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THE IMPERATIVE OF THE VERSATILE TEST REACTOR FOR NUCLEAR INNOVATION

by Jackie Toth and Khalil Ryan

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Atlantic Council
1030 15th Street NW, 12th Floor
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Introduction

The United States has a long and successful history of innovating with the atom. Recognizing the abundant energy generated through nuclear fission, the US government in the mid-twentieth century pivoted much of its wartime nuclear complex to the research and development (R&D) of peaceful uses for nuclear technologies. It invested in new capabilities to explore the performance of different reactor concepts and coolants. For many years, the federal government supported civilian nuclear energy testing infrastructure that has enabled continual enhancements of the productivity, safety, and economics of predominantly light-water reactors, the only type of nuclear reactor currently in operation in the United States.

These R&D investments helped cement the United States' role as a global leader in nuclear energy and nuclear security.[1] They have supported a strong domestic civil nuclear sector and supply chain that is now poised to evolve with the demonstration and deployment of new, advanced reactors. However, almost thirty years have passed since the shutdowns (largely due to funding considerations) of the Experimental Breeder Reactor II (EBR-II) in Idaho and the Hanford Fast Flux Test Facility (FFTF) in Washington state. Since then, the United States has not built any test facilities to fill the void left by these closures, and has lacked a dedicated fast neutron irradiation test facility, which is necessary for testing advanced reactor components.[2] Today, most of the nation's test reactors are more than fifty years old, oversubscribed, and insufficient to test the technologies for next-generation advanced reactors, particularly materials and fuels.[3]

Pivotal to the United States' ability to regain its international leadership role in nuclear energy is the development of a new civil nuclear testing facility that supports R&D into cutting-edge reactor technologies. Without it, the the nation risks facilitating the demonstration of advanced reactors absent the ability to identify how these and other reactors fare with exposure to neutrons over time; improve the reactors' economics; or show regulators how long their designs can safely operate. Existing nuclear R&D facilities are either incapable of performing these tests on a workable timescale or are unable to accommodate them.

Civilian nuclear energy, however, is unique in its potential for meeting the energy and climate challenges of the twenty-first century. These challenges include rapidly reducing emissions to address climate change, enhancing energy security and grid reliability, and preserving strong and shared norms for international nuclear security and nonproliferation. Civilian nuclear energy produces nonemitting, continually operating power; contributes to US national and energy security across its supply chains, personnel, and carbon-free attributes; and incents the United States to remain active and influential in international nuclear security fora.[4]

Policymakers in Congress and successive presidential administrations have recognized this wide set of benefits that nuclear energy offers. As a result, the federal government is supporting the demonstration of innovative, nonlight-water nuclear reactor concepts, many of which federal and private engineers explored in the United States during the twentieth century.

However, the sporadic and fickle nature of federal funding for new nuclear research facilities and maintenance on existing research infrastructure has contributed to the gradual loss of US dominance as the global leader in nuclear energy.[5] Competitor nations, including Russia and China, are forging ahead with civil nuclear programs supported by domestic nuclear R&D facilities. Russia, which already has the most comprehensive fast neutron testing capacity (the BOR-60) for advanced nuclear energy systems, is constructing an addi-

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[1] The United States currently has ninety-two operational nuclear reactors, which provide around 20 percent of US electricity generation but account for more than half of its zero-carbon electricity generation; see Nuclear Energy Institute, "Map of US Nuclear Power Plants," accessed on November 27, 2022, https://www.nei.org/resources/map-of-us-nuclear-plants.

[2] Thomas J. O'Connor, "Versatile Test Reactor Mission Need/Purpose," US Department of Energy (DOE), January 27-28, 2021, https://www.youtube.com/watch?v=NoVhgF2d3k0&ab_channel=U.S.DepartmentofEnergy.

[3] "Record of Decision for the Final Versatile Test Reactor Environmental Impact Statement," Idaho Operations Office, DOE, July 22, 2022, 3, https://www.energy.gov/sites/default/files/2022-07/ne-rod-vtr-eis-v12-signed-072222.pdf; and "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," May 2022, § 2-27, https://www.energy.gov/sites/default/files/2022-05/EIS-0542_Volume%201_Chapters.pdf.

[4] Robert F. Ichord Jr. and Bart Oosterveld, "The Value of the US Nuclear Power Complex to US National Security," Issue Brief, Atlantic Council, October 2019, https://atlanticcouncil.org/wp-content/uploads/2019/10/Nuclear-Power-Value-IB-final-web-version.pdf.

[5] Nuclear Energy Advisory Committee (NEAC), *Assessment of Missions and Requirements for a New U.S. Test Reactor* (with transmittal letter to the DOE Office of Nuclear Energy), February 2017, 6, https://www.energy.gov/sites/default/files/2017/02/f34/NEAC%20Test%20Reactor%20Charge%20Report%202-18-17.pdf.

tional fast neutron test facility that could come online as soon as 2027 (the MBIR).[6] Even prior to Russia's 2022 invasion of Ukraine, test facilities in Russia were all but inaccessible to US reactor companies and researchers. Now, the United States and its international partners cannot plausibly rely on Russia for access to the federation's test facilities. India is the only other country currently with a dedicated fast neutron testing capability,[7] while China is converting its small experimental fast reactor—which Russia helped construct—to test fuels and materials for use in future Chinese fast reactors.[8]

The Versatile Test Reactor (VTR), a proposed US civil nuclear energy testing facility, would fill a domestic gap by producing the fast neutrons necessary to perform accelerated testing of nuclear fuels, alloys, materials, sensors, detectors, and instrumentation, as well as to validate modeling and computer simulation tools for innovative new reactors.

A broad chorus of nuclear energy stakeholders has made clear that a public user facility like the VTR is a necessity for a healthy domestic nuclear innovation ecosystem. Reactor developers, major utilities, technical experts, and the US Department of Energy (DOE) have all asserted that the federal government should prioritize building a test reactor like the VTR. Developers have recognized that the fast spectrum testing capability that the VTR would afford is crucial to enable the design improvements necessary to capture global civil nuclear market shares.[9]

International nuclear allies are also interested in seeing the United States construct the VTR. Long before the Russian invasion of Ukraine, the United States established agreements with Japan and France to cooperate on the test reactor. Similar conversations over potential collaborations on the VTR are underway with South Korea and other countries.[10]

Recognizing the energy and security imperative of establishing a domestic fast neutron irradiation testing capability, Congress funded the VTR from fiscal year (FY) 2018 to FY 2021. Following the Nuclear Energy Advisory Committee's independent determination in 2017 that this capability is critical but cannot be met by existing US test reactors,[11] DOE's Office of Nuclear Energy (NE) established a program to develop the facility. Soon afterward, in 2018, Congress instructed DOE to consider whether such a facility would fill this gap, with the agency later that year affirming that it would.[12] That year, NE started the VTR program.[13] On February 22, 2019, the DOE identified the need for the VTR and formally initiated the project.[14] By September 11, 2020, the agency had developed a cost range and project alternatives for the reactor.[15] Following the completion of an environmental impact statement (EIS) required under the National Environmental Policy Act, NE signed (on July 22, 2022) its record of decision confirming its intention to build the VTR at the Idaho National Laboratory (INL), if and when funding is made available.[16]

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[6] "Completion of MBIR Reactor Brought Forward," *World Nuclear News*, February 9, 2022, https://www.world-nuclear-news.org/Articles/Completion-of-MBIR-reactor-brought-forward.

[7] D. Peti et al., *Advanced Demonstration and Test Reactor Options Study*, Argonne, Idaho, and Oak Ridge National Laboratories, January 2017, 132, https://art.inl.gov/ART%20Document%20Library/Advanced%20Demonstration%20and%20Test%20Reactor%20Options%20Study/ADTR_Options_Study_Rev3.pdf.

[8] "Russia to Supply More Fuel for China's Fast Reactor," Nuclear Engineering International (website), January 5, 2017, https://www.neimagazine.com/news/newsrussia-to-supply-more-fuel-for-chinas-fast-reactor-5709961; and Kemal Pasamehmetoglu (executive director, VTR project, Idaho National Laboratory), in communication with the author, August 15, 2022.

