Status Report – NuScale SMR (NuScale Power, LLC)
United States of America **2020/05/28**

NuScale Power is developing a new modular light water reactor nuclear power plant to supply energy for electrical generation, district heating, desalination, and other process heat applications. NuScale Power Module™ is a fully factory-fabricated small modular reactor (SMR) design that is capable of generating 60 MW of electricity using a safer, smaller, and scalable version of pressurized water reactor technology. A NuScale's power plant design is scalable as it can house up to 12 individual power modules. This scalable feature offers the benefits of carbon-free energy and reduces the financial commitments associated with gigawatt-sized nuclear facilities.

Indicate which booklet(s): [ ] Large WCR [X] SMR [ ] FR

The NuScale design is a 720 MWe integral pressurized water reactor (PWR) whose concept was conceived and has been in development and testing since the early 2000s under the U.S. Department of Energy (DOE) Multi-Application Small Light Water Reactor (MASLWR) Program. The design is based on proven PWR technology, but it is characterized for its reliance on natural phenomena and simple design. The safety systems use natural-driving forces such as gravity, natural circulation flow, conduction, and convection; and thus, do not use active components (e.g., pumps) that require safety-grade support systems (e.g., AC/DC power) to function. The reduction in active components significantly enhances the operability and maintainability of the systems in NuScale Power Module™. Probabilistic risk assessment results predict a very low core damage frequency and a low frequency of radiological release, which meet the goals established for advanced reactor designs due to the application of robust defence-in-depth principles, natural circulation for cooling, and small core. Additionally, radiation exposure reduction principles to keep worker dose as low as reasonably achievable is essential to the design. As a result of the reduced number of plant components, simplicity of operation, high reliability systems, and dedicated power conversion system, NuScale Power Modules™ will be produced in a factory, shipped, and installed in the reactor building in an incrementally matter to match load growth. Ultimately, these features minimize construction time and total cost. Key milestones in the development of the NuScale plant design are listed below.

Development Milestones

2003	Precursor concept developed (Multi-Application Small LWR—MASLWR Program)
2007	NuScale Power, Inc. created to commercialize new design
2011	Fluor Corporation became major NuScale investor and strategic partner
2013	NuScale won its first competitive U.S. Department of Energy funding opportunity
2017	Design certification application (DCA) submitted to U.S. NRC
2018	Phase 1 of DCA review completed
2019	Phase 2-4 of DCA review completed
2020	Expected DCA review completion
2023	Start fabrication/construction of first full-scale NuScale power plant (NPP) in the United States
2027	Commercial operation of first NuScale plant

Design organization or vendor company (**email**): communications@nuscalepower.com

Links (www…) to designer/vendor homepage: www.nuscalepower.com

Detailed Design Description: NuScale Design Certification Application (available at www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html)

Most Recent Licensing Application Support Document: NuScale Design Certification Application (available at www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html)

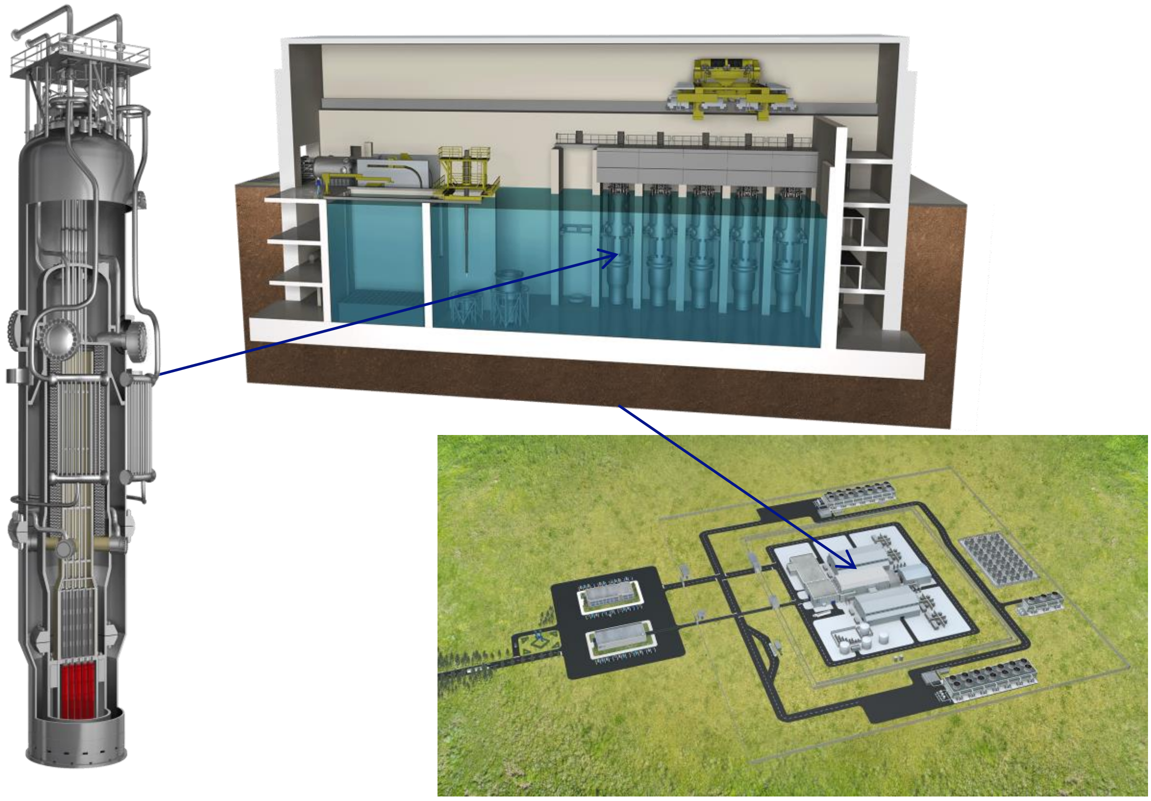

Figure 1. NuScale plant site overview

Table 1: ARIS Category Fields (see also Spreadsheet "Categories") for Booklet

ARIS Category	Input	Select from
Current/Intended Purpose	Commercial-Electric/Nonelectric	Commercial – Electric/Nonelectric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Base-load, Dispatchable, or Cogeneration	Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Nonelectric (specify)
Reference Location	Coast, Inland	On-Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)	Up to 12 modules	Single Unit, Dual Unit, Multiple Unit (# units)
Reactor Core Size (1 core)	Small	Small (<1000 MWth), Medium (1000-3000 MWth), Large (>3000 MWth)
Reactor Type	PWR	PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Core Coolant	H_2O	H_2O, D_2O, He, CO_2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Neutron Moderator	H_2O	H_2O, D_2O, Graphite, None, (Other-specify)
NSSS Layout	Integral	Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Natural	Forced (# pumps), Natural
Thermodynamic Cycle	Rankine	Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H_2O	H_2O, He, CO_2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly	Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Square	Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	264	#, n/a
Fuel Material Type	Oxide	Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Detailed	Conceptual, Detailed, Final (with secure suppliers)
Licensing Status	DCR	DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)

Table 2: ARIS Parameter Fields (see also Spreadsheet "Data") for Booklet

ARIS Parameter	Value	Units or Examples
Plant Infrastructure		
Design Life	60	years
Lifetime Capacity Factor	>95	%, defined as Lifetime MWe-yrs delivered/(MWe capacity * Design Life), incl. outages
Major Planned Outages	10d/24m (refueling)	# days every # months (specify purpose, including refuelling)
Operation/Maintenance Human Resources	300/+18	# Staff in Operation/Maintenance Crew during Normal Operation
Reference Site Design	Up to 12 modules	n Units/Modules
Capacity to Electric Grid	685	MWe (net to grid)
Nonelectric Capacity	--	e.g., MWth heat at x ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption	35	MWe
Plant Footprint	4877	m^2 (rectangular building envelope)
Site Footprint	140,000	m^2 (fenced area)
Emergency Planning Zone	Site boundary	km (radius)
Releases during Normal Operation	36/ 26 /41	TBq/yr (Noble Gases/Tritium Gas/Liquids)
Load Following Range and Speed	- 100	x – 100%, % per minute
Seismic Design (SSE)	0.5 horizontal/ 0.4 vertical	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary/secondary)	13.8/4.4	MPa(abs), i.e., MPa(g)+0.1, at core/secondary outlets
Primary Coolant Inventory (incl. pressurizer)	4.67E+04	kg
Nominal Coolant Flow Rate (primary/secondary)	666/87	kg/s
Core Inlet/Outlet Coolant Temperature	265/321	ºC/ºC
Available Temperature as Process Heat Source	N/A	ºC
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- dimensions	17.8/ 3.0 /260,000	m (length)/m (diameter)/kg (transport weight)
Reactor Vessel Material	SA-508	e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design	Helical	e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow

