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NuScale Power Plant Resilience Studies

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INTRODUCTION

Because nuclear power plants can operate continuously for periods exceeding one year without the need to refuel, nuclear power has always played an important role in providing reliable electricity to the grid. The advent of advanced SMR designs will further enhance the resiliency of nuclear power. In 2015, NuScale Power launched a research initiative to assess and enhance the resiliency of its plant design. The purpose of this summary is to provide a brief overview of the results of the internal and external collaborative research studies that have been completed and the status of resiliency projects that are currently underway. The basis for the studies was the 50 MWe NuScale power modules incorporated in a standard 12-module (600 MWe) nuclear power plant as shown in Figure 1.

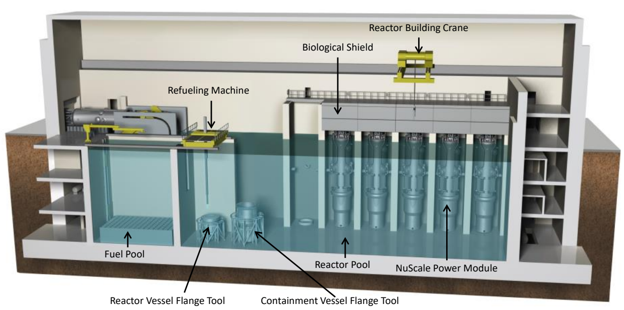

Fig. 1. A 12-Module NuScale reactor building houses the NuScale power modules, fuel pool, and ultimate heat sink for safety.

Plant Resiliency Studies

Metrics for plant resiliency are typically customer driven. That is, resiliency requirements for power to a mission critical facility such as a hospital, military base, or financial data center will be different than the resiliency requirements for power to residential areas. In general, plant resiliency shall be defined as *the ability of the plant to remain safe and available for power production against a pre-defined set of adverse conditions*. TABLE I lists the topics that were considered as part of the NuScale resiliency studies. Each topic and key results are discussed in the sections that follow.

TABLE I. NuScale Plant Resilience Study Topics

Nuclear Safety Studies	
- Loss of grid connection; loss of all AC/DC power	
Operational Reliability Studies	
- Plant Reliability	Reducing inadvertent reactor scrams, reliable power for mission critical facilities
External Events Studies	
- Natural Events	Assessing the impact of seismic, hurricanes, flooding, tornados, tsunamis, geomagnetic storm events
-Targeted Events*	Aircraft impact, cybersecurity, electro-magnetic pulse (EMP)
- Catastrophic Loss of Infrastructure	First responder power, long-term power without refueling.

**Physical security is a separate study*

SUMMARY OF KEY RESULTS

This section briefly summarizes the key results of the studies and resiliency features of a NuScale 12-module plant.

Nuclear Safety

A comprehensive assessment of the nuclear safety of the NuScale plant was performed and supporting information submitted to the US Nuclear Regulatory Commission (NRC) in January of 2017 as part of its design certification application. The application was docketed in March 2017 and details are publically available on the NRC ADAMS website, docket number 52-048. The passive safety systems of the NuScale plant provide significant resilience in terms of nuclear safety because they do not require AC or DC power to actuate. Upon loss of all AC and DC power, the nuclear reactors will shut down without operator or computer actions, and remain cooled for an unlimited period (i.e. no coping time limit) without the need to add water. In addition, cooling of the spent fuel pool can be achieved for 5 months without adding water. As a result, the NuScale plant is resilient to a loss of AC grid connection or complete loss of all AC and DC power.

In December 2017, the NRC released its Safety Evaluation Report (SER), approving NuScale Power's "Safety Classification of Passive Nuclear Power Plant Electrical Systems" Licensing Topical Report, where the company established the bases of how a design can be safe without reliance on any safety-related 1E electrical power (Ref 1). NRC's conclusion is a key step in the review process of the NuScale DCA.

Operational Reliability

An internal assessment has been performed to examine the resilience of a NuScale plant relative to existing commercial nuclear fleet reactor scrams. It is noted that the commercial nuclear fleet leads the power industry in capacity factors, typically exceeding 90% capacity factors annually. Figure 1 shows the results of the NuScale assessment. Approximately 73% (47 of 64) of the scrams observed in the commercial nuclear fleet in 2015 would be precluded because of innovative features of the NuScale design. Although actual NuScale plant capacity cannot be determined until the first plant is in operation, this result provides a very encouraging starting point. Three key factors can be attributed to the expectation of reduced number of NuScale reactor scrams. The first is that fewer and simpler systems result in fewer potential failures. The second reason can be attributed two key design features; Island Mode Power and 100% steam-turbine bypass. The NuScale plant is designed so a single module can supply all house loads for the entire plant to maintain power to a mission critical facility without external grid connection. The island mode feature coupled to 100% steam-turbine bypass means that the reactors do not need to scram on loss of grid connection.

