NuScale Safeguards by Design

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Abstract

In 2022, NuScale Power LLC, (NuScale) initiated an internal project to establish an international safeguards strategy for the NuScale VOYGR power plants. The strategy allows for stakeholders to ensure relevant safeguards obligations can be met domestically and internationally. In the absence of a 'model safeguards approach' for small modular reactors NuScale developed the major aspects of a safeguards program that meets International Atomic Energy Agency objectives. The key components of the international safeguards strategy include defining and incorporating requirements into the design, developing proposed solutions for safeguards activities (e.g. material control and accountability, containment and surveillance, and nondestructive analysis, etc.), and establishing a consensus on the proposed strategy. NuScale's generic safeguards strategy and experiences with safeguards by design will be presented.

Introduction

International safeguards has become a focus area as NuScale works toward full commercialization of the technology domestically and internationally. NuScale has established and funded an internal project to integrate international safeguards considerations into the design. By facilitating future safeguards implementation into the design phase, NuScale will assure stakeholders that international commitments can be met without costly changes to the design. This paper will discuss the application of the safeguards by design (SBD) concept to NuScale's VOYGR™ SMR power plant design to date.

NuScale Power Plant Overview

The VOYGR Plant uses a simplified small modular reactor (SMR) design that is based on light-water reactor technology with substantial improvements in nuclear safety. It consists of a 250 MWt reactor core housed with other primary system components in an integral reactor pressure vessel surrounded by a steel containment vessel, all of which is immersed in a large pool. The Nuclear Power Module (NPM), including containment, is factory-built and shipped to the plant site. Its innovative and comprehensive safety features provide stable, long-term r core cooling under all conditions, including severe accidents.

NuScale's VOYGR™ SMR power plant design can accommodate four, six, or twelve NPM's resulting in a total gross output of 308 MWe for a VOYGR-4 plant, 462 MWe for a VOYGR-6 plant and 924 MWe for a VOYGR-12 plant. The NuScale plant is the only near-term deployable and commercially viable advanced nuclear generation solution for communities seeking a reliable, safe, and carbon-free solution, and is the first and only in the world to be approved by the U.S. Nuclear Regulatory Commission (NRC). Each NPM can be safely operated independent of other NPMs. The plant includes design features that ensure the independence and protection of safety-related systems during design-basis events. Except for the ultimate heat sink, safety-related systems are modulespecific and functionally independent of shared systems. Some additional design features that are relevant to the safeguards conversation are included in the Table 1

An NPM is a collection of systems, sub-systems, and components that make up a modularized, movable, nuclear steam supply system. Each NPM comprises a reactor core, a pressurizer, and two steam generators integrated within a reactor pressure vessel and housed in a compact steel containment vessel. The plant is designed for up to six NPMs with the associated primary and secondary systems and components necessary to produce power and maintain the facility.

The design and safety features

- No alternating current (AC) or direct current (DC) power requirements for safe shutdown and cooling. During a Station Blackout, the NPM shuts down and self-cools indefinitely with no operator action, AC/DC power, or additional of water to the ultimate heat sink.
- Natural circulation for normal operation eliminates the need for large primary piping and reactor coolant pumps.
- NPMs are submerged in a below-grade pool of water housed in a Seismic Category 1 aircraft impact resistant building that serves as the ultimate heat sink for core cooling.
- Compact helical-coil steam generators with reactor pressure on the outside of the tubes.
- A high-strength steel containment partially immersed in a pool of water.
- Sub-atmospheric containment pressure during normal operation.
- A small core with a correspondingly small source term. Each NPM houses approximately 5 percent of the nuclear fuel of a conventional large light water reactor.
- Comprehensive digital instrumentation and controls.

Important features of a multi-module plant include

- A scalable plant design, which allows incremental plant capacity growth.
- A compact nuclear island.
- The ability to operate in "island mode."
- Black start.

Table 1 NuScale Power Plant Parameter or Feature

Design life (years)	60
Moderator	Light water
Gross electrical output	77 MWe
Core thermal output	250 MWt (Per NPM)
Thermal efficiency	>30%
Operating cycle length	18 months
Outage duration	10 days
Reactor type	Integral pressurized water reactor
	Containment parameters
Design Temperature	316°C (600°F)
Design Pressure	83 bar (1200 psia)
Nominal Operating Pressure	<0.07 bar (<1 psia)
	Reactor Core
Fuel Type	UO2
Fuel Enrichment	<4.95%
No. of Fuel Elements	37 (17 x 17 pin array)
	Primary system parameters
Design temperature	343°C (650°F)
Design pressure	152 bar (2200 psia)

Nominal operating pressure	138 bar (2000 psia

Design Features

The NuScale design includes several features that distinguish it from large light water reactor plants and other SMR designs. Some differences from traditional large light water reactor characteristics require additional consideration in the approach to safeguard the VOYGR plant. These include:

- Integral primary system design with natural circulation of the primary coolant
- Unique containment vessel that is a compact high-pressure steel vessel immersed in a large pool of water and operating at a deep vacuum
- Shared reactor pool with up to 6 modules
- Since the VOYGR plant does not require safety related power, an alternative solution to safety related power requirements may be necessary
- In-factory fabrication of the NPMs, including containment, with truck, rail, or barge shipment to the site
- Continuous power operation with one module being refueled while the other modules are operating
- Ability for staged installation of modules and build-out of the site to best match a customer's power demand profile
- Adaptability to non-electrical applications
- Island mode capability that allows operation of the NPMs without a connection to a transmission grid
- Comingled storage of fresh and spent fuel

Safeguards by Design

As NuScale expands into the international market it is important to demonstrate that the NuScale design can meet the safety, security, and safeguards requirements for each State. Potential customers, operators, and regulatory agencies require that the technology is viable, safe, and secure prior to selection. NuScale has started the safeguards by design process to integrate safeguards considerations into the design and build confidence that safeguards can be effectively and efficiently implemented.

