NuScale Plant Design Overview

September 16 2013

Revision 2

Nonproprietary

Docket: PROJ0769

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Note: The design presented in this document reflects the stage of engineering design at the time of writing. As the engineering effort progresses, information presented is subject to change.

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1.0 Executive Summary

The purpose of this document is to provide an introduction to the NuScale Power, LLC (NuScale), plant.

The NuScale plant is an innovative design based on 50 years of practical application of light-water-cooled pressurized-water reactor (PWR) technology. The design incorporates several features that reduce complexity, improve safety, and enhance operability.

The NuScale Plant design philosophy includes

- a design using proven standard technology.
- a modular nuclear steam supply system, the NuScale Power Module, built with shippable components.
- a below grade containment immersed in a pool of water.
- passive safety systems.
- a two-year fuel cycle.

A multi-unit NuScale power plant takes advantage of the unique features of the NuScale Power Module to provide plant owners with a highly reliable power plant capable of meeting customer energy demands.

Important features of a multi-unit plant

- scalable plant design allows for incremental plant capacity growth
- only eight (8) percent of a 12-unit plant is offline during a NuScale Power Module refueling
- 60-year design plant life
- compact nuclear island
- no operator action required for at least 72 hours following a postulated accident
- After 72 hours, reactor pool evaporation, pool water boil-off, and air cooling of containment are capable of providing unlimited decay heat removal without operator action, AC or DC power, or make-up water.

NuScale’s power plant design will allow plant owners to safely provide reliable electricity production to supply the needs of their customers.

2.0 Introduction

The NuScale Power Module (NPM) is a small, light-water-cooled PWR. The NuScale power plant is highly scalable and can be built to accommodate a varying number of NPMs to provide a customer's energy demands. Twelve modules is considered the maximum plant size and is the current reference plant size for design and licensing activities. The design takes advantage of existing design tools and available nuclear fuel options while leveraging the wealth of knowledge developed through more than 50 years of practical application of light-water-cooled PWR technology.

The plant design provides a simple, highly reliable, and safe reactor that can be manufactured in the United States while maximizing the use of existing manufacturing capabilities and qualified “off-the-shelf” components.

The plant design meets these objectives by providing the following:

- reliable and passively safe systems that are simple in design and operation
- safety features that assure a core damage frequency significantly lower than the current light-water reactor fleet
- reactor building designed to protect against aircraft impact while maintaining spent fuel pool integrity and preserving containment integrity, per 10 CFR 50.150
- 60-year design plant life
- significantly reduced construction schedule compared to nuclear plants of a comparable output
- modularization to enable in-shop fabrication of reactor and containment components
- use of half height traditional 17 x 17 nuclear fuel assemblies

2.1 Abbreviations and Definitions

Table 2-1. Abbreviations

Term	Definition
CNV	Containment vessel
CRHS	Control room habitability system
CVCS	Chemical and volume control system
DHRS	Decay heat removal system
ECCS	Emergency core cooling system
ESFAS	Engineering safety features actuation system
HFE	Human factors engineering
HVAC	Heating ventilation and air conditioning
LOCA	Loss-of-coolant accident
MWe	Megawatt electric
NCIS	Nonsafety control and instrumentation system
NPM	NuScale Power Module
NRC	Nuclear Regulatory Commission

Term	Definition
NSSS	Nuclear steam supply system
PWR	Pressurized-water reactor
RCIS	Rod control and information system
ROCA	Restricted owner controlled area
RPV	Reactor pressure vessel
RRV	Reactor recirculation valves
RTS	Reactor trip system
RVV	Reactor vent valves
SCIS	Safety control and instrumentation system
ZPA	zero period acceleration

2.2 NuScale Power Module

The NPM is a self-contained nuclear steam supply system (NSSS) composed of a reactor core, a pressurizer, and two steam generators integrated within the reactor pressure vessel (RPV) and housed in a compact steel containment vessel (CNV), as shown in Figure 2-1. The NPM's components are fabricated offsite and transported to the plant site.

The NPM is designed to operate efficiently at full power conditions using natural circulation as the means of providing core coolant flow, eliminating the need for reactor coolant pumps. As shown in Figure 3-1, the reactor core is located inside a shroud connected to the hot leg riser. The reactor core heats reactor coolant causing the coolant to flow upward through the riser. When the heated reactor coolant exits the riser, it passes over the tubes of the helical coil steam generators, which act as a heat sink. As the reactor coolant passes over the steam generator tubes, it cools, increases in density, and naturally circulates down to the reactor core, where the cycle begins again.

The NPMs are immersed in a reactor pool and protected by passive safety systems. Each NPM has a dedicated chemical and volume control system (CVCS), emergency core cooling system (ECCS), and decay heat removal system (DHRS).

Important features of the NPM include

- a small, modular design that allows for incremental refueling outages and system maintenance.
- an integral PWR NSSS that combines the reactor core, steam generators, and pressurizer within the RPV. Unlike a conventional PWR design, this design eliminates the external piping necessary to connect the steam generators and pressurizer to the RPV.
- buoyancy forces that drive natural circulation of the primary coolant, eliminating the need for reactor coolant pumps.
- an RPV housed in a steel containment immersed in water. The water provides an effective passive heat sink for long-term emergency cooling.
- the absence of RPV or containment penetrations below the top of the reactor core.
- a steel containment operated at a vacuum eliminating the need for insulation on the RPV.

- a modular design that can be built in a separate manufacturing facility, shipped to the site, and then installed, shortening the overall plant construction time resulting in significantly reduced costs for construction.

2.3 NuScale Power Module Construction

The NPM components are fabricated at an offsite manufacturing facility. Offsite manufacturing allows for the standardization and streamlining of the manufacturing process resulting in higher quality and lower NPM cost. Costs are controlled by the efficiency of manufacturing and assembling components offsite.

2.4 Safety

NuScale has achieved a substantial improvement in safety over existing plants through simplicity of design, reliance on passive safety systems, small fuel inventory, and use of additional fission product barriers. The integral design of the NPM eliminates external coolant loop piping, which eliminates large-break loss-of-coolant accident (LOCA) scenarios. The availability of passive safety systems for decay heat removal, emergency core cooling, containment heat removal, and control room habitability eliminates the need for external power under accident conditions. With these passive safety systems, small-break LOCAs do not significantly challenge the safety of the plant. The result is a design with a core damage frequency significantly lower than the current light-water reactor fleet.

The reactor in an NPM has a small radioactive source term with less than 4 percent of the fuel inventory of a conventional 1000 MWe nuclear reactor. Therefore, the amount of radioactive material available for release during a postulated accident is greatly reduced. NPMs are housed in a building designed to withstand a 0.5g zero period acceleration (ZPA) earthquake, immersed in a reactor pool, and covered with a biological shield. Although not credited in design basis accident analysis, the reactor building, reactor pool, and biological shield provide additional barriers to mitigate the release of radioactive material. The combined result of these features is a design that is extremely safe. See Table 2-2 for a listing of some of the features of an NPM.

2.5 Human Factors

The NuScale design effectively integrates Human Factors Engineering (HFE) into the development, design, and evaluation of the plant. HFE employs state-of-the-art principles to ensure NuScale products facilitate safe, efficient, and reliable performance of operations, maintenance, tests, inspections, and surveillance tasks. The NuScale design minimizes human error through fail-safe design functionality, allows multi-modular control capability with effective automation design, employs digital display design and soft control technology to enhance usability, and provides optimum workload management.

The HFE program satisfies all specific regulatory requirements and leverages human performance and operating experience from legacy systems. Using sound HFE procedures and processes, the NuScale design and implementation establishes thorough and successful growth capabilities to match customer needs.

