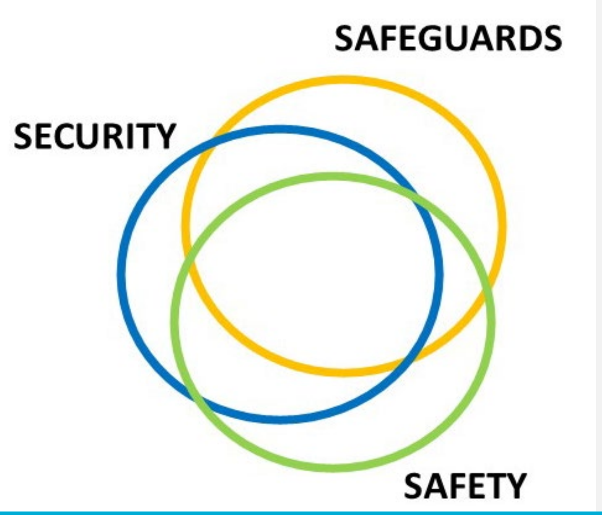
Example 2:
3S Implications from New Fuel Forms

- *Challenge*: shift 3S approaches from item to bulk/mass materials
- *Individual 'S' Considerations*:
  - Safeguards refocus on C&S (vs. NMA)
  - Increased uncertainty in safety calculations
  - More security challenge via insider threat
- *Interactions-based Solution(s)*:
  - Advanced technical & procedural measures
  - Balance relative "S" risk per material form

Example 3:
Impacts on Risk Management

- *Challenge*: how to handle new risk dynamics (vs. traditional elements of NPP risk)
- *Individual 'S' Considerations*:
  - Established PRA approaches → Safety
  - Established VAI approaches → Security
  - Passive technologies
- *Interactions-based Solution(s)*:
  - Incorporate passive/inherent safety → VAI
  - Overlapping "by-design" approaches

"3S-By-Design" Engineering Basis



Tomorrow's State of the art:

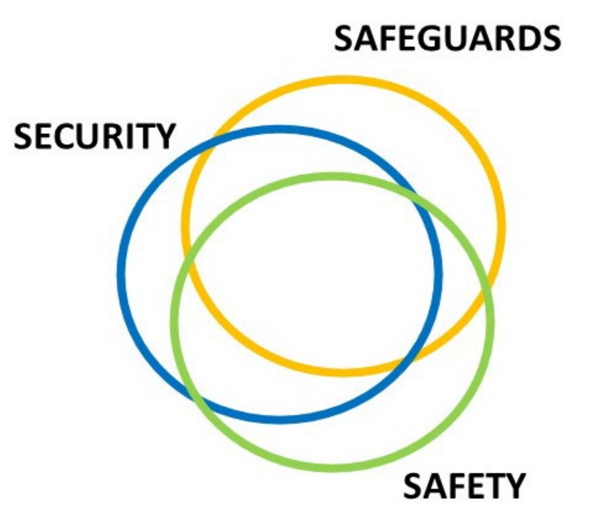
3S Interaction

"By-Design" characteristics

- Built "into", not "onto" or "around"
- Included "during" not "after the fact"
- Informed decisions to optimize across functions
- Reactor-technology neutral
- Allows opportunities for innovation

If "by-design" focuses on optimally arranging features and functions of nuclear facilities, *then* engineering design approaches can help facilitate 3S interaction

"3S-By-Design" Engineering Basis



"Security-By-Design" considerations (per conversations with participants in related IAEA consultancy meetings)

- "to reduce...vulnerabilities, improve...effectiveness related to design, layout, operations, maintenance"
- "to eliminate or mitigate vulnerabilities...using a graded approach before construction or manufacturing"

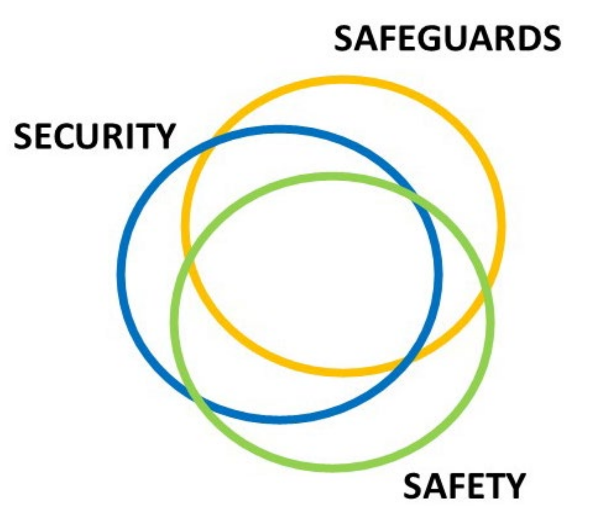
"Safeguards-By-Design" considerations (per J. Whitlock, *Safeguards by Design*, IAEA Bulletin 63-3 & IAEA NE No. NP-T-2.8, 2.9, 3.1, 3.2, 4.7, 4.8, 4.10)

- "earlier the discussion of safeguards the better"
- "improves the efficiency of safeguards by helping the IAEA to optimize their application"

"Safety-By-Design" considerations (per J. Liou, *Safety By Design*, IAEA Bulletin 62-1)

- "radical changes in the use of coolants, fuels, operating environments and system configurations"
- "increasing emphasis on inherent safety...and passive features and decreasing reliance on the operator"

"3S-By-Design" Engineering Basis



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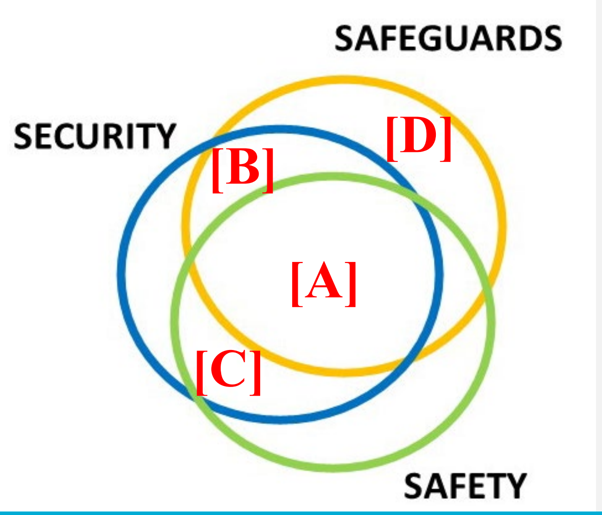
- "radical changes in the use of coolants, fuels, operating environments and system configurations"
- "increasing emphasis on inherent safety…and passive features and decreasing reliance on the operator"

"By-design" → Supports an "all-hazards" approach to engineering

“3S-By-Design” Engineering Basis



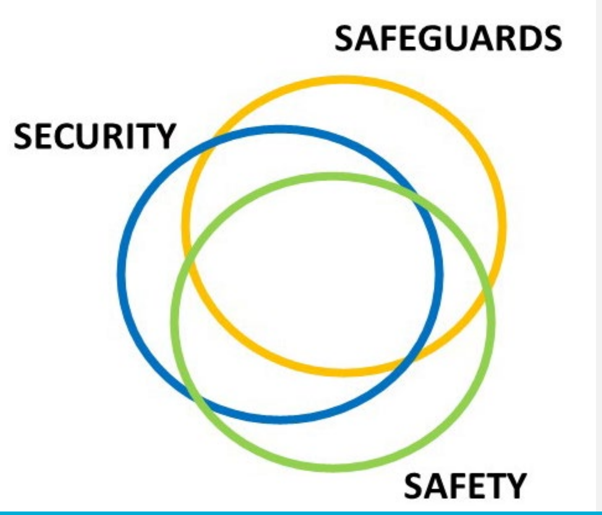
Tomorrow's State of the art:

3S Interaction

3S Interaction	Representative Example [Location on Venn Diagram]
Interdependency	Coordination of 3S responsibilities during emergency operations [A]
Conflict	Intrusive access control could impede evidence of peaceful uses (increase safeguards risk) [B]
Gap	Passive safety systems could be new targets for malicious acts (increase security risk) [C]
Leverage Point	Safeguards inspections could reveal a reactor vessel integrity issues (reduce safety risk) [D]

- System theory principles → hierarchy, emergence, interdependence
- Complex systems concepts → socio-technical, multidomain interactions

"3S-By-Design" Engineering Basis



Tomorrow's State of the art:

3S Interaction

3S Interaction	Systems Engineering Design Goal
Interdependency	Identify & (possibly) decouple
Conflict	Identify, eliminate, and/or reconcile
Gap	Identify, eliminate, and/or reconcile
Leverage Point	Identify & exploit

- Interactions *may* be desired, but *need* to be identified/understood
- Interactions *can be* categorized based on relational dynamics
- 3S interactions → facility design parameters to reduce risk

