NEDHO

NUCLEAR ENGINEERING DEPARTMENT HEADS ORGANIZATION

Needs and Importance of New and Advanced Testing, Research, and Training Reactors on University Campuses

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This report is aimed at the needs and importance of *new and advanced* testing, research, and training reactors on university campuses. The report has been prepared by the Nuclear Engineering Department Heads Organization (NEDHO) Executive Committee with input from several member programs.

Background

Following the first demonstration of electricity production by nuclear fission in Idaho in 1951, the U.S. government devoted significant resources to civilian use of nuclear power. Immediately following this investment, reactors were introduced at universities for testing, research, training, and workforce development for the emerging nuclear industry and to support the utilization of nuclear technology in science, engineering, and medicine. Within a short time, dozens of research and test reactors were built on college campuses across the United States. This rapid deployment of the technology from the early 1950s through the early 1970s, with the support of President Eisenhower's Atoms for Peace initiative, paved the way for more than 800 research reactors and subcritical facilities to be built to date around the world.

The currently operating fleet of nuclear power plants was designed and built to support an energy market that is quite distinct from that of today. Moreover, the design and operation of these reactors does not benefit from the great technological strides taken in recent decades. The DOE has already responded to the need for commercial advanced reactors through the ARDP program. Promising new reactor designs are being developed for nuclear power, including micro- and small modular reactors. However, without complementary research and workforce development components, there is significant risk that this multi-billion-dollar investment is not effectively leveraged. Universities can again be the early driver for development of the new workforce for these new technologies and for the technology maturation of new nuclear deployments.

While there are existing research reactors on several US campuses, what makes deployment of these new testing, research, and training reactors on university campuses critical is the fact that most new advanced reactor designs are substantially different from the conventional GEN-II and GEN-III reactors. New designs require a new set of assessments of safety, security, sustainability, and regulations, which are different from what was required for existing large light water reactors.

Very often in these new designs the coolant/moderator is not water, fuel may be different from the typical fuel and fuel structure used in PWRs and BWRs, and in some cases the reactor may even work with a different neutron spectrum. In addition, I&C and many other technologies have significantly evolved over the last 40 years. These new technologies are not used in existing testing, research, and training reactors. Other factors include emphasis on passive cooling and passive post-accident fission product retention.

Furthermore, advanced designs are being considered to repurpose shuttered coal power plants to nuclear, and for many uses other than just electricity, such as hydrogen production, district heating, and to decarbonize other industrial applications. These fundamental differences, advances, and new applications make it critical that the next set of workforces is trained on systems that are representative of the next generation of power production nuclear reactors. Some of the R&D needs for the new advanced reactor designs may also be significantly different from those that can be carried out in today's existing research reactors. These will include new advances in digital I&C, digital twin, cyber security, use of AI/ML in reactor design and operations, etc. New reactor concepts create a new set of opportunities and risks, including novel issues such as an emphasis on autonomous and remote operation, "walk-away" safety, where no human action is required to respond to a safety incident, new transportation risks for microreactors, and new community and societal acceptance approaches. Furthermore, academic research can help develop new risk-informed regulatory paradigms, which will be required to support these applications, and ensure safety and security, while factoring the specific risks of each technology. Designing, licensing, building, and operating advanced research reactor designs will facilitate the commercialization of these technologies.

Some specific and new research areas that are required, societal acceptance approaches, integrated energy systems, passive safety for cooling and fission product retention, techno-economic analysis, supply chain optimization, and decommissioning can be effectively addressed by multi-institutional collaborations around pilot platforms of new research reactors sited at university campuses. Advanced research reactors at universities may also be utilized and nonproliferation testbeds. This approach leverages not only access to academic experts but for land-grant institutions century-long mission-driven relationships with communities and regions that could be early-adopters of advanced nuclear technology. Role of the universities is of critical importance for public acceptance of "the new nuclear" and to for the deployment of advanced nuclear technology.

The role universities can play in the deployment and adoption of advanced nuclear technologies cannot be overstated. Universities have significant expertise in many of the emerging technologies supporting advanced nuclear such as novel materials, advanced manufacturing, and digital innovation. Land grant universities also have beyond their mission of education and research, their role in economic development of the region.