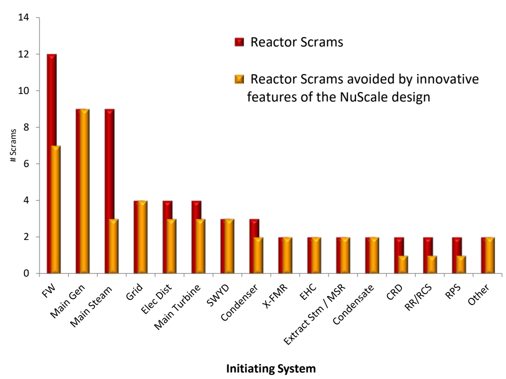

Fig. 1. Number of 2015 reactor scrams expected to be avoided by the NuScale design

Another feature of the 12-module design is that it consists of a redundant array of independent reactors (RAIR). This has two operational reliability benefits. It permits staggered refueling so the total plant continues to produce 550 MWe gross even during refueling. The second is a very high availability for power levels of 50-100 MWe. This range of power would be typical of is needed for facilities that require ultra-high reliability for mission critical processes. The study by Doyle, et.al., on highly reliable nuclear power for mission critical applications demonstrated that because of its configuration as a RAIR and its island mode capability, a 12-module NuScale plant can provide 100 MWe to a dedicated micro-grid at 99.95% reliability for the 60 year life of the plant. At 50 MWe, the reliability would be 99.98%, which corresponds to zero output for only 4 days over the 60-yr lifetime of the plant. Details of the analysis methods and results have been provided in Reference 2.

External Events Studies

With regard to natural external events, all nuclear power plants must be evaluated for seismic, high velocity winds and flooding events and already have significant resilience in these areas. Safety related buildings are designed to Seismic Category 1 standards as demonstrated by comprehensive, site-specific seismic analyses. Several features of the NuScale reactor building make it more resilient to natural events. First, everything needed to assure a safe shutdown of the plant is housed within the seismic category 1 reactor building. During normal operation, all 12 modules reside within the reactor building ultimate heat sink that consists of a water-filled stainless steel lined concrete pool located below grade. Because of the reduced elevation of the reactor building and the embedded pool, the reactor building is designed for 0.5 g horizontal and vertical zero period accelerations (ZPA) and peak accelerations of 1.1 g for frequencies from 3-12 Hz. This fact in combination with the fully passive safety systems (i.e. no AC/DC power for safety) means that the NuScale reactor building is resilient to a Fukushima type event.

Several externally targeted events have also been considered by NuScale. All nuclear power plants are required to perform a design-specific assessment of the effects on the facility of the impact of a large, commercial aircraft as per NRC 50.150. Applicants are required to use realistic analyses to identify and incorporate into the design those design features and functional capabilities to show that, with reduced use of operator actions, the reactor core remains cooled, or the containment remains intact; and spent fuel cooling or spent fuel pool integrity is maintained. This provides the existing commercial fleet significant resiliency to aircraft impact. The NuScale reactor building has been designed to withstand impact of a large, commercial aircraft as per NRC 50.150.

With regards to cyber security, NuScale is currently working with Brookhaven National Laboratory and the U.S. Department of Energy in an effort to develop a methodology to quantitatively assess the consequence of cyber-attacks on the safety, reliability, and availability of nuclear power plants. The NuScale plant does have some unique characteristics in this regard. It does not rely on computer systems for assuring the safe shutdown and long-term cooling of the reactors. Furthermore, the NuScale Module and Plant protection systems are non-microprocessor systems (i.e., they use field programmable gate arrays). As a result, NuScale safety systems do not use software and are therefore not vulnerable to internet cyber-attacks.

With regards to resilience against geomagnetic storms and electro-magnetic pulse events, NuScale has commissioned a study with Oregon State University in collaboration with a team of EMP experts to identify features of the NuScale plant that provide inherent EMP protection (e.g., passive systems, below grade, compact footprint). The team is also tasked with identifying components/systems that may require additional attention to achieve higher levels of EMP hardness. A key feature in this regard is that following an EMP event, a NuScale plant has "black-start" capability. That is, a NuScale plant can start up from cold conditions without external grid connections by using onsite back-up generators. The first phase of the study is expected to be completed in the summer of 2018.