“3S-By-Design” Engineering Basis

A/SMR Example	Safety	Security	Safeguards	[3S Interaction Type] Systems Engineering Design Goal
1	Capturing increased role of “less-critical” facility components as potential targets for malicious actions	Co-locating “critical” facility components to reduce security system footprint	(Similar challenges can be expected when considering fewer resources to support safeguards obligations)	[Conflict] Identify & reconcile → Security designs can incorporate facility/reactor physics
2	Verifying the burnup of each pebble/ concentration of liquid fuel during rotation for efficiency	Accounting for/locating each pebble or amount of liquid fuel to prevent potential use as RDD	Confirming location of pebbles/liquid fuel to prevent diversion	[Leverage points] Identify & exploit → Selected measurement solutions for process monitoring can support actinide accounting &/or asset tracking
2	Implementing traditional PSA-approaches can neglect important elements of A/SMR operational risk	Conducting traditional VAI techniques propagate/compound these missing elements of operational risk	(Similar challenges might be expected when acquisition pathway analysis borrows from traditional adversary path analysis)	[Gaps] Identify & eliminate → New VAI approaches should be able to include passive safety systems & conducted earlier in the facility design process

Conclusions, Insights & Implications

- New A/SMRs characteristics → *Opportunities to engineering for 3S interactions*
  - Risks may *not be* independent
  - Systems theory concepts → framework for *addressing interactions*
- Commonalities in "by-design" → *Foundation for unified 3S approach*
  - Emphasize "built into now" & not "around after" → *Innovation!*
  - Both *commonality & divergence* between 3S need to be addressed
- Engineering for *interactions* → *Can drive optimized A/SMR performance*
  - Exploring interactions can help *reduce uncertainty* in A/SMR operations
  - Additional 3S & operations benefits from *explicitly designing* for *interactions*

Conclusions, Insights & Implications

- Engineering-based approach → supports AdSec/INSAG Report No. 1 (2023) recommendations
  - Potential basis for "a common process of [safety & security that is] both more effective and more resource efficient"
  - *Directly* addresses 6 of the 10 key areas of interfaces, including: *identification of vital areas, optimization, human risk factors, information and communications, computer security, emergency preparedness* (and indirectly supports other 4)
- More specifically, this framing provides a possible structure for
  - "The identification and consideration of the interfaces between the well established nuclear safety system and the more recent nuclear security system…in order to reflect the equal value and priority given to nuclear safety and nuclear security"

QUESTIONS???

An Approach to Integrating 3S Modeling and Simulation

Stephen Reed, PE, P.Eng.

6 DEC 2023, 1300-1315

Presentation Overview

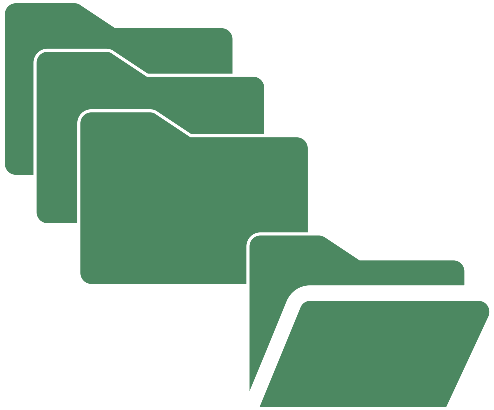
- When is Integrated 3S Beneficial?
- Key Aspects of Integrated 3S
- Integration of 3S
- Next Steps

2

When is Integrated 3S Beneficial?

Required

Trained



Organized

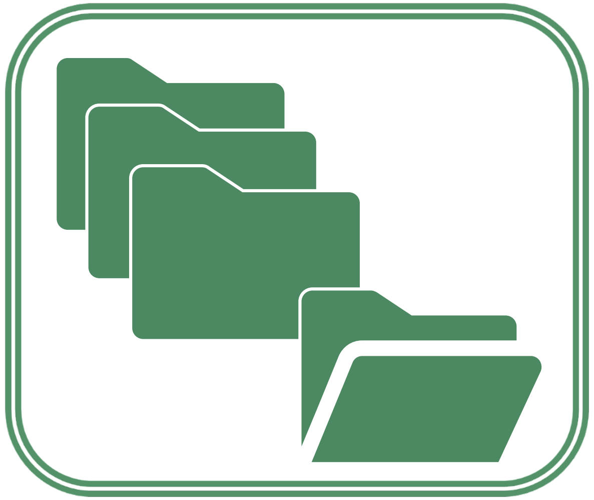
Living

- Are all 3 S's required by regulation?
- Deployment in NWS may not provide a business justification for building integrated 3S program
- Internal Points of Contact and Divisions of Responsibility defined

When is Integrated 3S Beneficial?

Required

Trained



Organized

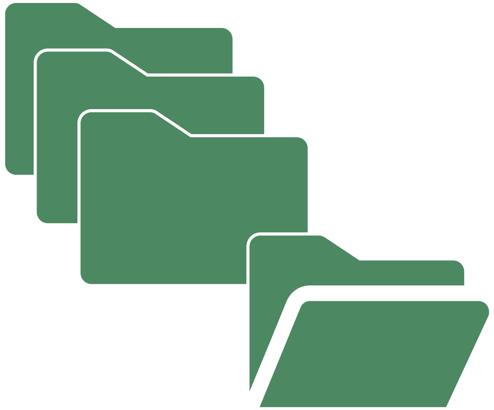
Living

- Is there a formal organizational program?
- Are there procedures available?
- Are the software and methodologies V&V'd? Approved?
- Are connections between methods and software well-defined?

When is Integrated 3S Beneficial?

Required

Trained



Organized

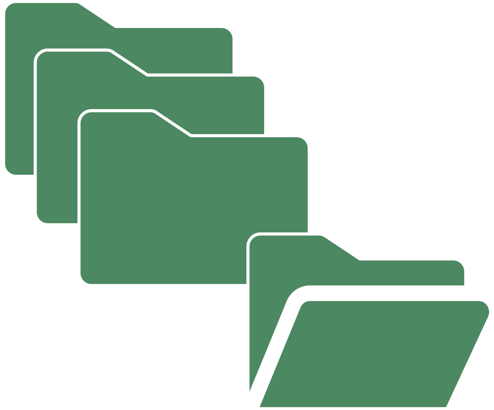
Living

- Is there a formal organizational training policy on integrated 3S?
- Who performs the training?
- Is the training focused on procedural adherence or qualification of individuals?

When is Integrated 3S Beneficial?


Required


Trained

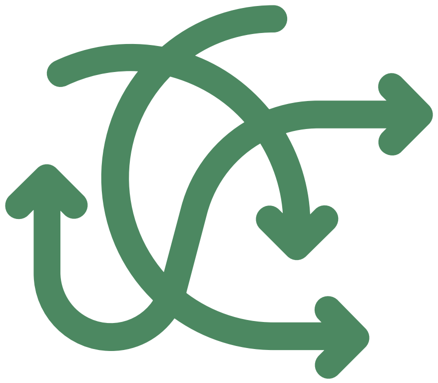

Organized


Living

- Is Integrated 3S a living program?
- Is the process/procedure/program update and altered as lessons learned are developed and reviewed?
- Are there SMEs within the organization?

6

Key Aspects of Integrated 3S



Integrated 3S is Complex

Key Aspects of Integrated 3S

Commitment from Leadership

Clear Positive Investment Case

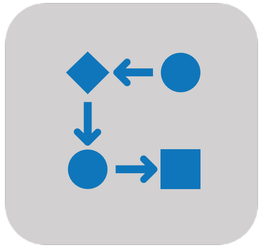
Well-defined Program Architecture

Industry Group Support

Key Aspects of Integrated 3S

- Commitment from Leadership
- Clear Positive Investment Case
- Well-defined Program Architecture
- Industry Group Support

Integration of 3S



- INS Integrated Mod/Sim project has begun
  - Objective to document areas of interface, methodologies, and software between the 3S's
- Aid in:
  - Definition of 3S
  - Organization of Program

- INS SeBD Business Case and Tabletop has begun
  - Objective to develop a clear picture of the benefits and risks of investing in 3SBD, SeBD
- Aid in:
  - Financial Justification
  - Leadership Commitment

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Other Steps

- Consider developing training and qualification matrix for SMEs
- Build industry groups or Include 3S, 3SBD, Integrated 3S into existing industry groups

Scott Ferrara
Chris Chwasz
Idaho National Laboratory

United States
Department of Energy
National Nuclear Security Administration
International Nuclear Security

NNSA INSTAR Multi-Lab FY23 Integrated Advanced Reactor Security Project Summary

Summary Methodology, Categorization, Unique Aspects

December 6, 2023

International Nuclear Security
Reducing Risk of Nuclear Terrorism

International Nuclear Security for Advanced Reactors (INSTAR)

Multi-Lab Integrated Project Overview

National Nuclear Security Administration

Scope and Objective:

To provide a logical framework to qualitatively characterize and risk-qualify advanced reactor security vulnerabilities early in the design and licensing process.

