Preferred site identified for first NuScale SMR plant

The attractiveness of small modular reactors has been an enduring theme within the nuclear industry for many decades, with a very large number of designs proposed over the years that have not progressed very far. The concept, however, now seems to be gaining some real traction, not least in the USA and notably UK, where the saga of Hinkley Point C – which has been characterised as "too big to fail, too huge to succeed" – has highlighted the challenges posed by "conventional" large nuclear.

Among the current developers of SMRs, NuScale (based in Portland, Oregon, and majority owned by Fluor) can be regarded as a frontrunner, with the recent announcement of a preferred site for a first project. An initial operational date of 2024 is being targeted for this plant (which, remarkably, would put it a little ahead of the current schedule for Hinkley Point C).

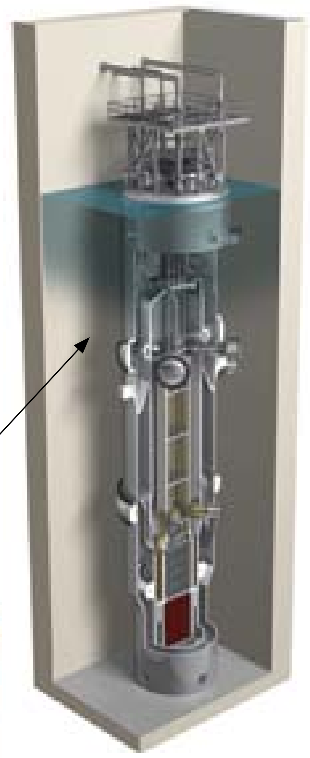
NuScale points out that it is the only SMR developer to be currently receiving US Department of Energy match funding ($217 million over five years, to support further development of the design and the securing of NRC design certification). It is also the only SMR developer to be close to submitting a design certification application to the US Nuclear Regulatory Commission (due to happen later this year), with "multiple active customer deployment

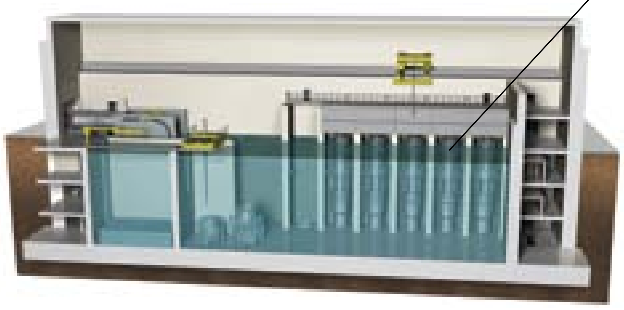
The NuScale concept

A NuScale power plant (below) would be made up of a number of 50 MWe modules (left). Each reactor measures 65 feet tall x 9 feet in diameter and sits within a containment vessel. The reactor and containment vessel operate inside a water-filled pool that is built below ground. The reactor operates using the principles of natural circulation; hence, no pumps are needed to circulate water through the reactor. Instead, the system uses convection, conduction and gravity to drive the flow of coolant inside the reactor vessel.

Pressurised water (called primary coolant, as in a conventional PWR) is heated as it passes over the core. As it heats up, the water rises within the interior of the vessel by natural convection and buoyancy. Once the heated water reaches the top of the riser, it turns downward, cascading over coiled steam generator tubes, which contain cooler non-pressurised water (called secondary coolant, again analogous to conventional PWR technology). When the hotter (primary) water contacts the steam generator tubes it gives up energy to heat the cooler (secondary) water inside the tubes, by conduction, causing it to flash to steam. This steam is then directed outside the containment vessel to drive individual steam turbines (one per module) that are attached by a single shaft to the electrical generator. After passing through the turbine, the steam is condensed back into liquid form in the condenser then pumped by the feed water pump back to the steam generator.

When the primary coolant gives up energy it becomes cooler, therefore more dense, causing it to be pulled by gravity back down to the bottom of the reactor vessel where it is again drawn over the core.



