NON-PROPRIETARY

Refueling Operations Report for the NuScale Power Module

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ACRONYMS

ANS	American Nuclear Society
ANSI	American National Standards Institute
CVCS	Chemical Volume Control System
DHRS	Decay Heat Removal System
ECCS	Emergency Core Cooling System
ID	Inner Diameter
MWt	Megawatt thermal
NRC	Nuclear Regulatory Commission
OD	Outer Diameter
OJT	On-the-Job Training
PWR	Pressurized Water Reactor
TPE	Task Performance Evaluation
U.S.	United States

FORWARD

This document is being submitted to the U.S. Nuclear Regulatory Commission (NRC) to facilitate discussions about the NuScale refueling operations during the design certification pre-application review phase. This document provides an overview of the refueling operations to be used in a NuScale Plant for the routine maintenance and refueling of a NuScale reactor module. It is intended to provide an introduction to how these modules will be refueled in comparison to methods used extensively by the existing nuclear industry. There are several aspects of refueling that are different for the NuScale design, and this report highlights those differences.

NuScale is currently in the process of finalizing the NuScale power plant design, and all of the design information presented in this report should be considered preliminary in nature. Minor design changes are expected up until the submittal of the design certification application. The figures provided in the report are illustrations intended to support the explanations provided in the document; they are not engineering or design figures.

1. OVERVIEW

This report presents a description of the refueling process for a multi-module NuScale plant. Each of the power modules in this plant is a small, passively safe, 150 MWt, pressurized water reactor (PWR). There are several key design features that differentiate the NuScale power module from a standard 3- or 4-loop PWR. These include:

- a small half-height core,
- primary coolant flow provided by natural circulation (i.e. no reactor coolant pumps),
- a steam generator and pressurizer inside the reactor pressure vessel,
- passive safety systems, and
- a high-pressure steel containment vessel.

The reactor modules sit in a borated pool that is common to all modules and acts as a heat sink during the first 72 hours of an accident when off-site power may be unavailable. This pool is an integral part of both the decay heat removal system and the containment heat removal system. Refueling of the modules occurs in a separate pool attached to the containment cooling pool by a central canal. This allows refueling operations to occur separate and distant from the operating modules. During refueling, the two pools are isolated from each other using a gate or installed weir. (Refer to Figure 1-1).

4a,b

Figure 1-1 Pool Layout

To initiate the refueling process, the reactor is shutdown and the primary system temperature is lowered using the normal feed system and the steam generators. Once the reactor has been cooled below 100°C via the steam generators, the containment vacuum is broken and the containment is partially flooded via the vacuum system to provide decay heat removal. Flooding the containment vessel provides a passive decay heat removal path that relies only on conduction and convection and, ultimately, the heat sink represented by the containment cooling/refueling pools. This cooling will be further augmented by the activation of the Decay Heat Removal System. While the pools are serviced by active cooling systems, they have a passive capacity to provide at least three days of cooling should an interruption of the active cooling system occur.

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Refueling the reactor in a separate pool allows refueling equipment and activities to have a permanent location. This simplifies the refueling process and will contribute to more consistent outage performance. There are several advantages to this arrangement that are detailed in the body of this report.

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2. MODULE SHUTDOWN

A NuScale power module will be shut down in a manner that is consistent with current nuclear industry standards. The operator will initiate a plant shutdown using the plant control computer following a pre-established plan. When reactor power has been sufficiently lowered, the turbine will be taken offline and the reactor will be tripped.

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The module will be cooled via the main feedwater system, using the steam generators, then exhausting to the condenser. This will allow the primary system to be cooled to below 100°C in a controlled fashion and takes advantage of the once-through steam generators and the natural circulation design of the primary system.

When the primary system has cooled down to less than 100°C, passive refueling heat removal will be established. (Refer to Figure 2-1). In the NuScale design, two refueling heat removal paths are used. The first is provided by flooding the containment vessel with borated water to a level approximately equal to the top of the steam generators. Flooding will be accomplished using the same line that is used to maintain the containment vacuum during normal plant operations. With the containment flooded, the heat flow path is:

- natural circulation flow consistent with normal operation that brings heat to the ID of the reactor vessel,
- conduction through the reactor vessel wall,
- natural circulation/convection from the OD of the reactor vessel to the ID of the containment vessel,
- conduction through the containment vessel wall, and
- natural circulation/convection on the containment OD to the pool.

The second heat removal flow path is provided by the Decay Heat Removal System (DHRS). Actuating this system will draw water in from low in the pool, heat it in the steam generators, and exhaust it to the top of the pool. The process for placing this system in service will secure the normal feedwater path.

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Figure 2-1 Passive Refueling Heat Removal

These two systems provide enough heat removal capacity to ensure that the primary system temperature remains low enough to support containment and reactor disassembly activities. By design, both systems travel with the module to the refueling pool so there is no discontinuity of cooling. Neither system requires any active components, making them very reliable. Additionally, if something happens to the DHRS, the flooded containment ensures there is always a sufficient heat removal path to maintain the core cooled and covered.

The ultimate heat sink for both heat removal paths is the pool itself. The heat rejection reservoir represented by the pool is sufficient to maintain the core cool for at least three days following a trip from full power. Should the active pool cooling systems be interrupted during the refueling process this heat sink will last considerably longer. In the NuScale refueling plan the potential for a loss of shutdown cooling accident is essentially eliminated.