Key Outcomes:

Provide a schema that:

- Informs developers early in the design and licensing process on Inherent Security Considerations to address security concerns for domestic application and potentially for streamlined international deployment.
- Can be applied by National Nuclear Security Administration (NNSA)/Department of Energy (DOE)/producers to provide Insight on Basic Risk/Consequence management of a particular class or design/class of advanced reactors (ARs).
- Contains no proprietary or sensitive information that would preclude an outward facing report for maximum impact to developers and end users (state or utilities).

Importance:

Provides comprehensive AR risk insight and mitigations that will help lower overall security risk profiles through security by design for emerging AR technologies.

Technology Considerations:

Domestic only, classes based on technology type (MSR, HTGR, SFR, A-LWR, Micro Subset), Technology Readiness Level (TRL) and publicly available information driven.

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Regulatory Consideration and Motivators for Security by Design

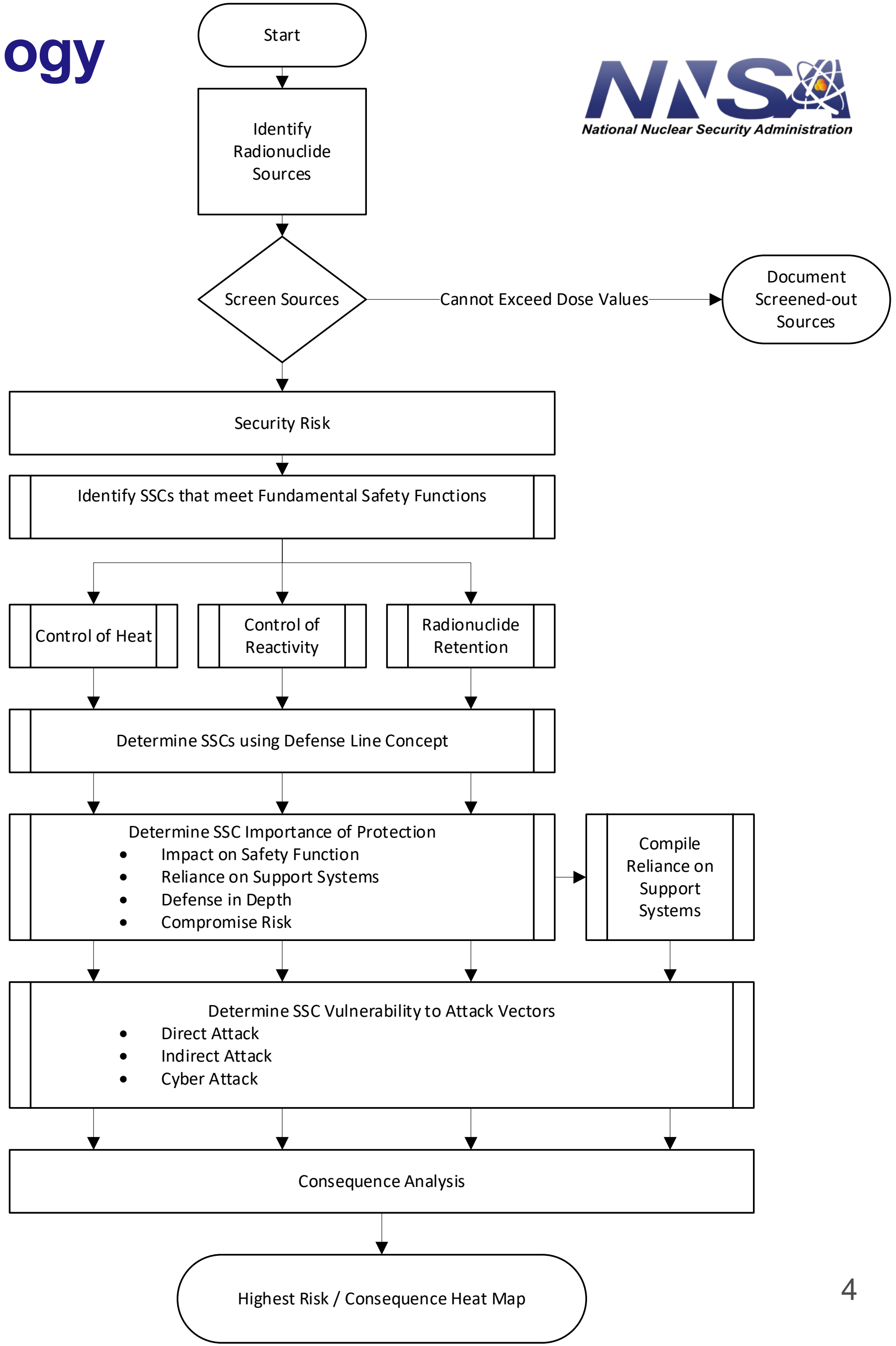
- **Regulatory Advantages to SeBD for Developers and Operators**
  - Security costs for current operators is 20% of Management and Operations (M&O) budget*
  - Security and Nuclear Safety nexus = enhancements that provide a safer, more marketable technology
  - Licensing case can be more straightforward and accomplished at reduced cost
  - Long term cost to operators may be reduced by decreased security staffing requirements

- **Domestic Policy Actions Supporting SeBD in A/SMR Designs**
  - Nuclear Regulatory Commission Limited Scope Security Rulemaking
    - Applies to current regulatory licensing constructs in 10 CFR Part 50 and 52
    - Allows for licensees to demonstrate through analysis where:
      - Nuclear safety and security design features can contribute to prevention or mitigation of radiological sabotage
        - Could result in reduced or no armed responders required onsite
  - New Regulatory Construct 10 CFR Part 53 (DRAFT) Rulemaking
    - New risk informed and technology agnostic construct
      - Provides for similar possible regulatory latitude to the limited scope rulemaking and much more related to risk informed alternative measures for meeting security performance objectives

*https://lwrs.inl.gov/Physical%20Security/Economic_Analysis_Physical_Security_NPP.pdf

Security Analysis Methodology

- **A first step technology and security neutral analysis method that evaluates all important sources of radioactivity for nuclear power plants**
- **Evaluates SSC importance, vulnerability, source consequence**
- **Updated methodology to IAEA NSS 16 Vital Area Identification**
  - Top-down analysis / Provides SSeBD and SeBD insights
  - Aligns with modern safety analysis methods (fundamental safety functions)
  - Includes consideration for cyber security
  - Compatible with hazards analysis methodologies for the identification of specific targets and sabotage modalities
- **Credits enhanced safety system performance and evaluates safety systems for importance of their protection based on:**
  - Fulfillment of the fundamental safety functions (FSFs) as determined using the SSeBD defense line concept:
    - Control of heat / Control of reactivity / Retention of radioactivity
  - SSC reliance on support systems / Defense in depth / Compromise risk