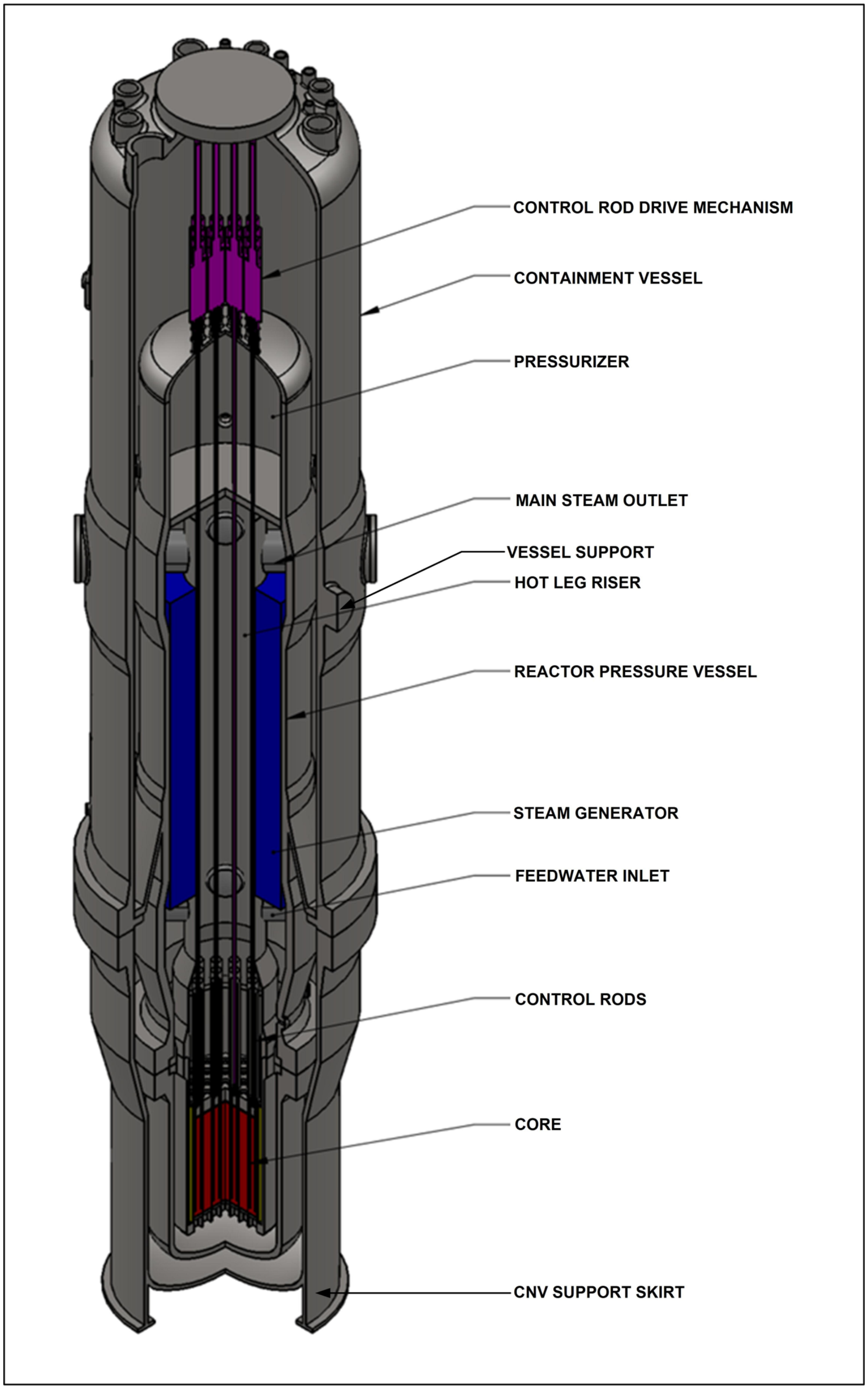

Figure 2-1. Cutaway view of the NuScale Power Module

Table 2-2. Features of a NuScale Power Module

NuScale Design Feature	Primary Impact	Safety
Reactor coolant system integral to the RPV	No large diameter primary coolant piping	Eliminates postulated large-break LOCA spectrum of accidents
Natural convection-cooled core	No reactor coolant pumps	Eliminates reactor coolant pump accidents, shaft breaks, pump seizure, missile generation and pump leaks
Once-through integrated steam generator with feedwater and steam inside the tube.	Steam generator tubes are in compression	Improved steam generator tube integrity with steam generator tube rupture frequency reduced
High containment design pressure	Containment equilibrium pressure for worst case design basis accident remains below containment design pressure	Containment integrity assured (due to the metallic CNV, molten core concrete interaction is not possible).
Modular NSSS and reactor vessel inside the CNV	Any water lost from reactor vessel stays within containment and is returned to reactor vessel by passive means	No postulated design basis small-break LOCA capable of uncovering nuclear fuel
Evacuated Containment	Sub-atmospheric pressure during normal operation	Increased steam condensation rates for containment heat removal during a postulated small-break LOCA. Any hydrogen postulated to be released is trapped in the CNV with little oxygen available to create a combustible mixture.
	No insulation on reactor vessel	Eliminates potential sump screen blockage and permits ex-vessel cooling
Low power core (160 MWt)	Reduces decay heat removal requirements	Enhances in-vessel retention; maintains low accident consequences; reduces fission product source term; simplifies emergency planning
Reactor pool with immersed NSSS and CNV	NSSS and CNV immersed in reactor pool	Provides passive long-term cooling and enhanced fission product retention
Passive safety systems	Safety systems cool and depressurize the CNV even in the event of loss of external power	Active safety systems are not required

3.0 NuScale Power Plant General Description

This section describes the NuScale Power Module (NPM) and associated power conversion system for a single-unit and a multi-unit plant.

3.1 Single-Unit Overview

A unit consists of a simplified power conversion system using a skid-mounted turbine-generator set, a standard condenser and cooling tower arrangement, and feedwater system dedicated to a single NPM, as shown in Figure 3-1. The power conversion system is based on readily available, off-the-shelf components. Use of off-the-shelf components simplifies the design and helps reduce long-term maintenance costs.

The modular concept allows multiple NPMs to be placed at a single site. Individual NPMs can be placed into service incrementally to meet construction schedules and grid demand as permitted by the site license. NPMs can also be taken off-line individually for refueling outages and maintenance.

Feedwater from the condenser is pumped by condensate pumps to the condensate polishing equipment, where impurities are removed. Downstream of the polishing equipment, variable speed feedwater pumps supply flow to the feedwater heaters before feedwater regulating valves control feed to the steam generators.

In unit operation, preheated feedwater is pumped into the tube side of the steam generators where it boils. As the steam continues to flow upwards in the tubes, it continues to be heated to produce superheated steam before leaving the steam generators. The superheated steam is directed to a dedicated steam turbine. A generator, driven by the turbine, creates electric power that is delivered to the utility grid through a step-up transformer. A turbine steam bypass is provided that will allow the reactor to remain in operation in the event of a turbine trip.

Steam is extracted from turbine stages to preheat the feedwater and increase the efficiency of the power plant. Exhaust steam from the turbine is directed to the condenser, where a circulating water loop removes heat and condenses the steam. Heat from the circulating water loop is rejected to atmosphere by an evaporative mechanical-draft cooling tower.

