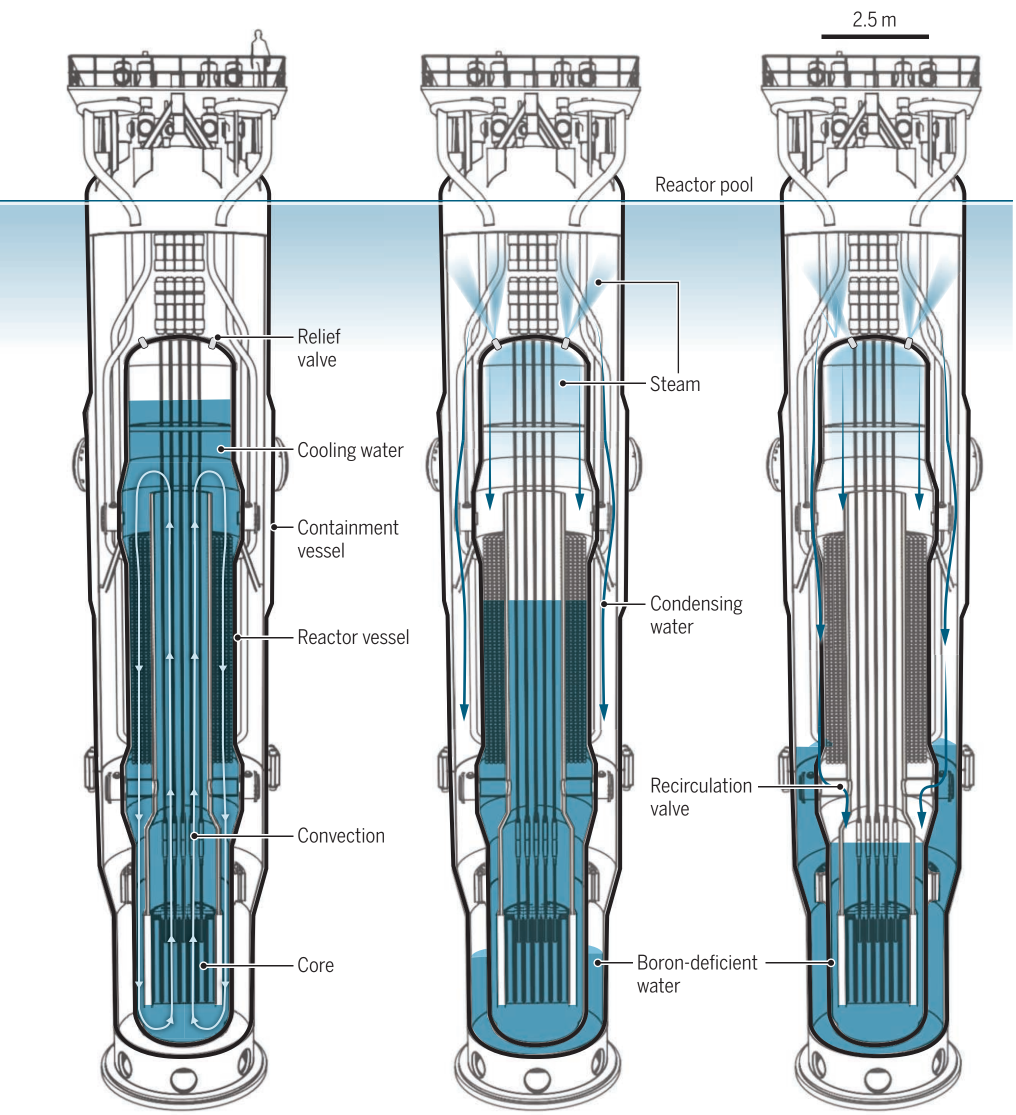
IN DEPTH

NUCLEAR POWER

# Critics question whether novel reactor is 'walk-away safe'

## Design approval nears for NuScale Power's small modular reactors, but deployment plans slip 3 years

*By* **Adrian Cho**




**PASSIVE SAFETY?** Normally, convection circulates water—laced with boron to tune the nuclear reaction—through the core of NuScale's reactor (left). If the reactor overheats, it shuts down and valves release steam into the containment vessel, where it conducts heat to a surrounding pool and condenses (center). The water flows back into the core, keeping it safely submerged (right). But the condensed water can be low in boron, and reviewers worried it could cause the reactor to spring back to life.

