Department of Energy's
National Nuclear Security Administration

Recommendations and Resources for Advanced Reactor Developers

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DISCLAIMER

This NNSA resource document is not a substitute for any domestic or international requirement. Industry members are responsible for knowing, understanding, and adhering to applicable international and domestic statutes and regulations for their work.

Introduction

The U.S. Department of Energy's National Nuclear Security Administration (DOE/NNSA) works with government and industry partners to prevent or limit the spread of materials, technology, and expertise related to nuclear and radiological weapons and programs around the world. Over decades of work, NNSA has developed deep expertise in nuclear security, safeguards, nuclear export control policy, and increasing the proliferation resistance of nuclear reactor cores.

NNSA is partnering with DOE's Office of Nuclear Energy (DOE-NE) to support the ongoing effort in the United States to develop, deploy, and export the next generation of advanced nuclear reactor technologies for civil energy purposes. As U.S. industry works towards these goals, both DOE and NNSA agree it is critical that U.S. advanced reactor companies understand early in their design processes the key requirements and considerations they must incorporate to ensure that U.S. companies produce products that are exportable around the world in accordance with the highest nonproliferation and security standards. U.S. competitiveness can be enhanced by having an edge in safety, security, and safeguards (3S). In today's dynamic and competitive environment, partnership between industry and government can ensure a competitive advantage that is consistent with international nonproliferation norms.

In this document, NNSA provides an overview of existing legal requirements, guidance, and policy/technical considerations in four areas that NNSA believes are critical for advanced reactor designers to understand and employ as they design, develop, license, and consider exporting their technologies: nuclear security; nuclear safeguards; 10 CFR Part 810 export control compliance; and proliferation resistance in reactor core design. This document does not address all technology-specific considerations, including important aspects related to safety and emergency preparedness and response. Rather, NNSA's objective is to provide industry with resources that will serve as the basis for deeper engagement in which NNSA can provide more detailed advice and technical expertise on individual projects and technologies to support their expedited deployment.

Within the U.S. Government, the Nuclear Regulatory Commission (NRC) is responsible for providing the regulatory framework and requirements for domestic security and safeguards. This document references several key NRC guidance documents for domestic reactor deployment. NNSA is focused on advising industry on the international frameworks and considerations in these areas that are critical for advanced reactor designers to understand and integrate into their reactor designs to be best positioned to export their technologies. Companies should reference the NRC's guidance and engage NRC early in the process should they have any questions on domestic technology licensing and deployment.

Each section of this document includes relevant online resources and may include contact information for NNSA experts in the section's focus area. NNSA encourages companies to contact these experts with further questions, or for clarification on this document.

1 Nuclear Security

Preventing nuclear terrorism cannot be seen in isolation from developmental goals such as providing clean energy sources and promoting peaceful uses of nuclear technology. NNSA leads international efforts to prevent the theft or sabotage of nuclear material and facilities worldwide. NNSA's Office of International Nuclear Security (INS) has worked for decades with countries to strengthen security at the national and facility level, and is committed to working with the U.S. advanced reactor community to ensure that U.S. technologies can be exported in a timely and efficient manner with nuclear security principles and technical solutions already factored into their designs. Below are key existing legal and policy requirements as well as initial considerations for security that are critical for advanced reactor developers to incorporate as they move forward with their designs.

1.1 International Framework

The International Atomic Energy Agency (IAEA) defines nuclear security as, "the prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities." Threats to nuclear security have led the IAEA to release multiple Nuclear Security Series (NSS) guidance documents covering many topics, including physical protection, sabotage, material accounting, information security, cyber security, and safety-security interface. NNSA advises that U.S. companies understand and adhere to the IAEA's baseline guidance on nuclear security.