NuScale Safeguards by Design Related Activities

NuScale has participated in activities related to international safeguards with Pacific Northwest National Laboratory. The engagements have helped increase NuScale's awareness about international safeguards and inform the broader community about important design aspects that pose challenges to the current safeguards tools. A brief summary of the work follows.

2013 – Pacific Northwest National Laboratory: "Trial Application of the Facility Safeguardability Assessment Process to the NuScale SMR Design"

The focus of this work was the development of a Facility Safeguards Assessment, but there are some valuable outcomes related to the application of SBD to NuScale. The study made the following recommendation that is relevant today, "the NuScale design is similar to that of the commonly safeguarded PWR, the use of multiple modules within a single facility and the frequent refueling scheme require a modified approach to implementing international safeguards."
2019 – Pacific Northwest National Laboratory: "Design Information Verification for Small Modular Reactors"

The authors surveyed notional International Atomic Energy Agency (IAEA) [Design Information Examination/Design Information Verification] DIE/DIV plans and conducted an engagement with NuScale Power to identify verification issues at SMRs. Considering the pre-construction, construction, commissioning, and operations phases, the study identified a range of potential issues, most of which would not significantly degrade the effectiveness or efficiency of IAEA verification activities. Adaptations to current practices, proactive planning, or modest increases in resource expenditure could sufficiently mitigate most challenges. The main issues relate to

- **Multi-unit SMRs** that might involve more frequent reporting and verification of design information, more complicated analysis of facility throughput, greater coordination with the State and the facility operator, and increased efforts to develop a safeguards approach (including the use of containment tools and unattended systems) due to the flexible and dynamic facility configuration.
- Verifying **essential equipment that is inaccessible** due to integrated module design.

2022 – NuScale initiated an internally funded project to address the international safeguards aspects of the design and will develop a plan to incorporate safeguards considerations into the design.

Safeguards Approach

The VOYGR plant is similar to a typical PWR in terms of reactor construction and operation, material types and flows, and general layout. It is reasonable to assume that the safeguards approach for NuScale will be like the current safeguards approach at power reactors around the world. A VOYGR plant will likely be an item facility[1] with a similar system of nuclear material accountancy, C/S measures, reporting requirements, and inspections as used at a PWR.

The IAEA has published various documents that provide insights into anticipated safeguards related activities the IAEA may undertake in States with a comprehensive safeguards agreement (CSA) and an additional protocol. Using these resources, NuScale has developed a plan to establish a VOYGR international safeguards design basis and identify areas of concern.

Developing Safeguards Design Basis

[1] *Definition. Item facility – A facility where all nuclear material is kept in item form and the integrity of the item remains unaltered during its residence at the facility.*

The plan for developing safeguards design basis for the VOYGR plant starts with identifying the potential activities to be done in the facility and defining the guidelines and protocols to ensure the activities can be conducted safely and efficiently. This includes:

1) Identify the features, equipment, and nuclear material relevant to the application of safeguards in the VOYGR plant.
2) Develop a list of items (e.g., equipment, systems, and structures) essential for the declared operation of the facility (i.e., an essential equipment list or EEL).
3) Outline requirements for verification of quantity and location of nuclear material, and
    a) Propose material balance areas (MBAs).
    b) Propose strategic points that can be key measurement points (KMPs) and other strategic points that may provide information necessary to support the KMPs.
4) Propose requirements for verification of quantity and location nuclear material.
5) Propose an appropriate combination of containment and surveillance (C/S) methods and techniques and their location.
6) Highlight indicators that could be used to confirm the operational status of the facility.

The steps listed above are designed to identify and define activities that interact with the plant or may result in design changes. The details are collected and serve as the foundation for requirements development. For example, the minimum installation requirements and specifications are necessary for any proposed equipment to be installed in the plant. As a minimum, these should include: i) space requirements, ii) power and utility requirements, iii) data transmission requirements, iv) cable and conduit dimensions, v) survivability and habitability requirements.

NuScale plans to move toward ensuring these activities are supported in the plant design by incorporating the requirements into the design change control process to address each requirement. Since the data for some equipment is not available, bounding, or enveloping assumptions will be used to support analysis or evaluations. There are no significant challenges expected with the physical equipment that NuScale expects to be used in the VOYGR plant. IAEA has significant experience in the installation of equipment for use in nuclear facilities around the world, and that IAEA equipment is designed and tested for nuclear applications.

The result of the safeguards design basis will be a comprehensive collection of requirements that are demonstrably satisfied and justified. It is intended to be a living document that is updated along with evolutions of the design and safeguards approach.

Unfortunately, there is currently no formal path available for a vendor to validate their SBD approach with the IAEA. NuScale plans to work closely with key stakeholders and the larger international safeguards community to share progress and build consensus and address open items.

Conclusion

The successful implementation of safeguards by design in the VOYGR plant is important to ensure the viability of international deployment of this innovative technology. By addressing international safeguards considerations, NuScale can identify and incorporate efficiencies to support effective implementation of safeguards by the IAEA.

In the near term, NuScale has the tools to develop requirements and incorporate them into the design. However, there are open questions that may require a more collaborative effort to resolve. Establishing success criteria and assessing the SBD outcomes in terms of safeguards performance is not yet possible. Some of the challenges facing NuScale are applicable to many other designs and they warrant serious attention. A sanctioned forum of exchange for technical information could be useful to support the imminent goals and provide valuable for the future evolution of SBD.

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