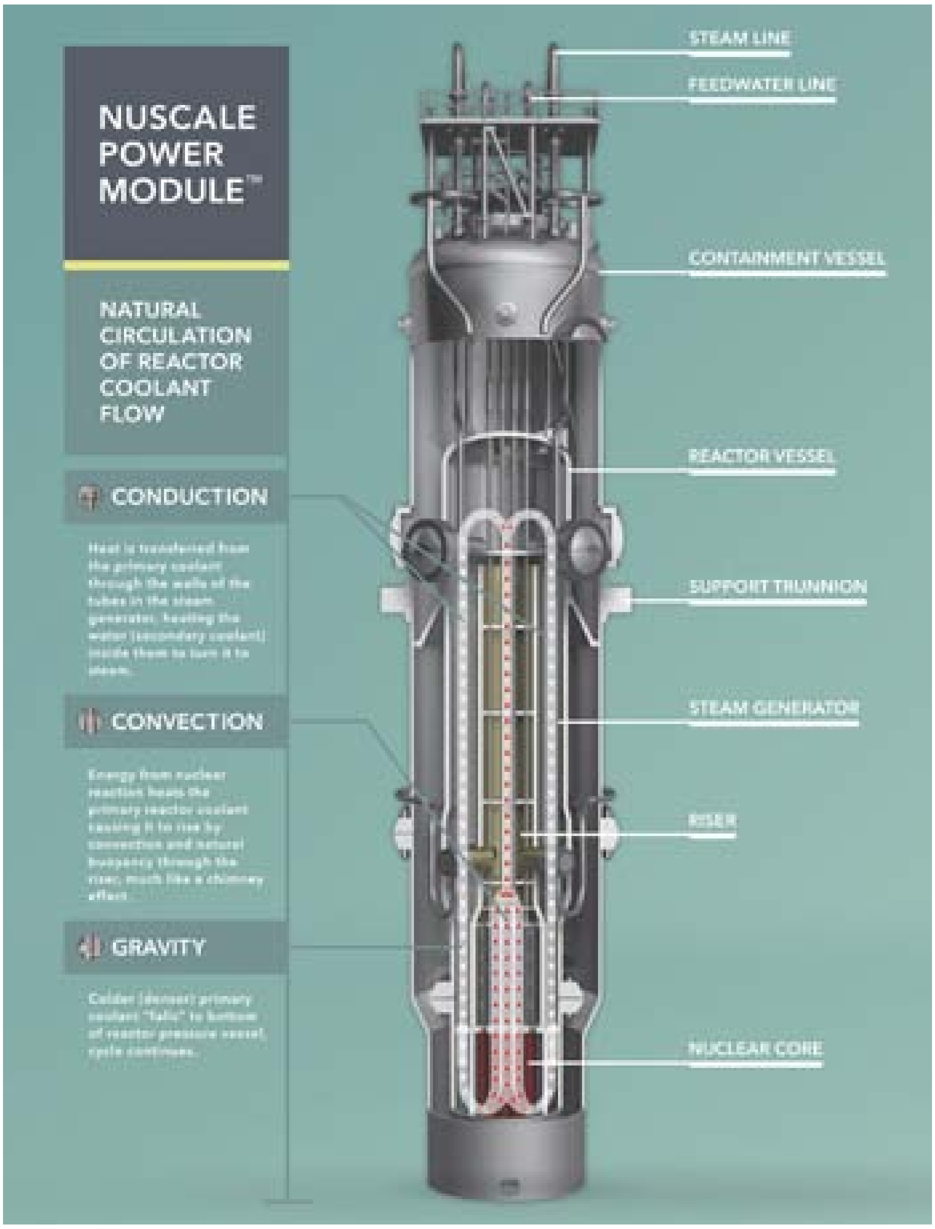


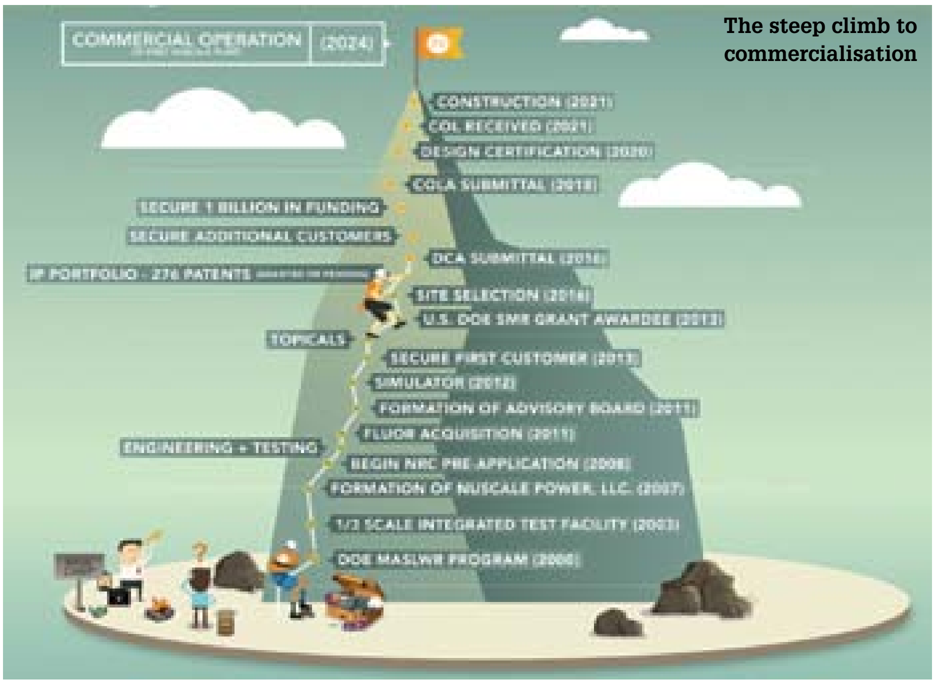
Some key features:

- ***No AC or DC power needed for safe shutdown and cooling:*** The NuScale plant's non-reliance on AC or DC power for safety has greatly simplified the electrical systems.
- ***Helical coil steam generators (HCSG):*** The use of compact HCSGs provides increased heat transfer surface area in a small volume with very low pressure drop to maximise natural circulation flow. The once-through counter-flow design enables the generation of steam superheat and good thermal efficiency without the use of reactor coolant pumps.
- ***High strength steel containment (rated at ~1000 psi) immersed in the cooling pool:*** Maintaining the space between the inside of the containment vessel and the outside of the reactor vessel at a vacuum limits heat exchange during normal operation. The NuScale containment vacuum minimises reactor vessel heat loss, limits oxygen content, and prevents component corrosion, eliminating the requirement for physical reactor vessel insulation and hydrogen recombiners. In an emergency core cooling system (ECCS) event the NuScale containment acts as a heat exchanger to provide reactor cooling and pressure control, eliminating the requirement for containment spray systems for cooling.
- ***Small, efficient core design limits source term:*** The NuScale reactor has 1/20 of the nuclear fuel of a large scale reactor. Its small decay heat, inherent stability, and reactor physics chracteristics eliminate fuel damage in all design basis events. For beyond design basis events, radiation from fuel damage is below safe limits at the plant site boundary.
- ***Digital instrumentation & control (I&C):*** NuScale's proprietary digital I&C system provides comprehensive monitoring and control of all plant systems in a single control room. The control room layout and panels are being designed using a state-of-the-art simulator as part of a comprehensive human factors engineering and human system interface.

Some basic data for a NuScale power module:	
Thermal capacity	160 MWt
Electrical capacity	50 MWe (gross)
Dimensions	76 ft x 15 ft cylindrical containment vessel module containing reactor vessel, pressuriser and steam generator
Weight	~ 680 tons as shipped from fabrication shop
Transportation	barge, truck or train
Cost	numerous advantages due to simplicity, off-the-shelf standard items, modular design, shorter construction times, < $5100/kW
Fuel	standard LWR fuel in 17 x 17 configuration, each assembly 2 m (~ 7 ft) in length; 24-month refuelling cycle with fuel enriched to less than 4.95%

The RPV head photographs on page 34 (upper right) are reproduced courtesy of Sheffield Forgemasters International Ltd. All other illustrations in this article are used with the permission of NuScale Power





The steep climb to commercialisation

projects underway" and hoping to submit a combined construction and operating licence application (COLA) in 2018.

The preferred site for the lead NuScale plant, in the southern part of the US Department of Energy's 890 square mile Idaho National Laboratory site, has been identified by UAMPS (Utah Associated Municipal Power Systems), which would be owner/operator of what is called the UAMPS Carbon Free Power Project.

UAMPS, an agency of the state of Utah, develops and operates power generation facilities to supply wholesale electricity to community-owned municipal power providers in Arizona, California, Idaho, Nevada, New Mexico, Oregon and Wyoming, as well as Utah. UAMPS is working on the CFPP along with NuScale, Energy NorthWest and Enercon Services.

The purpose of the CFPP, launched in 2013, is "to provide for additional mid-sized baseload electrical generating capacity to meet the expected future needs of members", says UAMPS, which has determined that "new carbon free baseload capacity is necessary to replace the expected retirement of coal fired generating assets" and that its members "need to have a carbon-free baseload generating asset as part of a balanced portfolio of generating assets." Thus far thirty three of UAMPS' 45 members have elected to participate in the CFPP.