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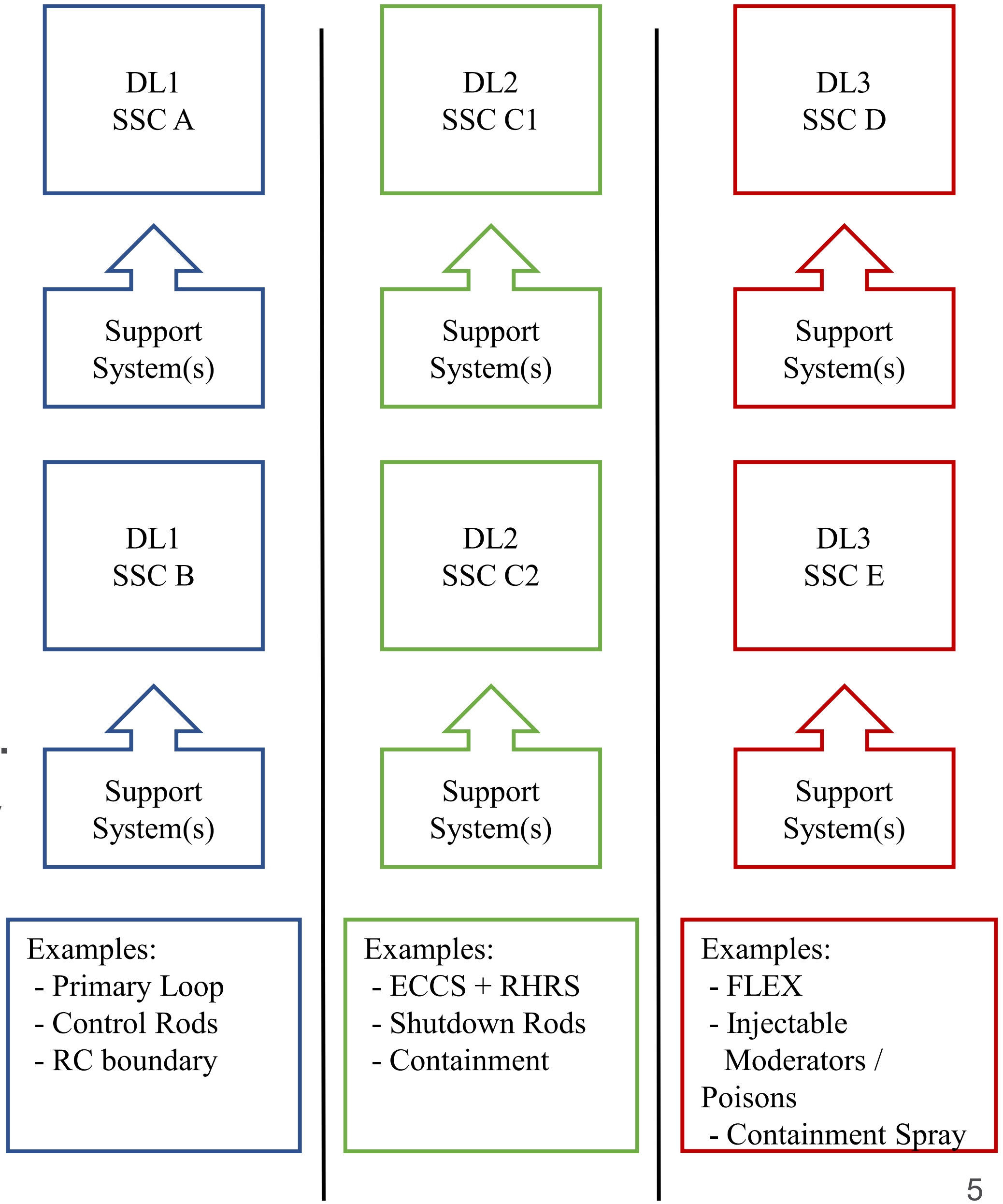
Security Analysis Methodology (cont.)

- **Evaluates System Security Vulnerability to**:
  - Direct adversary attack (adversary at target)
  - Indirect adversary attack (adversary defeats or compromises from remote location)
  - Cyber adversary attack (is vulnerable to insider / adversary cyber-attack)
- **Direct / Indirect Vulnerability Risk evaluated by SSC:**
  - Accessibility
  - Within adversary capabilities
  - Timeframe to defeat / compromise
- **Cyber Attack vulnerability evaluated by SSC:**
  - Degree of control by CDA / Degree of information reliance on CDA
- **Defense line concept groups SSCs by functionality, and importance.**
  - DL1 SSCs may fully fulfill FSFs (some AR designs rely on passive reactivity control) or ultimately rely on a DL2 SSC.
  - DL2 SSCs will likely have higher importance than DL1 and DL3 SSCs
  - DL3 SSCs provide design defense in depth the fulfillment of an FSF
  - More than one SSC may be required to fully meet an FSF



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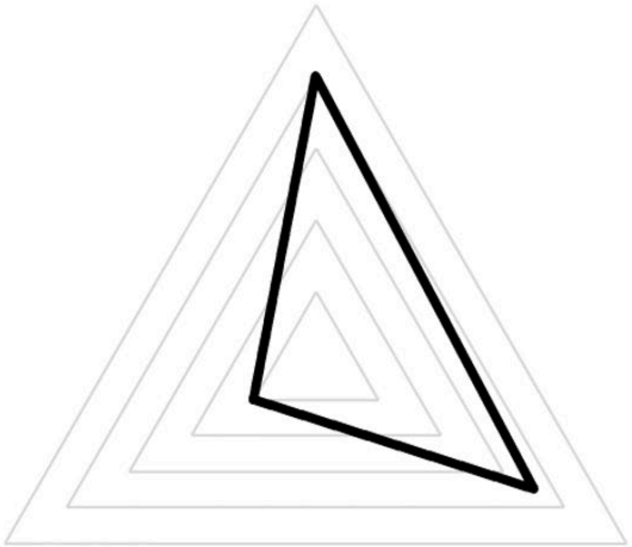
Nuclear Consequence Assessment

Methodology

Consequence Potential Ranking:



Dose Impact*	
Level	**Maximum Potential Dose Impact**
Very High	Possible wide area early health effects
High	Possible early health effects
Medium	Possible late health effects
Low	Possible exceedance of EPA PAG
Screen	Below screening limit (EPA PAG)

*Simplified total effective dose equivalent (TEDE) calculation performed using a preliminary radionuclide inventory estimate and postulated X/Q dispersion metric.

Barriers to Radionuclide Release*	
Level	**Description**
High	No inherent barriers or single applied barrier
Medium	Single inherent barrier or multiple applied barriers
Low	Multiple inherent barriers or mix of inherent/applied barriers

*Radionuclide retention barrier assumptions can be assessed independently or modified in coordination with the security analysis results. For example, if the attack compromises one or more of the radionuclide retaining barriers.

Dispersibility*	
Level	**Description**
High	Very limited or no energy needed for dispersal
Medium	Energy needed to initiate dispersal or small amount of continuous energy
Low	Significant energy needed for dispersal

*For example, a noble gas decay tank requires no energy for radionuclide dispersal once opened. In contrast, significant energy may be needed to liberate and disperse radionuclides from stored spent TRISO fuel.

Consequence Potential

The sources of radioactivity can be evaluated based on the following characteristics:

1. **Magnitude of source:** Quantity and type of radioactive material
2. **Potential dose impact:** Potential impact on human health
3. **Dispersibility:** Inherent ability of the source to be dispersed to the environment
4. **Barriers to release:** Radionuclide retention barriers preventing release of the source to the environment not security barriers to sabotage, but may overlap

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Example Assessment Tables- Liquid Metal Fast Reactor (LMFR)

NNSA National Nuclear Security Administration

Table 5-26. Summary of SFR risk consequence rankings for various sources.

Reactor Type	Source	Maximum Dose Potential Ranking	Dispersibility Ranking	Barrier Ranking1
SFR	Core	Very High	Low	Low
	Cesium trap	Medium	Medium	Low
	Sodium cold trap	Medium	Medium	Low
	Noble gas decay tanks	Low	High	High
	Used subassembly wash station	High	Medium	Low
	Used fuel storage pool (Na)	Very High	Low	Low
	Used fuel storage pool (H2O)	Very High	Low	Medium

NOTE: Multiple barriers, inherent or applied, results in a lower ranking. For example, the "Low" ranking is characterized by multiple inherent or mix of inherent/applied barriers while the "High" ranking is characterized by no inherent barrier or a single applied barrier. Section 4.3. provides a more detailed description of these rankings.

Table 5-27. SFR core security assessment rankings.

Safety Function	Structures, Systems, and Components	Defense Line	SSC Importance	SSC Vulnerability
Heat removal	PHTS	1	Low	Very High
	DRACS/RVACS	2	Medium	Medium
Reactivity control	Inherent reactivity feedback	1	Low	Low
	Control rods	1	Medium	Medium
	Safety rods	2	High	Medium
Radionuclide retention	Fuel/cladding	1	Low	Low
	Coolant	1	Medium	Low
	Primary coolant boundary	1	Medium	Medium
	Guard vessel	2	Low	Low
	Confinement (HVAC)	3	Low	Very High
Chemical hazards	Oxygen	N/A	Low	Medium
Support systems	Power	1	Low	Very High
	I&C	1,2	Medium	High
	Plant cooling	1	Low	Very High

NOTE: The defense line value represents the typical use of the SSC in an operational plant according to the defense line concept in this report, SSC Importance is the relative importance of protection of that SSC (and not necessarily the direct importance of that SSC to the safety of the plant), and the SSC Vulnerability represents the relative vulnerability of the SSC to direct, indirect, and cyber-assisted adversary action.