Roles of University Reactors

1) ***Testing, Research, Education and Training***

Deployment of new reactors on university campuses for testing, research, and training can establish facilities to support the nuclear technology needs of the US and de-risk, accelerate, and optimize commercial deployment through alignment with the following critical needs:

Nuclear Reactors for Engineering, Science, and Medicine: Advanced university reactors can be utilized as multipurpose instruments to support the institutional, regional, and national science and engineering needs. An example of this aspect is providing unique capabilities to perform crucial irradiation testing of materials, fuel, and components that are highly needed for the deployment of advanced nuclear power reactors. Additional examples include providing experimental capabilities for neutron scattering studies of matter that are currently oversubscribed at national facilities such as ORNL and NIST, expanding research and production of medical and industrial isotopes, enabling work on nuclear thermal propulsion for space exploration, and supporting research in fundamental science. Currently, these types of capabilities are lacking in the US. Furthermore, such reactors also support much of the research, education, and training, objectives stated below.

Nuclear Power Related Research: Micro- and small modular reactors represent a paradigm shift in nearly all aspects of nuclear power deployment and operation. In contrast to traditional nuclear power, wide adoption will require streamlined factory fabrication, limited site preparation, long core life, minimal operations and maintenance demands, small footprint for co-location with energy demand, flexible dispatch of electrical and thermal energy, and seamless return of the host site to greenfield. These requirements are substantial, but they are also their opportunity. With a robust, research-focused reactor deployment on a university campus such design constraints can be overcome. Direct research with a reactor includes instrumentation and monitoring systems, operations and control methodologies, validation of reactor analysis codes, optimization of system components and performance, system integration with existing power generation infrastructure, system coupling with energy intensive processes such as hydrogen production, and many other areas currently being considered in the project planning.

Workforce Development: Licensing and operating advanced nuclear reactors will require training facilities representative of those technologies. Between 1958 and 1972, over 50 U.S. university research reactors were built. Many of these university facilities were shut down in the 1980s & 1990s in response to waning federal funding and student enrollments. In the 2000s, student enrollment in nuclear engineering and enthusiasm for carbon-free nuclear energy rebounded mightily. However, no new university research reactors have been built in 30 years. Simultaneous with an unprecedented launch of next-generation reactor demonstrations, the gap in student access to hands-on training is widening. The workforce of regulatory bodies face a similar drought in human capital capable of evaluating the ever-growing backlog of construction permits and operating licensing applications. Domestic and foreign governmental oversight organizations are tasked with answering the call to ensure public health and safety. Engineers who have hands on experience at advanced facilities will be better equipped to apply congressional mandates, the code of federal regulations, and guidance documents in novel reactor technologies. To realize the full potential of advanced nuclear reactor technologies, attention should be given to developing the future workforce needed for these technologies to be successful.

Public Engagement: Research reactors on campuses have historically been a powerful driver of public engagement. Their low risk profile and variable operational posture make them accessible to the public, valuable to the communities in which they are embedded, and underpinned by trusted university researchers. Notably, recent findings from University of Oklahoma researchers at the National Institute for Risk and Resilience indicate that university scientists are the most trusted group in the context of controversial nuclear matters, such as the management of used nuclear fuel (UNF). For maximum impact, microreactor demonstrations should prioritize sites where the public can witness, understand, benefit, and recognize the case for nuclear power. New university research, education, and training reactors can further enhance public confidence and trust in nuclear power, and it can provide credibility for the safe siting and operation at locations of energy demand.

Licensing: The licensing of research and test reactors has its roots in the Atomic Energy Act of 1954, as amended, and the NRC has accommodated this requirement in the Code of Federal Regulations, 10 CFR 50, by including a standalone regulatory pathway for such reactors, known as “Class 104(c)” type reactors. This pathway provides a rapid, familiar, prototype-friendly option for technology demonstration while at the same time, it ensures that it receives the full force of regulatory rigor expected from NRC in carrying its public health and safety mission. The development of a set of future licensing requirements and guidance for commercial microreactors can be developed in connection with an operating research reactor on a university campus. This need is particularly acute for advanced reactor operations and controls which will require a new paradigm to have widespread adoption of the technology.