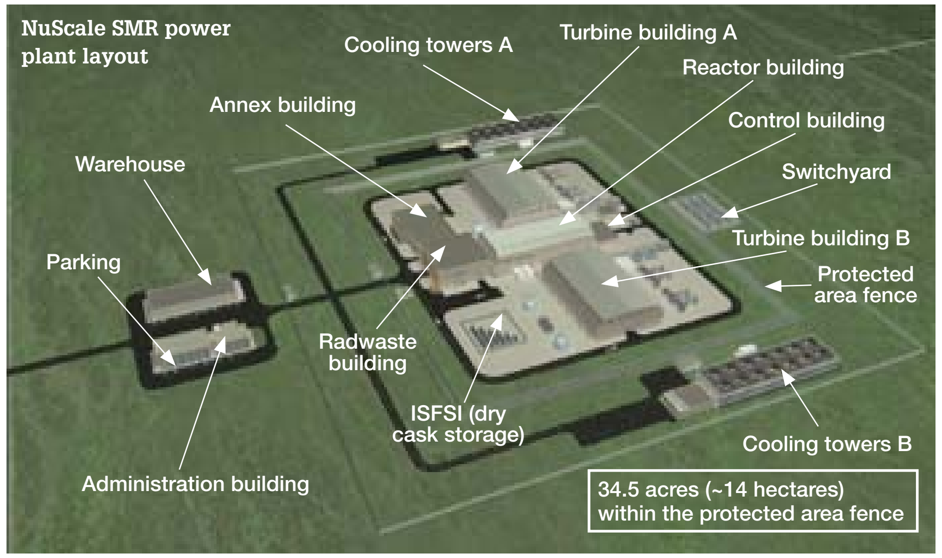
Following the granting of a permit by the US Department of Energy in February 2016 allowing UAMPS to perform site selection and characterisation activities within the INL site, the preferred location was chosen, consisting of about 35 acres within an approximately 1000-acre plot about 6 miles (10 km) southeast of the Lost River Rest Stop, near the junction of US Highways 20 and 26. This location was chosen from four options within the INL boundary.

Developing the supply chain

In August 2016 NuScale said it would start the process of selecting fabrication partners with a one day event, called NuFAB, to be held on 3 November 2016 in Atlanta, Georgia. "We are at the start of a process that will define the partners and partnerships to help deliver a groundbreaking SMR to the market," stated Scott Bailey, NuScale Power vice president, supply chain.

Meanwhile, in the UK – where NuScale intends to participate in a government competition aiming to identify the best value SMR option with a view to seeing SMRs deployed in the UK in the 2020s, and potentially being developed as an exportable technology – it has announced it will work with Sheffield Forgemasters International Ltd (SFIL) to develop "the manufacturing techniques that will be required for the future deployment of SMRs in the UK."

SFIL will forge a large civil nuclear reactor vessel head by the end of 2017, as part of a programme supported by Innovate UK,



Forging of NuScale RPV head ingot (diameter 150in, height 30in, weight 142000 lb) by Sheffield Forgemasters and machining of RPV head

the UK's innovation agency, to develop and validate innovative forging and fabrication solutions for the nuclear industry. NuScale Power says it is providing funding to "support the use of the geometries required by its innovative SMR design."

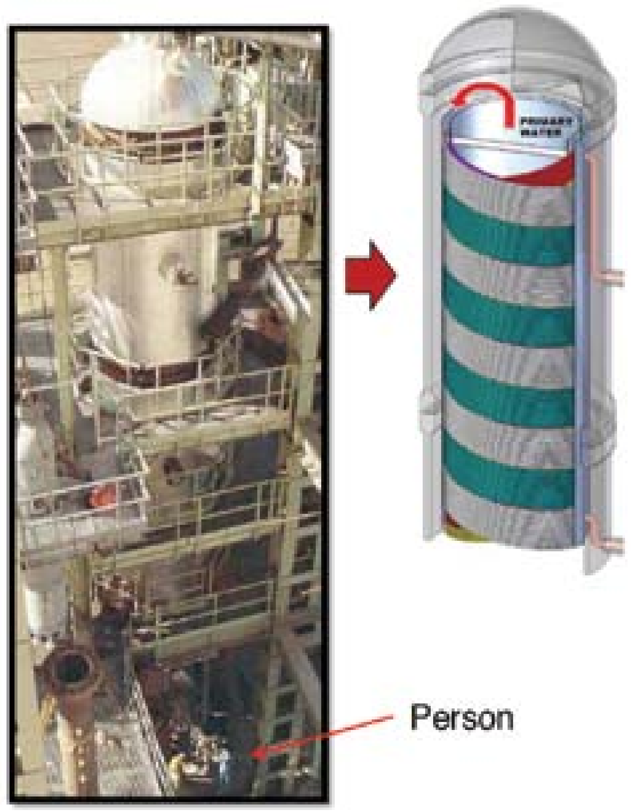
SFIL Chief Executive Graham Honeyman said: "Small modular reactors could revolutionise the civil nuclear power industry, by creating more flexible power generation solutions. The efficient factory manufacture of major components will be crucial to seeing them deployed cost-effectively."

