Needs for University Nuclear Reactor Refurbishments, Upgrades, and New Reactors

Report to Congress

April 2024

United States Department of Energy
Washington, DC 20585

Message from the Secretary

The Explanatory Statement for the Consolidated Appropriations Act, 2023, directs the Department of Energy (DOE) to submit to Congress "not later than 180 days after enactment of this Act a report detailing the needs of university reactor refurbishments and the potential need to upgrade or build additional university reactors. The report shall include a detailed plan including total lifecycle costs and associated funding profiles for potential new university reactors." The report fulfils this direction by describing the current state of United States (U.S.) university nuclear research infrastructure; additional capabilities needed to maintain the U.S. leadership role in global nuclear research and to develop the workforce supporting U.S. industry-driven innovation; and preliminary discussions of the lifecycle cost range and funding profile needed to support potential new university reactors.

Pursuant to statutory requirements, this report is being provided to the following Members of Congress:

- **The Honorable Patty Murray**
  Chair, Senate Committee on Appropriations

- **The Honorable Susan Collins**
  Vice Chair, Senate Committee on Appropriations

- **The Honorable Patty Murray**
  Interim Chair, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable John Kennedy**
  Ranking Member, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable Kay Granger**
  Chairwoman, House Committee on Appropriations

- **The Honorable Rosa DeLauro**
  Ranking Member, House Committee on Appropriations

- **The Honorable Chuck Fleischmann**
  Chairman, Subcommittee on Energy and Water Development
  House Committee on Appropriations

- **The Honorable Marcy Kaptur**
  Ranking Member, Subcommittee on Energy and Water Development
  House Committee on Appropriations

If you have any questions or need additional information, please contact me or Ms. Meg Roessing, Deputy Director for External Coordination, Office of Budget, Office of Chief Financial Officer, at (202) 586-3128.

Sincerely,

Jennifer Granholm

Executive Summary

The Explanatory Statement for the Consolidated Appropriations Act, 2023 (P.L. 117-328), requests the Department of Energy (DOE) to prepare a report detailing the needs for university reactor refurbishments and the potential need to upgrade or build additional university reactors, including a detailed plan with total lifecycle costs and associated funding profiles for potential new university reactors.

The United States (U.S.) nuclear industry can only fully realize the value of advanced nuclear innovations and maintain its leadership in nuclear science and engineering and related disciplines if it is supported by a well-trained workforce and a domestic research infrastructure that is equally innovative, especially at its universities. Research reactors are particularly critical in the education of the nuclear workforce, providing a hands-on tool for instruction in a safe and controlled environment. There are currently 25 operating U.S. university research reactors. In addition to serving as instructional tools, these reactors perform a wide range of research missions, with benefits extending far beyond the nuclear field, extending into areas such as biotechnology, nanotechnology, aerospace, automotive applications, archaeology, and criminology, among others.

In response to the request, this report describes (1) the current state of research reactors at U.S. universities, including their technologies, utilization, and needed maintenance and upgrades; (2) advanced reactor research and workforce development needs not met by existing domestic capabilities; and (3) preliminary planning information for establishing new advanced university research reactors, including a discussion of their costs, potential areas of government support, and means by which DOE would manage the government cost and risk if it were to support such projects.

Needs for University Nuclear Reactor Refurbishments, Upgrades, and New Reactors

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I. Legislative Language

This report addresses the request in the Explanatory Statement for the Consolidated Appropriations Act, 2023 (P.L. 117-328), which states:

> "The Department is directed to provide to the Committee not later than 180 days after enactment of this Act a report detailing the needs of university reactor refurbishments and the potential need to upgrade or build additional university reactors. The report shall include a detailed plan including total lifecycle costs and associated funding profiles for potential new university reactors."

II. Introduction

Nuclear science and engineering infrastructure at U.S. universities, which includes university research reactors and laboratories, originated in the 1950s and 60s. To better support continued nuclear industry innovations, the U.S. must ensure the continued operation of these existing capabilities, while also developing upgraded, world-class university research facilities that can (1) develop a workforce with hands-on experience with advanced reactor concepts mirroring those being deployed by industry; (2) offer research capabilities that address emerging technical challenges; and (3) ensure that access to the opportunities and benefits of these facilities are equitably provided, such as through seeking specific ways to include communities that have historically faced limits in accessing these capabilities.

The Department of Energy (DOE) and its predecessor agencies have provided support for university research reactors for decades, as these reactors provide critical support for the advancement of peaceful uses of nuclear technology. The DOE Office of Nuclear Energy (NE) supplies fuel to university research reactors through its University Fuel Services (UFS) program (formerly known as the Research Reactor Infrastructure program) and offers competitively awarded reactor upgrade funding via its Nuclear Energy University Program (NEUP) to support improvements to reactor safety, performance, control, and/or operational reliability.