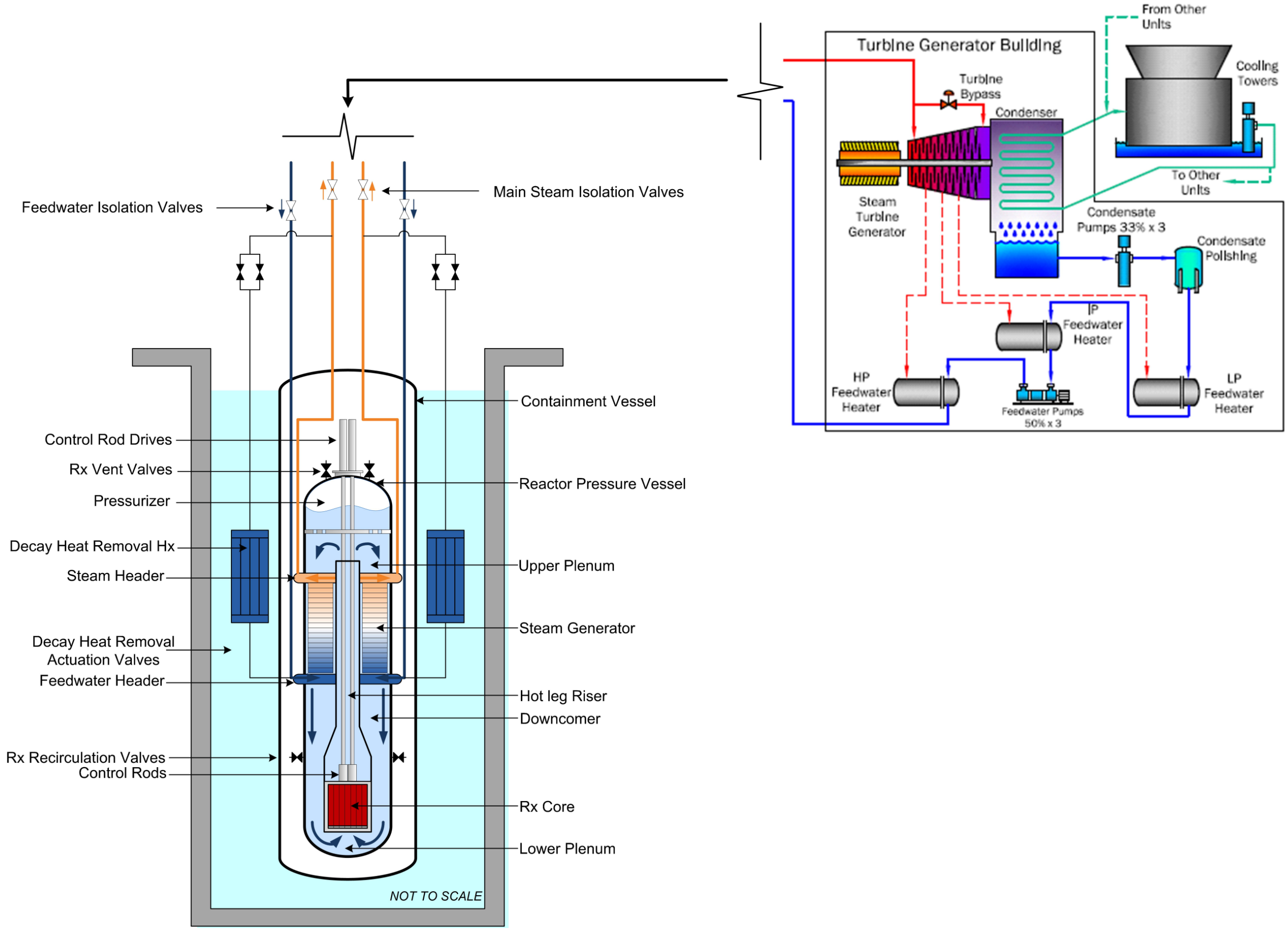

Figure 3-1. Schematic of a single NuScale unit

3.2 Plant Overview

Figure 3-2 presents the layout of a multi-unit plant. Each NPM is immersed in its own bay of the common reactor pool. Each reactor bay is approximately 20 ft wide by 20 ft long and built into the nearly 84 ft deep pool with a normal water level of approximately 80 ft. The entire pool is lined with stainless steel for leakage control. Each bay has a concrete cover that serves as a biological shield. The cover also serves to prevent deposition of foreign materials onto an NPM. The reactor pool is located in a Seismic Category I building designed to withstand postulated adverse natural conditions and aircraft impact.

The turbine-generator sets are skid-mounted and housed in the turbine buildings adjacent to the reactor building. Laydown area for turbine maintenance is provided in each of the turbine buildings.

NuScale Power Modules in a multi-unit plant are refueled on a staggered 24-month cycle resulting in a high plant capacity factor. The 24-month cycle allows for required in-service inspection of each module, as well as fuel shuffling or partial core replacement.

Table 3-1 presents the overall characteristics of the plant.

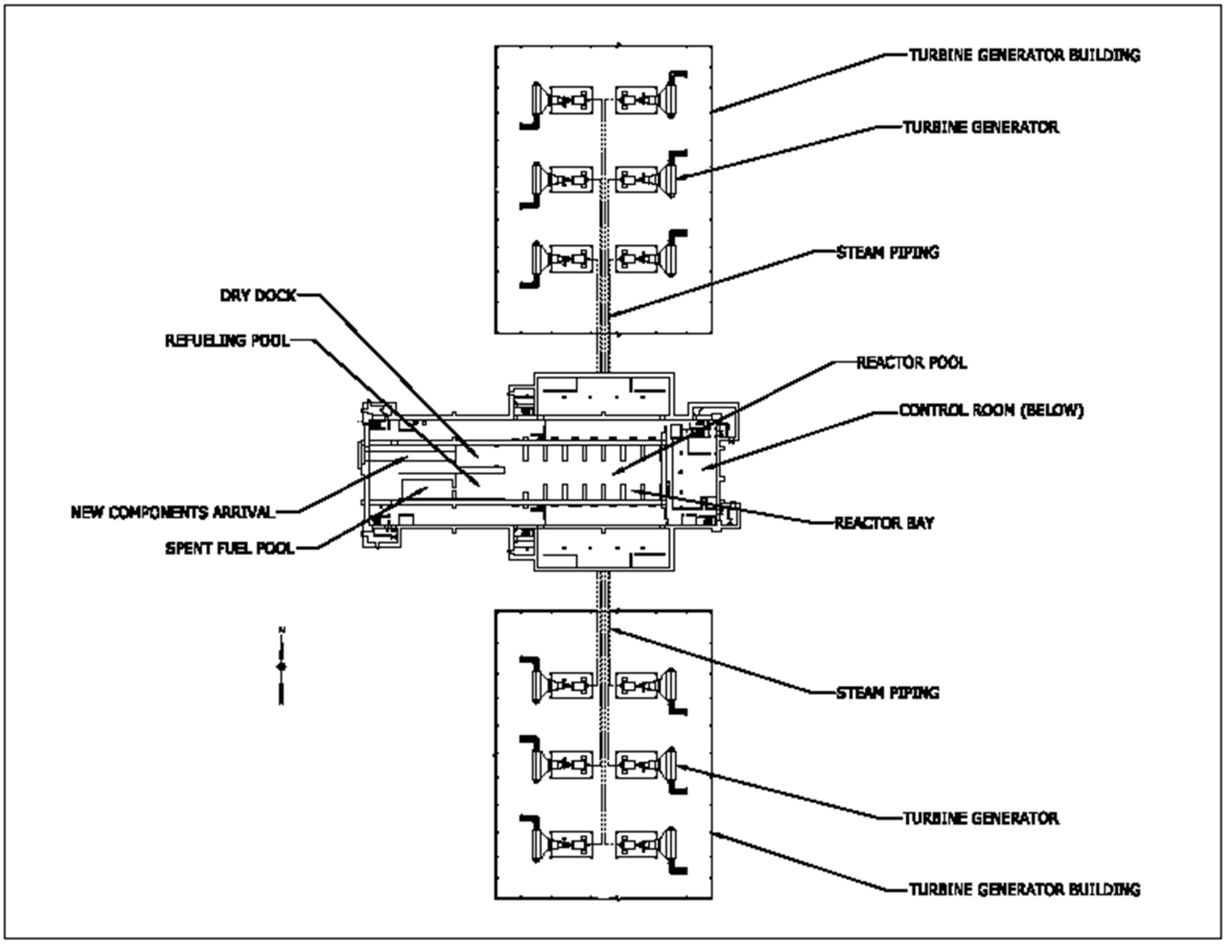

Figure 3-2. Layout of a multi-unit power plant

Table 3-1 Characteristics of a 12-unit power plant

Overall Plant	
Net power output	> 540 MWe
Number of power units	12
Nominal plant capacity factor	>95%
Power Unit	
Number of reactors	One
Thermal power rating	160 MWt
Gross Thermal Efficiency	>30%
Steam generator number	Two
Steam generator type	Vertical helical tube
Steam cycle	Rankine – subcritical regenerative with superheat
Turbine type	3600 rpm, condensing, with extraction

Reactor coolant system normal operating pressure	1850 psia
Reactor Core	
Fuel	UO2 (< 4.95% enrichment)
Refueling intervals	24 months

3.3 Nuclear Steam Supply System

The nuclear steam supply system (NSSS) consists of a reactor core, helical coil steam generators, and a pressurizer within a single pressure vessel. The NSSS is enclosed in a cylindrical CNV that sits in the reactor pool structure as shown in Figure 3-3. The reactor core is located below the helical coil steam generators inside the RPV. Using natural circulation, the primary reactor coolant flow path is upward through the riser, and then downward around the steam generator tubes with return to the bottom of the core via an annular downcomer. As the primary reactor coolant flows across the outside of the steam generator tubes, heat is transferred to the secondary side fluid inside of the steam generator tubes. The secondary side fluid is heated, boiled, and superheated to produce steam for the turbine-generator unit.