For example, consider NSS No. 13, *Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)* which calls for both capabilities to locate and recover missing nuclear material, and efforts to mitigate the effects of sabotage. Specifically, the INFCIRC/225/Revision 5 requires the consideration of three types of security risk for the protection of nuclear material and nuclear facilities: (1) Risks associated with unauthorized removal and the intent to construct a nuclear explosive device; (2) Risk associated with the unauthorized removal which could lead to subsequent dispersal; and (3) Risk associated with sabotage. Other IAEA implementing guides applicable to advanced reactors and small modular reactors (SMRs) are (but not limited to) NSS No. 27-G, *Physical Protection of Nuclear Material and Nuclear Facilities (Implementation of INFCIRC/225/Revision 5)* and NSS No. 35-G, *Security During the Lifetime of a Nuclear Facility*. NNSA recognizes, however, that there is a lack of an international regulatory framework on how security-by-design principles should be incorporated into advanced reactor designs. DOE and NNSA fully support government, industry, and international organization collaboration to fill this void.

1.2 Domestic Legal, Regulatory, and Policy Framework

The NRC regulates and provides guidance for the security of domestic nuclear facilities through 10 CFR Parts 73 and 74, the overarching NRC regulations to address systems to protect nuclear facilities and materials in the United States against theft and sabotage. 10 CFR Part 73 "Physical Protection of Plant and Nuclear Materials" specifies requirements for administrative and engineered systems that provide key security functions for protecting against theft of nuclear material and sabotage of nuclear facilities, while 10 CFR Part 74 "Material Control and

Accounting of Special Nuclear Material" establishes requirements related to material control and accounting at sites and during transfer of material. Advanced reactor developers must adhere to all security requirements in these regulations.

The NRC also provides the following guidance for advanced reactor designers to consider during the facility design process:

- "Policy Statement on the Regulation of Advanced Reactors," (73 FR 60612; October 14, 2008), which states that the design of advanced reactors should "include considerations for safety and security requirements together in the design process such that security issues (e.g., newly identified threats of terrorist attacks) can be effectively resolved through facility design and engineered security features, and formulation of mitigation measures, with reduced reliance on human actions."
- "DRAFT Non-LWR Physical and Cyber Security Design Considerations – March 2017" (Agency-wide Document Access and Management System (ADAMS) Accession No. ML16305A328), in which the NRC provides seven physical security design considerations and three cyber security considerations:

  Physical Security

  1. Intrusion detection
  2. Intrusion assessment systems
  3. Security communication systems
  4. Security delay systems
  5. Security response
  6. Control measures protecting against land and waterborne vehicle bomb assaults
  7. Access control portals

  Cyber Security

  1. Defense model architecture
  2. Cyber security defense-in-depth
  3. Least functionality

1.3 NNSA Resource Recommendations

If direct collaborations begin with U.S. advanced reactor designers, NNSA's early security-by-design technical recommendations will not only address physical security and nuclear material accounting, but also insider threats, cyber security, transport security, and sabotage mitigation capabilities. For companies that would like to export their technologies, NNSA and the national laboratories strongly recommend that advanced reactor designers take all appropriate technical resources into consideration when incorporating security into their designs. NNSA and the national laboratories will continue to develop and share best practices and relevant technical resources for advanced reactors, which include, but are not limited to:

- The Sandia National Laboratories'(SNL) "Security-by-Design Handbook" (SAND2013-0038)
  - Provides guidance on incorporating a physical protection system (PPS) into a new nuclear power plant or nuclear facility at the system level to minimize the risk of malicious acts leading to nuclear material theft and facility sabotage.
  - Presents a four-element strategy – an integrated design team, risk-informed design, a facility design/operations life cycle, and application of "Security by Design" principles and practices – to achieve a robust, durable, and responsive security system.
  - Can be found at https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2013/130038.pdf (note: SNL is working to update this for more direct applicability to new advanced reactor technologies and general design parameters.)
- Idaho National Laboratory's *Cyber-Informed Engineering* report (INL/EXT-16-40099)
  - Provides a framework for bridging the gap between engineering design and cybersecurity to identify and address cyber vulnerabilities at the earliest stages in the design process. In response to an ever increasing cyber threat-scape, cyber-informed engineering (CIE) principles are also incorporated into security-by-design of digital assets serving a critical role in nuclear operations, safety, and/or security systems.
  - Can be found at https://inldigitallibrary.inl.gov/sites/sti/sti/7323660.pdf