[9] Letter from members of the Fast Reactor Working Group, *Response to NEAC Assessment of Missions and Requirements for a New US Test Reactor*, February 13, 2017; *The U.S. Nuclear R&D Imperative*: *A Report of the American Nuclear Society Task Force on Public Investment in Nuclear Research and Development*, American Nuclear Society, February 2021, https://www.ans.org/file/3177/2/ANS%20RnD%20Task%20Force%20Report.pdf; and "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 1-4.

[10] Kemal Pasamehmetoglu, "Versatile Test Reactor Overview," Idaho National Laboratory, January 29–31, 2019, 8, https://gain.inl.gov/SiteAssets/VersatileTestReactor/VTR_OVERVIEW.pdf. Personal communications with Kemal Pasamehmetoglu indicated that preliminary conversations in the early phases of the project also occurred with the United Kingdom and Canada about potential collaborations.

[11] NEAC, *Assessment of Missions and Requirements for a New U.S. Test Reactor.*

[12] Nuclear Energy Innovation Capabilities Act of 2017, Pub. L. No. 115-248, 115th Cong., 132 Stat. 328 (2018), https://www.congress.gov/bill/115th-congress/senate-bill/97/; and "Mission Need Statement for the Versatile Test Reactor (VTR) Project: A Major Acquisition Project," DOE, December 2018, https://s3.amazonaws.com/ucs-documents/nuclear-power/FOIA-Approved-Mission-Need-Statement-for+Versatile-Test-Reactor-Project.pdf.

[13] Tony Hill, "Versatile Test Reactor (VTR) Overview," Idaho State University and Idaho National Laboratory, November 7, 2018, 3, https://indico.bnl.gov/event/5067/contributions/24667/attachments/20687/27794/CSEWG_2018-VTR_Overview-Hill.pdf.

[14] Thomas J. O'Connor, "Versatile Test Reactor," DOE, December 7, 2020, 2, https://www.nationalacademies.org/event/12-07-2020/docs/DF00F2BCCD5ED60CEBDE2DBDBDB424731758290B34F1.

[15] O'Connor, "Versatile Test Reactor."

[16] "Record of Decision for the Final Versatile Test Reactor Environmental Impact Statement," Idaho Operations Office, Department of Energy, July 22, 2022, 22, https://www.energy.gov/sites/default/files/2022-07/ne-rod-vtr-eis-v12-signed-072222.pdf; and "DOE Selects Sodium-Cooled Fast Reactor Design for Versatile Test Reactor in Idaho," DOE, July 27, 2022, https://www.energy.gov/ne/articles/doe-selects-sodium-cooled-fast-reactor-design-versatile-test-reactor-idaho.

Chairwoman Lisa Murkowski (R-AK) speaks during a hearing of the Senate Committee on Energy and Natural Resources on Capitol Hill in Washington. March 13, 2018. REUTERS/Eric Thayer

In total, Congress directed $215 million toward the VTR before pausing funding in FY 2022—a shortsighted decision that imperils the success of the United States' ability to reclaim the mantle of global nuclear leadership.[17] The federal government is now at risk of failing to take an integrated approach to civil nuclear energy. It risks supporting the success of a handful of first-of-a-kind advanced reactors without facilitating the R&D necessary to improve upon these early prototypes to facilitate and sustain a thriving domestic nuclear energy ecosystem.[18] Without the VTR, reactor designers will have nowhere to innovate their designs and a limited capacity to promise customers that their products will improve over time. The United States also risks weakening its own case in promoting US-made advanced reactors for export.

If the United States fails to construct the VTR, it runs a parallel national strategic risk of indefinitely ceding leadership on global nuclear energy, nuclear security, safeguards, and nonproliferation issues. Russia is moving fast to modernize its test infrastructure and outcompete the United States on nuclear innovation, which threatens the United States' ability to serve the growing global market for nuclear energy and encourage customer countries to maintain high nuclear security standards.[19] The imperative is clear: Congress must reverse course and resume robust year-on-year funding toward the VTR project, or the United States will fail to counter competitor nations' ascent and continue to lose its ability to influence international norms in nuclear security.

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[17] "Advanced Nuclear Reactor Development Benefits from Versatile Test Reactor," US Nuclear Industry Council, January 24, 2020, 1, https://files.constantcontact.com/14bf1850201/4ec1f64f-b4ba-49a1-9c69-4b1c35a6aebb.pdf.

[18] Suzanne Baker et al., "The VTR Will Play a Key Role in the Nuclear Energy Innovation Ecosystem," *EnergySource* (blog), Atlantic Council, September 28, 2021, https://www.atlanticcouncil.org/blogs/energysource/the-vtr-will-play-a-key-role-in-the-nuclear-energy-innovation-ecosystem/.

[19] Thomas Graham Jr. and Richard W. Mies, "The Versatile Test Reactor Is Crucial for U.S. Global Leadership in Nuclear Energy," *National Interest*, August 3, 2021, https://nationalinterest.org/feature/versatile-test-reactor-crucial-us-global-leadership-nuclear-energy-191085.

This report explores the singular role a VTR would play in ensuring that a new generation of safer, more efficient reactors can contribute toward emissions reduction, national and energy security, and local and national economic growth. To contextualize test reactors' role in a healthy nuclear ecosystem, the report identifies the role that current and past US-funded test reactors have served to date in studying and improving the economics, operation, and safety of nuclear reactors. Next, the report provides an explanation of the need for a US-based VTR in a global nuclear marketplace populated with both allied and competitor reactor vendors and governments. It concludes with a set of policy recommendations for building the VTR and capitalizing on the ingenuity of national laboratories, universities, and other scientists to support a thriving, sustainable domestic nuclear energy ecosystem:

- **Beginning with FY 2024, resume and maintain funding for the VTR each fiscal year until the facility enters into operation**. The VTR design process must run concurrently with the demonstration of advanced reactors in the United States to ensure that these first-of-a-kind power reactors can realize their full potential to benefit the US economy, bolster its national security, and address global climate change.

- **Revive bilateral and multilateral dialogues with international civil nuclear allies**. Russia's war on Ukraine has underlined the security and innovation risks of relying on an aggressor nation for access to civil nuclear testing infrastructure. The United States should immediately revive high-level dialogues with its international partners on the imperative of developing a public, US-based, fast-spectrum irradiation user facility.

- **Identify contingencies to accommodate fast neutron testing absent the VTR.** If constructing the VTR is infeasible due to budgetary constraints, Congress must authorize and fund DOE to identify and develop alternatives, including international alternatives, to the VTR.

The Imperative of the Versatile Test Reactor for Nuclear Innovation

The US Congress has charged NE with supporting nuclear energy science and technology in service of domestic energy, environmental, and economic needs.[20] Bipartisan support exists in Congress for the deployment of advanced reactors, i.e., new reactor designs that offer improved safety, efficiency, and flexibility over existing nuclear plants.[21] Compared to the 1000-megawatt (MW) light-water reactors generating electricity in the United States today, many developers are designing smaller (under 300 MW) advanced reactors that can be built in factories, supporting cost reductions over time. Many advanced reactors are expected to reduce proliferation risks by requiring less frequent refueling and by incorporating greater safety and security features by design. Unlike light-water reactors that use hydrogen to slow neutrons into the thermal energy range, some new reactors operate with a fast-neutron spectrum. Fast reactors offer several advantages over thermal reactors, including a closed fuel cycle, a more compact design with a higher power density, low-pressure operations with passive safety for most fast reactor concepts, and significantly increased utilization of energy from natural uranium, which reduces their fuel needs.[22]

Today, the United States lacks a facility that can regularly test components of these new fast reactors, a significant gap that the VTR would fill. A VTR would produce neutrons in sufficient number in the fast neutron energy range to enable a significant acceleration in the testing of advanced driver fuels (those that power reactors) and experimental fuels, sensors, and materials for new reactors that operate with fast neutrons. Advanced reactors are characterized in part by their use of nonlight-water coolants, including sodium, molten salt, gas, helium, lead, and lead-bismuth, all of which the VTR could test to identify how they perform and corrode over time.[23]

As a “versatile” test facility, the VTR would provide accurate measurements of performance and allow for examination of the effects of irradiation on the tested materials.[24] Using the VTR, developers could identify and validate how their reactor components will hold up as they face increasing radiation damage over time or get exposed to high heat. These tests would yield data on the safety and reliability of reactor components, as well as information that developers could use to increase the lifetimes of advanced reactor cores and improve fuel performance.[25] As currently envisioned, the VTR would accommodate a minimum of ten experiments simultaneously, or many more, depending on whether individual experiments have large quantities of neutron-absorbing materials or produce neutrons themselves, such as in fuel tests. Six tests could run as loops with online instrumentation.