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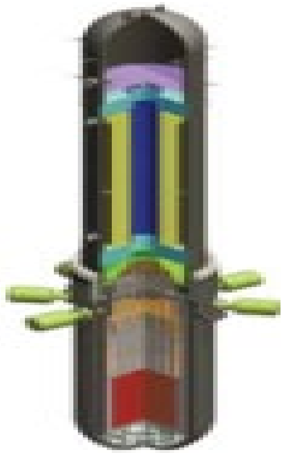
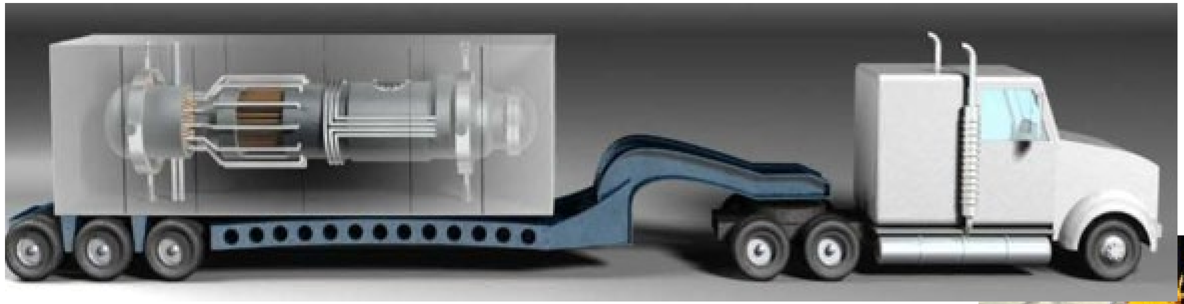
Advanced Reactor Classes and Attributes of Interest

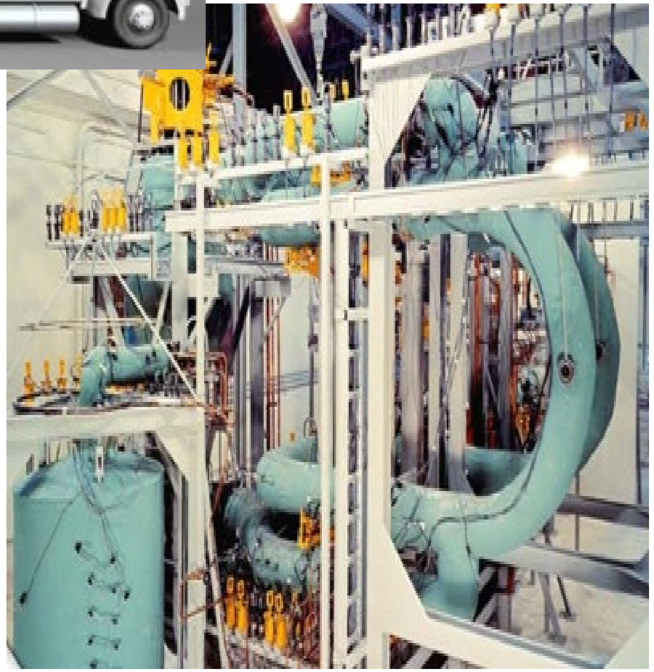
National Nuclear Security Administration



- **Advanced Pressurized Water/Boiling Water Reactors**
- **High Temperature Gas Reactors**
- **Molten Salt Reactors**
- **Liquid Metal Fast Reactors**
- **Microreactors**

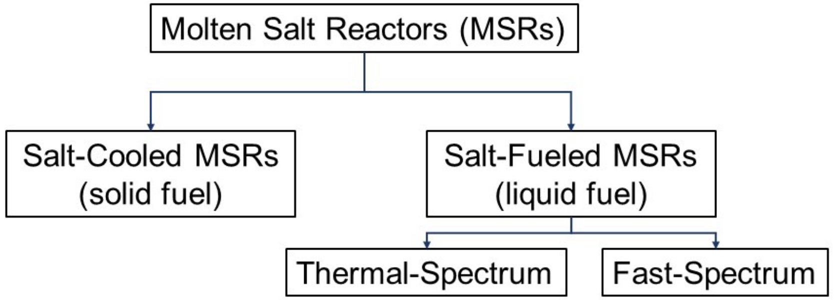


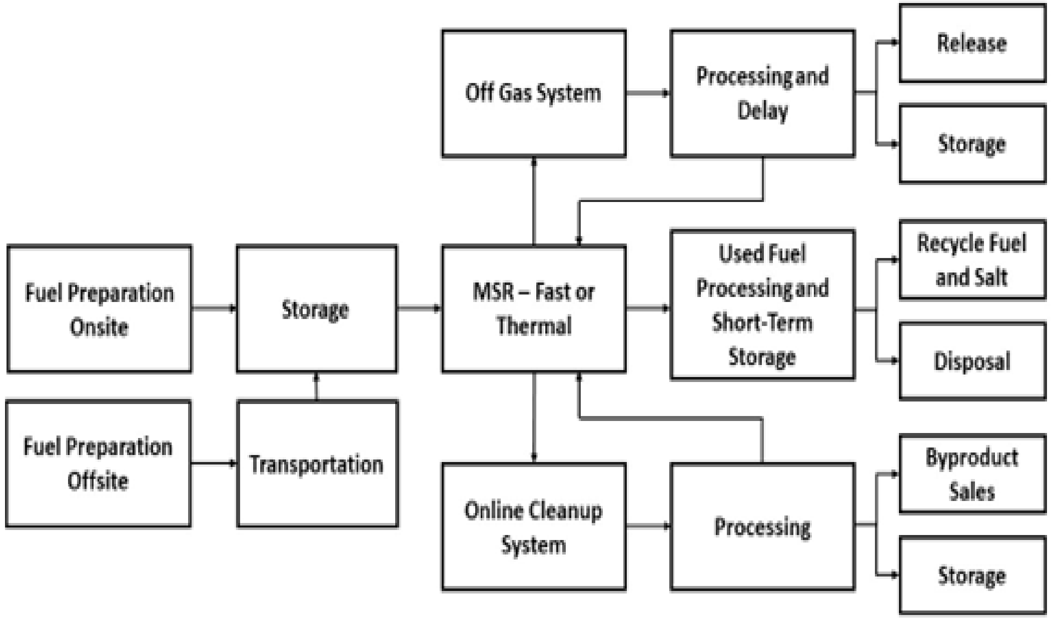
- Common Considerations
  - Passive Decay Heat Removal
  - Final Security Barrier Protection of Critical Systems and Source Terms
  - Ex-Core Source Targets
  - Functional Containments
  - Control Systems and Remote Operations (Cyber)
  - Dispersibility Models for Advanced Fuels Related to Radiological Sabotage



Molten Salt Reactor Considerations

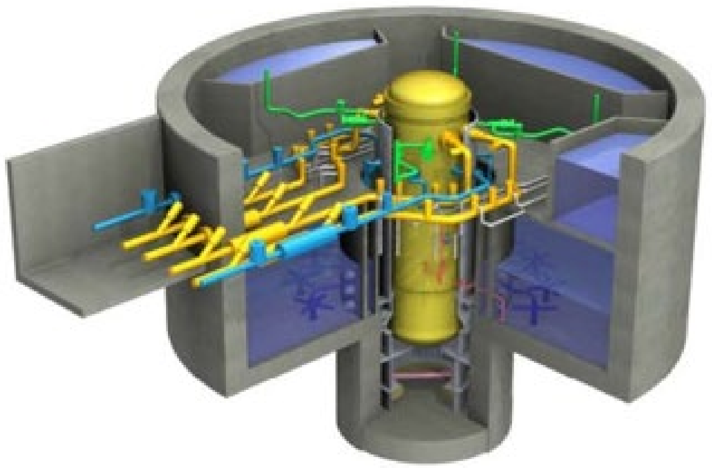
- **Platforms:**
  - **Pool and Forced Flow, Thermal and Fast, Homogeneous Dispersed and Rodded Fuels**
- **Key MSR Considerations:**
  - Keeping the fuel salt and off-gas in-vessel reduces the number of locations for large quantities of radioactive materials during operation and thereby the number of potential targets for an adversary.
  - Salt Drain Tank Design
  - Decay Heat Removal Systems
  - Off Gas System Management for Source Term Reduction (design and operations)
  - Fuel Salt on-line processing systems
  - Fuel Salt Waste Processing (waste form processing and stabilization)
  - Refueling Line Concerns