ARIS Parameter	Value	Units or Examples
Secondary Coolant Inventory	2.54E+04	kg
Pressurizer Design	Integral	e.g. separate vessel, integral, steam or gas pressurized, etc.
Pressurizer Volume	16.4/9.8	m^3/m^3 (total/liquid)
Containment Type and Total Volume	/	Dry (single/double), Dry/Wet Well, Inerted, etc./m^3
Spent Fuel Pool Capacity and Total Volume	18 years/4500	years of full-power operation/m^3
Fuel/Core		
Single Core Thermal Power	200	MWth
Refuelling Cycle	24 months	months or "continuous"
Fuel Material	UO_2	e.g., UO_2, MOX, UF_4, UCO
Enrichment (avg./max.)	<4.95	%
Average Neutron Energy		eV
Fuel Cladding Material	M5 (Framatome)	e.g., Zr-4, SS, TRISO, E-110, none
Number of Fuel "Units"	37 Assemblies	specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit	250	kg
Total Fissile Loading (initial)	9250 (UO_2)	kg fissile material (specify isotopic and chemical composition)
% of fuel outside core during normal operation	N/A	applicable to online refuelling and molten salt reactors
Fraction of fresh-fuel fissile material used up at discharge		%
Core Discharge Burnup	>30	MWd/kgHM (heavy metal, eg., U, Pu, Th)
Pin Burnup (max.)	62	MWd/kgHM
Breeding Ratio	NA	Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing	None	e.g., None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Control rods, Boric acid	e.g., Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber	Gd_2O_3	e.g., Gd_2O_3,
Core Volume (active)	4.3	m^3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary	--	N/m^2-s
Max. Fast Neutron Flux	4.30E+13	N/m^2-s

ARIS Parameter	Value	Units or Examples
Safety Systems		
Number of Safety Trains	Active/Passive	% capacity of each train to fulfil safety function
- reactor shutdown	--/ Passive	/100
- core injection	--/ Passive	--/100
- decay heat removal	--/Passive	--/100
- containment isolation and cooling	--/Passive	--/100
- emergency AC supply (e.g., diesels)	N/A	--/--
DC Power Capacity (e.g., batteries)	N/A	hours
Events in which ***Immediate Operator Action*** is required	None	e.g., any internal/external initiating events, none
Limiting (shortest) ***Subsequent Operator Action*** Time	0.5	hours (that are assumed when following EOPs)
Severe Accident Core Provisions	IVMR	e.g., no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)	3E-10/module (internal events)	x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions	--	e.g., H_2 ignitors, PARs, filtered venting, etc.
Large Release Frequency (LRF)	2E-11/module (internal events)	x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (n^{th} of a kind)	36	months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort	--	person-years (PY) [DP&P]
Construction and Commissioning Effort	--	PY [C&C]
Material and Equipment Overnight Capital Cost	--	Million US$ (2015) [M&E], if built in USA, nth of a kind
Cost Breakdown	%[C&C]/%[M&E]	
- Site Development before first concrete	--/--	(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (-----------) (to add up to 100/100)
- Nuclear Island (NSSS)	--/--	
- Conventional Island (Turbine and Cooling)	--/--	
- Balance of Plant (BOP)	--/--	
- Commissioning and First Fuel Loading	--/--	
Factory/On-Site split in [C&C] effort	--/--	%/% of total [C&C] effort in PY (e.g., 60/40)

1. *Plant Layout, Site Environment, and Grid Integration*

SUMMARY FOR BOOKLET

1.1. Site Requirements during Construction

Plant Arrangement

A rendering of the site layout for a 12-module NuScale plant is shown in Figure 2.. All safety systems are located in the reactor building positioned at the center of the site. The reactor building is flanked by two turbine buildings containing six turbine-generator sets each, the control room building, and the radioactive waste handling building. Forced draft cooling towers are used for condenser cooling. The site also includes a switchyard, administration building, warehouse, and interim spent fuel storage facility. The total area within the protected boundary is nominally 140,000 m^2. A plan view of the site layout is shown in Figure 3.

Buildings and Structures

Reactor Building

The reactor building houses the NPMs and systems and components required for plant operation and shutdown. The building is essentially a rectangular configuration that is approximately 107 m long and 46 m wide and extends approximately 25 m above nominal plant grade level. The building is a Seismic Category I, reinforced concrete structure with design considerations for the effects of aircraft impact, environmental conditions, postulated design-basis accidents (internal and external), and design-basis threats.

Control Building

The control building houses the main control room, where all control panels are installed for the NPMs, technical support center, and other related space for operations.

Radioactive Waste Building

The radioactive waste building houses equipment and systems for processing radioactive gaseous, liquid, and solid waste and for preparing waste for off-site shipment. It includes equipment to prepare low-level radioactive waste for compaction to reduce volume and provides temporary storage for radioactive waste.

Turbine Generator Building

A NuScale power plant has two separate turbine generator buildings. Each building houses six turbine generator sets along with their auxiliaries, condensers, condensate systems, and feedwater systems. A laydown area and overhead crane for installation and maintenance activities are also included.

Annex Building

The annex building serves several functions. It provides controlling access to both radiologically and non-radiologically controlled areas of the reactor building; houses various personnel support services such as locker rooms, showers, toilet facilities, lunch and conference rooms, and first aid; provides space for personnel and component decontamination equipment and employee dosimeter processing; and, houses a portion of the facilities that support plant security.

Security Buildings

The security building is the primary access control building. It serves to monitor and control personnel and vehicle entry, as well as, monitoring access into areas of the plants.