GRAPHIC: C. BICKEL/*SCIENCE*

Engineers at NuScale Power believe they can revive the moribund U.S. nuclear industry by thinking small. Spun out of Oregon State University in 2007, the company is striving to win approval from the U.S. Nuclear Regulatory Commission (NRC) for the design of a new factory-built, modular fission reactor meant to be smaller, safer, and cheaper than the gigawatt behemoths operating today (*Science*, 22 February 2019, p. 806). But even as that 4-year process culminates, reviewers have unearthed design problems, including one that critics say undermines NuScale's claim that in an emergency, its small modular reactor (SMR) would shut itself down without operator intervention.

The issues are typical of the snags new reactor designs run into on the road to approval, says Michael Corradini, a nuclear engineer at the University of Wisconsin, Madison. "I don't think these things are show-stoppers." However, M. V. Ramana, a physicist who studies public policy at the University of British Columbia, Vancouver, and has been critical of NuScale, says the problems show the company has oversold the claim that its SMRs are "walk-away safe." "They have given you the standard by which to evaluate them and they're failing," Ramana says.

Even critics expect that next month NRC will issue a safety evaluation report approving the NuScale design, which will be a major milestone, says José Reyes, NuScale's co-founder and chief technology officer. "This is the document that says, 'This design is safe,'" says Reyes, who hatched the idea for the reactor in 1999. NuScale will resolve the lingering technical issues before anything gets built, he says.

However, NuScale's likely first customer, Utah Associated Municipal Power Systems (UAMPS), has delayed plans to build a NuScale plant, which would include a dozen of the reactors, at the Department of Energy's (DOE's) Idaho National Laboratory. The $6.1 billion plant would now be completed by 2030, 3 years later than previously planned, says UAMPS spokesperson LaVarr Webb. "UAMPS is still very committed to the project," Webb says. "Our members really want to decarbonize their electric supply and replace coal." The delay will give UAMPS more time to develop its application for an NRC license to build and operate the plant, Webb says. The deal depends on DOE contributing $1.4 billion to the cost of the plant, he adds.

A nuclear reactor is essentially a boiler. In its core, uranium atoms split, releasing heat and neutrons, which split other uranium atoms in a chain reaction. Highly pressurized cooling water circulates through the core and carries heat to a steam generator,



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where it boils water in a separate circuit to drive turbines and generate electricity. The cooling water also slows the speeding neutrons, increasing the probability that they will split the uranium atoms.

Expense and safety worries have stalled nuclear power despite increasing demand for carbon-free electricity. NuScale's remedy is a radically new design. A conventional reactor relies on huge pumps and pipes to drive the cooling water through its core and ferry it to the steam generator. A NuScale reactor—which would be less than 25 meters high, hold about one-eighth as much fuel as a large power reactor, and generate less than one-tenth as much electric power—would rely on natural convection to circulate the water (see diagram, p. 888).

It is also designed to shut itself down in a pinch. Each reactor fits within a steel containment vessel, which in turn sits in a pool of water holding up to a dozen modules. Ordinarily, the space between the reactor and containment vessel remains evacuated, like the vacuum jacket in a thermos bottle. Should the core overheat or the reactor leak, relief valves would vent steam into the evacuated space, where it would conduct heat to the pool and condense into the bottom of the containment vessel. When enough water had accumulated, it would flow back into the reactor to keep the core safely submerged. NuScale is so confident in the design that it has asked NRC to allow its plants to run without the standard 32-kilometer-wide emergency planning zone.

In March, however, a panel of independent experts found a potential flaw in that scheme. To help control the chain reaction, the reactor's cooling water contains boron, which, unlike water, absorbs neutrons. But the steam leaves the boron behind, so the element will be missing from the water condensing in the reactor and containment vessel, NRC's Advisory Committee on Reactor Safeguards (ACRS) noted. When the boron-poor water re-enters the core, it could conceivably revive the chain reaction and possibly melt the core, ACRS concluded in a report on its 5–6 March meeting.