By operating as a user facility, the VTR could flexibly support many research interests. It would also support the development of thermal reactor materials and expand the benefits of testing access beyond the fission reactor community to university researchers, fusion companies, high-energy physics researchers, and international partners.[26]

Without the VTR, testing fuels or materials within operating power reactors themselves would take years or decades longer because of a lack of fast neutrons or an insufficient speed of the neutrons present.[27] For example, an experiment to qualify new cladding that would run for five years in a thermal reactor could be completed in just a few months in the VTR.

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[20] “About Us,” Office of Nuclear Energy, DOE, accessed July 28, 2022, https://www.energy.gov/ne/about-us.

[21] *Advanced Nuclear Reactor Technology: A Primer*, Nuclear Innovation Alliance, July 2022, https://nuclearinnovationalliance.org/advanced-nuclear-reactor-technology-primer.

[22] “Final Versatile Test Reactor Environmental Impact Statement: Volume 1,” May 2022, § 1-4; “Fast Reactors,” International Atomic Energy Agency, accessed July 28, 2022, https://www.iaea.org/topics/fast-reactors; and “Fast Neutron Reactors,” World Nuclear Association, August 2021, https://world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx.

[23] “Final Versatile Test Reactor Environmental Impact Statement: Volume 1,” § 2-5, https://www.energy.gov/sites/default/files/2022-05/EIS-0542_Volume%201_Chapters.pdf.

[24] NEAC, *Assessment of Missions and Requirements for a New U.S. Test Reactor*, 5.

[25] *Office of Nuclear Energy: Strategic Vision*, DOE, January 1, 2021, 28, https://www.energy.gov/sites/default/files/2021/01/f82/DOE-NE%20Strategic%20Vision%20-Web%20-%2001.08.2021.pdf; and “Final Versatile Test Reactor Environmental Impact Statement: Comment Response Document,” May 2022, § 2-6, https://www.energy.gov/sites/default/files/2022-05/final-eis-0542-versatile-test-reactor-summary-2022-05.pdf.

[26] “FAQs,” VTR (website), Idaho National Laboratory, accessed July 28, 2022, https://inl.gov/vtr/frequentlyaskedquestions/.

[27] “Final Versatile Test Reactor Environmental Impact Statement: Volume 1,” § 1-2.

Designers conceptualize the VTR as a pool-type, sodium-cooled fast neutron spectrum reactor with a power level range of 300 megawatts-thermal (MWt). Project developers selected a sodium-cooled design due to the maturity of the technology compared to other advanced reactor coolants amid a recognition by Congress and the nuclear community that the US nuclear enterprise needs this testing ability in the near term.[28] Domestically, sodium-cooled technology has been safely and successfully demonstrated in the EBR-II and FFTF, and at the Enrico Fermi Nuclear Generating Station in Michigan,[29] as well as the Southwest Experimental Fast Oxide Reactor in Arkansas and the Sodium Reactor Experiment in California.[30] As of 2018, NE indicated that sodium-cooled reactor technology has benefited from more than one hundred cumulative years of operating experience.[31] Tests performed in 1986 at the EBR-II showed the technology can operate with inherent and passive safety.[32] Through strongly negative reactivity feedback with increasing fuel temperature and gravity-assisted convection, these facilities can cool automatically when shut down. Several national laboratories also examined the suitability of a high temperature gas-cooled reactor for a theoretical fast neutron test facility, but identified that the gas coolant would not offer the high fast flux of a sodium-cooled fast reactor.[33]

The current planned design for the VTR would use a metal driver fuel composed of uranium, plutonium, and zirconium that was extensively tested in the EBR-II and the FFTF.[34] This fuel blend allows the VTR to be designed with a much smaller footprint and less thermal power than if it were to forego the use of plutonium. INL scientists identified that using plutonium in the VTR would improve performance of the core, increase flexibility in designing the driver fuel assemblies compared to low-enriched uranium, and increase the volume of test locations.[35] The United States has decades of experience safely managing plutonium and is best positioned internationally to guide the use of this and other radioactive elements for peaceful purposes.

The VTR project team identified the ability to use a reactor type, primary heat removal system, and set of safety systems that is similar to GE Hitachi Nuclear Energy's Power Reactor Innovative Small Module (PRISM) reactor for the design of the VTR.[36] In November 2018, INL formally provided GE Hitachi, TerraPower, and Bechtel National Inc. with an award to support the conceptual design of the VTR project.[37] By January 2020, GE Hitachi and TerraPower announced that the two reactor developers would seek to collaborate on the next phase of design and build the test facility.[38] Additionally, a memorandum of understanding (MOU) came into effect between NE, INL, Bechtel, GE Hitachi, and TerraPower in June 2021 for coordination between TerraPower's Natrium reactor demonstration in Kemmerer, Wyoming, and the VTR project.[39]

Investments in a VTR, like other R&D programs, will support the kinds of innovations that ultimately reduce costs and improve the efficiency of US advanced fission technol-

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[28] Jordi Roglans-Ribas et al., "The Versatile Test Reactor Project: Mission, Requirements, and Description," *Nuclear Science and Engineering* 196, no. SUP1 (2022): 1-10, https://doi.org/10.1080/00295639.2022.2035183.

[29] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-3.

[30] "Advanced Nuclear Reactor Development Benefits from Versatile Test Reactor," US Nuclear Industry Council Policy Brief, January 24, 2020, 2, https://files.constantcontact.com/14bf1850201/4ec1f64f-b4ba-49a1-9c69-4b1c35a6aebb.pdf.

[31] "Mission Need Statement for the Versatile Test Reactor (VTR) Project," DOE, 11; and see Roglans-Ribas et al., "The Versatile Test Reactor Project," S4.

[32] Roglans-Ribas et al., "The Versatile Test Reactor Project."

[33] Peti et al., *Advanced Demonstration and Test Reactor Options Study*, ix.

[34] *Final Versatile Test Reactor Environmental Impact Statement: Summary*, May 2022, iii, https://www.energy.gov/sites/default/files/2022-05/EIS-0542_Summary_0.pdf; and O'Connor, "Versatile Test Reactor Mission Need/Purpose."

[35] Sonat Sen et al., *Preliminary Options Assessment of Versatile Irradiation Test Reactor*, Idaho National Laboratory, January 2017, vi, 14, https://inldigitallibrary.inl.gov/sites/sti/sti/7323665.pdf.

[36] Roglans-Ribas et al., "The Versatile Test Reactor Project."

[37] "GE Hitachi Awarded Subcontract for Work Supporting Proposed Versatile Test Reactor," Idaho National Laboratory, November 13, 20108, https://inl.gov/article/subcontract-awarded-for-versatile-test-reactor/.

[38] "GE Hitachi Nuclear Energy and TerraPower Announce Collaboration to Support Versatile Test Reactor Program," General Electric, January 21, 2020, https://www.ge.com/news/press-releases/ge-hitachi-nuclear-energy-and-terrapower-announce-collaboration-support-versatile.

[39] Kemal Pasamehmetoglu, "Versatile Test Reactor: Enabling U.S. Leadership in Civil Nuclear Energy," Versatile Test Reactor Project, May 2022, 12, https://uploads-ssl.webflow.com/5f05cd440196dc2be1636955/6314cb367f16c9c30de485d6_5-22%20Versatile%20Test%20Reactor.pdf.

ogies. In September 2020, DOE approved a cost range for the VTR of $2.6 billion to $5.8 billion, with a point estimate of $3.6 billion, on an aggressive schedule to complete the facility in 2026, with four years of uncertainty out to 2030.[40] The department made preliminary revisions to the cost and schedule projections after signing the MOU to coordinate with the Natrium team; it planned for VTR to lag the Natrium project supported by the Advanced Reactor Demonstration Program (ARDP), discussed below, by two to four years to maximize technological and supply chain risk reductions for the two projects. Officials placed the preliminary new cost estimate at $2.8 billion to $5.97 billion, with a point estimate of $3.96 billion and a completion schedule between 2032 and 2034.[41] The new VTR upper-end cost estimate reflected the reduction in uncertainty, from an initial 60 percent from the initial cost estimate to 50 percent, conservatively crediting the benefits of lagging Natrium.[42] If Congress were to fund VTR design work at an adequate level of approximately $150 million per year, its engineering design could be completed in six years at a total cost of about $900 million, at which time construction could begin.[43] Because the VTR will be a user facility, some portion of the upfront cost of the VTR will be recoupable through assessing fees on the developers, researchers, and international partners who use it.