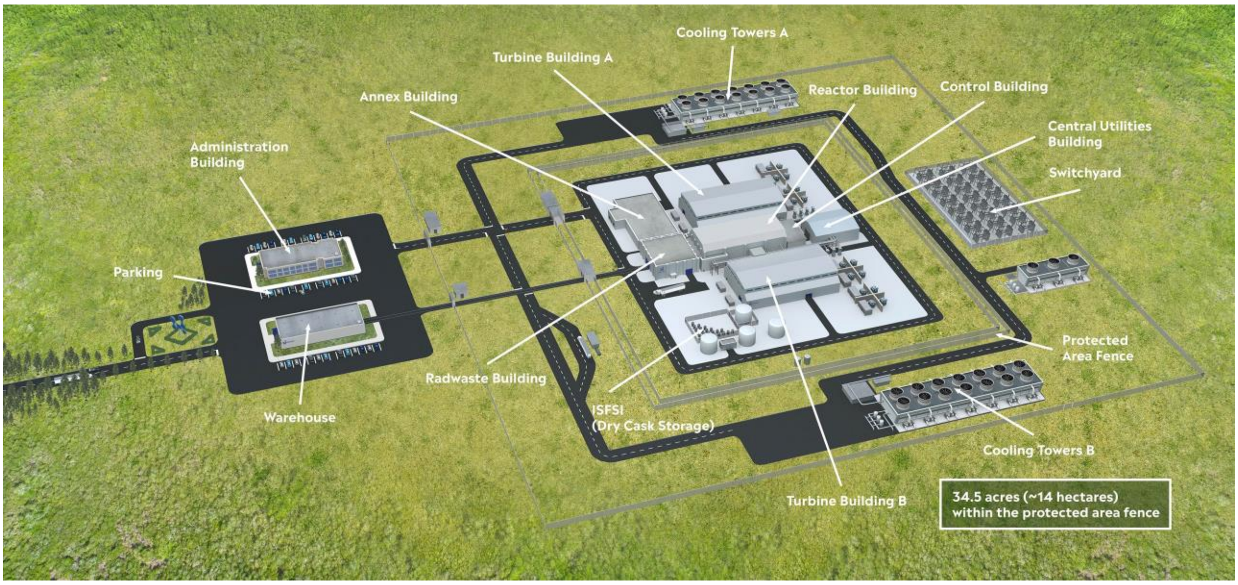

Figure 2. Layout of a 12-module NuScale power plant

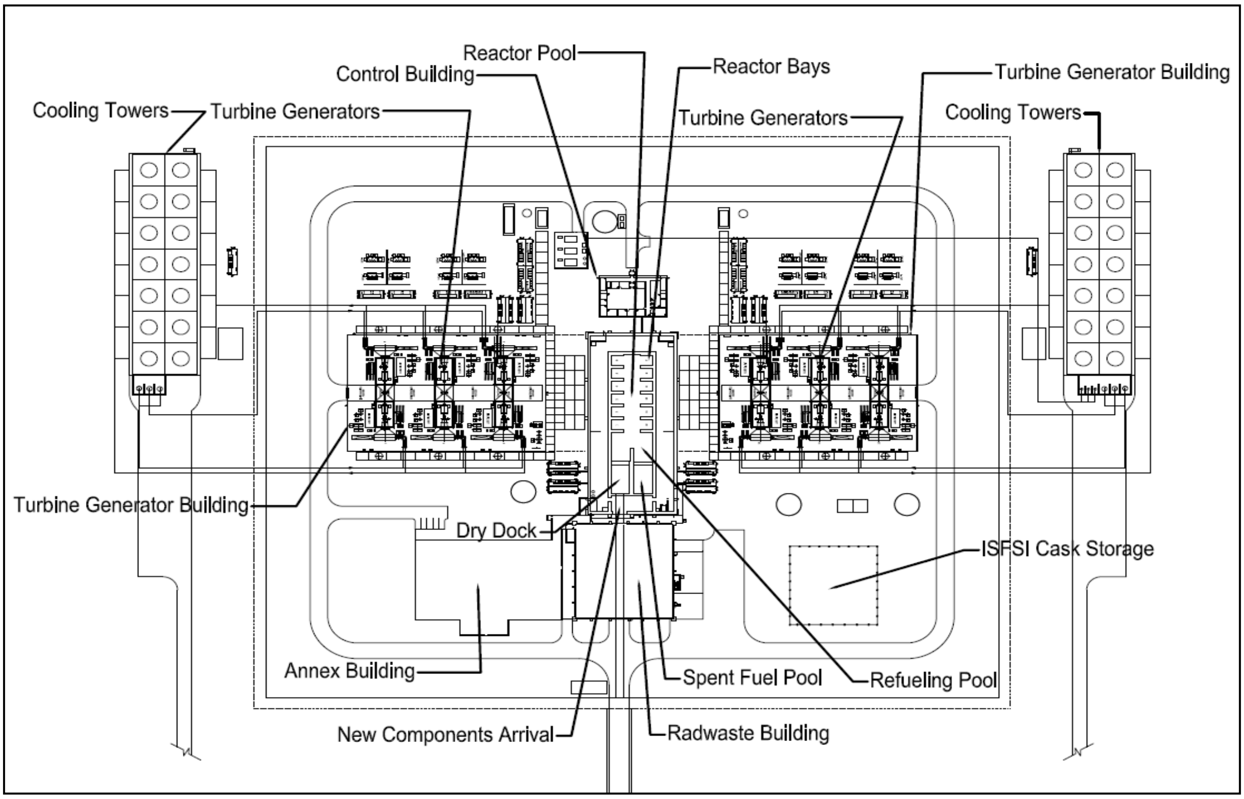

Figure 3. Plan view of a 12-module NuScale power plant

2. *Technical Nuclear Steam Supply System (NSSS)/Power Conversion System Design*

SUMMARY FOR BOOKLET

2.1. Primary Circuit

The basic configuration of a single NuScale Power Module™ (NPM) is shown schematically in Figure 4. The integrated design contains the nuclear core, two interwoven helical coil steam generators (SG), and a pressurizer (PZR) within the reactor pressure vessel (RPV) and is housed in a steel containment vessel (CNV). The RPV is approximately 17.8 m long and 3.0 m in diameter.

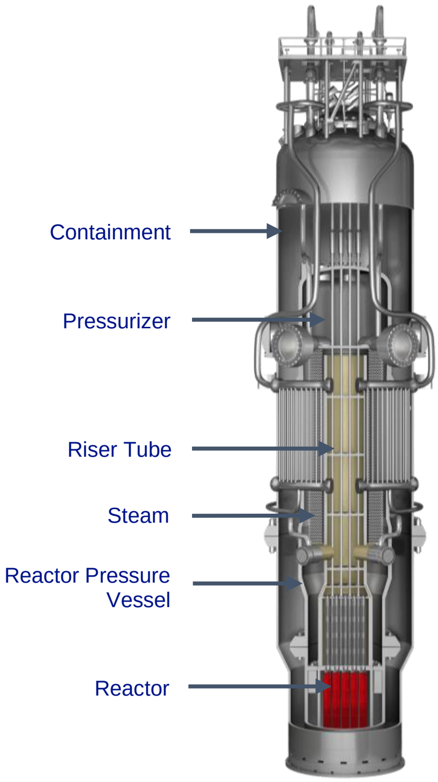

Figure 4. Key features of a NuScale Power Module™

The reactor core consists of an array of 37 half-height typical LWR fuel and 16 control rod assemblies followed by a riser tube, where two helical coil steam generators wrap around it. Feedwater is pumped into the tubes where it boils to generate superheated steam. Pressurizer heaters and sprays are located in the upper head of the vessel to provide pressure control. The modules are operated below-grade level in a 28,000 m^3 steel-lined pool of water.

Other major systems include

- Ultimate heat sink (UHS), which is a large, stainless steel-lined, reinforced concrete pool located in the reactor building below plant-grade level and it has the capacity to absorb all the decay heat produced by a full complement of 12 modules for greater than

30 days. Additionally, the pool serves as a medium to: (1) reduce and delay the release of fission products in the unlikely event of fuel damage, (2) provide radiation shielding outside containment, and, (3) enhance physical security. The ultimate heat sink consists of the reactor pool area, the refueling pool area, and the spent fuel pool area.

- Chemical and volume control system (CVCS), which recirculates a portion of the reactor coolant through demineralizers and filters to maintain reactor coolant purity 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.
- Decay heat removal system (DHRS), which is closed-loop, two-phase natural circulation cooling system and provides secondary side reactor cooling for non-LOCA events when normal feedwater is not available

2.2. Reactor Core and Fuel

The reactor core within each of the modules consists of 37 fuel assemblies and 16 control rod assemblies. The fuel assemblies for the NPMs are a modified Framatome HTP2™ fuel design, which is currently being used in existing PWRs. The new fuel, named NuFuel-HTP2™, is different from Framatome's proven HTP™ fuel only with respect to the fuel assembly length, which is half-height. The ceramic UO_2 pellets are enriched to up to 4.95 percent and are encapsulated in a M5® cladding material with an active fuel length of approximately 2 meters. The temperature coefficient of reactivity of the core is also negative. Fuel rods with gadolinium oxide (Gd_2O_3) as a burnable absorber homogeneously mixed within the pellet are used in specific location to establish favourable radial power distribution. All aligned using Framatome's HTP™ and HMP™ grid spacer. Lastly, the core is surrounded by a stainless steel heavy neutron reflector to improve fuel utilization and prevent the radial escape of neutron. Additionally, as an envelope to the core, it directs the flow through it. While there is no specific design limit on cycle average burnup, the core average cycle exposure is designed such that the peak fuel rod exposure is up to 62 GWd/MTU.

Mechanical and thermal-hydraulic testing of NuFuel-HTP2™ assemblies has been completed using Framatome's test facilities. By using proven fuel, cladding, and structural materials in the fuel assemblies, NuScale draws upon a vast amount of operational experience of the fuel's performance during operations, both wet and dry storage, and eventual disposal. The fuel assembly radionuclide composition and radiotoxicity are well understood, which will facilitate transport to an interim storage facility and final disposal in a national fuel repository when available.

2.3. Fuel Handling

Modules are refueled on a staggered 24-month cycle, equivalent to a 12 GWd/MTU cycle, by moving them via an overhead crane to a common refueling area adjacent to the spent fuel pool following disassembly. An overhead and cut-away view of the reactor building showing its layout and a full 12-module array is given in Figure 5. and Figure 6.
Each module resides under a biological shield in a three-sided bay that is open to the common pool. Also included in the pool is the module assembly/disassembly facility, which is used for installation of new modules into the plant and also for module refueling. The

reactor building layout permits refueling to be completed for a single module while the other modules continue to generate power. This staggered refueling of individual modules can be done by a small, permanent team of plant personnel rather than employing a large temporary workforce. At the owner's or operating utility's discretion, refueling operations can be conducted throughout the year or clustered during low-demand periods.