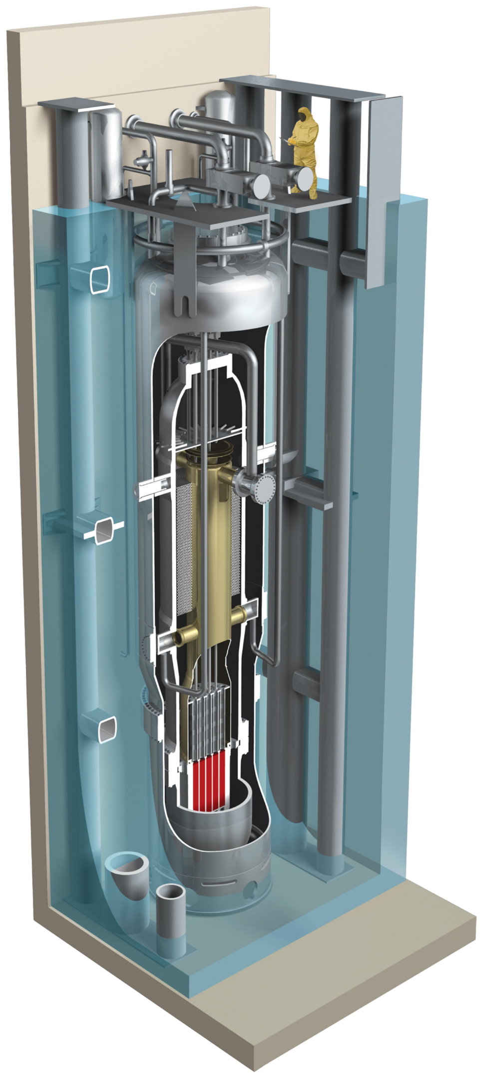

Figure 3-3. Three-dimensional rendering of a single NuScale Power Module

3.4 Reactor Pressure Vessel

The RPV consists of a steel cylinder with an inside diameter of approximately 9 ft and an overall height of approximately 65 ft and is designed for an operating pressure of approximately 1850 psia. To ensure safety and stability, ring forgings located at the steam and feed headers are thickened to provide reinforcement for the vessel nozzles. The upper and lower heads are elliptical, and the lower portion of the vessel has flanges to provide access for refueling.

The RPV upper head supports the control rod drive mechanisms. Nozzles on the upper head provide connections for reactor safety valves, reactor vent valves, and primary system piping.

To provide a barrier between the saturated water in the pressurizer and the reactor coolant system fluid, a steel pressurizer baffle plate is located above the steam generator. The pressurizer baffle plate has orifices to limit the in and out surge of water and to act as a thermal barrier.

3.5 Steam Generator

Each NPM uses two once-through helical-coil steam generators for steam production. The steam generators are located in the annular space between the hot leg riser and the reactor vessel inside diameter wall. The steam generator consists of tubes connected to feed and steam plenums with tubesheets. Preheated feedwater enters the lower feed plenum through nozzles on the RPV. As feedwater rises through the interior of the steam generator tubes, heat is added from the reactor coolant and the feedwater experiences a phase change and exits the steam generator as superheated steam. See Figure 3-4, below.

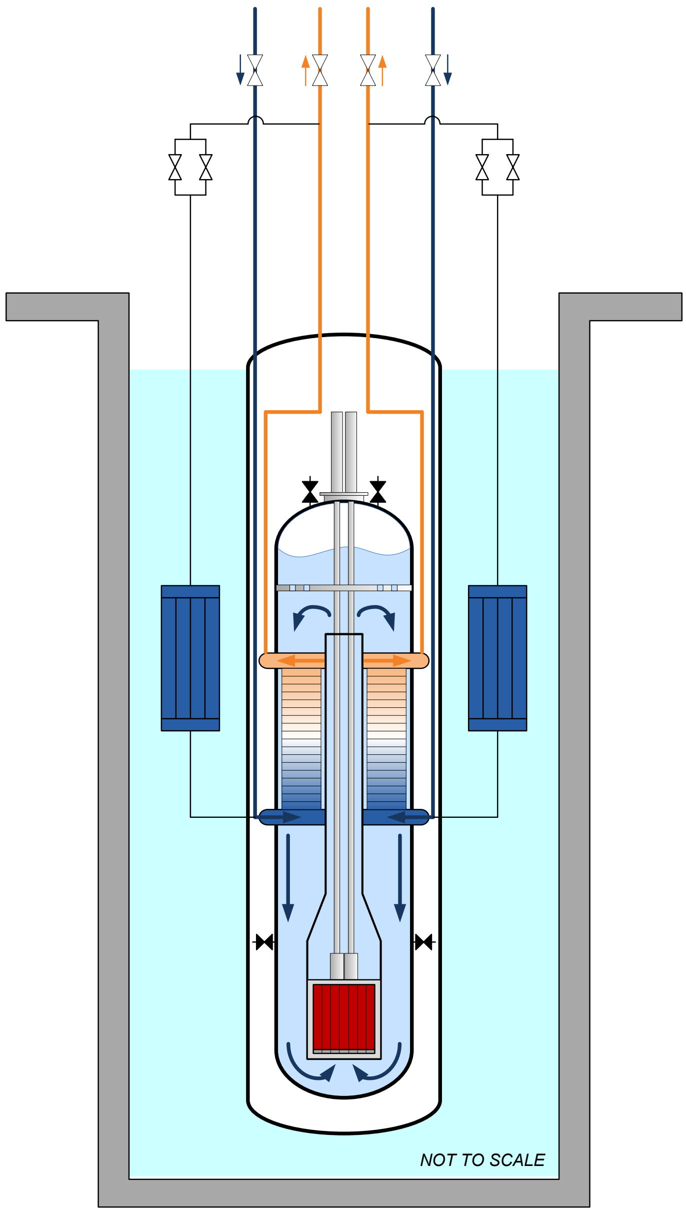

Figure 3-4. Steam generator and reactor flow

3.6 Pressurizer

The pressurizer provides the primary means for controlling reactor coolant system pressure. It is designed to maintain a constant reactor coolant pressure during operation. Reactor coolant pressure is increased by applying power to a bank of heaters installed above the pressurizer baffle plate. Pressure in the reactor coolant system is reduced using spray provided by the CVCS.

3.7 Reactor Core

The core configuration for the NPM consists of 37 fuel assemblies and 16 control rod assemblies. The control rods are organized into two groups: a control group, and a shutdown group. The control group, consisting of four rods symmetrically located in the core, functions as a regulating group that is used during normal plant operation to control power. The shutdown group (12 rods) is used during shutdown and scram events.

The fuel assembly design is modeled from a standard 17 x 17 PWR fuel assembly with 24 guide tube locations for control rod fingers and a central instrument tube. The assembly is nominally half the height of standard plant fuel and is supported by 5 spacer grids. The fuel is UO_2 with Gd_2O_3 as a burnable absorber homogeneously mixed within the fuel for select rod locations. The U-235 enrichment is below the current U.S. manufacturer limit of 4.95 percent enrichment. A list of baseline fuel design parameters is presented in Table 3-2.

Table 3-2 Reactor core and fuel parameters

Core Parameters	Dimensions
Fuel Pins (Standard 17 x 17 PWR Enriched UO2 Fuel with Zircaloy Cladding)	
Rod outside diameter	0.374 inches
Pellet outside diameter	0.322 inches
Clad thickness	0.0224 inches
Active height	2 meters (6.5 ft.)
Fuel Assembly (17x 17 Square Array)	
Assembly pitch	8.466 inches
Pin pitch	0.496 inches
Control Rods (B_4C Absorber)	
Absorber material diameter	0.339 inches
Control rod outside diameter	0.378 inches
Control rod length	2 meters (6.5 ft.)

3.8 Chemical and Volume Control System

The CVCS is simple in design and is not required to function during or after an accident. During normal operation, the CVCS recirculates a portion of the reactor coolant through demineralizers and filters to maintain reactor coolant cleanliness and chemistry. A portion of the recirculated coolant is used to supply pressurizer spray for controlling reactor pressure. Reactor coolant inventory is controlled by injection of additional water when reactor coolant levels are low or letdown of reactor coolant to the liquid radioactive waste system when coolant inventory is high. Additionally, during the power module startup process, the CVCS will be used to add heat to the reactor coolant to establish natural circulation flow in the reactor coolant system.

Boron concentration in the reactor coolant system is controlled by a feed-and-bleed process. Injection pumps provide borated water or clean demineralized water that is delivered into the reactor vessel with excess reactor coolant being letdown to the radioactive waste system.

4.0 Safety Features

Each NPM incorporates several simple, redundant, and independent safety features. These features are discussed in detail in the following sections.

4.1 Containment Vessel

The major safety functions of the CNV are to contain the release of radioactivity following postulated accidents, protect the RPV and its contents from external hazards, and to provide heat rejection to the reactor pool following ECCS actuation.

Each CNV consists of a steel cylinder with an outside diameter of approximately 15 ft and an overall height of approximately 80 ft. The CNV houses the RPV, control rod drive mechanisms, and associated piping and components in support of the NSSS.

Flanges are provided on the CNV to allow for disassembly and to allow access to the RPV during refueling operations and maintenance. Containment vessel manways provide access to components located inside the CNV. Penetrations on the CNV upper head are provided for process piping, electrical power, and instrumentation.

The CNV is laterally supported by the lateral support lugs at the steam plenum elevation and is laterally and vertically supported by the support skirt attached to the CNV lower head. Internal to the CNV, the RPV is laterally and vertically supported by the RPV support skirt at the steam plenum elevation and is laterally supported by shear lugs near the CNV flange elevation.