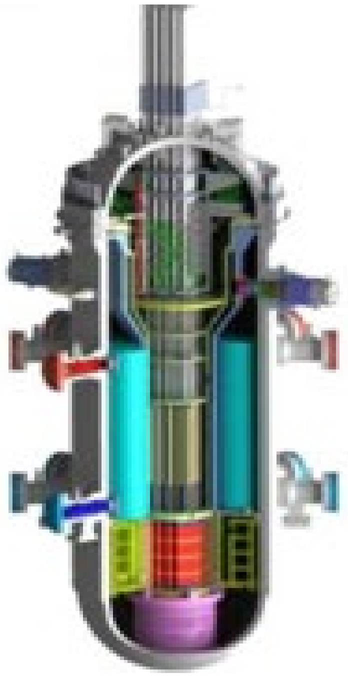




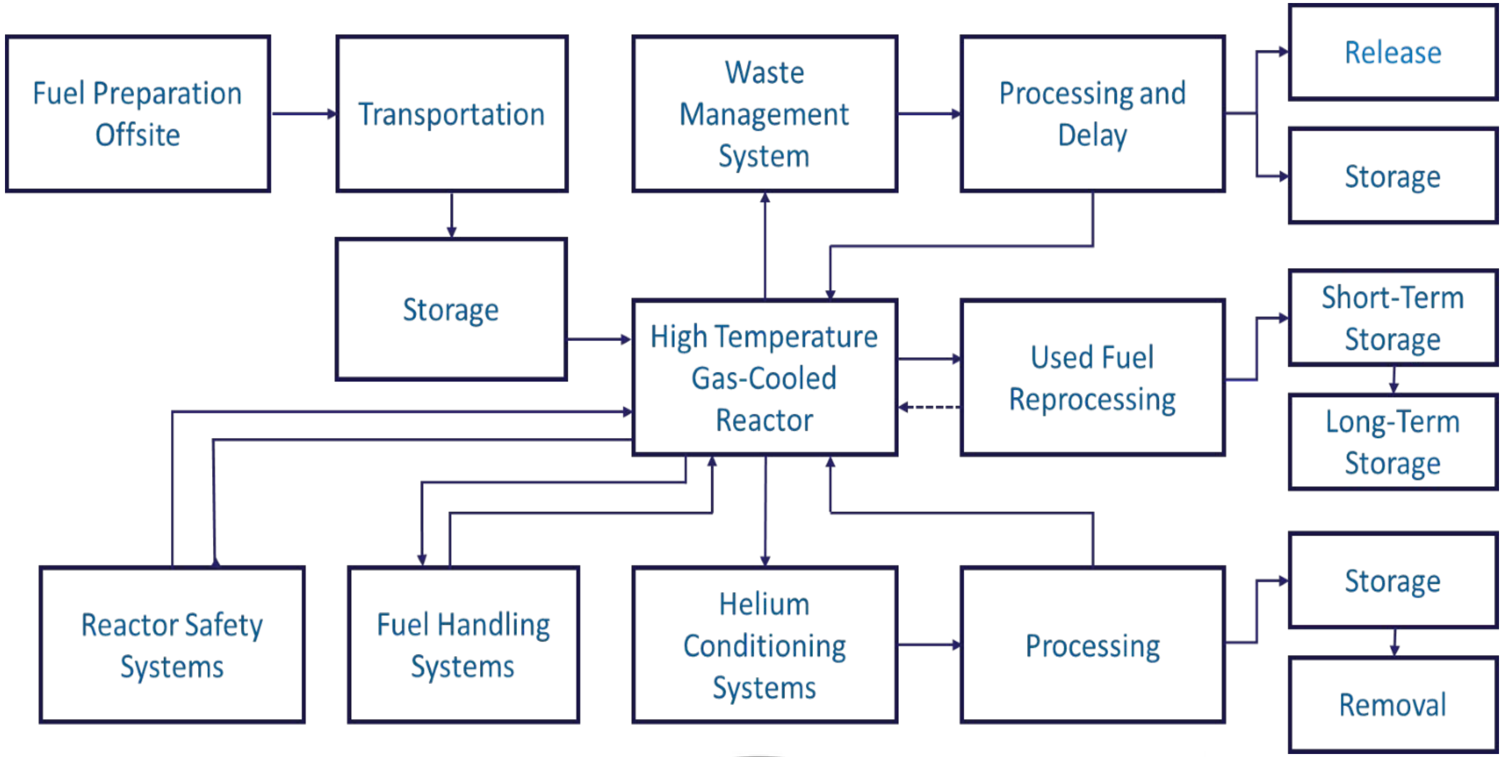
Advanced Light-Water Reactors

- **Platforms:**
  - -Advanced Pressurized Water Natural Convection Flow Reactors
  - -Advanced Boiling Water Reactors
- **Key ALWR Considerations:**
  - Passive Decay Heat Removal
  - Final Security Barrier Protection of Critical Systems and Source Terms
  - Critical Systems Vessel Integrity
  - Functional Containments
  - Control Systems and Remote Operations (Cyber)
  - Dispersibility Models for Advanced Fuels Related to Radiological Sabotage

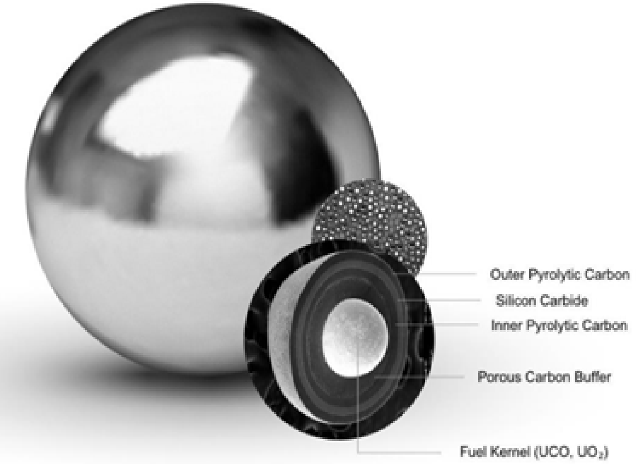




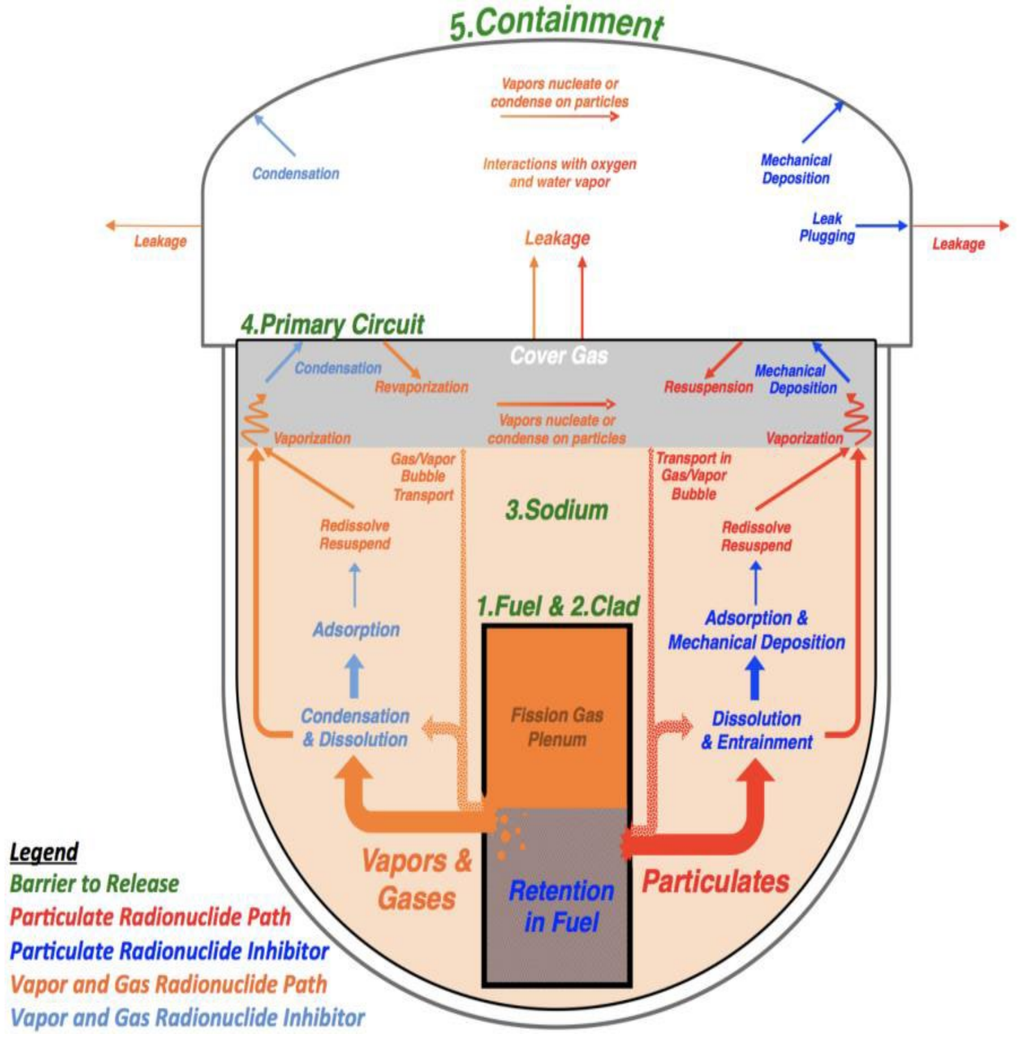
HTGR Considerations



- **Platforms:**
  - Prismatic
  - Pebble Bed
- **Key HTGR Considerations:**
  - Online Fueling/Refueling Systems
  - Helium purification system
  - Moisture events
  - Final RN barriers to release and grade
  - Reactor building design (barrier)
  - Gaseous and liquid waste support systems
  - Prismatic vs PBR