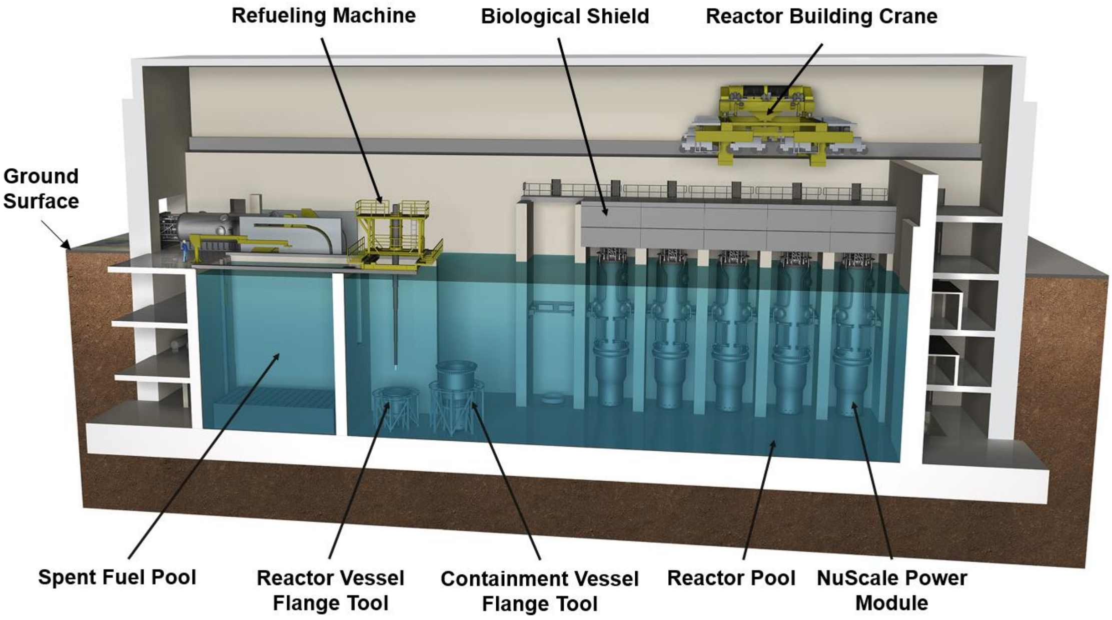

Figure 5. Reactor building cut-away view

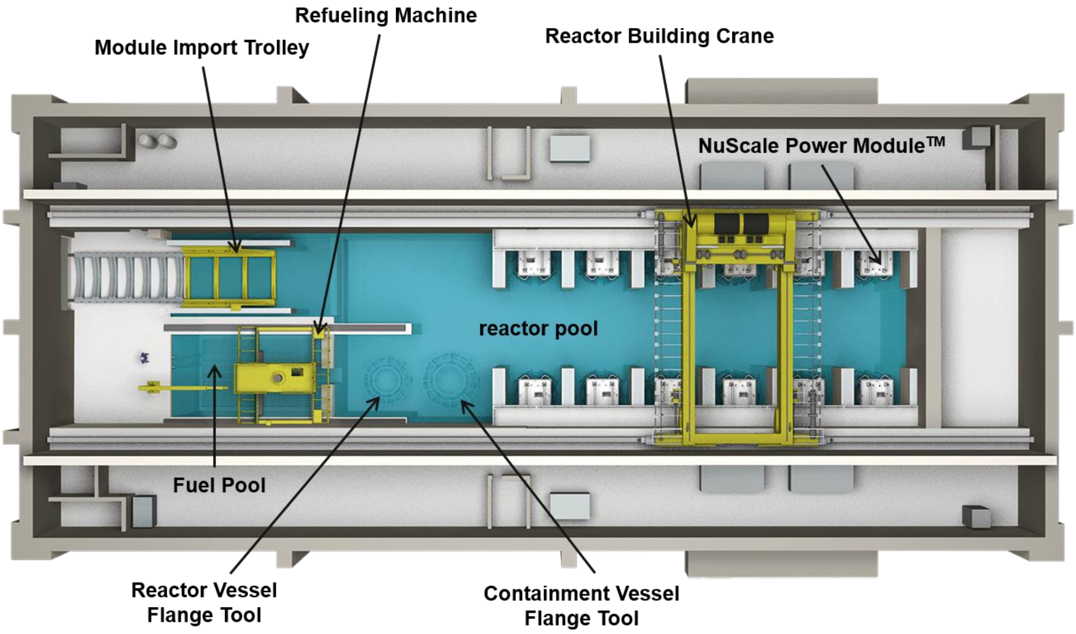

Figure 6. Reactor building overhead view of a 12-module plant

Refueling of a single module is expected to require 10 days. After initial cool-down, the module is disconnected from its supporting fluid systems and I&C leads. It is then moved via an overhead crane to the module assembly/disassembly facility where it is remotely disassembled into the lower containment vessel, the lower reactor vessel (includes the reactor core), and the upper module section. While the core is being refuelled, the upper module section is moved to a partial dry-dock facility for inspection and maintenance. Refueling of the core is accomplished by transporting upright fuel assembles between the lower reactor vessel section and the adjacent spent fuel pool via a weir located in the wall that separates the spent fuel pool from the reactor pool. During the refueling process, nominally one-third of the fuel assemblies are removed from the NPM's core. Remaining assemblies are shuffled to a different core position using an "out-in" shuffle scheme. Removed assemblies are stored in the used fuel pool for initial cool-down and later moved to an on-site dry-cask storage facility or interim fuel storage facility if available. After refueling, the module is reassembled, moved to its operating location, and reconnected to all support lines.

2.4. Reactor Protection

The NuScale design uses two independent reactivity control systems that comprise control rods and soluble boron. The control rods and associated rod control system are designed with a positive means for inserting the rods and reliably controlling reactivity changes during normal operation, including anticipated operational occurrence. Sixteen of the fuel assembly positions contain control rod assemblies (CRAs) that are divided into two banks: regulating and shutdown. Each consisting of four CRAs. The concentration of soluble boron in the reactor coolant system is controlled by the CVCS. Adjustments to the concentration can be made to account for reactivity changes due to core burnup, fission product poisoning, and/or power manoeuvring. Furthermore, using soluble boron preserves the capability of the CRAs to rapidly reduce power and protect fuel design limits.

2.5. Secondary Side

After the conversion of the secondary coolant into steam, the steam energy is then converted to electrical power in the turbine generator system. Each module is connected to its dedicated 60 MWe conventional steam turbine-generator system. A diagram of the balance of plant systems for each NuScale module is shown in Figure 9. . These are readily available and widely used in the fossil fuel power generation industry. The steam exhausted from the turbine flows through a condenser, a condensate polishing unit, and a succession of feedwater heaters before re-entering the steam generator. The turbine and condenser units are designed to allow 100 percent steam bypass of the turbine, and the condenser can be cooled by either water or air (to reduce plant water consumption).

The small power rating allows for air cooling of the generator, thus avoiding maintenance and safety issues associated with hydrogen cooling of the generator. The small physical size allows the turbine-generator set to be skid mounted for easy transport to the site and removal for maintenance. Using a dedicated turbine-generator set for each module eliminates the "single shaft" risk (i.e., the temporary shutdown of a single module does not require shutdown of the entire plant). Also, in the case of cogeneration plants, the balance of plant can be configured differently for different modules, thus allowing the owner to optimize electricity and heat output from the plant.