The CNV, as the outer portion of the NPM, is immersed in the reactor pool, which provides a passive heat sink for containment heat removal under LOCA conditions. The CNV is designed to withstand the environment of the reactor pool as well as the high pressure and temperature of any design basis accident.

The CNV pressure is maintained at a vacuum under normal operating conditions. Maintaining a vacuum provides for reduced moisture that could contribute to component corrosion and impact the reliability of instrumentation and other systems within the CNV. The vacuum essentially eliminates convection heat transfer removing the need for “direct-contact” RPV insulation that greatly reduces potential debris generated in the CNV. Due to a lack of appreciable amounts of air, the vacuum also enhances steam condensation rates that would occur during an accident with ECCS actuation (see Section 4.3 for details) and limits the formation of a combustible mixture of hydrogen and oxygen during a severe accident.

Following an actuation of the ECCS, heat removal through the CNV rapidly reduces the containment pressure and temperature and maintains them at less than design conditions indefinitely. Steam is condensed on the inside surface of the CNV, and is passively cooled by conduction and convection of heat to the reactor pool water.

4.2 Decay Heat Removal System

The DHRS provides secondary side reactor cooling for non-LOCA events when normal feedwater is not available. The system, as shown in Figure 4-1, is a closed-loop, two-phase natural circulation cooling system. Two trains of decay heat removal equipment are provided, one attached to each steam generator loop. Each train is capable of removing 100 percent of the decay heat load and cooling the reactor coolant system. Each train has a passive condenser immersed in the reactor pool. The condensers are maintained with sufficient water inventory for stable operation.

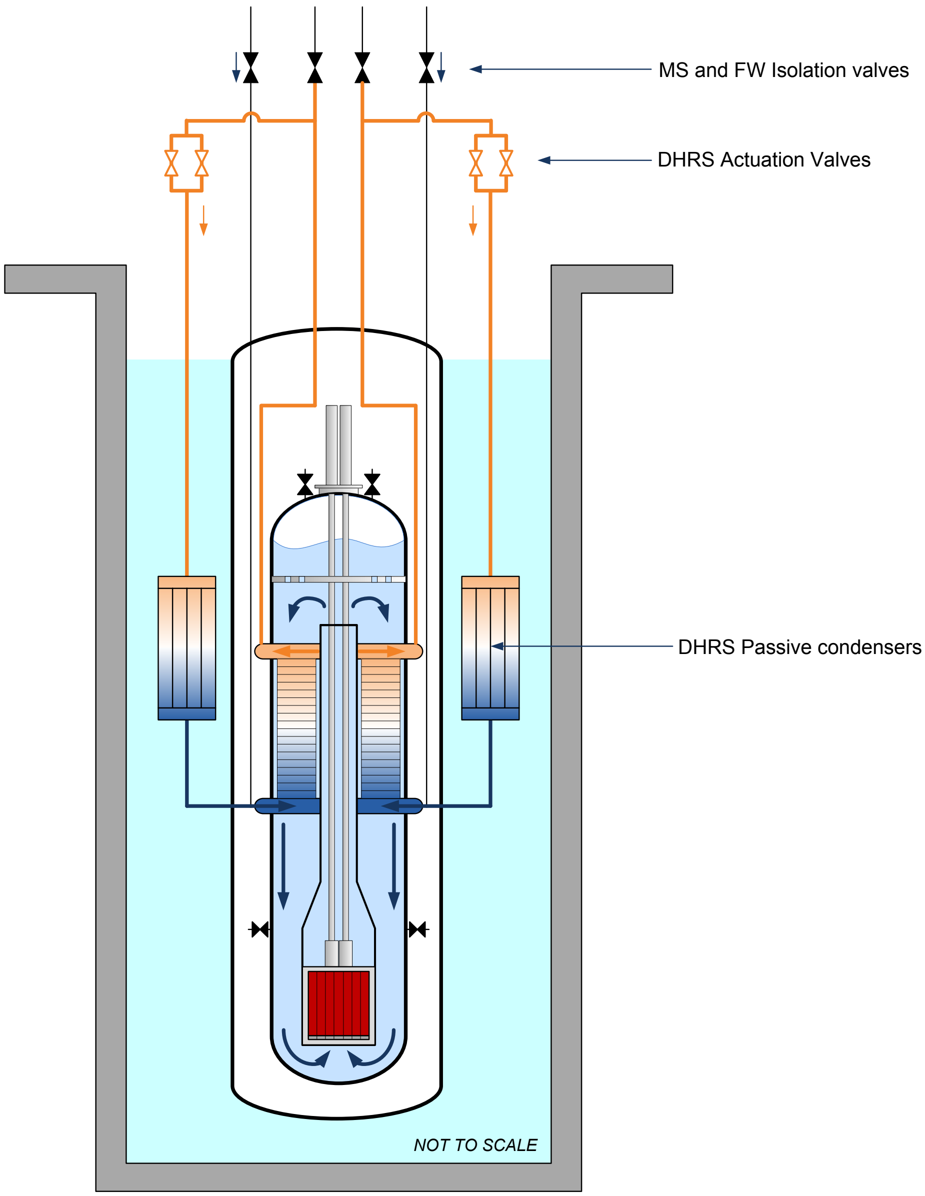

Figure 4-1. Decay heat removal system

Upon receipt of an actuation signal, feedwater and steam line valves are closed and the DHRS valves open. This allows water from the passive condensers to travel to the steam generators where it is turned to steam. The steam then travels through the steam generator back to the condenser where it is condensed by the reactor pool water, and the cycle is repeated. Heat is removed via the steam generators, thus preserving natural circulation within the reactor coolant system.

4.3 Emergency Core Cooling System

As shown in Figure 4-2, the ECCS consists of two independent reactor vent valves and two independent reactor recirculation valves. For LOCAs in the containment, the ECCS returns coolant from the CNV to the reactor vessel. This ensures that the core remains covered and that decay heat is removed. The ECCS provides a defense-in-depth means of decay heat removal in the unlikely event of a loss of feedwater flow, combined with the loss of both trains of the DHRS.

The ECCS removes heat and limits containment pressure by steam condensation on, and convective heat transfer to, the inside surface of the CNV. Heat is then transferred by conduction through the CNV walls and convection to the water in the reactor pool. Long-term cooling is established via recirculation of reactor coolant to the RPV through the ECCS recirculation valves.

The ECCS is initiated by opening the two reactor vent valves (RVVs) in lines exiting the top of the RPV (the pressurizer region) and the two reactor relief valves (RRVs) on lines entering the RPV in the downcomer region at a height above the core. Opening the valves allows a natural circulation path to be established. Water that is vaporized in the core leaves as steam through the RVVs, is condensed and collected in the CNV, and is then returned to the downcomer region inside the reactor vessel through the RRVs. The RVV and RRV components fail to the open (safe) position upon loss of power, thus enabling reliable long-term cooling without operator actions, AC or DC power, or make-up water.