The report describes:

- the current state of U.S. university research reactors;
- research and workforce development needs of the emerging U.S. advanced reactor fleet; and
- planning considerations for revitalizing the U.S. university nuclear research infrastructure through reactors and related capabilities.

III. Current State of U.S. University Research Reactors

NE has previously examined capability gaps in domestic research reactor capabilities [1] and has received input from stakeholders supporting the need for upgrades and improvements. Some of the overarching issues contributing to infrastructure challenges include equipment aging/obsolescence, unavailability of replacement parts, and regulatory processes for upgrades such as digital consoles. Stakeholder input and NE experience supporting existing university research reactors offer consistent information on the types of reactors and their condition and the potential benefits of reactor upgrade investments.

In 1980, there were 63 university research and test reactors in the United States. As of 2023, 24 domestic universities operate 25 reactors at their on-campus facilities (one university hosts two reactors). The reduction in the number of research reactors is a result of multiple factors, primarily related to their age. The sustained challenges of maintaining aging equipment, updating equipment to meet evolving modern standards, and obtaining parts and expertise to support obsolete components have all strained university budgets. The emergence of these issues during periods of lower public support for nuclear energy, reflected in both student enrollment levels and external funding availability, was also a likely factor in decisions to cease operations. Historical downward trends in nuclear energy commercial investment and in student enrollment have since reversed, increasing the demand for the training and services offered by university reactors while the financial and logistical challenges associated with operating them remain.

Currently, operational university research reactors across the U.S. include a variety of capabilities and sizes depending on their educational and research missions. These reactors serve vital national roles in educating and providing experience to nuclear engineers, nuclear scientists, and other professionals critical to our National Laboratories, DOE, Department of Defense, Nuclear Regulatory Commission (NRC), nuclear power, nuclear medicine, small businesses, and homeland security. Properly equipped and managed on-campus reactors offer unique advantages in terms of hands-on education and research experience in running small-scale experiments that would be impractical to perform at larger, power-producing reactor facilities. The age of the 25 operating research reactors is between about 30 and 70 years old, the newest of which is at the University of Texas at Austin (achieving criticality in 1992) and the oldest of which is at Pennsylvania State University (PSU) (achieving operations in 1955) [2]. To achieve mission objectives, maintain safety, and operational capabilities, each university reactor facility must perform periodic improvements or upgrades to its respective infrastructure.

NEUP has been providing yearly infrastructure grants since 2009 to support university reactors with available funding between $2.5-$3 million (M) per year. Between 2009 and 2023, NE has funded 122 reactor upgrade projects totaling approximately $39.1M at all 24 universities that host research reactors. The awards focus on safety and security, with an emphasis on procuring spare components to maintain operations into the future. Due to the age of equipment and components, long-term vendor support is limited. The small market and increasing acquisition costs for equipment supporting aging research reactors is a risk that has the potential to eliminate services. For example, control rod drive mechanisms for Training, Research, Isotopes, General Atomics (TRIGA) reactors are no longer manufactured or supported by General Atomics. Extensive time is required to find similar components for replacements. In some cases, license amendments may be necessary for new components that ultimately dramatically extend overall outage timelines. Other crucial niche components are at similar risk of obsolescence.

Infrastructure upgrade projects face a combination of regulatory, acquisition, and cost challenges. Based on the information available to DOE, needed upgrade project costs are anticipated to require significant investments. For example, PSU recently completed a facility upgrade with a total cost of approximately $20.65M. The university provided approximately $9.5M of this cost, equipment worth approximately $9.8M was donated for this upgrade, and $1.36M was provided by a 2013 DOE grant. [3] The upgrade included the addition of five neutron beam ports requiring a significant expansion of the building and regulatory approvals. In 2012, Purdue University initiated a digital nuclear instrumentation and control system conversion with a DOE infrastructure grant (~$1.27M), completed in 2022 with commercial partners covering remaining costs. While it is possible to modernize and add capabilities to the existing university research reactor fleet, the cost of doing so would require significant investments by the private and public sector.

The Consolidated Appropriations Act, 2023, provided up to $12M to revitalize existing university nuclear research infrastructure, especially in support of nuclear cyber-physical protection, new digital technologies in advanced nuclear reactors, and the development and safety assessments of small modular reactors (SMR). DOE intends to use a portion of these funds to continue its existing infrastructure support funding opportunities, and a portion for a new approach that would encourage consortia and partnerships to address infrastructure challenges holistically across institutions. The intent is to seek solutions that offer the most benefits for the available funding, advancing capabilities that can support advanced reactor-relevant research and development (R&D) without the construction of new research reactors, such as simulators and test facilities. Even with the incorporation of such new approaches, revitalization of the current infrastructure to the level needed to best address modern challenges like advanced digital technologies, cyber-physical protection and safety assessments of advanced reactors would require significant, sustained investments.