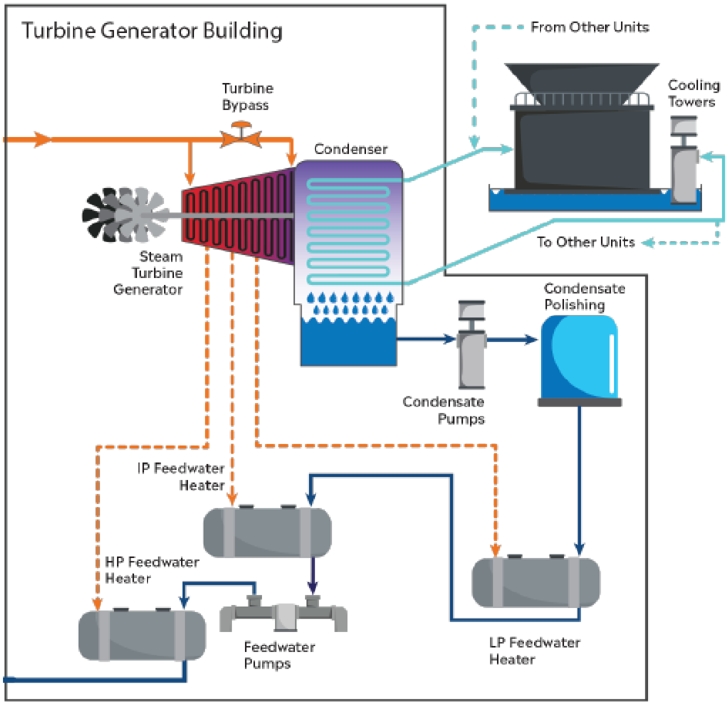

Figure 7. NuScale balance of plant systems dedicated to each module

2.6. Containment/Confinement

The NuScale containment vessel is a cylindrical vessel-type containment that houses the RPV, and associated NSSS piping and components. The CNV has an overall height of approximately 23 m and an outside diameter of approximately 4.5 m, and at normal conditions, it operates at a vacuum pressure and a temperature of 37ºC. It is designed to provide passive heat removal to the reactor pool following an emergency core cooling system actuation and to contain the release of radioactive material following postulated accidents. Its internal design pressure and temperature are 8.3 MPa and 316ºC respectively.

2.7. Electrical, I&C, and Human Interface

The design of NuScale's instrumentation and control (I&C) systems is based on four fundamental design principles: independence, redundancy, predictability and repeatability, and diversity and defense-in-depth. Each NPM has its dedicated monitoring and protection systems that are based on the interconnection for the plant's structure, systems, and components for both safety and non-safety-related systems, which complies with multiple Institute of Electrical and Electronics Engineers (IEEE) standards such as 603-1991 and 7.4.3.2-2003. Furthermore, the robust design eliminates the requirement for Class 1E power systems. Class 1E is the regulatory standard set for the design of safety-related nuclear power plant electrical systems. In January 2018, the U.S. Nuclear Regulatory Commission (NRC) released its safety evaluation report, approving NuScale's "Safety Classification of Passive Nuclear Power Plant Electrical Systems" Licensing Topical Report, in which the company established the bases of how a design can be safe without reliance on any safety-related electrical power. The NRC has limited its approval to only NuScale Power's design; all existing nuclear plants in the U.S. are required to have Class 1E power supplies to ensure safety. NRC's conclusion is a key step in the review process of NuScale's design certification application.

The NuScale design includes a fully-digital control system based on the use of field programmable gate array (FPGA) technology. Another key step in the design certification approval process was the NRC's approval of NuScale's highly-integrated plant protection system (HIPS) in July 2017. The HIPS platform is comprised of four module types that can be interconnected to implement multiple configurations to support various types of reactor safety systems. It also uses FPGA technology that is not vulnerable to internet cyber-attacks.

A unique feature of a NuScale multi-module plant is the control room strategy. The demands on the reactor operators is significantly reduced relative to traditional large reactors due to the reduced operating requirements afforded by the simplicity of the design, advancements in digital controls, and the fact that there are no operator-initiated safety functions. Comprehensive human factors engineering and human-machine interface studies have been conducted using a full 12-module control room simulator, as shown in Figure 10. . Based on the results of extensive task performance analyses, it is expected that six reactor operators (three operators and three senior operators) will be required to manage plant control functions for all 12 reactors.

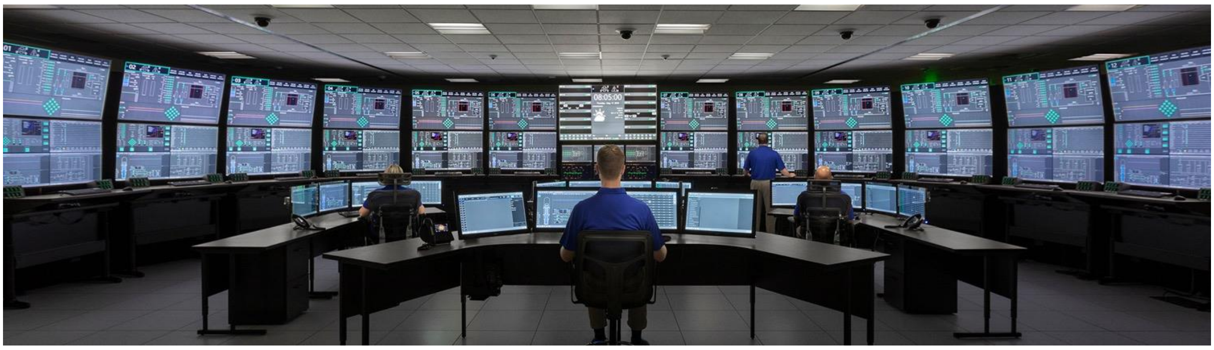

Figure 8. NuScale 12-Module Control Room Simulator Facility

2.8. Unique Technical Design Features (if any)

There are four essential features of the NuScale plant, which in combination, distinguish it from other small nuclear plants being developed today:

1. *Compact size*. Each module, which includes its containment, can be entirely prefabricated in a factory and shipped by rail, truck, or barge to the power plant site for assembly and installation with other operating modules. Fabrication of the modules in a factory environment reduces fabrication cost, improves quality, reduces construction schedule, and increases schedule confidence.
2. *Natural circulation*. As depicted in Figure 11. , the nuclear core is cooled entirely by natural circulation for power generation and for safety-system heat removal. Primary coolant is heated in the nuclear core to produce a low density fluid that travels upward through the riser. The steam generator helical coils wrapped around the outside of the riser transfers heat from the primary coolant to secondary fluid, causing its density to increase. The density difference acting over an elevation difference between the core and the steam generator results in a buoyancy force that drives the fluid flow around the loop. Natural circulation operation provides a significant advantage in that it eliminates pumps, pipes, and valves and, hence, the maintenance and potential failures associated with those components. Furthermore, it reduces in-house plant loads.

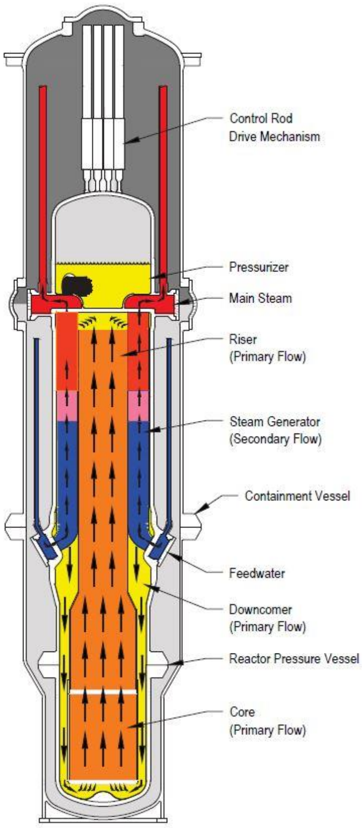

Figure 9. Primary coolant flow paths in a NuScale Power Module™

3. *Proven technology*. The design relies on well-established LWR technology. The NuScale plant can be licensed within the existing LWR regulatory framework, drawing on a vast body of established research and development (R&D), proven codes and methods, and existing regulatory standards.
4. *Testing-based design development*. The NuScale design effort has been supported from the outset by a one-third-scale, electrically-heated integral test facility that operates at full pressure and temperature. Operation of an integral test facility has contributed to continuous validation of safety performance and is essential for establishing regulator and customer confidence in the design.

The unique engineered design features and their improvement on safety are further described throughout the document and are summarized in

Table 1.