The longer Congress waits to fund the project, the higher overall design and construction costs are likely to escalate. Failing to fund the project and leaving it on standby carries several risks. The pause in funding results in a loss of resources used to conduct the safety analysis and work on the conceptual design, reduces continuity of the supply chain, and curtails the opportunity to incorporate synergies from the ARDP into the design. The lack of appropriations also ends the ability to train a new generation of nuclear engineers on designing a state-of-the-art test reactor.

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[40] O’Connor, “Versatile Test Reactor,” 5.

[41] Pasamehmetoglu, “Versatile Test Reactor: Enabling U.S. Leadership in Civil Nuclear Energy,” 10-12, 18.

[42] Pasamehmetoglu, in communication with the author.

[43] Pasamehmetoglu, in communication with the author.

Domestic Precedents of the VTR

For decades, federally supported civil nuclear test reactors have produced data enabling significant and compounding improvements to light-water reactor operations. Researchers have used these thermal test facilities to run tests and improve light-water reactor fuels and cladding that have doubled fuel burnup over the past few decades and increased US nuclear reactor availability from about 60 percent in the 1980s to more than 90 percent today.[44] Some national laboratory and university reactors have also looked to thermal test reactors for fusion research and medical isotope production. The VTR would similarly support innovation of both thermal and fast reactors and enable research for other, nonfission applications.

Notably, the VTR's fast neutron test reactor predecessors enabled important studies into the functionality and safety of liquid metal reactors. Those test reactors, which have not operated for decades, in many ways paved the way for today's advanced reactor developers to design prototypes of fast reactors based on real data.

Select Thermal Neutron Test Sources

ADVANCED TEST REACTOR

The Advanced Test Reactor (ATR) at INL, operating since 1967, is one of the world's most technologically advanced nuclear test reactors to study fuels and materials for use in reactors that operate with thermal (or slowed) neutrons. The ATR accommodates many of the testing needs of DOE, the US Navy, universities, developers, and international researchers. For decades, ATR experiments have enabled continuous fuel performance improvements for naval reactors,[45] sup-

Aerial photograph of the ATR complex/reprinted with permission granted by INL.

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[44] "FAQs," VTR (website).

[45] Frances M. Marshall, "Advanced Test Reactor Capabilities and Future Operating Plans," Idaho National Laboratory, September 2005, 3, https://inldigitallibrary.inl.gov/sites/sti/sti/3303753.pdf.

ported the development of low-enriched uranium fuels to replace high-enriched uranium fuels in order to reduce the risk of proliferation, tested the viability of a new particle fuel for high-temperature gas-cooled reactors, and determined which materials can reduce the need for long-term spent fuel storage.[46]

HIGH FLUX ISOTOPE REACTOR

Starting in 1965, the light-water-cooled High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory has provided a source of thermal and cold neutrons, enabling the testing of reactor fuels and materials as well as the production of isotopes for medical and industrial uses.[47] For instance, the HFIR is the only Western producer of californium-252, which is crucial to cancer therapy and the detection of pollution and concealed explosives.[48]

No technological industry can thrive without consistent innovation, iteration, and invention. For instance, the first cell phones were bulky and prohibitively expensive and could only place and receive calls, but constant improvements have resulted in sleeker, cheaper, Internet-connected devices. Similarly, the ATR and other thermal research reactors have afforded light-water reactor designers and operators the test data necessary to ramp up these plants' capacity safely. But thermal neutron spectrum test reactors, like the ATR and the HFIR, are poor substitutes for the VTR.[49] Thermal test reactors cannot achieve the concentrations, or flux, of neutrons needed for fast spectrum systems or accelerated testing of either fast or thermal reactors. It would be prohibitively expensive or impossible to retrofit existing test reactors to enable tests of non-light water coolants.[50] The DOE has identified that radiation damage tests for fast reactor materials would also take excessively long to finish in the existing test reactors.[51] The ATR, for example, fails to meet VTR performance needs and is vastly oversubscribed: in 2020, more than 90 percent of the ATR's key test locations were booked for the next five years or longer.[52] These existing commitments—and the ATR's importance to the US Navy—make the ATR a poor substitute for the VTR.[53] The HFIR is similarly poorly suited for fast neutron irradiation and plays a critical role as a producer of domestic isotopes.[54]

Select Fast Neutron Test Sources

EXPERIMENTAL BREEDER REACTOR-II

The Experimental Breeder Reactor-II (EBR-II) was a 62.5-MWt liquid sodium-cooled fast breeder reactor. Building off the success of the EBR-I, which had shown it is possible for this type of reactor to produce more fuel than it consumes, the EBR-II demonstrated that a closed fuel cycle involving the reprocessing or recycling of fuel also is possible. From 1964 to 1994, scientists learned through the operation of the EBR-II that, among other things, fast reactors are inherently safe: in 1986, the EBR-II showed it could shut down without incident if its safety systems malfunctioned.[55] The research carried out at the EBR-II has helped inform many of today's advanced reactor concepts, though developers will need to be able to perform more tests to improve fuel performance and increase commercial competitiveness past their first designs.

TRANSIENT REACTOR TEST FACILITY

The Transient Reactor Test Facility (TREAT) is an air-cooled thermal spectrum test facility designed to evaluate reactor fuels and structural materials at the Materials and Fuels Complex of INL.[56] Developers initially intended TREAT to support EBR-II R&D but later diversified the facility to support other nuclear technology R&D. TREAT's experimental capabilities enable it to produce a variety of power-transient shapes and test high-burnup fuels for many reactor types.[57] TREAT's experiments of testing future reactor fuels in accident conditions provide an opportunity to ensure the viability and safety of future reactor designs. TREAT's operations initially ended in 1994 following a loss of interest in transient testing and the closing of the EBR-II and FFTF. However, as interest increased in the shorter pulse testing that TREAT

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[46] D. Sean O'Kelly, "The Advanced Test Reactor," in *Encyclopedia of Nuclear Energy*, ed. Ehud Greenspan (2021): 63, https://doi.org/10.1016/B978-0-12-819725-7.00032-5.

[47] "History of the High Flux Isotope Reactor," Oak Ridge National Laboratory, Neutron Sciences Directorate (website), accessed July 29, 2022, https://neutrons.ornl.gov/hfir-history.

[48] "History of the High Flux Isotope Reactor," Oak Ridge National Laboratory.

[49] "Mission Need Statement for the Versatile Test Reactor (VTR) Project," DOE, 11.

[50] Peti et al., *Advanced Demonstration and Test Reactor Options Study*, xiv.

[51] Mission Need Statement for the Versatile Test Reactor (VTR) Project," DOE, 11.

[52] O'Kelly, "The Advanced Test Reactor," 62.

[53] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-27.

[54] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-28.

[55] Catherine Westfall, "Vision and Reality: The EBR-II Story," *Nuclear News*, February 2004, 25-32, https://www.ne.anl.gov/About/reactors/EBR2-NN-2004-2-2.pdf; and Jeff Pinkham, "Historic Reactor Dome Gets a Face-Lift," Idaho National Laboratory (website), April 3, 2020, https://inl.gov/article/historic-reactor-dome-gets-a-facelift/.

[56] D.C. Crawford, "Experimental Capabilities of the Transient Reactor Test (TREAT) Facility" (1998 American Nuclear Society Winter Meeting in Washington, DC), https://www.osti.gov/biblio/10911-experimental-capabilities-transient-reactor-test-treat-facility.

[57] Nicolas Woolstenhulme, "The Transient Reactor Test Facility (TREAT)," in *Nuclear Reactors: Spacecraft Propulsion, Research Reactors, and Reactor Analysis Topics*, ed. Chad Pope (London: IntechOpen, 2021), 10.5772/intechopen.101275.

allows, the facility was reactivated in 2018 to support experimental programs developing light-water reactors, advanced reactor fuels, and space nuclear programs.