IV. Advanced Reactor Research and Workforce Development Needs

All existing university research reactors currently operating are based on designs originating over sixty years ago. These reactors continue to meet their critical research, training, and isotope production missions; however, the emerging commercial advanced reactor marketplace will diverge significantly from these designs. The differences range from the innovations in scale, manufacturing methods, approaches to safety and operational concepts offered by light-water SMRs to advanced, non-light-water reactors that use different coolants and fuel forms. The U.S. nuclear research reactor infrastructure is not adequately prepared to train students and test or demonstrate operational concepts related to these advanced reactors.

Some advances have already been made through the installation of NuScale Small Modular Reactor simulators at universities and by upgrading some existing research reactors to use digital consoles. Other universities have installed test loops to investigate advanced materials, such as a molten salt test loop installed at the Massachusetts Institute of Technology research reactor. Additional value can be achieved through continuing this practice, examining areas where simulators or other non-nuclear capabilities can fill gaps and seeking upgrades to additional existing research reactors. There are limits to the utility of such practices, however, and the ideal solution is constructing advanced research reactors that use the same types of fuels, coolants and control processes as new designs being deployed commercially. These new reactors and other, lower-cost capabilities should be developed thoughtfully to allow synergies, for example by incorporating data obtained from new reactors into simulators or digital twins that may be in use elsewhere.

Several universities have indicated that they are considering projects to establish advanced reactors on their campuses, with two notable projects already planned and being discussed publicly. The University of Illinois at Urbana-Champaign (UIUC) plans to site a Micro-Modular Reactor (MMR) from Ultra Safe Nuclear Corporation next to the university's Abbott power plant where it will provide both electricity and steam to meet campus power needs. The MMR is a 5-10 Megawatts-electric (MWe), helium-cooled reactor that will use high-assay, low-enriched uranium (HALEU) fuel. While the proposed reactor would support education, training and research, the university has indicated that the nature of the research will differ from traditional, irradiation-based research reactor work. The intent is to instead focus on research that supports broad, economically viable deployment of microreactors, such as in operations, instrumentation and controls, and synergistic technologies such as hydrogen production and industrial processes. The emergence of microreactors as a commercial concept offers potential advantages not available from existing reactors, which the UIUC partnership with MMR may demonstrate. In addition to its training and research missions, the campus reactor would aid the university in meeting its carbon reduction goals and would serve as a demonstration of the MMR commercial reactor. If successful, the commercial reactor will also be deployed broadly, so that the campus reactor and commercial fleet can mutually benefit. The campus reactor could be used to test and demonstrate concepts under consideration for commercial use, while the existence of a robust commercial fleet could help ensure supply chains and expertise are available to support the campus reactor.

The other university publicly discussing a project in progress is Abilene Christian University (ACU), which is taking a different approach from UIUC. ACU has partnered with three other universities to form a consortium known as Nuclear Energy eXperimental Testing Research

Alliance (NEXTRA). NEXTRA is using private investments to develop a custom molten salt reactor (MSR). Unlike current commercial and research reactors, this type of MSR would use fuel in a liquid form flowing in a loop through the reactor. This type of reactor offers many potential advantages in safety and waste management, but there is limited operating experience available on which to base commercial designs. The ACU research microreactor will build on a concept demonstrated at Oak Ridge National Laboratory in the 1960s known as the Molten Salt Reactor Experiment (MSRE). The university has indicated that it intends to use and build on lessons and data from MSRE to test materials, components, and operational concepts for flowing-loop MSRs. The U.S. has no other operating reactors of this type. Its technical features and operations are significantly different from light-water reactors, so a facility of this type could significantly advance the U.S. knowledge base and workforce capabilities, as well as offer technical data in support of eventual commercial deployment of MSRs.

The above projects are a snapshot of the types of new research reactors under consideration. The universities investing in new reactors have indicated areas where DOE support would help to ensure project success. The willingness of universities to begin investing in these projects now, without DOE support, is a clear indicator of their assessment of needs that cannot be met using the current generation of research reactors. While all reactors can perform irradiation experiments, and materials testing can be conducted using nonreactor test loops, there are a variety of other research and workforce training needs that can only be met using advanced reactors. Small-scale research reactors offer an excellent opportunity to pursue such research while simultaneously providing opportunities for workforce development using real advanced reactors with modern features.