In addition to the above resources, NNSA advises that advanced reactor developers consider the following important principles to design robust security into their systems as early as possible:

- Security-by-design is not only about physical security. It also incorporates material accounting to prevent insider threats, cyber security, transport security, and sabotage mitigation capabilities.
- For optimum efficiency and effectiveness, security should be addressed as part of a comprehensive systems approach along with safety and safeguards (3S).
- Take physical protection into account as early as possible in site selection and design.
- Work with governments of countries, especially regulatory authorities, to which your company plans to export to define the design basis threat and unacceptable consequences. Threats from both insider and external adversaries should be included in the design basis threat.
- Use a graded approach to security where the level of physical protection should depend on the categories of the nuclear material or levels of unacceptable consequences.
- Consider both likelihood and consequence of theft and sabotage in evaluating system effectiveness of physical protection systems.

NNSA recognizes that security features and capabilities incorporated into a reactor design might have cost implications that companies must weigh as they establish and refine their business cases.

NNSA and national laboratory experts are willing to work with U.S. companies to find the right balance between security, efficiency, and cost in the process of ensuring that U.S. designs are competitive and successful in the global marketplace.

Additionally, NNSA works with the IAEA and like-minded IAEA Member States to ensure that the international security framework for advanced reactors is consistent with U.S. requirements and standards, as appropriate to the host country's threat environment, to support deployment of new U.S. reactors internationally.

2 International Nuclear Safeguards

NNSA's Office of Nonproliferation and Arms Control (NPAC) enhances the capabilities of the International Atomic Energy Agency (IAEA) and partner countries to implement safeguards obligations[1]. International nuclear safeguards are technical measures used to verify a country is in compliance with its legal agreements with the IAEA and not diverting nuclear material to weapons programs or pursuing undeclared nuclear activities. By understanding and implementing international safeguards and safeguards-by-design concepts early in their projects, advanced reactor developers can achieve cost, schedule, and licensing benefits that can make their projects more competitive globally.

2.1 International Framework

The IAEA's nuclear safeguards objectives are to:

- Detect the diversion of nuclear material from facilities;
- Detect the undeclared production of nuclear material; and
- Detect undeclared nuclear material or activities in the state as a whole.

The IAEA's technical measures include, among other things:

- Nuclear Material Accountancy: item counting, weighing, and non-destructive and destructive assay measurements
- Containment and Surveillance: the use of tamper indicating devices and cameras to maintain continuity-of-knowledge
- Design Information Verification: in-field observations by inspectors to confirm that a facility is being built as declared

International safeguards are pursuant to the Treaty on the Nonproliferation of Nuclear Weapons (NPT). Under Article III of the NPT, all non-nuclear weapon states are required to conclude a comprehensive safeguards agreement (CSA) with the IAEA, and the *de facto* requirement for nuclear cooperation with the United States includes a state having an Additional Protocol in force

[1] NPAC coordinates closely with the DOE Office of Nuclear Energy's Advanced Reactor Safeguards sub-program, which supports near-term research in areas related to domestic requirements for material control and accounting and physical protection to help facilitate the deployment of advanced reactor designs.

with the IAEA as well[2]. As signatories to these agreements, countries have specific reporting requirements to the IAEA about their nuclear fuel cycle activities. With respect to new nuclear facilities, the application of safeguards requires that a country submit detailed design information about the facility before construction begins and throughout the build process, and facilitate IAEA design information verification to confirm consistency of the as-built facility with the country's required annual nuclear material declarations. The international safeguards requirements for commercial nuclear material and facilities in the U.S. are given in 10 CFR Part 75, "Safeguards on Nuclear Material -- Implementation of Safeguards Agreements between the United States and the International Atomic Energy Agency." Facilities also often have to make physical or operational accommodations for IAEA equipment and inspection activities.