On 13 July NuScale held a "supplier day", attracting over a hundred companies from the civil nuclear and engineering sectors, at the Advanced Manufacturing Research Centre in Sheffield, aimed at "giving UK-based engineering, manufacturing and construction companies the opportunity to learn about the company's programme of work."

NuScale has also become a supporting partner of the AMRC. Of the Nuclear AMRC, NuScale Power's chairman and CEO, John Hopkins, said it was "a true leader in the UK for developing the advanced manufacturing techniques that will help to further reduce the cost and schedule of fabricating major engineered equipment such as the NuScale power module."

Mike Tynan, CEO of the Nuclear AMRC, said there was a real opportunity for the UK "to develop lasting value from SMR technology developed and installed in the UK, and exported into the global civil nuclear market."

Helical tube steam generator testing (full length) at SIET



The NuScale design

NuScale's technology, initially developed and tested at Oregon State University, starting in 2000, uses pressurised water reactor technology, which has the benefit of being well established and proven, but at small scale with maximum use of passive safety features, enabling reactor coolant pumps and large bore piping to be eliminated.

It is envisaged that the plant will use half height, but otherwise standard, 17x17 PWR fuel assemblies, with average 3.8% enrichment.

The NuScale concept can be characterised as an "integral" PWR in that the reactor vessel, (helical coil) steam generator, pressuriser and containment are incorporated into a single integrated module, which can be factory assembled and then shipped to a prepared site for easy deployment.

A nuclear power plant using NuScale's technology would be comprised of a number of 50 MWe (gross) modules, each with its own factory-built combined containment vessel and reactor vessel, and its own packaged turbine-generator set, and condenser.

A power plant could include up to 12 modules operated from a single control room, providing an installed capacity of 600 MWe gross (570 MWe net, nominal, after house loads), as envisaged for the UAMPS project.

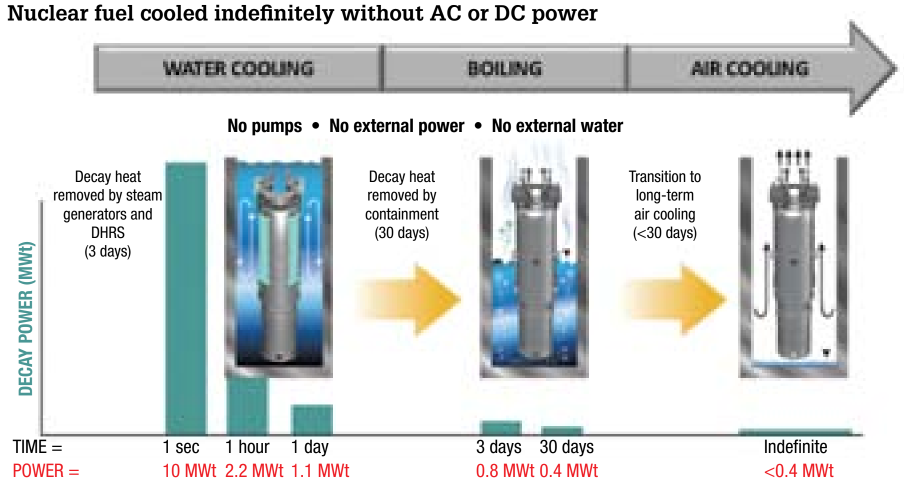
The reactor coolant system uses convection, conduction and gravity to drive the flow of coolant in the reactor. In the case of a loss of all off-site power to the plant, the NuScale power module shuts itself down and self-cools for an unlimited period, with no operator action required, no need for additional water, and no AC or DC power. NuScale power plants are described as "scalable" – in that additional modules can be added when demand for electricity increases. NuScale says its technology is also ideally suited to heat supply applications, such as district heating and desalination.

A further aspect that NuScale is working on is operational flexibility, in particular load following capabilities and complementing intermittent renewables.