Table 1. NuScale Design Features Contributing to Enhanced Safety

NuScale Design Feature	Primary Impact	Safety Benefit
Reactor coolant system integral to the RPV	Eliminates large diameter primary coolant piping	Eliminates postulated large-break LOCA spectrum of accidents
Natural convection-cooled core	Eliminates the need for reactor coolant pumps	Eliminates reactor coolant pump failures, e.g., shaft breaks, pump seizure, missile generation, and pump leaks
Metallic containment pressure vessel	Smaller containment volume wiht high design pressure. Vessel is constructed in compliance with established pressure vessel standards	Containment integrity assured (molten core concrete interaction is not possible due to the metallic CNV). Design and construction as a pressure vessel increases integrity assurance compared to large containment structures
Modular NSSS and reactor vessel inside the CNV	Coolant lost from RPV stays within containment and is returned to RPV by passive means	No postulated design-basis LOCA capable of uncovering nuclear fuel. No coolant is required to be added to the NPM for all design-basis events
Evacuated containment	Sub atmospheric pressure during normal operation	Increased steam condensation rates for containment heat removal during LOCA events. Any hydrogen released is trapped in the CNV with little oxygen available to create a combustible mixture
	No insulation on reactor vessel	Eliminates potential degradation of core cooling systems due to insulation debris and permits ex-vessel cooling
Small core size	Reduces decay heat removal requirements and fission product inventory	Enhances in-vessel retention; maintains low accident consequences; reduces fission product source term; thus simplifies emergency planning
Reactor pool	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 in the event of loss of external power	Electrical power is not required for safety. No operator actions are required for safety

3. Technology Maturity/Readiness

SUMMARY FOR BOOKLET

3.1. Deployed Reactors

The unique set of features, specifically the synergy created by plant simplicity, reliance on existing technology, and the availability of an integral test facility, all combine to position the NuScale plant for early deployment. To date, several utilities are actively engaged with NuScale Power and participate in the NuScale Advisory Board. One utility, the Utah Associated Municipal Power Systems (UAMPS), has announced the intent to build a NuScale plant in Idaho. UAMPS has selected a preferred site, which is located on the federal reservation of Idaho National Laboratory, and expects to have the first-of-a-kind commercial NuScale plant operational in 2027.

3.2. Reactors under Licensing Review

NuScale initiated pre-application discussions with the U.S. NRC in 2008 and submitted a design certification application in January 2017. Phase 1 of the design certification review, which is the most rigorous portion of the full review, was completed on schedule in April 2018. Currently, the design is on Phase 5 out of the six different phases; all projected to be completed on schedule. Final certification of the design is projected to be completed by 2020. Additionally, several topical reports on specific design methods have been submitted to the NRC and some have already received approval, including the acceptability of NuScale's design for a highly-integrated plant protection system and the absence of a need for Class 1E safety grade power.

<u>Research and Testing Program</u>
A comprehensive set of testing programs has been conducted using best-in-class facilities to validate many aspects of the NPM design. In general, the tests focus on design features for which applicable data or operational experience did not previously exist. A summary of key tests is given in

Table 2. A structured risk-informed process was used to identify and prioritize required tests, which supports reactor safety code development, reactor design development, technology maturation, and final product demonstration.

Early in the development of the NuScale design, a 1/3-scale, full-pressure and full-temperature integral test facility (shown in Figure 10.) was built at Oregon State University (OSU). NuScale, through its technology transfer agreement with OSU, has exclusive use of the test facility. The NuScale Integral System Test (NIST) facility has been updated to remain current with the commercial design and is being used to evaluate design improvements and to conduct safety validation tests for NRC certification.

Table 2. Key testing programs for validation of NuScale design

Test Program	Test Facility
Critical Heat Flux– Preliminary Fuel Design	Stern Lab, Canada
Critical Heat Flux – NuScale NuFuel HTP2TM	Areva, Karlstein, Germany
Steam Generator Tube Inspection Feasibility	Oregon Industrial, Albany, OR
Steam Generator: 3-Coil, Full-Length, Electrically Heated	SIET, Piacenza, Italy
Steam Generator: 252-Coils, Full-Length, Prototypic Fluid-to-Fluid Heat Transfer	SIET, Piacenza, Italy
Steam Generator Flow Induced Vibration	SIET, Piacenza, Italy
Steam Generator Orifice Hydraulics	Alden Lab, Holden, MA
Upper Module Mock-up	Oregon Iron Works, Vancouver, WA
Fuel Mechanical and Hydraulic	Areva, Richland, WA
Control Rod Assembly and Drive Shaft Alignment and Drop	Areva, Erlangen, Germany
Control Rod Assembly and Guide Tube Flow Induced Vibration	Areva, Erlangen, Germany
Integral System Safety Performance	OSU, Corvallis, OR

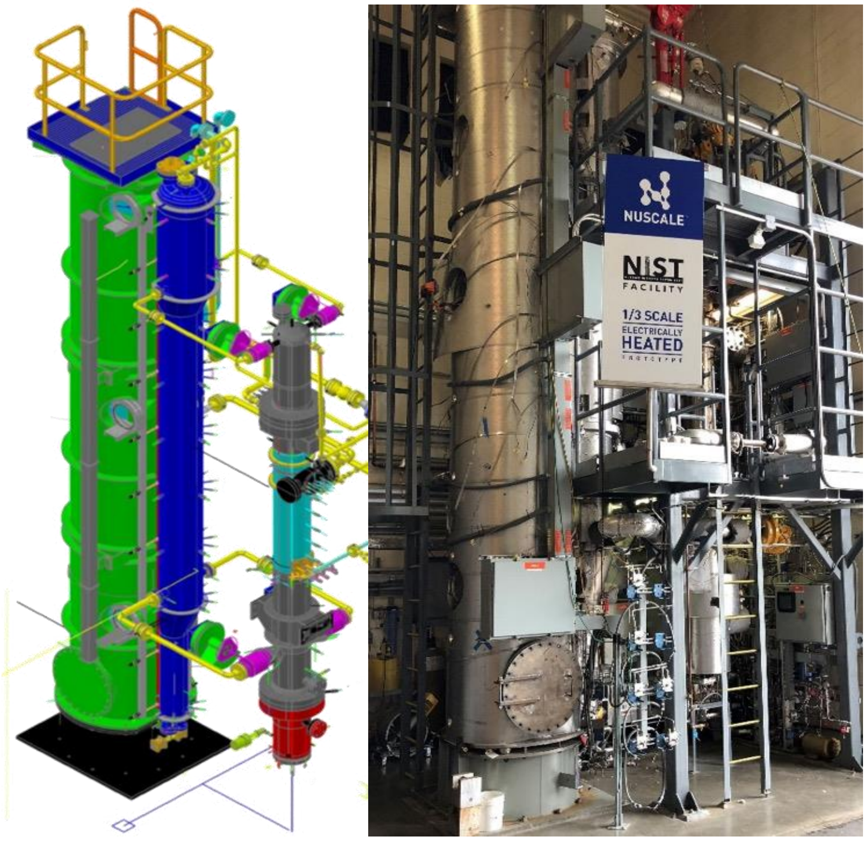

Figure 10. NuScale Integral System Test (NIST) facility

4. *Safety Concept*

SUMMARY FOR BOOKLET

4.1. Safety Philosophy and Implementation

NuScale's plant design provides multiple levels of defense for accident mitigation (defense-in-depth), resulting in extremely low core damage probabilities. The plant includes a comprehensive set of engineered safety features designed to provide stable long-term nuclear core cooling under all conditions, along with severe accident mitigation. Physical boundaries that prevent the release of radiation include the fuel cladding, reactor pressure vessel, reactor coolant system, containment vessel, reactor pool, and a seismic Category I building. Passive heat removal systems and severe accident mitigation features can automatically establish and maintain core cooling for a significant amount of time without operator action, AC/DC power, or resupply of cooling water.

Safety Systems and Features

Each NuScale module includes two independent and redundant passive safety systems to provide pathways for decay heat to reach the reactor pool, namely: the decay heat removal system (DHRS) and the emergency core cooling system (ECCS). These systems, shown in Figure 11, are normally actuated by the module protection system, but also fail-safe on loss of power. Furthermore, the entire NSSS, including its containment, is immersed in a pool of water capable of absorbing all decay heat generated from a full complement of 12 modules for greater than 30 days followed by air cooling for an unlimited length of time, as shown in Figure 12.