FAST FLUX TEST FACILITY (FFTF)

The FFTF is a deactivated test reactor that was established in 1982 to meet global interest in liquid metal breeder reactors.[58] Before concluding operations in 1992 and fully deactivating in 2009, the 400-MWt fast neutron flux test reactor at the DOE's Hanford site enabled research into the safety attributes of liquid metal reactors and demonstrated the failure-free operation of certain fuels.[59] Its sodium coolant enabled its internal temperature not to rise too far above the temperature of the coolant, limiting the possibility of the fuel overheating. Notably, tests at the FFTF estimated that, given its liquid metal-cooled design, a severe accident at the site was one hundred times less likely than at a standard commercial light-water reactor, augmenting the safety case for fast reactor technology.[60]

While operators could theoretically reactivate the FFTF to support some accelerated testing in support of fast reactors, the facility could not test the full range of components that the VTR could. Unlike the VTR, whose mission would run for sixty years, the deactivated FFTF would only have ten years left remaining in its anticipated lifetime.[61] In addition, a restart may be infeasible under modern reactor safety requirements: the sodium in the FFTF has been drained, and restarting it could risk corrosion. The site would require significant surveillance or replacement of insufficient components before it could reenter operation. In 2007, a technical consulting firm tallied at least $500 million (in 2007 dollars) in necessary modifications and repairs to the facility over five years before the FFTF could reenter operation,[62] but updated estimates for cost and timeline to restart would be necessary prior to actions toward a restart.[63]

The Complementarity of Advanced Nuclear Investments

In order for the United States to regain the mantle of global nuclear energy leadership, the federal government must show that it is truly invested in supporting a long-lived domestic advanced nuclear enterprise, not just a handful of one-off reactor demonstrations.

DOE is already making investments to kickstart the deployment of domestic advanced nuclear technologies through the ARDP. Through 50/50 public-private cost shares, DOE NE and the Office of Clean Energy Demonstrations are supporting the demonstration of two advanced reactors: TerraPower's Natrium, a sodium fast reactor with a molten salt energy-storage system, and X-Energy's Xe-100, a high-temperature gas-cooled reactor.[64] Both of these demonstrations are to be operational later this decade. Under ARDP, NE is also providing 80/20 cost-shared support to other advanced reactor technologies in earlier stages of development. This Risk Reduction for Future Demonstration program is supporting vendors such as Kairos Power, Westinghouse Electric Co., and BWX Technologies with funding for design, licensing, and other activities. Many of the awardees under the risk reduction program use advanced fuels and materials in their reactor designs.[65] Through the third and final component of the ARDP—the Advanced Reactor Concepts-20 (ARC-20) program—DOE is further supporting reactor designs that are even more nascent.[66]

At Congress's direction, DOE is taking additional steps to spur the development of a domestic, market-based supply chain for the high assay low-enriched uranium (HALEU) that many advanced reactor designs will require in order to operate but whose only current supplier is a Russian-owned company.[67] Just as Russia's invasion of Ukraine has made it impossible for domestic and international reactor vendors to rely on Russian fast neutron testing capabilities, the conflict

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[58] D. L. Nielsen, "FFTF: A History of Safety & Operational Excellence," Fluor Hanford, Conference, June 2002, https://www.osti.gov/biblio/808099-fftf-history-safety-amp-operational-excellence.

[59] Columbia Basin Consulting Group, *Siting Study for Hanford Advanced Fuels Test & Research Center*, Prepared for Tri-City Industrial Development Council, April 30, 2007, 18, https://atomicinsights.com/wp-content/uploads/FFTF-GNEP-Report-FINAL-091027-2017.pdf.

[60] Columbia Basin Consulting Group, *Siting Study for Hanford*.

[61] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-28.

[62] Columbia Basin Consulting Group, *Siting Study for Hanford*, 32, 53.

[63] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-28.

[64] "U.S. Department of Energy Announces $160 Million in First Awards under Advanced Reactor Demonstration Program," DOE, October 13, 2020, https://www.energy.gov/ne/articles/us-department-energy-announces-160-million-first-awards-under-advanced-reactor.

[65] "Energy Department's Advanced Reactor Demonstration Program Awards $30 Million in Initial Funding for Risk Reduction Projects," DOE, December 16, 2020, https://www.energy.gov/ne/articles/energy-departments-advanced-reactor-demonstration-program-awards-30-million-initial.

[66] "Energy Department's Advanced Reactor Demonstration Program Awards $20 Million for Advanced Reactor Concepts," DOE, December 22, 2020, https://www.energy.gov/ne/articles/energy-departments-advanced-reactor-demonstration-program-awards-20-million-advanced.

[67] "Industry Day: High-Assay Low-Enriched Uranium (HALEU) Supply," Draft PowerPoint, DOE, October 14, 2022, https://sam.gov/api/prod/opps/v3/opportunities/resources/files/6f34d971d2564154836f43ffc1905172/download?&token=; and Patrick White (lead author), *Catalyzing a Domestic Commercial Market for High-Assay, Low-Enriched Uranium (HALEU)*, Nuclear Innovation Alliance, April 2022, https://nuclearinnovationalliance.org/catalyzing-domestic-commercial-market-haleu.

also has cast into doubt the long-term accessibility of Russian uranium for US reactor developers.

Together, the ARDP program, the fuel availability program, and the VTR project are three pillars of a successful, integrated US nuclear energy ecosystem.[68] The ARDP will show domestic and international buyers the viability of US advanced reactor products; the fuel availability program will help develop a domestic high-assay, low-enriched uranium fuel cycle to power these reactors; and the VTR will fill a major gap in the R&D infrastructure by fostering improvements in advanced reactor designs that improve their economics, increase their efficiency, and reduce their cost. Funding one or two of these activities but not the others will fail to create a domestic advanced nuclear market. Each project requires sustained appropriations from Congress if the DOE is to meet its congressional direction to support R&D, demonstration, and commercial application of advanced reactors.[69]

Key Versatile Test Reactor Legislation

Bill	Bill Number/Public Law	Summary of VTR Provisions
Nuclear Energy Research Infrastructure Act of 2018	H.R. 4378, 115th Cong.; passed in the House but never enacted.	Would have directed DOE to provide a versatile reactor-based fast neutron source. Had targeted start of operations by Dec. 31, 2025, and authorization of $1.985 billion through FY 2025.
Nuclear Energy Innovation Capabilities Act (NEICA)	Pub. L. No. 115-248, 115th Cong., 132 Stat. 3154 (2018).	Called on DOE to identify the mission need for a versatile reactor-based fast neutron source. Targeted start of operations by Dec. 31, 2025.
Energy Act of 2020 (Division Z, Consolidated Appropriations Act, 2021)	Pub. L. 116-260, 116th Cong., 134 Stat. 1182 (2020).	Directed DOE to construct a versatile fast neutron source. Targeted start of operations by Dec. 31, 2026. Authorized $2.286 billion through FY 2025.

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[68] Suzanne Baker et al., "The VTR Will Play a Key Role in the Nuclear Energy Innovation Ecosystem," *EnergySource* (blog), Atlantic Council, September 28, 2021, https://www.atlanticcouncil.org/blogs/energysource/the-vtr-will-play-a-key-role-in-the-nuclear-energy-innovation-ecosystem/.

[69] Consolidated Appropriations Act, 2021, Pub. L. No 116-260, 134 Stat. 1182 (2020), § 2003, https://www.congress.gov/116/plaws/publ260/PLAW-116publ260.pdf.

A Sprint and a Marathon: Advancing the VTR in Tandem with Reactor Demonstrations

The United States is in a sprint to demonstrate the next generation of advanced nuclear reactors successfully and on time. But the country also is in a marathon to deploy nuclear energy at scale to address the climate challenge.[70] The VTR would help the United States win this marathon by enabling innovation over as long as six decades, giving regulators the confidence they need to sign off on reactor modifications and giving potential customers the confidence they need to purchase many US advanced reactors.