Liquid Metal Fast Reactors



Platforms:

- Pool and Forced Flow Loop Types,
- Fast Spectrum

Key Considerations:

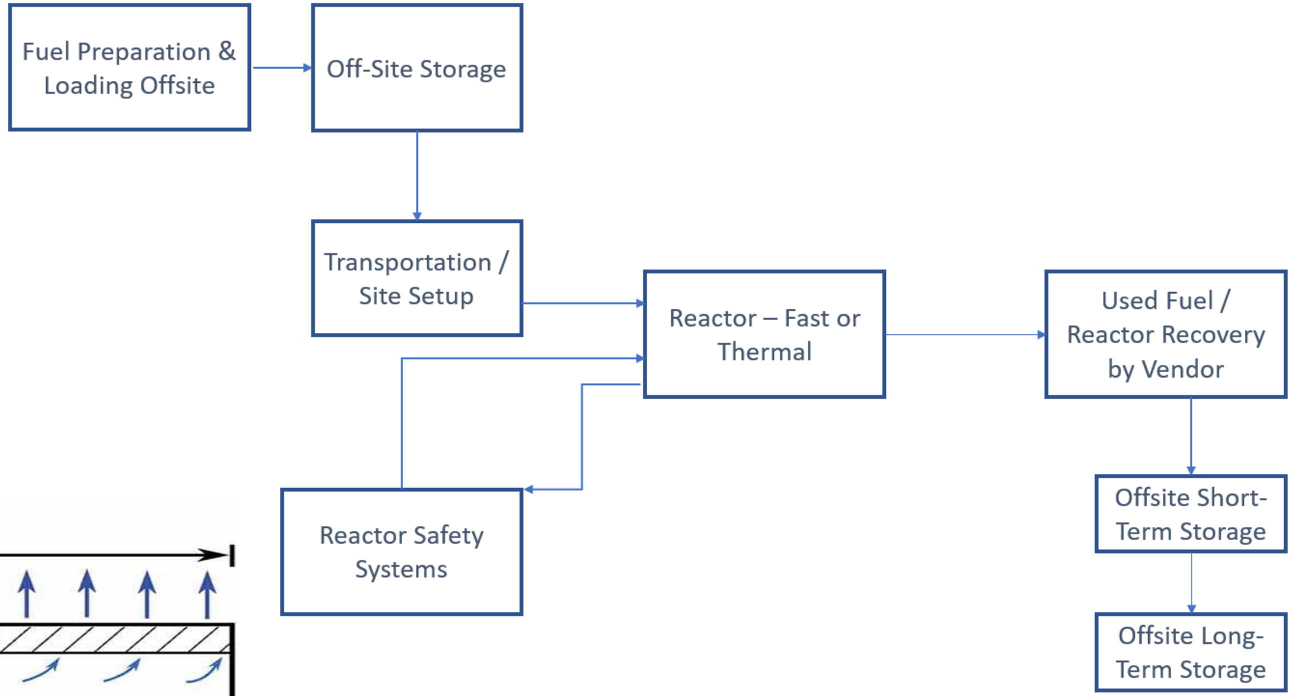
- Passive Decay Heat Removal
- Final Security Barrier Protection of Critical Systems and Source Terms
- Cover Gas Cleanup System Sources
- Na Purification System: Cesium Cold Trap / Cleanup System & Support Systems
- Na Air / Water Interactions
- Control Systems and Remote Operations (Cyber)

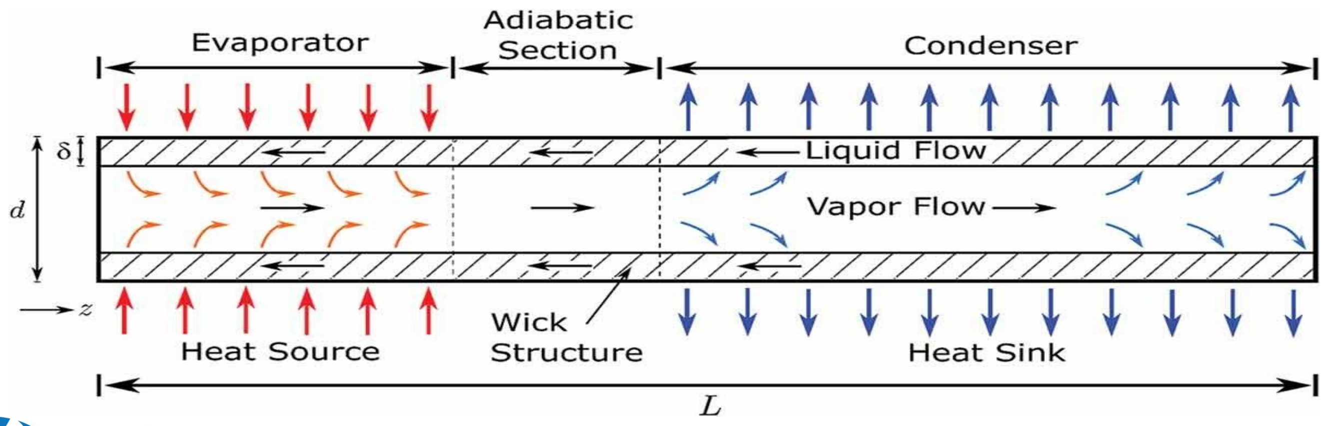
Micro-Reactors

- **Types of Platforms:**

  -Molten Salt Reactors -High Temperature Gas reactors -Heat Pipe Reactors

- **Key Considerations:**
  - Compact Nature, Footprint, Source Strength
  - Final Barriers (RN Retention and Security)
    - Re-enforced / below grade
  - Passive Decay Heat Removal
  - Heat Pipe Energy Transfer Reversals and Ramp Rates (HP Protection by design)
  - Remote Operations Considerations





Summary Status of Report Availability and Closing

National Nuclear Security Administration

- Actions to Validate the Process
  - A peer review of the process by Sandia National Lab experts will further inform/refine the approach
  - Test case use to be performed on a developer design as part of the NNSA NEXUS collaborative support process
- Finalize the report and release to OSTI and NEXUS Website for use by developers and bi-lateral partners internationally
- Finalize the one-page technology summary sheets for deployment on the NNSA NEXUS website for reference by interested partners

https://nuclear-nexus.anl.gov/nexus/

https://nuclear-nexus.anl.gov/nexus/#/international-nuclear-security/security-by-design#how-can-industry

NNSA International Advanced Reactor Deployment Goals

INS International Nuclear Security

Reducing Risk of Nuclear Terrorism

United States
Department of Energy
National Nuclear Security Administration
International Nuclear Security

Economic Reasons for 3S-by-design

December, 2023

Bobby D. Middleton, PhD

Release number

International Nuclear Security
Reducing Risk of Nuclear Terrorism

Overview

- Nuclear Construction Costs – Recent History
- Nuclear O&M Costs
- Translating to ASMRs
- Regulatory Questions
- Example: Measuring Financial Benefits of SeBD
- Investor Perspective

Some Recent History in Nuclear Construction costs

- Vogtle Units 3 and 4
  - Cost of $30 Billion (with Unit 4 still under construction)[1]
  - Total expected to be more than $35 Billion
  - Two 1117 MWe AP1000s
  - Expected overnight costs of ~$8000/kWe with total costs (including cost of money) about twice that[2]
- VC Summer
  - In 2008, estimated costs expected to be $9.8 Billion
  - By 2017, this had grown to $25 Billion
  - Westinghouse filed for bankruptcy
  - Project abandoned by Santee Cooper and SCANA

O&M Costs

- Different estimates exist for nuclear O&M costs
  - (Burli, Yadav; 2020) ~ $19.69/MWh
    - Assuming:
      - $31.88/MWh cost to produce electricity (LWRS study)
      - 93% capacity factor (~industry average)
      - Obtain O&M ~ $160 M/yr for 1000 MWe plant
    - => ~ $160/kWe physical security costs
  - (Middleton, Drennen; 2021)
    - ~ $86/kWe **without security costs** (in 2020 dollars)
    - Security costs depend on design and response time
      - Baseline design (Fences and badge readers) with 10 minute response time: $36.03/kWe
      - Baseline design (Fences and badge readers) with 1 minute response time: $45.03/kWe
    - => ~ $122 - $131/kWe O&M costs
    - Advanced design (Baseline plus Xray, BMS, PIDAS, vibration cables)
      - Baseline design with 10 minute response time: $64.44/kWe
      - Baseline design with 1 minute response time: $73.44/kWe
    - => ~ $150 - $159/kWe O&M costs
    - **Construction costs are also highly dependent on design ($15-$300/kWe).**

Translating to ASMRs (Discussion)

- How does security cost scale with power output?
  - Anything less than a proportional scaling is likely not going to be acceptable for commercial power production).
  - Niche markets
    - Remote villages (Shungnak)
    - DoD
    - Space nuclear
- Who pays for the design work?
  - It would seem that any 3S-by-design work would need to be done by the vendor at an early stage.
  - Even if it is successful, the designers' must be paid.
  - This cost must be rolled into the cost that the vendor charges the owner/operator.
- Who pays for the PPS upgrades?
  - Who is responsible for ensuring the PPS is constructed correctly?
  - Who interacts with the contractor?
  - If contractor can't deliver on budget, who is responsible?