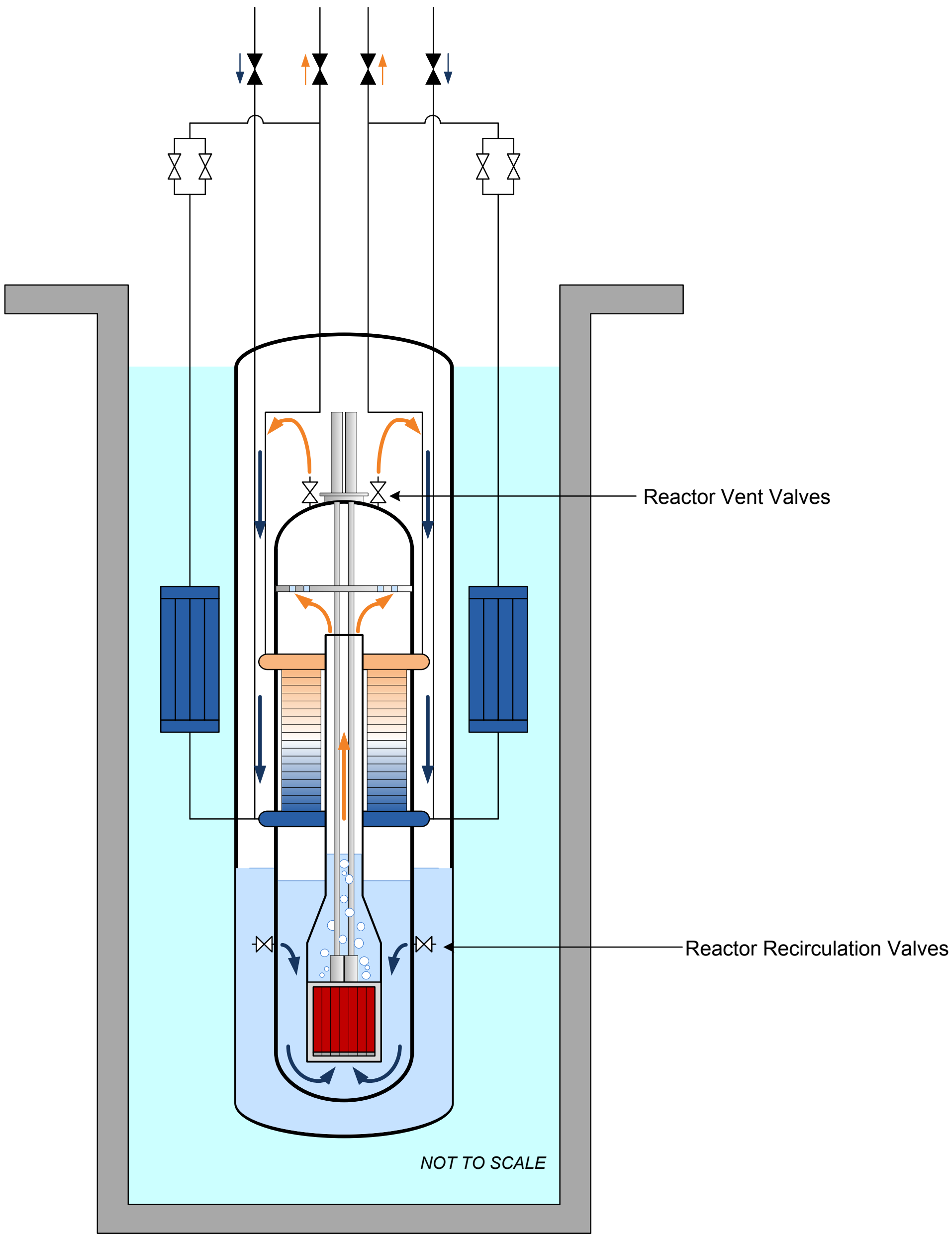

Figure 4-2 Emergency core cooling system

4.4 Reactor Pool

The reactor pool is a large stainless steel lined pool located below the plant ground level. Water in the pool provides cooling for the NPM for a minimum of 72 hours following any LOCA. During normal plant operations, heat is removed from the pool through a cooling system and ultimately rejected into the atmosphere through a cooling tower or other external heat sink. In an accident where offsite power is lost, heat is removed from the NPMs by allowing the pool to heat up and boil. Water inventory in the reactor pool is large enough to cool the NPMs for greater than 72 hours without adding water. After 72 hours, reactor building pool water boil-off, and ultimately passive air cooling of the NPMs, provides adequate cooling for long-term decay heat removal. Although not credited, the reactor pool provides an additional means of fission product retention beyond that of the fuel, fuel cladding, RPV, and the containment for certain events.

4.5 Instrumentation and Controls Systems

The NuScale Instrumentation and Controls architecture consists of the following systems:

- Nonsafety control and instrumentation system (NCIS)
- Safety control and instrumentation system (SCIS)

The NCIS provides control and monitoring of the following systems:

1. Nonsafety nuclear steam supply system (NSSS), such as secondary steam bypass to condensers, pressurizer heaters and spray, and feedwater control
2. Balance of plant systems, such as turbine control
3. Rod control and information system (RCIS)

The SCIS protection functions are limited to automated safety responses to specific initiating events. The SCIS functional response to an initiating event is a reactor trip, followed by an integrated safety response from one or more of the passive safety systems; the DHRS and ECCS.

The SCIS is composed primarily of the reactor trip system (RTS) and the engineered safety features actuation system (ESFAS). The RTS consists of four independent separation groups with independent measurement channels to monitor plant parameters that can generate a reactor trip. Each measurement channel trips when the parameter exceeds a predetermined set point. The RTS coincident logic is designed so that no single failure can prevent a reactor trip when required, and no failure in a single measurement channel can generate an unnecessary reactor trip.

The ESFAS consists of four independent separation groups with independent measurement channels that monitor plant parameters that activate the operation of the engineered safety features systems. Each measurement channel trips when the parameter exceeds a predetermined set point. The ESFAS coincident logic is designed so that no single failure can prevent a safeguards actuation when required, and no single failure in a single measurement channel can generate an unnecessary safeguards actuation.

Transients requiring decay heat removal are addressed by the DHRS, which provides cooling through one or both of the steam generators. For a steam generator tube rupture, the affected steam generator is isolated and the DHRS provides cooling through the intact steam generator. A transient requiring reactor coolant system inventory addition is first mitigated by the functioning of the nonsafety-related CVCS. If the CVCS is inadequate to address the decrease in reactor coolant level, containment isolation occurs and the ECCS is actuated.

The physical design of the reactor vessel precludes large-break LOCAs. The DHRS can provide additional capacity for decay heat removal during the initial blowdown period of a LOCA, but it is not required nor credited for such events.

4.6 Control Room Habitability System

The control room habitability system (CRHS) ensures that plant operators are adequately protected against the effects of accidental releases of toxic and radioactive gases. The CRHS is a passive system that provides clean compressed breathable air to the control room in the event of a radioactive release or when AC power is not available. Areas served by the CRHS are maintained at positive pressure relative to adjacent areas. Compressed breathable air storage capacity can provide clean air to the control room spaces for at least 72 hours following an initiating event.

5.0 Plant Arrangement and Operations

The multi-unit plant consists of a power generation complex and common facilities. The power generation complex for the NuScale plant consists of up to 12 power generation units (12 NPMs and associated turbine generators), module assembly equipment, fuel handling equipment, turbine maintenance equipment, and radioactive waste processing equipment. A 12-unit plant net total output is approximately 540 MWe. Figure 5-1 presents a layout of the plant site.

Figure 5-1. Conceptual plant site layout

The majority of the site buildings are located within the protected area and surrounded by a double fence and intrusion-detection equipment. The protected area is located within the restricted owner controlled area (ROCA) surrounded by an additional single fence. Only the administration building and the warehouse are located outside of the ROCA.

5.1 Site Facilities

The site contains several facilities that are important to the operation and support of the plant. (Refer to Figure 5-1 for building number cross-references.) The following facilities are included in the plant design:

1. Administration Building – houses the administration services and the training center
2. Annex Building – provides space for the following facilities:
   - Personnel Services – houses various personnel support services such as locker rooms, showers, toilet facilities, lunch and conference rooms, and first aid.
   - Access Control – controls access to both radiological-controlled and non-radiological-controlled areas of the reactor building

- Health Physics – provides space for plant contamination evaluation and employee dosimeter processing
- Security Services – a significant portion of the facilities that support plant security such as security briefing room, armory, security manager's office, etc.

3. Reactor Building – located above and below grade, it provides space for all safety-related equipment and houses the following facilities (see Section 5.2):
   - Spent Fuel Pool – stores used fuel
   - Reactor Pool – location for the NPMs during operation
   - Fuel Handling Areas – (see Section 5.4)
   - Control Room – houses the plant's Main Control Room (see Section 5.3)
   - Technical Support Center – located below the Main Control Room, outside the radiological controlled area; provides space to support emergency operations and personnel
   - Remote Shut Down Station – provides space for the plant auxiliary shutdown system
   - Primary Systems and all safety-related systems
   - Safety-Related Power Systems
4. Turbine Building – houses the plant's turbine-generators (see Section 5.7.)
5. Radioactive Waste Building – provides space for heating ventilating and air conditioning (HVAC) radiation filtering equipment; radioactive waste treatment and storage equipment; and for servicing all potentially radioactive and non-radioactive tooling, fixtures, and instrumentation (see Section 5.6).
6. Warehouse Building – provides handling and hoisting equipment as well as space for controlled storage of spare NSSS modules, spare parts, and tools
7. Water Treatment Building – houses common plant services such as demineralized water, potable water, fire protection water, and auxiliary steam. The building also houses the equipment and systems needed to treat all plant non-radioactive wastes before offsite disposal. The building is an above-grade, one-story structure with large storage tanks located outside.
8. Cooling Towers – provides the water to air heat sink for the circulating water system
9. Pump house – houses pumps for the circulating water system
10. Security Building – provides controlled access into the secured areas of the plant
11. Primary Access Control Building – provides for controlled access into the restricted, owner controlled area

5.2 Reactor Building

The reactor building, as depicted in Figure 5-2, houses the systems and components required for plant operation and shutdown. The reactor building is a Seismic Category I reinforced concrete structure designed to withstand the effects of aircraft impact, environmental conditions, natural phenomena, postulated design basis accidents, and design basis threats. The reactor building also provides radiation protection to plant operation and maintenance personnel.