Revised deployment timelines for the VTR place the start of operation at 2032 to 2034.[71] As Congress required, DOE selected applicants for the ARDP demonstration awards that could show their readiness to construct their designs within five to seven years of DOE making the awards, so the completion of the demonstrations is likely to precede the availability of a US fast neutron testing capability. After demonstration, the ARDP awardees still want to run fast-spectrum irradiation tests: TerraPower has been clear that, while it never intended to rely on access to a VTR to advance toward commercialization of its reactors,[72] the company will ultimately need to be able to run fast neutron tests to meet its goals, for example, to achieve high-burnup fuels with high-fluence cladding.[73]

Versatile Test Reactor: History of Budget Requests, Appropriations, and Authorizations

Fiscal Year	President's Budget Request (millions)	Appropriation (millions)	Current Authorization (millions)
2018	$10	$35	–
2019	$15	$65	–
2020	$100	$65	–
2021	$295	$45	$295
2022	$145	$0	$348
2023	$45	–	$525
2024	–	–	$534
2025	–	–	$584

SOURCES (BY FISCAL YEAR):

2018: DOE, Department of Energy FY 2018 Congressional Budget Request, Vol. 3, May 2017, https://www.energy.gov/sites/default/files/2017/05/f34/FY2018BudgetVolume3_0.pdf, 544; and US House of Representatives, Consolidated Appropriations Act, 2018: Committee Print-Pub. L. 115-141, 732, https://www.govinfo.gov/content/pkg/CPRT-115HPRT29456/pdf/CPRT-115HPRT29456.pdf.

2019: DOE, Department of Energy FY 2019 Congressional Budget Request, Vol. 3, Part 2, March 2018, 293, https://www.energy.gov/sites/default/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf; and House of Representatives, Conference Report to Accompany H.R. 5895, September 2018, 155, https://www.congress.gov/115/crpt/hrpt929/CRPT-115hrpt929.pdf.

2020: DOE, Department of Energy FY 2020 Congressional Budget Request, Vol. 3, Part 2, March 2019, 279, https://www.energy.gov/sites/default/files/2019/04/f61/doe-fy2020-budget-volume-3-Part-2.pdf; and House of Representatives, Further Consolidated Appropriations Act, 2020: Committee Print-Pub. L. No. 116-94 (January 2020), https://www.govinfo.gov/content/pkg/CPRT-116HPRT38679/pdf/CPRT-116HPRT38679.pdf.

2021: DOE, Department of Energy FY 2021 Congressional Budget Request, Vol. 3, Part 2, February 2020, 12, https://www.energy.gov/sites/default/files/2020/04/f73/doe-fy2021-budget-volume-3-part-2.pdf; and House of Representatives, Consolidated Appropriations Act, 2021: Committee Print-Pub. L. No. 116-260 (March 2021), 940, https://www.congress.gov/117/cprt/HPRT43749/CPRT-117HPRT43749.pdf; and Department of Energy Civilian Nuclear Infrastructure and Facilities, 42 U.S.C. § 16275, accessed September 4, 2022, https://www.law.cornell.edu/uscode/text/42/16275.

2022: DOE, Department of Energy FY 2022 Congressional Budget Request, Vol. 3, Part 2, May 2021, 11, https://www.energy.gov/sites/default/files/2021-06/doe-fy2022-budget-volume-3.2-v3.pdf; and US Congress, Division D—Energy and Water Development and Related Agencies Appropriations Act, 2022, 133, https://docs.house.gov/billsthisweek/20220307/BILLS-117RCP35-JES-DIVISION-D.pdf; and Department of Energy Civilian Nuclear Infrastructure and Facilities, 42 U.S.C. § 16275.

2023: DOE, FY 2023 Congressional Budget Justification, 4, https://www.energy.gov/sites/default/files/2022-04/doe-fy2023-budget-volume-4-ne.pdf; and Department of Energy Civilian Nuclear Infrastructure and Facilities, 42 U.S.C. § 16275.

2024 and 2025: Department of Energy Civilian Nuclear Infrastructure and Facilities, 42 U.S.C. § 16275.

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[70] Kathryn Huff, "Demonstration and Test Reactors: Both Are Necessary for Innovation," DOE, July 30, 2021, https://www.energy.gov/ne/articles/demonstration-and-test-reactors-both-are-necessary-innovation.

[71] Pasamehmetoglu, "Versatile Test Reactor: Enabling U.S. Leadership in Civil Nuclear Energy," 10.

[72] NEAC, *Assessment of Missions and Requirements for a New U.S. Test Reactor*, 15.

[73] "The Versatile Test Reactor Is Essential to Reestablishing U.S. Nuclear Leadership," TerraPower, June 17, 2020, https://www.terrapower.com/versatile-test-reactor-us-nuclear-leadership/; and "Technical Rebuttal of Mr. Lyman's Opinions on Versatile Test Reactor," Idaho National Laboratory, March 2018, 3, https://s3.amazonaws.com/ucs-documents/global-security/Lyman-Rebuttal-Mar-2018.pdf.

Key Differences between Power Reactors and Test Reactors

NE has identified similarities in design and supply chain between the demonstration of TerraPower's Natrium reactor and the VTR project, and intends to reduce risk for the VTR project by taking advantage of these synergies.[74] However, test reactors like the VTR differ significantly from demonstration reactors like Natrium. While the VTR project will benefit from the lessons learned with the GE-Hitachi PRISM and Natrium design teams, test reactors fundamentally differ from power reactors. Combining a demonstration reactor and a test reactor would fail to meet the missions of either effort. Specifically, the VTR:

- **Has a different mission**. Demonstration reactors show that a new reactor design works, giving confidence to buyers in other markets that the designed reactor will produce electricity, heat, or hydrogen as promised. Any testing that a demonstration reactor might enable would be limited to tests on its own fuels or materials.[75]
  - Test reactors optimize neutron production, whereas demonstration reactors optimize electricity or heat production.
  - Test reactors have a wider, more flexible safety envelope to enable more innovative tests and frequently shut down to allow experimenters to insert and remove test materials. Power reactor operators are trained to run plants as simply as possible—not to accommodate frequent experimentation.
- **Will not produce power**. The VTR requires no power conversion system.[76] Instead, test facilities require different infrastructure to run experiments.
- **Uses different fuels**. The VTR would use high power density fuels that operators frequently replace to maximize neutron flux during the test. In contrast, power reactor operators want longer-lived fuels that can power the plants for a year or more and improve plant economics.[77]
- **Supports a broader community of scientists**. Test reactors provide easy access to many researchers, whereas commercial nuclear developers will be loath to share proprietary test data from their power reactors with competitors.
- **Allows access to supporting R&D infrastructure**. The VTR would be built at INL near other supportive infrastructure, such as post-irradiation examination facilities, while power reactor siting is optimized for grid connection.[78]

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[74] DOE FY 2023 Budget Request–Vol 4: Nuclear Energy (March 24, 2022), 88, https://www.energy.gov/sites/default/files/2022-04/doe-fy2023-budget-volume-4-ne.pdf.

[75] NEAC, *Assessment of Missions and Requirements for a New U.S. Test Reactor*, 1.

[76] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-3.

[77] "FAQS", VTR Project (website), Idaho National Laboratory, accessed July 28, 2022, https://inl.gov/vtr/frequentlyaskedquestions/.

[78] "Record of Decision for the Final Versatile Test Reactor Environmental Impact Statement," Idaho Operations Office, Department of Energy, July 22, 2022, 1, https://www.energy.gov/sites/default/files/2022-07/ne-rod-vtr-eis-v12-signed-072222.pdf.