NuScale modified its design to ensure that more boron would spread to the returning water. The small changes eliminated any potential problem, Reyes says. However, at a 21 July meeting, ACRS concluded that operators could still inadvertently drive deborated water into the core when trying to recover from an accident. "I'm not saying that this [scenario] is going to happen," ACRS member Jose March-Leuba said, according to the meeting transcript. "I don't see a calculation that proves it wrong."

Ultimately, whoever applies for a license to build and operate a NuScale plant—presumably UAMPS—must devise an operating procedure that ensures such a scenario never occurs. But NuScale should provide guidance, Vesna Dimitrijević, a nuclear engineer and ACRS member, argued at the meeting. The issue demonstrates how slippery a seemingly black-and-white technical issue can be. "The applicant thinks there isn't a problem here," Corradini says. "The ACRS isn't so sure and want the staff and the applicant to think through the steps to make sure this isn't a problem." The NRC staff, which writes the safety evaluation report, thinks it can be dealt with in the operating license, he adds.

The issue pokes a hole in NuScale's credibility, says Edwin Lyman, a physicist with the Union of Concerned Scientists. "This is a case of the public relations driving the science instead of the other way around," he says. Sarah Fields, program director of the environmental group Uranium Watch, says the safety questions argue against NuScale's request to operate without an emergency planning zone. "That's a crazy thing to do for a reactor design that's totally new and with which you have no operating experience."

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> **José Reyes**, NuScale Power

Reyes says the company's analysis justifies that request. NuScale's studies show that under any credible scenario, the radiation at the plant periphery will not exceed NRC's limits for the edge of the traditional emergency planning zone, he says. Permission to forgo the buffer zone could help NuScale market its plants where space is tight, he says.

ACRS found a few other problems, including one with NuScale's novel steam generator, which sits within the reactor vessel and could be prone to damaging vibrations. Still, on 29 July, ACRS recommended that NRC issue the safety evaluation report and certify NuScale's design. "If there really was a fatal flaw, ACRS would not have published a positive report," Reyes says.

NRC plans to publish its safety evaluation report next month, and by year's end it is expected to issue draft "rules" that would essentially approve the design. But that won't end the regulatory odyssey. The current design specifies a reactor output of 50 megawatts of electricity, whereas the UAMPS plan calls for 60 megawatts. The change requires a separate NRC approval, Reyes says, during which NuScale will resolve the outstanding technical issues. That additional 2-year review should start in 2022. ■

QUANTUM THEORY

# Paradox puts objectivity on shaky footing

## Quantum test of venerable thought experiment suggests facts are relative

*By* **George Musser**

Nearly 60 years ago, Nobel Prize–winning physicist Eugene Wigner captured one of the many oddities of quantum mechanics in a thought experiment. He imagined a friend of his, sealed in a lab, measuring a particle such as an atom while Wigner stood outside. Quantum mechanics famously allows particles to occupy many locations at once—a so-called superposition—but the friend's observation "collapses" the particle to just one spot. Yet for Wigner, the superposition remains: The collapse occurs only when he makes a measurement sometime later. Worse, Wigner also sees the friend in a superposition. Their experiences directly conflict.

Now, researchers in Australia and Taiwan offer perhaps the sharpest demonstration that Wigner's paradox is real. In a study published this week in *Nature Physics*, they transform the thought experiment into a mathematical theorem that confirms the irreconcilable contradiction at the heart of the scenario. The team also tests the theorem with an experiment, using photons as proxies for the humans. Whereas Wigner believed resolving the paradox requires quantum mechanics to break down for large systems such as human observers, some of the new study's authors believe something just as fundamental is on thin ice: objectivity. The puzzle could mean there is no such thing as an absolute fact, one that is as true for me as it is for you.

"It's a bit disconcerting," says co-author Nora Tischler of Griffith University. "A measurement outcome is what science is based on. If somehow that's not absolute, it's hard to imagine."

Some physicists dismiss thought experiments like Wigner's as interpretive navel gazing. But the study shows that the contradictions emerge in actual experiments, says Dustin Lazarovici, a physicist and philosopher at the University of Lausanne who was not part of the team. "The paper goes to great lengths to speak the language of those