Portions of the reactor building are located above grade, while others are located below grade. The NPM, reactor pool, and the spent fuel pool are located at or below nominal plant grade level, while the hoisting and handling equipment is located above grade. Also located below grade are

the 1E batteries, main control room, most primary systems, and some radioactive waste equipment.

The surface of the reactor pool water is located a few feet below grade level. The NPMs are installed in a vertical position and are arranged into two rows of up to six NPMs along the external reactor pool walls. Concrete walls separate the NPMs into individual reactor bays. Additionally, an extra bay is located adjacent to the units for NPM maintenance or storage of an optional spare NPM. A central channel is provided between the rows of NPMs to allow for movement between the reactor pool and the adjacent refueling pool.

Piping interfacing with the NPM (i.e., feedwater piping, steam piping, the chemical and volume control system, containment evacuation system, instrumentation, and power connections) is located above the water level. Pipe fittings are provided in this area to permit manual connection and disconnection during NPM installation, refueling outages, and during replacement or removal of NPMs.

To the maximum extent practical, equipment rooms or vaults within the reactor building are partitioned to provide separation between power generation units.

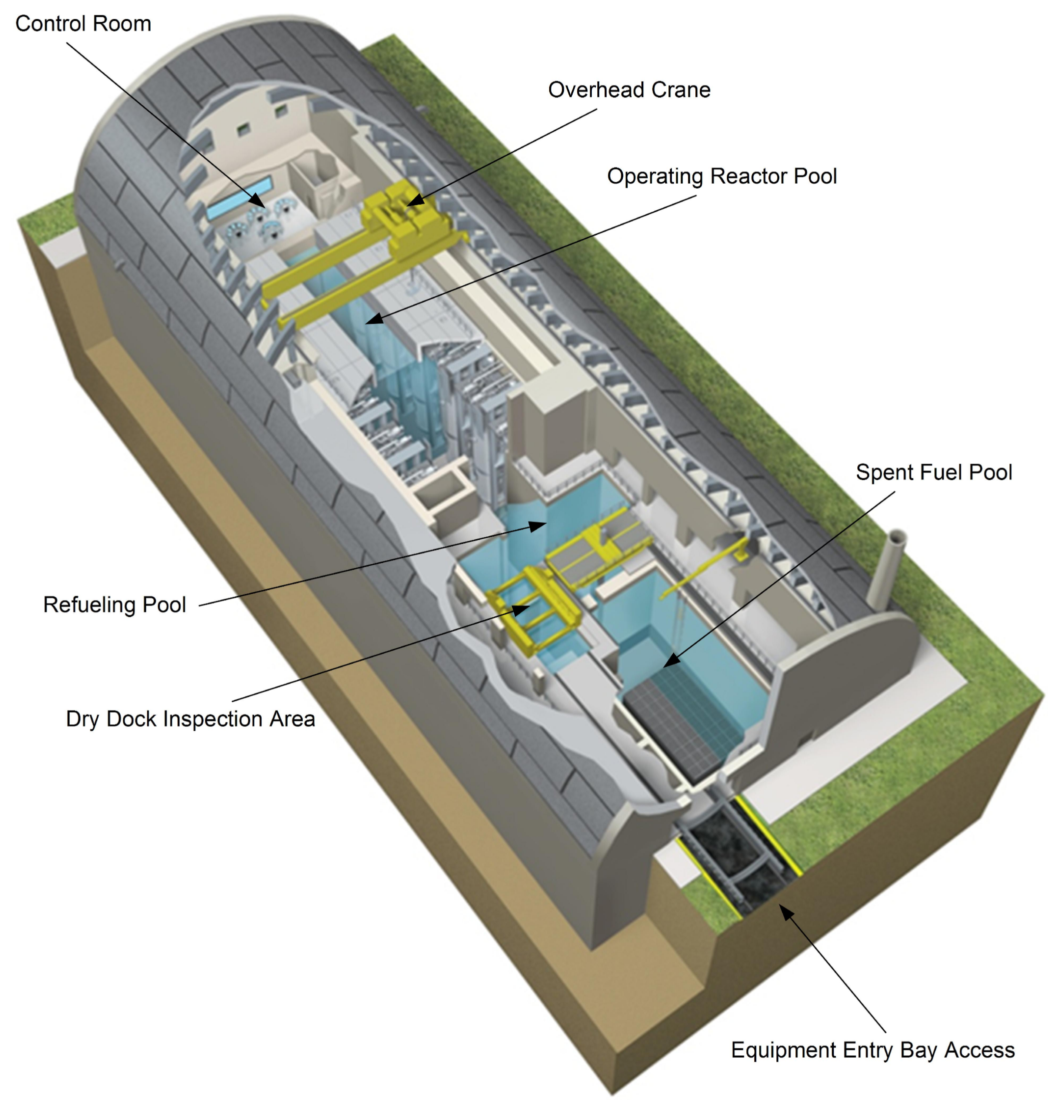

Figure 5-2. Reactor building view

5.3 Control Room

The main control room is housed below grade in the reactor building. The plant will have a control console in the main control room for all installed units. Each reactor operator will monitor and control multiple units from the control room console.

A digital control system will be implemented in a manner that provides complete isolation between the SCIS and NCIS. Each reactor control system display provides the monitoring for a specific reactor. Additional display stations, including a separate display for shared plant systems not associated with a single unit, provide control room operators with access to a wide range of plant information for trending and diagnostics.

The reactor operators monitor the automated control system for each reactor. Each reactor is outfitted with monitors provided with soft controls and some select manual push buttons for operator control. The supervisor station provides an overview of all reactors using multiple monitors. All monitor displays are designed using human factors analysis to enhance simplicity. The display layout and design uses graphical representations of plant systems and components.

The following monitoring and control activities are typical control room functions:

- initiate NPM startup
- initiate NPM shutdown
- set or correct set points that control the NPM or plant functions
- take corrective actions if any NPM or plant system does not operate as intended
- provide permission for the control systems to continue on past predefined “hold points” in major operations using automated control system functions

The plant’s main control room enhances supervisory control of the NPM and plant systems by providing alarm annunciation on the plant group-view overview display monitor as part of the alarm management system. This system includes information from the individual NPMs via the SCIS system, the NCIS, and the shared instrumentation and control systems common to all the NPMs. In the unlikely event that the main control room becomes uninhabitable, a remote shutdown station provides a secondary location for shutdown of the reactors.

5.4 Fuel Handling and Reactor Maintenance Areas

The fuel handling and reactor maintenance areas include space for

- new fuel storage
- spent fuel pool
- refueling pool
- dry dock

The fuel handling and maintenance areas are housed within the reactor building and consist of pools and operating level storage and handling areas. The pools include the refueling pool, spent fuel pool, and dry dock. The operating areas provide space for the operation of handling equipment, access to the upper portion of NPMs while the reactor core is being refueled, and space for the storage of new fuel assemblies.

The refueling pool is connected directly to the reactor pool via an open channel able to accommodate transport of the NPM through the pool water. An open channel between the refueling pool and spent fuel pool provides access for fuel assembly transport under water during the refueling process. The fuel handling and maintenance areas are designed to provide radiation protection for plant operation and maintenance personnel who are working in those areas.

The new fuel storage area contains a fuel receiving area, new fuel storage racks, and a jib crane for loading new fuel assemblies into the new fuel elevator. The area has forklift access to aid in new fuel receiving activities.

The spent fuel pool provides storage space for the accumulated spent fuel assemblies prior to removal for dry storage and temporary storage for new fuel assemblies before being moved to a reactor core location. In preparation for refueling, new fuel assemblies are moved from dry storage and temporarily stored in racks in the spent fuel pool before being placed in the reactor core. After being removed from the reactor core, spent fuel assemblies are placed in spent fuel storage racks in the spent fuel pool. Within approximately 5 years, the thermal load of the spent fuel assemblies is reduced significantly, and the assemblies can be moved to a secure dry storage area. The plant site layout includes space allocation adequate for the dry storage of all of the spent fuel for the 60-year life of the plant.

The refueling area contains the bolting tools to disassemble and reassemble the NPM during refueling. The reactor core remains in the lower head of the RPV while in the refueling pool for refueling and fuel management. A fuel handling machine moves new and used fuel through a submerged access channel between the refueling pool and spent fuel pool.

The dry dock area contains the module inspection rack and is separated from the refueling pool by a gate. With the gate closed, the dry dock water level can be lowered and maintenance activities on the upper NPM can be completed. This area includes the necessary inspection and testing equipment needed for the NPM.

The dry dock provides maintenance access to the upper section of the NPM. The dry dock is also used for placing new NPM components into the reactor building pool system and preparing them for assembly. Additionally, it provides access for shipment of used NPM offsite.