The Domestic Benefits of a VTR

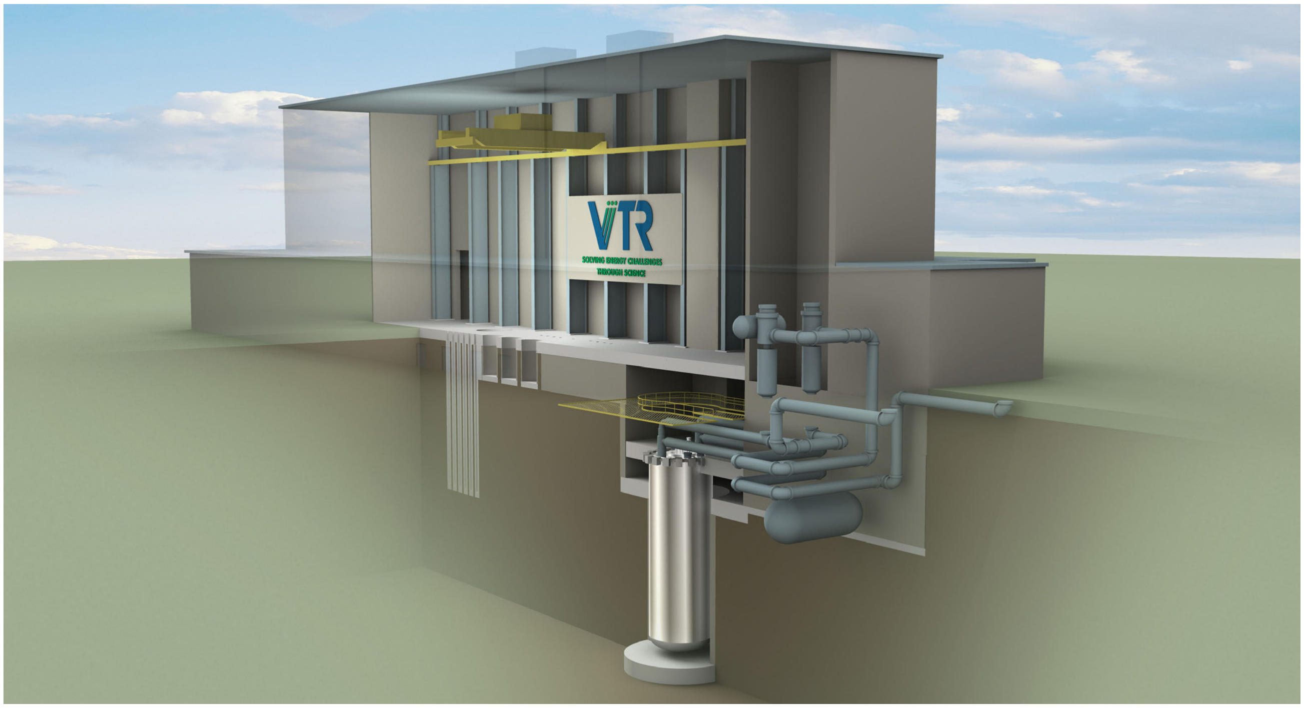
Beyond the contributions the VTR would make toward keeping the United States on the cutting edge of nuclear innovation, the test reactor project would support—or has already supported—local and national economic growth; partnerships between and across universities, national laboratories, and the private sector; and action toward addressing climate change and other key functions.

LOCAL ECONOMIC BENEFITS

DOE has selected INL as the site of the VTR project, amplifying the laboratory's role as a powerhouse in domestic nuclear innovation. Its trained workforce, existing facilities, and infrastructure make it the best-suited location for the VTR, according to DOE.[79] In FY 2021, INL contributed an estimated $120 million to state and local tax revenues and was Idaho's sixth-largest employer, directly employing more than 5,200 workers and indirectly supporting nearly 10,000 additional jobs in the state.[80] The VTR is projected to support as many as 300 to 588 new jobs at the site during operation.[81]

US ECONOMIC GROWTH

Tests that the VTR can facilitate will support improvements and enhancements to advanced reactors, resulting in efficiencies and better economics of operation that improve marketability and sustain a strong supply chain for nuclear technologies. The development, construction, and operation of new reactors will bring economic benefits to communities while also fostering a thriving US nuclear export market. The International Trade Administration of the US Commerce Department in 2016 estimated that the global civil nuclear market value stands



Artist's rendering of the VTR facility/reprinted with permission granted by INL.

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[79] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," § 2-30.

[80] *Economic Impact Summary: FY 2021*, Idaho National Laboratory, March 31, 2022, 3, https://inl.gov/wp-content/uploads/2022/03/22-50074_Economic_Impact.pdf.

[81] "Final Versatile Test Reactor Environmental Impact Statement: Volume 1," §§ 2-39, 2-55.

between $500 billion and $740 billion over the decade, with more than $100 billion possible in US exports.[82]

SCIENTIFIC PARTNERSHIPS

The VTR is unique in involving a diverse set of project contributors from across the country. At the last count, the project was convening nineteen universities, six national laboratories, and nine industry partners on planning and development.[83]

The project is a singular opportunity to train a range of workers, from engineers to construction workers, to design and build a nuclear reactor project from start to finish, resulting in a trained workforce ready to work on other reactor projects.[84] The VTR also has supported the studies of students and postdoctoral researchers in fast reactor fuels and materials testing, financing as many as fifty to sixty students' masters or doctoral studies across the country.[85] With consistent funding for the project, the VTR will continue to encourage current and prospective students in their studies and in finding careers in nuclear engineering, nuclear policy, and other related fields.[86]

TESTING OF EMERGING NUCLEAR TECHNOLOGIES

Operating the VTR would enable testing on the effectiveness of new nuclear technologies, such as digital twins, artificial intelligence, and machine learning, which developers will be able to use in commercial reactors.

INNOVATION ACROSS SCIENTIFIC FIELDS

In addition to tests that support and inform the operation of nuclear reactors, the VTR could support experiments to improve nuclear safeguards technologies. It could further enable, for example, "research on long-term fuel cycles, fusion reactor materials, and neutrino science/detector development," according to a DOE assessment, as well as advance research on high irradiation dose materials for high-energy physics.[87]

CLIMATE CHANGE

Scientists estimate that countries have a finite and rapidly closing window to achieve meaningful reductions in carbon emissions. Advanced reactors hold unique promise to contribute domestically and toward the global growth market for clean energy technologies while providing stability to the grid and fostering energy security. Companies and scientists are exploring new applications for nuclear energy, for example, to provide process heat for industrial applications, produce hydrogen, run microgrids and clean transportation hubs, desalinate water, and support other functions to contribute toward reductions in carbon emissions and address a climate-constrained future.[88]

OPTIONS FOR COMMUNITIES

Innovative new applications for nuclear energy can support a broader set of local communities, whose economies and interests vary but who all need electric power. Advanced reactors will have applications beyond power, which will include desalination, process heat, and hydrogen production. This range of uses for advanced reactors will offer interested communities new technology options to meet their unique priorities, which could include encouraging new job creation and economic growth, exercising greater control of where their energy comes from, reducing local air pollution, or addressing climate change.

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[82] "2016 Top Markets Report Civil Nuclear," International Trade Administration, May 2016, 7, http://large.stanford.edu/courses/2017/ph241/morris-s1/docs/ita-may16.pdf.

[83] "DOE Selects Sodium-Cooled Fast Reactor Design for Versatile Test Reactor in Idaho," DOE, July 27, 2022, https://www.energy.gov/ne/articles/doe-selects-sodium-cooled-fast-reactor-design-versatile-test-reactor-idaho; and "Our Partners," VTR (website), Idaho National Laboratory (website), accessed July 28, 2022, https://inl.gov/vtr/partners/.

[84] "FAQs," VTR Project.

[85] Kemal Pasamehmetoglu, in communication with the author, August 17, 2022.

[86] "Mission Need Statement for the Versatile Test Reactor (VTR) Project," DOE, 9.

[87] DOE, *Final Versatile Test Reactor Environmental Impact Statement*, Volume I, May 2022, § 2-6, https://www.energy.gov/sites/default/files/2022-05/EIS-0542_Volume%201_Chapters.pdf.

[88] "Advanced Nuclear Energy and the Road to a Carbon-Free Future," Third Way, YouTube video, February 24, 2021, https://www.youtube.com/watch?v=wyrdhWc_gsY.

The International Case for a Domestic VTR

The VTR is an important element for reestablishing the United States as a climate leader, tightening US bilateral and multilateral relationships with allied nations developing nuclear energy, preventing further loss of US nuclear leadership to Russia and China,[89] and cementing the United States' continued ability to influence international nuclear security, safeguards, and nonproliferation standards.