Disaster Mitigation and Grid Resiliency

In January 2018, the Federal Energy Regulatory Commission (FERC) issued an Order initiating a proceeding (Docket No. AD18-7-000) to "holistically examine the resilience of the bulk power system." FERC states that affordable and reliable electricity is vital to the country's economic and national security. Nuclear power plants already play an important role in grid resiliency by being a reliable source of base load power. Nuclear power could also play an important role in disaster mitigation by becoming a source of *first responder power* following a natural disaster. The Disaster Mitigation Act of 2000 (Reference 3) was enacted by Congress to require States to identify the risks to natural disasters, to implement adequate measures to reduce losses from natural disasters and to ensure that the critical community services and facilities will continue to function after a natural disaster. As a result of the Act, many cities and States have established programs to develop pre-disaster hazard mitigation measures. The safety culture of the nuclear industry makes it an ideal partner for cities and states developing disaster mitigation plans.

NuScale has performed a study to examine the role of a NuScale plant to provide long-term power to mission critical facilities following a catastrophic loss of the macro-grid and transportation infrastructure. It is assumed that a catastrophic event results in major damage to the macro-grid and prevents nuclear fuel delivery to the plant for an extended period (i.e, in excess of 2 years). It is also assumed that the State disaster mitigation plan has resulted in hardened mission critical micro-grids that remain intact or can be quickly recovered following a natural disaster. The study sought to determine if a NuScale plant could be a first responder source of power to the grid and how long it could provide power to a hardened 100 MWe mission critical facility without the delivery of new fuel to the site. Two resilience features of the NuScale plant played an important role in responding to such a catastrophic event. First, the black-start capability of the plant allows a single power module to start without a connection to the macro-grid. Second, the island mode capability of the plant allows a single module to carry the house loads for any or all of the 12 modules. Therefore, a 12-module NuScale plant could serve as a first responder power source; providing power in 50 MWe increments as portions of the macro-grid are rebuilt. The study also concluded that a 12-module NuScale plant can provide 100 MWe to the micro-grid of a mission critical facility for 12 years without delivering new fuel to the site.

CONCLUSIONS

Table 2 summarizes the resilience features for a 12-Module NuScale plant.

TABLE 2. NuScale Plant Resilience Features

Nuclear Safety	A NuScale plant does not require operator or computer actions, or AC/DC power, or additional water to keep the reactors safe for an unlimited period.
Increased Operational Reliability	Eliminated >70% of existing 2015 commercial fleet reactor scrams by design.
Redundant Array of Independent Reactors (RAIR)	RAIR permits staggered refueling so plant continues to produce 550 MWe gross during refueling.
Black-Start Capability	A NuScale Plant can start up from cold conditions without external grid connections using small onsite back-up generators.
Island Mode Power	A single module can supply all house loads for the entire plant to maintain power to a mission critical facility without external grid connection.
Highly Reliable Power for Mission Critical Facilities	A NuScale plant can provide 100 MWe at 99.95% reliability or 50 MWe at 99.98% reliability over the 60-yr lifetime of the plant
First Responder Power with 100% Turbine Bypass	On loss of offsite grid, all 12 modules can remain at full power or be ramped down while rejecting 100% steam to its condensers. Able to provide power to the grid in 50 MWe increments as soon as the grid is restored.
Resilience to Natural Events	The reactor modules and fuel pools are located below grade in a Seismic Category 1 Building; Capable of withstanding a Fukushima type seismic event, hurricanes, tornados, and floods
Resilience to Aircraft Impact	The reactor building is able to withstand aircraft impact as specified by the NRC air-craft impact rule.
Resilience to Catastrophic Loss of Grid and Transportation Infrastructure	A 12-module NuScale plant can provide 100 MWe to a mission critical facility micro-grid for 12 years without new fuel following a catastrophic loss of offsite grid and transportation infrastructure.

NuScale has performed several studies to examine the resilience of its 12-module plant. This includes NuScale plant resiliency to a loss of grid connection, loss of all AC/DC power, reduction of inadvertent reactor scrams, and reliable power for mission critical facilities. A variety of external events, both natural and targeted have also been considered. Three additional studies are underway, *Assessment of Effects of EMP and Geomagnetic Storms on a NuScale Plant* with Oregon State University and EMP expert consultants ; *Consequence Evaluations of Cyber-Attacks on Nuclear Power Plants Using Adaptive Sampling of Attack Scenarios* with Brookhaven National Laboratory and DOE; and *Micro-grid Reliability and Resilience w*ith the Tennessee Valley Authority and University of Tennessee.

REFERENCES

1. Safety Evaluation Report for NuScale Topical Report, TR-0815-16497, "Classification of Passive Nuclear Power Plant Electrical Systems," Revision 1, US Nuclear Regulatory Commission, Washington, DC 20555, NRC ADAMS website, ML17340B031, December 13, 2017.
2. J. DOYLE, et., al. "Highly Reliable Nuclear Power for Mission Critical Applications," *Proc.* ICAPP 2016, San Francisco, California, April 17-20, 2016 American Nuclear Society (2000).
3. Disaster Mitigation Act of 2000, US Public Law 106-390 of 106th Congress, October 30, 2000.