5.5 Refueling Operations

In a multi-unit plant, an individual NPM is refueled while the remaining NPMs remain online. During refueling, the NPM is moved from its operating bay in the reactor pool to the refueling pool by the reactor building crane. The reactor building crane is used to lift the NPM off its supports. The NPM is moved to the open channel in the center of the reactor pool, which then serves as a pathway to transport the NPM to the refueling area.

In the refueling area, separate dedicated flange bolting tools are used to detach the lower CNV and the lower RPV. The lower RPV, including the core, is staged in the reactor bolting tool. After detaching the lower vessel sections, the reactor building crane transports the upper sections of the NPM to the module inspection rack in the dry dock. Inspection, testing, and maintenance are performed while the core is being refueled using a dedicated fuel handling machine.

After inspection, maintenance, and testing are complete and the reactor core has been refueled, the upper portion of the NPM is moved from the dry dock to the refueling pool where the NPM is reassembled using the flange tools. Following reassembly, the NPM is moved into the reactor pool and returned to its operating bay by the reactor building crane. In the operating bay, startup tests are performed and the reactor is prepared for restart. After the NPM has passed all necessary tests and inspections and the reactor coolant is at startup conditions, the NPM is brought online, and steam and power production begins.

5.6 Radioactive Waste Building

The radioactive waste building houses equipment and systems for processing the plant’s radioactive gaseous, liquid, and solid waste and for preparing waste for shipment offsite. The building houses equipment to prepare low level radioactive waste for compaction to reduce volume and provides temporary storage for radioactive waste. HVAC equipment for providing radioactive waste building high-efficiency particulate air filtration is located in the building. The

building is designed to maintain radiation exposures to operators and maintenance personnel at the lowest achievable levels.

5.7 Turbine Generator Buildings

A large multi-unit plant has two separate turbine buildings, each housing up to six turbine-generators. The turbine buildings are above-grade structures that house the turbine-generators with their auxiliaries, the condensers, condensate systems, and the feedwater systems. An emblematic turbine generator is shown in Figure 5-3. Each turbine-generator is associated with a single NPM and has dedicated condensate and feedwater pumps. Each turbine-generator is supported by an above-grade pedestal. Each condenser is located adjacent to the turbine-generator. An overhead crane is provided for the installation and maintenance in each turbine building. The turbine buildings are steel-framed structures with insulated metal wall siding and roof decking.

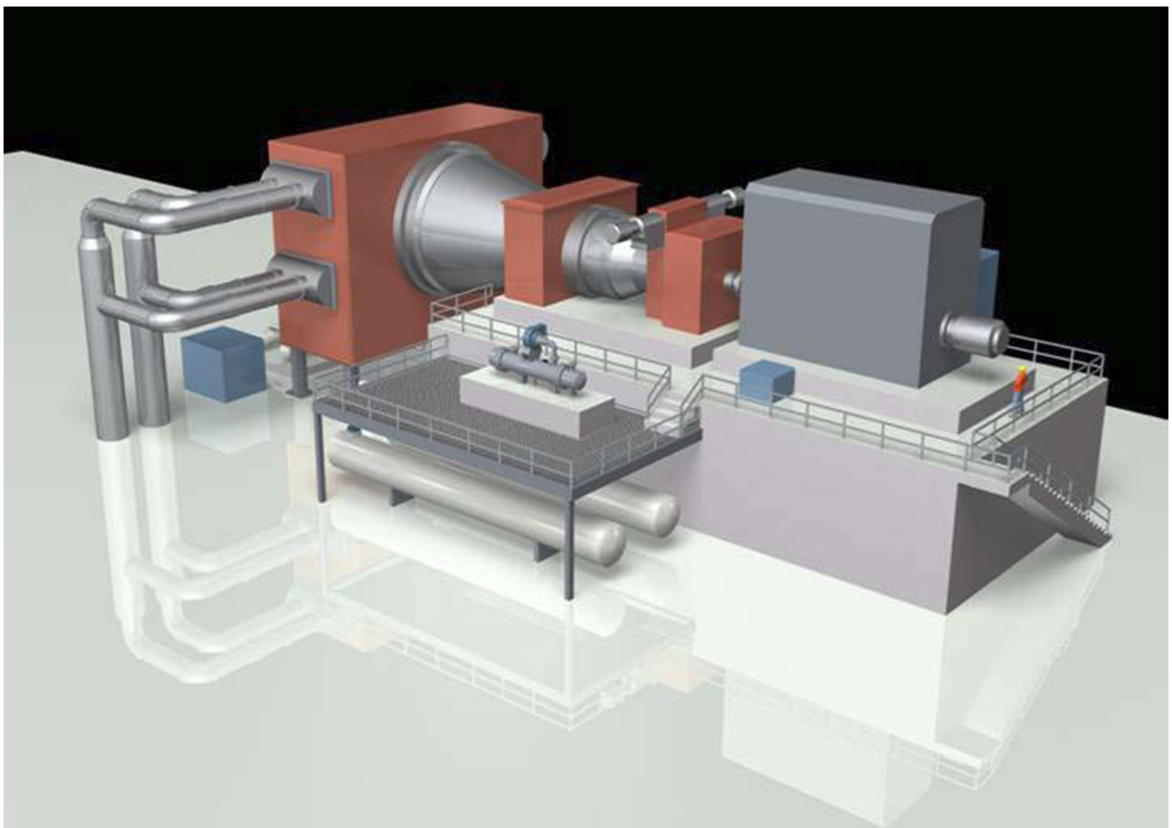

Figure 5-3 Turbine-generator set

5.8 Plant Cooling Systems

The plant cooling systems include several systems that are important to supporting plant operation. These systems include the following:

- The site cooling water system provides a continuous supply of cooling water to the chilled water system, the balance of plant component cooling water system, the spent fuel pool cooling water system, and the reactor pool cooling water system. Heated water from these systems is returned to a set of mechanical draft cooling towers. The cooled water is collected in a common basin where it then feeds the site cooling water pumps, which return the cooled water to the systems serviced.

- The circulating water system provides a continuous supply of cooling water to the plant turbine condensers. Heat from up to six condensers in one turbine building is returned to a set of mechanical draft cooling towers. The cooled circulating water collects in a common basin where it then feeds circulating water pumps, which return the cooled water to the condensers.
- The balance of plant component cooling water system provides cooling water to the turbine building loads other than the turbine condensers noted above.
- The reactor component cooling water system is a nonsafety-related, closed-loop cooling system that transfers heat from various plant components to the site cooling water system. The reactor component cooling water system provides cooling to the control rod drive mechanisms, the non-regenerative heat exchangers for each CVCS, and the primary sampling system coolers.
- The reactor pool cooling water system and the spent fuel cooling water system transfer heat from the pools to the site cooling water system.

5.9 Electric Power Systems

Under normal operating conditions the AC electrical power distribution system supplies reliable and continuous power to equipment required for startup, normal operation, and shutdown of the plant. The NuScale plant does not require offsite AC electrical power to cope with design basis events. No backup power is required for safety system actuation. In the event of failure of the AC electrical power supply, the 1E DC backup supply system provides the necessary AC power through inverters to ensure continuous operation of post-accident monitoring instrumentation.

The power systems within the plant are described below:

- 13.8 KV and SWYD (switchyard) system - consists of the set of electrical circuits and associated equipment that are used to interconnect the off-site transmission system, the plant main generator, and the on-site electric power distribution systems. It includes the plant switchyard, the main step-up transformers, the high voltage tie lines, and their associated auxiliary systems, including protective relays and local instrumentation and controls.
- Medium voltage AC electrical distribution system - consists of the on-site electric power distribution circuits that operate at 4.16 KV and supply power to medium voltage loads.
- Low voltage AC electrical distribution system - consists of the on-site electric power distribution circuits that supply power to plant loads at 600 volts or less. The system does not include the low voltage vital AC power supply system or the normal and emergency lighting systems.
- Backup diesel generator system - consists of the on-site standby AC power sources (backup diesel generator) and associated power supply circuits up to the source breakers connecting to the on-site AC distribution systems. The system is designed to supply AC power to the plant permanent nonsafety loads in the event of a main generator trip and loss of off-site power. Operation of the system is not required to ensure nuclear safety.
- Safety DC electrical and essential AC distribution system - The essential low voltage AC power supply system consists of the electric power supply and distribution equipment and circuits that provide low voltage AC power for continuous operation of safety instrument loads and computer systems. The system is designed to provide continuous, reliable electric power for control and instrumentation loads such as the reactor protection and safety features actuation systems, and to other important loads required for plant startup, normal operation, and normal or emergency shutdown.
- Nonsafety DC electrical and AC distribution system - supplies low voltage DC and AC to all the nonsafety control and instrumentation loads in the plant.