2.2 Safeguards-by-Design Concept

Safeguards-by-Design (SBD) is a voluntary process to integrate features into a nuclear facility's design to facilitate the application of IAEA safeguards and allows the IAEA to tailor the application of international safeguards to a facility design. SBD aims to prevent safeguards requirements from unduly interfering with the smooth construction and operation of a facility.

SBD is an iterative process of communication between the designer/operator of a facility, the state's regulatory body, and the IAEA. The main objectives of SBD are to:

- Reduce risk to project scope, schedule, and budget;
- Avoid costly and time-consuming redesign work or retrofits of facilities;
- Mitigate the potential for negative impact on facility licensing (e.g. if retrofits are required for international safeguards purposes after successful licensing action, will those retrofits affect the license?);
- Make the actual implementation of IAEA safeguards more effective and efficient; and
- Help build public confidence.

SBD is voluntary in that the IAEA does not require including safeguards accommodations in the preliminary facility design phase. Additionally, sharing design information during the SBD process may precede the legal requirements to provide design information to the IAEA. Often in the past, nuclear facility designers and operators have added safeguards features to their plants following design completion or even after construction. Under the SBD process, States, industry, and the IAEA would discuss safeguards requirements much earlier, during the design phase. Such early coordination and planning could influence decisions on key design features, such as chemical processing, equipment design, material storage and handling, and facility layout, in a manner that simplifies safeguards implementation. Thus, early consideration of SBD has the potential to save the vendor significant costs, avoid schedule delays, and have a large impact on the nonproliferation

[2] The two governing legal documents for IAEA safeguards are: (1) The Comprehensive Safeguards Agreement (INFCIRC/153), which gives the IAEA the right and obligation to ensure that safeguards are applied on all nuclear material in all peaceful activities, and (2)The Model Additional Protocol (INFCIRC/540), which strengthens the effectiveness and improves the efficiency of safeguards by expanding the information provided by the State, expanded access to locations in a State, and measures that facilitate in-field verification activities.

field by promoting intrinsic facility or process features that enable enhanced safeguards, thereby reducing the safeguards cost to the State, the operator, and the IAEA over the long term.

Safeguards may be a little known or low priority area for some designers and vendors; however, they may have an interest in SBD because a design that facilitates the incorporation of international safeguards requirements is likely to be more appealing to a customer in a State where safeguards are obligatory. The operator ultimately is responsible for supporting IAEA safeguards implementation within the facility, and having a facility that includes safeguards requirements features potentially lowers the costs and impact on operations at that facility (e.g., the potential for fewer inspection days for physical inventory taking and verification). NNSA strongly recommends that advanced reactor developers engage in the SBD process early with the IAEA and countries to which they are interested in exporting their technologies to be able to realize the benefits listed above.

Depending on facility type and design specifications, the SBD process results can range from better implementation of a known safeguards approach to implementation of new and more effective approaches. The IAEA can use facility design information to select material balance areas, strategic measurement points, and a safeguards approach, and to develop an annual safeguards implementation plan that includes a design information verification plan throughout the life cycle of a facility.

2.3 Resources for Designers

Interactions between and among facility designers, national regulators and operators, and the IAEA typically are very formal and must go through State institutions. To prepare for these conversations, however, NNSA's NPAC sponsors SBD projects that bring together DOE experts with various stakeholders, including industry partners, to evaluate how international safeguards requirements can be integrated better into the design process of new nuclear facilities. Additionally, NPAC works closely with the IAEA on the development of guidance documents for the international community to promote the widest-possible distribution of good practices for the consideration of safeguards.