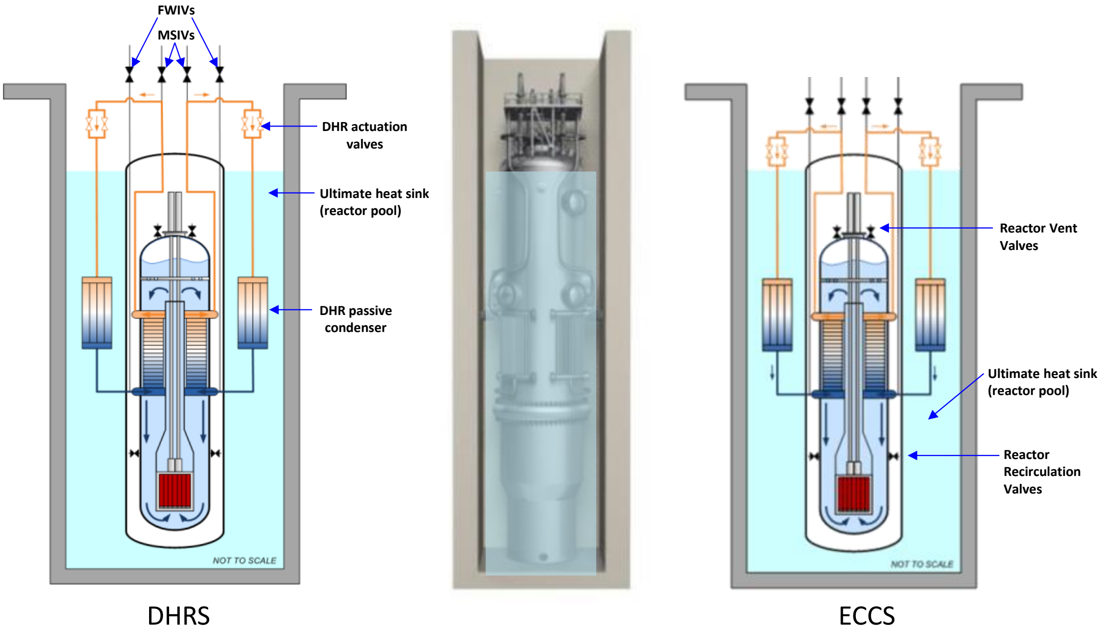

Figure 11. Diagrams of the decay heat removal system (left) and emergency core cooling system (right) (Also shown is solid body model of NuScale Power Module)

Integral Primary System

The integral primary system with natural circulation of primary coolant has the important benefit of eliminating the possibility of a large-break loss-of-coolant accident (LOCA) by reducing the number of components and eliminating the challenges associated with external piping. The piping external to the RPV is short length and small diameter.

Containment Pressure Vessel

The containment vessel has several features that distinguish it from existing containment designs. During normal power operation, the containment atmosphere is evacuated to provide an insulating vacuum that significantly reduces heat loss from the reactor vessel. As a result, the reactor vessel does not require fibrous surface insulation. This eliminates the potential for insulation debris to interfere with core cooling capability. Furthermore, the vacuum improves steam condensation rates during any sequence where safety valves vent steam into this space. Evacuation of containment gases prevents the creation of a combustible hydrogen mixtures (i.e., little to no oxygen) in the unlikely event of a severe accident, thus eliminating the need for hydrogen recombiners. Finally, the containment vessel has been designed for a maximum pressure of approximately 8.3 MPa. This design pressure bounds all design-basis events, which lead to increased containment pressure (e.g., pipe-break LOCAs) and the equilibrium pressure between the reactor vessel and the containment vessel in the event of a LOCA is achieved rapidly.

Emergency Core Cooling System

The ECCS provides a means of removing core decay heat in the event the steam generator tube bundles are not available to remove heat from the primary system. It operates by opening the vent valves located on the reactor head. The system removes heat and limits containment pressure by steam condensation on, and convective heat transfer to, the inside surface of the containment vessel. Heat is then transferred by conduction through the containment vessel walls to the reactor pool. Long-term cooling is established via recirculation of reactor coolant to the reactor vessel through the ECCS recirculation valves. When primary system steam is vented from the reactor vessel into the containment where it condenses on the containment surfaces. The condensate collects in the lower containment region and when the liquid level in the bottom of the containment rises above the top of the recirculation valves, the recirculation valves are opened to provide a natural circulation path from containment back through the core and out through the vent valves.

Passive Residual Heat Removal

The DHRS provides secondary-side reactor cooling for non-LOCA events when normal feedwater is not available. It is a closed-loop, two-phase natural circulation cooling system. Two redundant trains of decay heat removal equipment are provided, one attached to each steam generator loop. Each train has a passive condenser immersed in the reactor pool and is capable of removing 100 percent of the decay heat load.

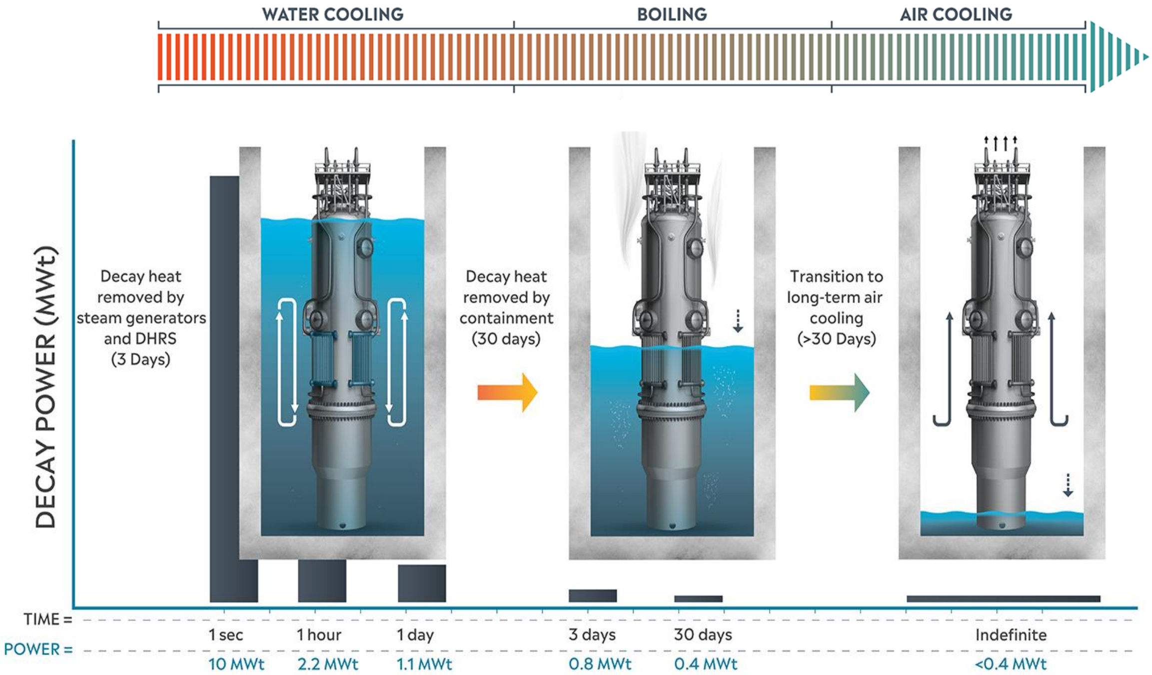

Figure 12. Innovative advances in reactor safety

4.2. Transient/Accident Behaviour

The NuScale plant design offers significant severe accident mitigation features. Because the small core size and the reliance on natural driven forces, each module has a reduced source term and fewer components. The containment is sized so that the core does not uncover for initiating events associated with loss of reactor coolant system inventory inside containment or pipe breaks outside the containment vessel that are isolated; normal operation at vacuum results in an oxygen deficient environment that limits the formation of a combustible hydrogen mixture for postulated severe accidents; and being immersed in the reactor pool, allows passive heat transfer from the core to the ultimate heat sink.

The results of probabilistic risk assessment studies performed by NuScale show that for design-basis small-break assumptions, there is no scenario in which the core becomes exposed or uncovered (e.g., it will always be under water). Thus, cooling pathways are always available to remove decay heat. Because of the assured heat removal path and the fail-safe nature of the ECCS valves, which passively open upon loss of power, the reactor can be safely cooled for an unlimited time with no AC or DC power, no operator action, and no additional makeup water. Additionally, it has been estimated that during full power operation a mean internal events core damage frequency (CDF) of approximately $3X10^{-10}$ and a large release fraction (LRF) of approximately $2x10^{-11}$ per module critical year, which are much lower than for larger nuclear power plants, as shown in Figure 13. This is attributed to the simplicity of the design, its highly-reliable passive safety features, small source term, fission product barriers, and the independence of each module.