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With the containment vessel flooded, the Reactor Vent and Recirculation Valves open, and the primary system temperature stable, the protective covers over the module bay can be removed. These covers are segmented to support disassembly and storage. These moves will be performed by the single-failure-proof transfer crane. Storage locations and load paths designs will minimize the impact of a load drop on either the shutdown module or any of the operating modules. With the module exposed, the transfer crane and lifting rig are attached to the module prior to any disassembly activities. Administrative controls and interlocks will be in place to ensure that no module lifts occur prior to the completion of disassembly activities. (Refer to Figure 2-2).

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Figure 2-2 Cover Removal and Vessel Lift Rig Configuration

3. MODULE DISCONNECTION

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Figure 3-1 Transfer Crane Instrumentation Configuration

Finally, to support module transfer, the trunion caps are removed. The trunions support the module from docks on the bay walls during operation. The trunion caps lock the containment vessel trunions in place during operation. Once the vessel has been attached to the crane, these caps can be removed, and the vessel is ready for transfer. Several cap designs are still under consideration, but all incorporate the ability to free these constraints using remote tools.

4. MODULE TRANSPORT

The movement of the reactor and containment vessel to a refueling location is a unique feature of the NuScale concept. (Refer to Figure 4-1). It also represents a potential challenge to shutdown safety. The design will integrate several steps to mitigate this issue.

The crane used to move the vessel is a single-failure-proof crane, consistent with the requirements of NUREG-0554, “Single-Failure-Proof Cranes for Nuclear Power Plants,” and fitted with a lift rig that meets the requirements of American National Standards Institute (ANSI) N14.6-1993, “Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More.”

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The crane speed is controlled to prevent vessel swing and is aided by the buffering provided by the pool. The transfer crane is used to lift the vessel, transit to the refueling pool, and align with the containment flange disassembly rig. Alignment with the disassembly rig is verified using match marks, interlocks and cameras.

The safe movement of a fueled reactor vessel and containment vessel will be the primary focus of all future work to support the design of equipment associated with refueling. NuScale will continue to evaluate lessons learned from the movement of dry fuel storage casks. Dry fuel storage evolutions involve moving larger volumes of fuel and include lifts to significantly higher lift heights, which make the experience gained by the industry in these areas particularly useful to NuScale.

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Figure 4-1 Module Transfer and Crane Configuration

5. MODULE DISASSEMBLY AND TESTING

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Figure 5-1 Containment Vessel Disassembly

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4a,b

Figure 5-2 Reactor Vessel Disassembly

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4a,b

Figure 5-3 Steam Generator Tube Sheet Access

It is believed that having a permanent location for these refueling support activities will contribute to more efficient refueling outages and more consistent performance of refueling tasks. The refueling and test equipment will be more reliable since it will be readily accessible for maintenance. Having a permanent location will also limit potential contamination control issues associated with the transport and storage of the refueling equipment. The activities associated with the transport of refueling equipment at existing facilities can also generate significant amounts of low-level radioactive waste. This waste will be avoided in NuScale’s design. In addition, a fixed refueling station should enhance employee training as the equipment will be more accessible, allowing On-the-Job Training (OJT) and Task Performance Evaluation (TPE) to occur at times other than during refueling outages. The refueling pool will also support a more elaborate fixed camera installation with permanent remote viewing capability. It will also be possible for the facility to install permanent telecommunication and teledosimetry equipment.

6. RETURN TO SERVICE

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7. SPENT FUEL POOL

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Figure 7-1 Spent Fuel Pool

8. REFUELING PROCESS OUTLINE

The following list provides a high-level overview of the refueling process.

1. Unit power reduced
2. Turbine tripped
3. Reactor tripped
4. Reactor borated
5. [ ][4a,b]
6. Primary system cooled via steam generators
7. Containment partially flooded
8. Decay Heat Removal System actuated
9. Feedwater secured
10. [ ][4a,b]
11. [ ][4a,b]
12. Lift rig and crane connected to module
13. [ ][4a,b]
14. Electrical services and piping disconnected from module
15. Trunion caps removed/disengaged
16. Vessel lifted
17. [ ][4a,b]
18. Module moved to refueling pool and staged in containment vessel disassembly rig
19. [ ][4a,b]
20. [ ][4a,b]
21. Module lowered into containment vessel disassembly rig
22. Containment fully flooded
23. Containment flange detensioned
24. Reactor and upper containment lifted
25. Reactor and upper containment placed in reactor vessel disassembly rig
26. [ ][4a,b]
27. Reactor vessel flange detensioned
28. Upper reactor and containment vessels taken to test rig
29. Core reloaded via shuffle
30. Upper reactor and containment vessels returned to reactor vessel disassembly rig
31. [ ][4a,b]
32. Reactor and upper containment returned to reactor vessel disassembly rig
33. Containment flange tensioned
34. Containment partially drained
35. Module lifted
36. [ ][4a,b]
37. [ ][4a,b]
38. Module returned to normal operating location

39. { }[4a,b]
40. Trunion caps put in place
41. Piping and electrical connections restored
42. { }[4a,b]
43. Crane and lift rig removed
44. Module covers restored
45. Feedwater restored
46. { }[4a,b]
47. Containment drained and vacuum established
48. Module ready for startup

9. REFUELING CHALLENGES

Recognized technical challenges to the NuScale refueling process are listed in Table 9-1, along with proposed success paths for addressing each challenge.

Table 9-1 NuScale Refueling Technical Challenges

Challenge	Success Path
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Table 9.1 (Continued)

Challenge	Success Path

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