- NPAC and the national laboratories have implemented several SBD projects with the advanced reactor community, including in direct partnership with a number of small modular reactor vendors. Facility specific guidance is found here: https://www.energy.gov/nnsa/downloads/safeguards-design-guidance-documents
- NPAC is partnering with the Office of Nuclear Energy's Molten Salt Reactor program to consider the nonproliferation and safeguards aspects of these proliferation-sensitive technologies.
- NPAC, in partnership with other NNSA programs, is working with the Nuclear Energy Institute's Advanced Reactor Working Group to ensure that nonproliferation, safeguards, security, and regulatory aspects of these new technologies are considered early in the design process.
- NPAC has established an SBD working group to provide SBD information and material to U.S. industry including lessons learned and practical examples of how SBD has been

applied to nuclear facilities. Contact Wayne Mei at Wayne.Mei@nnsa.doe.gov for more information.

3 10 CFR Part 810 Export Control Compliance

NNSA implements the requirements under Section 57b. of the Atomic Energy Act of 1954, as amended, and Part 810 of Title 10 of the Code of Federal Regulations (Part 810) to authorize exports of unclassified civil nuclear technology.[3] That may include, but is not limited to, exports of blueprints, designs, computer codes, training, and assistance. Assistance may include public speaking or lecturing, or technical support or instruction to a foreign counterpart, including those that may already legally possess covered technology but need U.S. expertise to properly apply that technology. It is a *legal requirement* that the Secretary of Energy approve this type foreign engagement, and both civil and criminal penalties for failure to ensure the activity is approved may apply.

3.1 Threat of Foreign Theft or Diversion of U.S. Advanced Reactor Technology

According to the 2017 National Security Strategy, "every year, competitors such as China steal U.S. intellectual property valued at billions of dollars." In the 2018 U.S. Policy Framework on Civil Nuclear Cooperation with China, advanced reactor technology is considered significant, and is subject to a ***presumption of denial*** for transfers to China. The potential appropriation of advanced reactor technology by foreign governments or entities is not only contrary to U.S. law, but also poses a threat to U.S. companies' intellectual property.

Additionally, unauthorized exports of such technology may be subject to both civil and criminal penalties. Willful Part 810 violations may be subject to criminal investigation by the Federal Bureau of Investigation (FBI), and prosecution. Additionally, NNSA received authority under the *John S. McCain National Defense Authorization Act of Fiscal Year 2019* to impose civil monetary penalties for Part 810 violations. If a U.S. company becomes aware of a Part 810 violation, NNSA strongly recommends it voluntarily self-disclose that violation within 30 days. NNSA will take self-disclosure into account when considering enforcement actions.

3.2 Understanding and Complying with the Part 810 Regulation

NNSA has delivered awareness training to an estimated 500 industry, university, and national laboratory personnel since 2018 to ensure that exporters of technology understand, and are in compliance with, Part 810 requirements. The training highlights common misunderstandings about the Part 810 regulations and helps individuals understand their enduring, personal obligation to protect controlled nuclear technology. NNSA highly encourages U.S. companies to remain vigilant to any potential theft or unauthorized transfer of Part 810 controlled assistance and

[3] The Nuclear Regulatory Commission licenses the export of nuclear materials and technology through its regulations found at Title 10 of the Code of Federal Regulations, Part 110, "Export and Import of Nuclear Equipment and Material.

technologies and looks forward to deepening collaboration with advanced reactor designers to ensure that they understand Part 810 requirements as they pertain to advanced reactor technologies.

NNSA's Part 810 training outlines key areas that are critical for U.S. companies to understand and put into practice as they begin considering how to deploy their technologies globally. The entire training, as well as other resources on the Part 810 regulations, is available at https://www.energy.gov/nnsa/10-cfr-part-810.

4 Proliferation Resistance in U.S. Advanced Reactor Concepts

In addition to its ongoing work in Safeguards, Security, and Part 810 guidance, NNSA has launched a program to coordinate efforts between government and industry to increase proliferation resistance during the reactor design stage. This program, Proliferation Resistance Optimized Cores (PRO-Core), provides a framework for assessing reactor system designs in order to minimize special nuclear materials production (e.g., plutonium) and diversion pathways, and maximize performance for stated peaceful uses (e.g., nuclear energy, neutron science, materials irradiation, medical isotope production, etc.).