The power output from a NuScale facility can be varied in several ways, such as:

- **Dispatchable modules** – taking one or more reactors offline for extended periods of low grid demand or sustained wind output.
- **Power manoeuvrability** – adjusting reactor power for one or more modules (intermediate time frames).
- **Turbine bypass** – bypassing turbine steam to the condenser (short time frames).

Nuclear fuel cooled indefinitely without AC or DC power



- 30 days is a minimum based on very conservative estimates.

* Alternate 1E power systems design eliminates the need for 1E qualified batteries to perform ESFAS protective functions – Patent Pending

In partnership with UAMPS and Energy Northwest, NuScale is exploring operational integration of the SMR facility with the Horse Butte wind farm in Idaho.

Testing, testing

While building on pressurised water reactor technology NuScale places particular emphasis on the component testing it is doing at a number of facilities around the world, with an estimated $30 million spent on testing to date.

Testing activities include the following: NuScale Integral System Test (NIST-1) facility in Corvallis, Oregon; critical heat flux testing at Stern Laboratories in Hamilton, Ontario Canada; helical coil steam generator (HCSG) testing at SIET (Società Informazioni Esperienze Termoidrauliche) in Piacenza, Italy; fuels testing at AREVA's Richland Test Facility (RTF), Washington; critical heat flux testing at AREVA's KATHY loop in Karlstein, Germany; control rod assembly drop/shaft alignment testing at AREVA's KOPRA facility in Erlangen, Germany; steam generator flow induced vibration testing at AREVA's PETER Loop in Erlangen, Germany; control rod assembly guide tube flow induced vibration testing at AREVA's MAGALY facility in Le Creusot, France.

NIST-1 is a one-third scale electrically-heated prototype test facility which has been in operation since 2003.

It replicates the entire NuScale power module and reactor building cooling pool. It uses an electrically heated core to bring the system up to operating temperature and pressure. Stability testing ensures that throughout the expected operating conditions, natural circulation is stable.

The facility has demonstrated the viability of NuScale's concept and provides a good representation of NuScale's current reactor design and can be used for safety code and reactor design validation.

NuScale's SMR design uses compact, highly efficient helical coil steam generators with many proprietary design features. NuScale contracted with SIET in Piacenza, Italy, to obtain test data to validate HCSG design under conditions that result from natural circulation flows in the NuScale reactor coolant system.

Tests, completed in early 2014, focused on the secondary side performance and consisted of an electrically-heated, highly instrumented, full-length three-tube bundle. The second test, completed in 2015, focused on overall primary and secondary side performance and consisted of a prototypic tube bank operated at prototypic primary and secondary flow conditions.

As already noted, the NuScale SMR uses natural circulation driven flows in the reactor coolant system to provide reliable core heat removal during normal plant operation and for accident conditions.

To obtain critical heat flux test data suitable for validating the fuel bundle design, NuScale completed a major test programme on its preliminary fuel design at Stern Laboratories in Ontario, Canada. Testing was conducted over a wide range of natural circulation flow rates and pressures with both uniform and non-uniform power profiles.

Results from the Stern testing are being used to inform design optimisations and testing of the final fuel design.

Testing of the final fuel design is underway at the AREVA KATHY multifunction thermal-hydraulic test loop in Karlstein, Germany. This facility tests both steady-state and transient thermal-hydraulic behaviour of the fuel assemblies.

Thermal-hydraulic fuel testing requirements extend beyond the need for CHF characterisation, and the AREVA Richland Test Facility has been employed to complete lift-off, pressure drop, and hydraulic characterisation of the final fuel design.

Additionally, mechanical testing of the new fuel design has been conducted at the Richland Test Facility to measure the physical capabilities of the design.

Prototypes of the NuScale control rod assembly, guide tube, supports and fuel assembly have been fabricated and shipped to the AREVA GmbH test site in Erlangen, Germany.

Fabrication of the prototype drive shaft is in process. The tests will measure the CRA insertion rate under different operational conditions.

NuScale has in addition enlisted AREVA, SIET, and Premier Technologies to perform helical coil steam generator flow induced vibration (FIV) tests. The goal will be to determine natural frequencies and mode shapes of prototypic tubes and supports. Tests will also characterise dynamic pressure fluctuations, tube stresses/strains and tube support stresses/strains.

Further, a feasibility study has been completed by NuScale on the use of eddy current probes to inspect the helical coil steam generator tubes. Helical coils with prototypic lengths, diameters, curvatures and inclination angles were examined using a conventional eddy probe system. MPS

NIST-1, control room simulator and upper module mock-up