V. Planning Information for Advanced University Research Reactors and Related Upgrades

Although significant benefits could be realized through investments in non-reactor infrastructure, these would be most impactful alongside one or more new advanced research reactors. The language directing this Report specifically requests an assessment of the life cycle costs of advanced university research reactors. In general, the term “life cycle cost” refers to all costs from “cradle to grave” for a project, or from concept through decommissioning. Limited information exists on these potential life cycle costs. This report provides available information on the life cycle costs, as well as general factors that could affect these costs and associated funding profiles.

Table 1 summarizes the life cycle costs of a university research reactor. Additional details on possible costs and their sources follow the table.

Table 1: Life Cycle Cost Elements for University Research Reactors and Complementary Capabilities

Life Cycle Cost Category	Government Role(s)
Design and Planning	* DOE does not contribute to these costs.
Licensing	* DOE does not contribute to these costs.
Construction	* DOE does not contribute to these costs.
Operations and Maintenance	Historically, DOE has not typically contributed to these costs.
Fuel Supply and Takeback	The initial fuel supply needed to start a reactor would be considered part of the associated reactor construction project. For ongoing operations, the University Fuel Services Program could potentially support additional fuel supply needs where commercial fuel sources are available, as is the case for existing reactors.
Fuel Storage and Disposition	These costs are expected to be borne by DOE as part of a broader DOE used fuel management strategy.
Future Upgrades	Universities could apply for support under existing competitive opportunities if they exist at that time.
Reactor Decommissioning and Disposition	Historically, DOE has not typically contributed to these costs.

Although DOE would prefer to cite publicly available cost estimates for university research reactor projects, none have been identified. Based upon input received from interested stakeholders, DOE currently estimates that planning, licensing, and construction of a new advanced university research reactor will cost between $150M and $300M per project. The associated budget profile would vary by project, but capital projects typically experience large peaks at the transition from planning to construction or manufacturing.

For the purposes of estimating fuel supply costs, DOE has assumed that new university research reactors would be treated equitably with existing reactors, for which DOE supports the provision of fuel and related services, including disposition. New reactors may affect future costs of the UFS program. The current average cost of fuels provided to existing reactors is likely not an appropriate estimating basis for advanced reactors, which would typically use new fuel types for which market costs are not established. Offsetting this cost uncertainty, however, are some operational concepts that include long-duration operations without refueling, even over the entire reactor lifetime in some cases. Even for those that would use a single fueling cycle to support the reactor’s entire operating life, the source of the initial fuel load needs to be understood and cannot be easily estimated at this time. DOE does not anticipate supporting a new university research reactor project unless an existing or emerging commercially available fuel source is identified that has a near-term customer base broader than the proposed university reactor.

VI. Summary

The 25 existing U.S. university reactors perform a wide range of research and instructional missions, with benefits extending far beyond the nuclear field. However, the costs for maintaining their continued operation, in addition to the significant upgrades required to best support research into modern technologies such as digital control and cyber-physical security, are increasing chiefly due to the advancing age of these reactors. Such upgrades and maintenance investments are critical to sustaining the availability of these reactors, whose value as R&D resources is not diminished by the emergence of advanced reactors being deployed in the U.S. marketplace.

At the same time, the potential rapid expansion of the emerging U.S. commercial advanced reactor fleet has introduced additional R&D and workforce development needs that would be best served by adding new research and training capabilities. Revitalizing the U.S. nuclear research infrastructure through a responsible combination of upgrades and maintenance of the existing fleet and addition of new advanced reactors and complementary technologies such as test facilities and simulators would allow the U.S. to:

- retain its leadership role in world-class nuclear science and technology research;
- continue to realize value from the existing fleet of research reactors, including their wide-ranging critical missions and opportunities for hands-on reactor training; and
- add new capabilities that can uniquely support the emerging advanced reactor fleet.

U.S. university nuclear research infrastructure can be revitalized through partnerships and consortia that can maximize the value of resources by designing them to be complementary and widely accessible.

VII. References

[1] B. Heidrich, J. Geuther, M. Lund and B. Meffert, "University Research Reactor Fitness Study Report," Idaho National Laboratory, Idaho Falls, 2020.

[2] International Atomic Energy Agency, "Research Reactor Database," [Online]. Available: https://nucleus.iaea.org/rrdb. [Accessed 23 May 2023].

[3] A. Wenners Herron, "Penn State Breazeale reactor achieves first simultaneous neutron beam operations.," 17 November 2022. [Online]. Available: https://www.psu.edu/news/engineering/story/penn-state-breazeale-reactor-achieves-first-simultaneous-neutron-beam-operations/. [Accessed 21 April 2023].

[4] American Nuclear Society, "Paragon, Thermo Fischer reach license agreement on neutron flux monitoring systems.," 16 January 2023. [Online]. Available: https://www.ans.org/news/article-4647/paragon-thermo-fisher-reach-licensing-agreement-on-neutron-flux-monitoring-systems/. [Accessed 21 April 2023].