4.1 Importance of Proliferation Resistance

Proliferation resistance refers to the adoption of reactor and fuel cycle concepts that would make the diversion of civilian nuclear fuel cycle capabilities and technologies for weapons purposes more difficult, time-consuming, and transparent. It is distinct from, but complementary to safety, safeguards, and security concerns.

As highlighted by the IAEA and recent U.S. congressional legislation, it is critical to national and international security that current and future peaceful nuclear technology be developed with proliferation resistance in mind. Finding ways to improve proliferation resistance while maintaining the function and performance of reactors will encourage the confidence in and promotion of nuclear technologies domestically and globally. Identifying possible proliferation pathways and addressing those concerns during the design phase will improve fundamental proliferation resistance of the reactor in the most cost effective manner and make it less likely that proliferation measures can be reversed.

4.2 NNSA Resources

PRO-Core provides consultation with a team of experts from across the U.S. national laboratory complex to work with the reactor designer to identify potential proliferation concerns in the core, primary system design, and ancillary systems and facilities, and to suggest adjustments to the design to minimize those concerns. In return, the PRO-Core team will provide consulting advice to help with optimizing reactor performance for the reactor operator's stated purposes and with licensing and startup of the reactor.

The PRO-Core program works with reactor designers and operators to define performance requirements and then to review the reactor design using a proliferation resistance assessment framework currently being developed with the national laboratories. While each reactor type and design will require a customized assessment, the PRO-Core program is developing a comprehensive framework that will help identify the relevant design areas for further assessment in each reactor and the program team will work with the designer to balance proliferation resistance with appropriate performance margin and flexibility. Some areas that the team will review are:

- Reactivity control system, excess reactivity, and the associated power distribution;
- Power levels and cooling capacity;
- Position, spacing, and dimensions of fuel and core; and
- Balance of plant features: key attributes for the ancillary systems and infrastructure that are integrated with the plant in a way that are aligned with stated peaceful uses.

4.3 NNSA Collaboration

NNSA seeks industry partners to further develop implementation of proliferation resistance for both advanced reactors and research reactors. PRO-Core assessments require close collaboration with reactor designers and, on a case-by-case basis, their clients. This collaboration is conducted to protect proprietary information and to maintain the highest level of trust between stakeholders. NNSA recognizes the industry priority for performance and the concern that this assessment introduces an additional step into the reactor design process. The collaboration process offers incentives to both the reactor designer and operator for collaborating on proliferation resistance, including:

- Technical design review, integrated with other nonproliferation priorities and programs, including next generation safeguards and security by design elements;
- Technical assistance with licensing and commissioning, including coordination with the NRC and other regulators as appropriate, informational meetings, assistance on application submission and responses to regulator questions;
- Support for operators in other countries to assess the need for or define regulatory resources or bodies, if regulatory resources do not exist; and
- National laboratory consultation and expertise on core and primary system optimization and efficient fuel performance.

4.4 Existing Standards

Currently, there are no existing standards for defining or increasing proliferation resistance in power or research reactors, but there has been increased attention to this topic domestically and internationally. The IAEA's 2019 General Conference resolution on nuclear energy "calls upon the Secretariat and Member States in a position to do so to investigate new reactor and fuel cycle technologies with improved utilization of natural resources and enhanced proliferation resistance." In addition, fiscal year 2020 congressional appropriations and authorization bills have called for research and development of nuclear technologies that demonstrate improved proliferation resistance[4]. In line with those calls to improve proliferation resistance of reactor and fuel cycle

[4] Legislation includes the *Further Consolidated Appropriations Act, 2020*, the *Senate Bill 2368 Nuclear Energy Renewal Act of 2019*, and the *House Bill 6097 Nuclear Energy Research and Development Act*

technologies, PRO-Core is developing efficient and accessible implementation frameworks to include consultation and support from U.S. national laboratory experts.

NNSA looks forward to working with U.S companies to optimize the proliferation resistance and performance of their reactor core designs. For information on how to engage with NNSA on PRO-Core, please contact Jaci Dickerson at Jaci.Dickerson@nnsa.doe.gov.