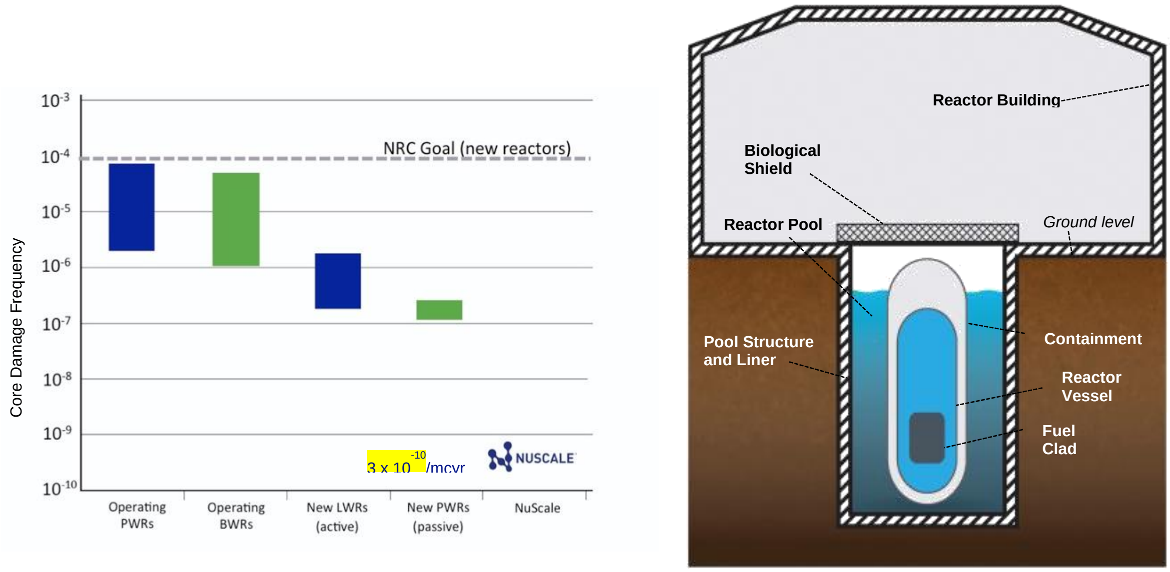

Figure 13. *Risk reduction and additional release barriers*

As with conventional large LWR designs, the fuel pellet, cladding, reactor vessel, and containment prevent transport of fission products to the outside atmosphere. However, the small, low power density of the NuScale core and uninsulated RPV enhance the potential for in-vessel retention (IVR) of core debris in the RPV in the event of core damage. The steel containment immersed in a stainless steel-lined pool eliminates the potential for molten concrete coolant interactions. Additionally, the ability to reliably equilibrate containment and reactor pressure prevents the possibility of a high-pressure "corium" melt ejection. As previously described, the reactor pool, the steel-lined pool structure, the biological shield, and finally the reactor building are additional barriers that further reduce the potential for severe accident releases. As a result of the safety philosophy and implementation, the analysis methodology for emergency planning zone sizing developed by the Nuclear Energy Institute [1] shows that the NuScale design can adopt an emergency planning zone at the site boundary.

5. *Fuel and Fuel Cycle*

SUMMARY FOR BOOKLET (optional)

5.1. Fuel Cycle Options

NuScale's reactor building and plant design incorporated a proven safe, secure, and effective used fuel management system. The spent fuel storage pool is connected to the ultimate heat sink, and therefore, is protected by the Seismic Category 1 reinforced concrete reactor building. The racks are designed to store fuel enriched to a maximum of 5 percent U-235 by weight. The spent fuel storage racks include storage locations for 1,404 fuel assemblies including five defective fuel assemblies and for non-fuel core components such as a control rod assembly. This is equivalent to approximately 18 years of operation. After cooling, used fuel will be placed into certified casks for which the plant design includes sufficient on-site storage space for all the spent fuel produced during the 60-year life of the plant. By utilizing well-known fuel technology, no new challenges or uncertainties are introduced into the nuclear fuel cycle.

Studies have been conducted that confirm that recycled fuel and mixed uranium-plutonium oxide (MOX) fuel are suitable for use in the NuScale SMR design with minimal impact on operations.

6. Safeguards and Physical Security (1 – 2 pages)

SUMMARY FOR BOOKLET (optional)

6.1. Safeguards

The NuScale design has been evaluated for safeguard-ability at a high level and is similar to existing light water reactor designs with regards to fuel, processes, and implementation of international safeguards. Many of the security-by-design attributes in the NuScale design considered the prevention of theft and diversion of nuclear material. Safeguards monitoring devices already deployed in existing reactors could be utilized within the NuScale design. I&C sensors for normal plant operation will be evaluated for dual use to provide Continuity of Knowledge (CoK).

6.2. Security

Fencing and intrusion systems are employed to establish a perimeter boundary and indication of unauthorized attempt to enter the area. The robust plant design and use of passive safety systems that do not require AC/DC power not only enhanced safety but also enhanced security by virtue of significantly reduced system vulnerabilities and failure consequences. Placement of the entire NSSS, the containment, the control room, and the spent fuel pool below grade level allows for a low facility profile that reduces vulnerabilities to external or internal malevolent acts of sabotage, or other potential security threats.

7. Project Delivery and Economics

SUMMARY FOR BOOKLET (optional)

7.1. Project Preparation and Negotiation

NuScale initiated preapplication discussions with the U.S. NRC in 2008 and submitted a design certification application in January 2017. Phase 1 of the design certification review, which is the most rigorous portion of the full review, was completed on schedule in April 2018. Additionally, several topical reports on specific design methods have been submitted to the NRC and some have already received approval, including the acceptability of NuScale's design for a highly-integrated plant protection system and the absence of a need for Class 1E safety grade power. Final certification of the design is projected to be completed by 2020.

The current NuScale plant design continues to manifest many of the design features of the original MASLWR concept, which was explicitly developed to support a diverse range of energy applications. Key features maintained in the NuScale design include a small core, a highly-robust module design, and a multi-module plant configuration. Several recent studies have been completed to evaluate the technical and economic viability of using the NuScale plant to support non-electric or combined heat and power (CHP) applications [2]. Specifically, studies have demonstrated the suitability and benefits of coupling a NuScale plant to various desalination technologies, oil refining, and hydrogen production. In each application, the same standardized NPM can be used, although the balance of the plant may be customized to accommodate the specific application. In practice, a single plant can be configured to provide energy, in the form of electricity or heat, to meet the diverse needs of a community or region while optimizing energy resources by dynamically balancing electricity and heat outputs to meet grid demand or, for example, clean water.

7.2. Construction and Commissioning

NuScale NPM is designed to make use of modern modular construction techniques that optimizes: labor efficiency, quality, reliability, ease of inspections, and a centralized and stable skilled workforce. The entire nuclear module, including the containment vessel will be completely fabricated within a factory environment. NuScale predicts that the simplified design and factory fabrication of the modules will shorten plant construction schedule and increase schedule certainty, which will help to make the cost per kilowatt of a NuScale plant equal to or better than large nuclear scale nuclear plants. In addition, the lower initial capital costs compared to a large plant, the ability to add new modules incrementally as demand dictates, and the predicted short construction period (36 months) will substantially reduce the cost of interest charges and financial risk.

7.3. Operation and Maintenance

Simple design is expected to result in low operation and maintenance costs. Substantially fewer components decreases maintenance costs, both planned and unplanned. Reliance on natural phenomena simplifies the design and reduces staffing requirements. Elimination of active components results in a substantial reduction in inspection and tests. In addition, because only one SMR module is refueled at a time, 92 percent of the power from a 12-module plant can remain online during refueling, providing continuous power throughout the plant’s lifetime.

References

[1] NEI, *PPROPOSED METHODOLOGY AND CRITERIA FOR ESTABLISHING THE TECHNICAL BASIS FOR SMALL REACTOR EMERGENCY PLANNING ZONE,* Nuclear Energy Institute, 2013.

[2] D. Ingersoll, Z. Houghton, R. Bromm, C. Desportes, M. McKellar and R. Boardman, “EXTENDING NUCLEAR ENERGY TO NON-ELECTRICAL APPLICATIONS,” 2014.