Climate change poses a growing threat to the global economy and human health. The projected global increases in electrification of the power and transportation sectors will require significant boosts in energy production. In response, more countries are turning to nuclear energy to reduce their dependence on fossil fuels and meet their electricity needs with a reliable source of clean power. Meanwhile, Russia's invasion of Ukraine has turned many countries' reliance on Russian gas into a liability and has demonstrated that Russia is an unreliable partner in nuclear or other energy ventures. Some companies and countries are already taking protective steps to distance themselves from reliance on Russian energy. In May 2022, Finnish-led energy consortium Fennovoima canceled an engineering, procurement, and construction (EPC) contract (related to a new nuclear plant) with the Finnish branch of Rosatom, a Russian state-owned company.[90] Meanwhile, the government of Germany has reversed course and moved to keep its remaining nuclear power plants operating through mid-April 2023 amid a global natural gas shortage and price spike stemming from a reduction in Russian gas exports.[91] Other countries have taken similar steps.[92]

Robust global interest in nuclear energy for climate and national security underlines the need to test and improve new reactor concepts in the United States—long a trusted partner among allied nations on nuclear cooperation. By moving the VTR project forward, the United States has the opportunity to counter foreign dominance in fast reactor testing infrastructure and demonstrate that it remains a serious and reliable player in nuclear energy—able to provide state-of-the-art nuclear technology through equitable bilateral partnerships. As a scientific user facility, the VTR is anticipated to be available to other countries and international and domestic vendors who wish to pay for access to the VTR's offerings. To date, the US government has signed an MOU with Japan and an implementing agreement with France to facilitate potential future collaboration on the VTR, with dialogues continuing between the United States and South Korea.[93]

Prior to Russia's 2022 invasion of Ukraine, US advanced reactor developers indicated that they faced bureaucratic delays tied to export controls or had difficulties in scheduling access to high-demand international test reactors.[94] The use of competitor-nation test reactors also raises intellectual property concerns.[95] Amid the current conflict in Ukraine, neither the United States nor its democratic civil nuclear allies can plausibly rely on Russia for access to its test facilities.

While allied nations with domestic nuclear industries are keen to see the VTR constructed, they are unlikely to support the project financially until the VTR advances further into the design phase. Nevertheless, as early as 2017, the Nuclear Energy Advisory Committee recognized the need

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[89] "DOE Announces Preparation of an Environmental Impact Statement to Examine Building a Versatile Test Reactor in the U.S.," DOE, August 5, 2019, https://www.energy.gov/ne/articles/doe-announces-preparation-environmental-impact-statement-examine-building-versatile-test.

[90] "Finnish Group Cancels Rosatom Nuclear Plant Contract Over Risks Exacerbated by Ukraine War," Radio Free Europe/Radio Liberty, May 2, 2022, https://www.rferl.org/a/finland-russia-nuclear-power-plant-hanhikivi/31830444.html.

[91] "Germany Extends Lifetime of Remaining Nuclear Plants," Deutsche Welle, October 17, 2022, https://www.dw.com/en/germany-extends-lifetime-of-all-3-remaining-nuclear-plants/a-63466196.

[92] Matthew Dalton, "Western Countries Breathe New Life Into Old Nuclear Plants," *Wall Street Journal*, August 28, 2022, https://www.wsj.com/articles/western-countries-breathe-new-life-into-old-nuclear-plants-11661684401.

[93] Pasamehmetoglu, "Versatile Test Reactor Overview," 8. As noted above, personal communications indicate that the UK and Canada participated in preliminary conversations in the early phases of the project.

[94] NEAC, *Assessment of Missions and Requirements for a New U.S. Test Reactor*, 16.

[95] "FAQs," VTR (website).

for the United States to consider exploring binding international commitments toward a US fast test reactor as a means of financing the project.[96] To the extent that Russia's war on Ukraine has shifted countries' calculus, the US government has a window of opportunity to identify international partners willing to contribute toward the VTR project under the guarantee that these partners would have access to the facility upon completion. Precedents exist for international cooperation toward nuclear test facilities: fifteen project partners, including reactor developers and utilities, across ten countries and Euratom are currently financing the construction of the Jules Horowitz Material Test Reactor Project in France.[97] For their contributions toward the project, participating entities will receive prioritized access to irradiation testing for the life of the reactor and voting rights on decisions about the reactor.

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[96] NEAC, *Assessment of Missions and Requirements for a New U.S. Test Reactor*, 18.

[97] "Organisation: International Consortium," Réacteur Jules Horowitz (website), accessed July 30, 2022, https://jhrreactor.com/en/organisation/#consortium.

Policy Recommendations

The Energy Act, enacted in December 2020, is explicit: the DOE is to construct the VTR.[98] Yet in FY 2023, the US House and Senate rebuffed the DOE's request of $45 million toward the VTR.[99] [100]

The imperative is clear. The NE's VTR project mission need statement of December 2018 identified that the failure to produce a fast neutron spectrum testing capability "will lead to further degradation of the US ability to develop advanced nuclear energy technologies."[101]

Therefore, policymakers should take the following steps:

- **Beginning in FY 2024, resume and maintain funding for the VTR each fiscal year until the facility enters into operation**. Congressional lawmakers should reverse course and provide robust funding for the VTR project in FY 2024. DOE's ability to execute the project will rely on timely and consistent year-on-year funding, which should proceed concurrent with appropriations toward the demonstration of advanced reactors and the establishment of a domestic, market-based high-assay, low-enriched uranium fuel cycle to foster a strong advanced nuclear innovation ecosystem. Congress should fund VTR at a level sufficient to restart the program and begin incorporating synergies from the Natrium demonstration. In subsequent fiscal years, Congress should, to the maximum extent possible, fund the project at the levels already authorized under the Energy Act of 2020. At a minimum, Congress should appropriate funding of approximately $150 million per year for each of six years to complete the design of the VTR and begin construction in 2029 in order to signal to international partners that the United States intends to complete the VTR by a date that ensures the test reactor is useful to advanced reactor developers.

- **Revive bilateral and multilateral dialogues with international civil nuclear allies**. Bilateral engagement on the VTR to date has demonstrated significant interest among allied nations in the construction of a US fast neutron test facility. To ensure that the United States meets its own needs to test new reactor concepts while strengthening international partnerships with energy allies and countering Russia's dominance in fast neutron testing, the US government should immediately resume talks with its international civil nuclear allies on opportunities for cooperation or collaboration on the VTR.

- **Identify contingencies to accommodate fast neutron testing absent the VTR**. Both Congress and DOE have identified the need for a versatile fast neutron source to enable a healthy domestic advanced nuclear sector. If the VTR cannot be constructed in the United States due to budgetary constraints, Congress must provide DOE with the necessary authorizations and funding to identify alternatives, including international alternatives, to the VTR to conduct fast spectrum irradiation.

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[98] Energy Act of 2020, Division Z, Consolidated Appropriations Act, 2021, Pub. L. No. 116-260, 134 Stat. 1182 (2020), https://www.congress.gov/bill/116th-congress/house-bill/133/.

[99] "DOE FY 2023 Budget Request—Vol. 4: Nuclear Energy," 92.

[100] House Comm. on Appropriations Report on the Energy and Water Development and Related Agencies Appropriations Bill, 2023, June 22, 2022, https://docs.house.gov/meetings/AP/AP00/20220628/114966/HMKP-117-AP00-20220628-SD005.pdf; and Senate Comm. on Appropriations Explanatory Statement for the Energy and Water Development Appropriations Bill, 2023, July 28, 2022, https://www.appropriations.senate.gov/imo/media/doc/EWFY23RPT.PDF.

[101] "Mission Need Statement for the Versatile Test Reactor (VTR) Project," DOE, 4.

About the Authors

Jackie Toth is deputy director of Good Energy Collective, a research organization making the progressive case for nuclear energy to contribute toward a climate-constrained, equitable energy future. A former journalist, from 2015-2019 Jackie reported on federal energy and environmental law and regulations for CQ Roll Call and Morning Consult. Afterward, she led public opinion research and developed policy and communications strategies on nuclear energy and other technologies for the Climate and Energy Program at Third Way, a D.C.-based think tank. Jackie holds a B.A. in international studies and a minor in linguistics from American University.

Khalil Ryan is a policy analyst with the Good Energy Collective, focusing on a project concerning nuclear diplomacy to aid in the gradual decarbonization of global energy sources. Khalil's main area of work is introducing civil nuclear energy to nations seeking to move away from the traditional carbon-based energy infrastructure through partnerships with the United States civil nuclear export regime. Besides his main focus of work, Khalil is also working on several short papers concerning the global fuel supply chain and the current leading global nuclear export regimes.

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1030 15th Street, NW, 12th Floor,
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(202) 778-4952
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