Regulatory Questions

- For niche markets, who regulates security?
  - Military bases
  - DOD bases
  - Space
  - Remote villages (assume this one is NRC, but how to have NRC reps on-site)

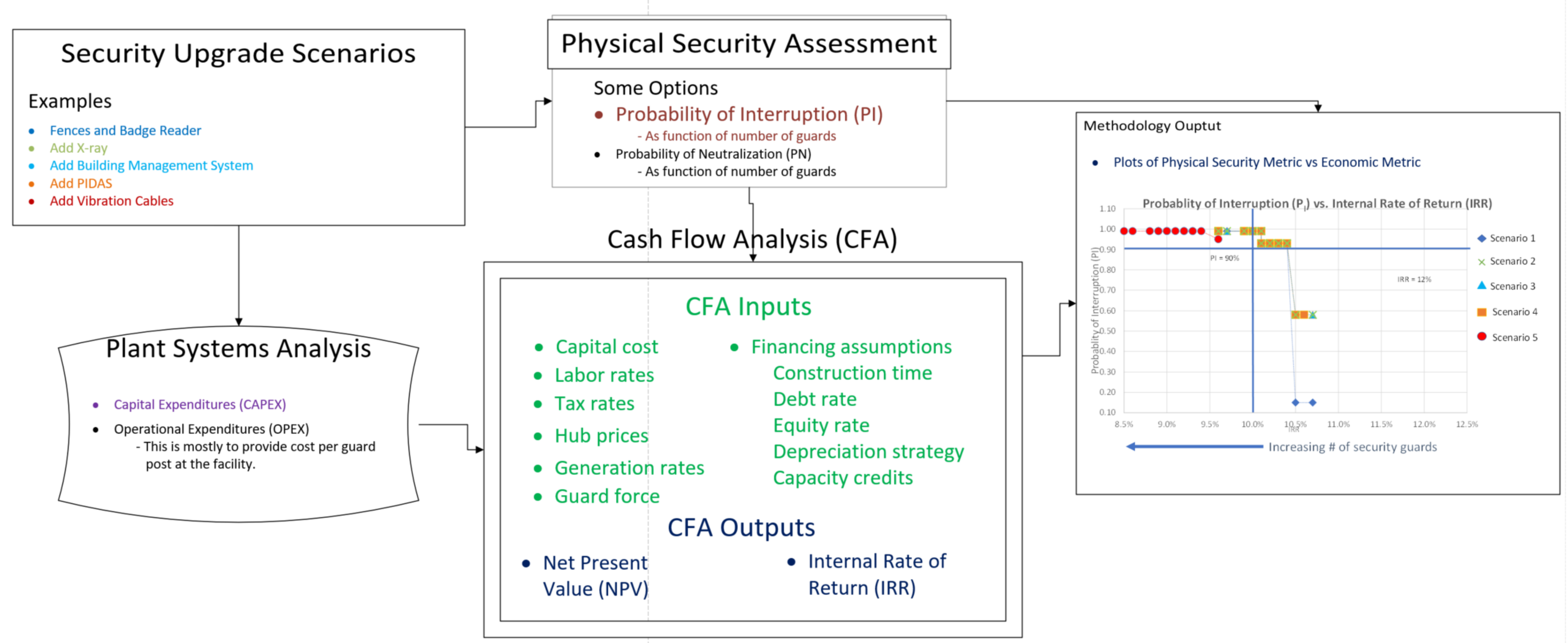
- How will the NRC handle security regulations at various ASMRs?
  - First of all, some people at Sandia may already know this (not my expertise)
  - Smaller LWRs (e.g., one NuScale unit)
  - Advanced reactors (e.g., molten salt, gas-cooled, liquid metal)
  - HALEU fuel

- **How do regulations translate from traditional to smaller reactors?**

Example: How do we measure financial benefit of security-by-design (SeBD)?

NNSA National Nuclear Security Administration

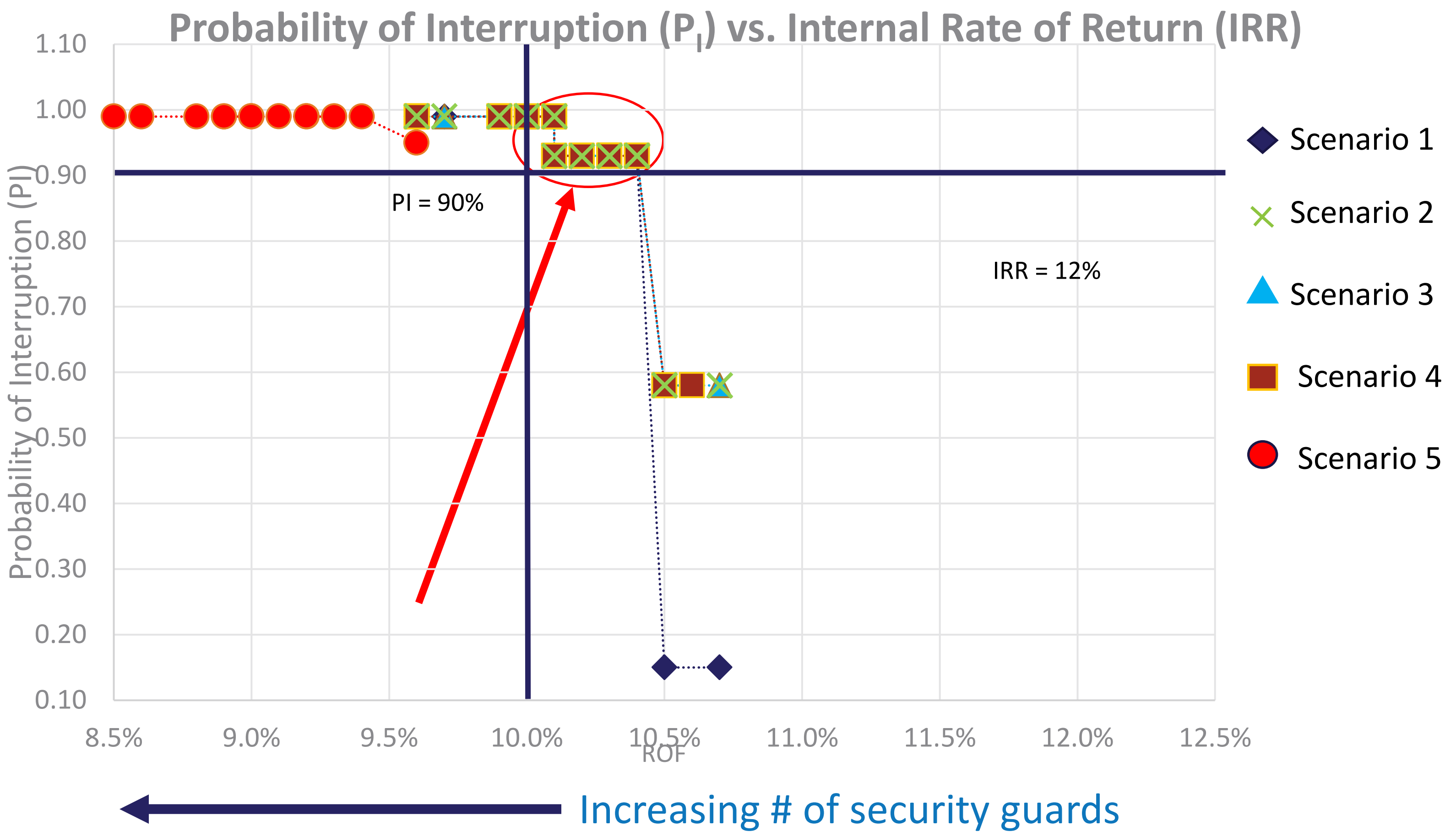
- Sandia, INL, and ORNL developed a methodology for combining standard financial tools to SeBD



Investor Perspective

National Nuclear Security Administration

Investors typically have a minimum rate of return (ROR) requirement. For a required ROR of 10%, 5 or 6 scenarios are profitable.



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Discussion/Questions