Fuel: Fuel leasing agreements between universities and the DOE Research Reactor Infrastructure (RRI) Program can be leveraged with the program's standard fuel leasing and takeback arrangement with university-based research reactors. The mission of that program is to supply fresh nuclear fuel to domestic universities at no or low cost to the university. Additionally, the title of the fuel remains with the U.S. government, and the fuel is returned when universities have fulfilled their operational mandate. Further, unlike a commercial deployment which currently has no U.S. commercial fuel supply for the necessary enrichment levels of leading advanced reactor designs, research and test reactors at universities qualify for an existing fuel stockpile available to the DOE. The rapid succession of reactor deployment — made possible by a campus demonstration — can provide the economic incentive for prompt scale up of a U.S.-based commercial fuel supplier of High-Assay Low-Enriched Uranium (HALEU).

Advanced Reactor Markets: As signatories of the American College and University Presidents' Climate Commitment, hundreds of campuses across the country have pledged to become carbon neutral by the year 2050. Large U.S. university campuses are a microcosm of the national landscape of energy needs and source diversification. The commercial viability and applicability can be demonstrated through interfacing with existing university-owned power generation and distribution infrastructure. Beyond their role as research, education and training reactors, these reactors have the potential to be commercially viable power sources for a large number of existing university, medical, industrial, and military campuses. University demonstration can provide an example of advanced reactor performance for broadly anticipated new reactor markets, such as high-performance computing and data storage, steam production for local heating, hydrogen generation for energy storage and decarbonization of transportation, resilient backup of critical infrastructure, traditional coal power replacements, and remote microgrids. A university demonstration of microreactor operation in an existing microgrid can be a catalyst for rapid expansion to these non-traditional nuclear markets. These projects can provide credibility to co-location of microreactor technology with energy intensive installations, and installations with minimal siting flexibility.

2) Going Beyond Testing, Research, Education, and Training

In addition to the testing, research, education, and training goals, power produced by the new research reactors at university campuses may also be fruitfully used to help decarbonize campuses. Although the advanced research reactor deployment is not meant as a solution to campuses' clean energy needs, it is a recognition of the potential for new nuclear to support decarbonization efforts broadly and where renewables are ill equipped to provide a solution (such as district heating). Integration with existing power production facilities at university campuses will enable 1) critical research, innovation, and education in integrated energy systems, 2) education and training of operations solutions in energy diverse grids, 3) demonstration of reactor capability to integrate with existing power generation infrastructure, and 4) utilization of otherwise wasted energy produced while carrying out the testing, research, education, training, and outreach mission of the reactor. Some campuses own and operate their own electrical, steam, and chilled water distribution system. Deployment of new research reactors, that also produce power, within this existing embedded grid can enable the critical research necessary for wide technology adoption and train the next-generation nuclear workforce.

Costs of University Reactors

To support education and research in nuclear science and engineering, US universities, through the TRTR and NEDHO organizations, spearheaded an effort to achieve the objectives described above, which materialized in the CHIPS Act of 2022 (Subtitle L, sections 10741-10744). I this case, funding was requested based on the following considerations:

1) The total cost of building 3-4 university reactors was estimated to be nearly $600 million with a cost of $150-$200 million per reactor. This cost estimate is based on the experience of TRTR and NEDHO members through participation in different research reactor projects nationally and internationally as well as on historical data and industry trends. The CHIPS Act allocated $390 million for establishing new “Test and Research” reactors.

2) The Operation and Maintenance (O&M) costs are reactor specific since it depends on reactor type, mode of operation and utilization. For an active MWth class university test and research reactor, its order of magnitude is $1000K-$4000K. It is expected that the O&M cost would be provided by the university.

3. Fuel costs for university reactors are currently covered by DOE’s University Fuel Services Program. The addition of 2-4 university reactors is expected to keep the cost to DOE in the range of its current budgetary request limits for the fuel of university reactors. The costliest fuel demands will be for reactors that operate continuously. Some estimates indicate about $25M for fuel (including stock material, fuel fabrication, and fuel transport). This cost is included in the $150- $200M per reactor cost indicate above.

3) As with current reactors, no regulatory costs are expected for new university reactors.

4) The lifecycle costs for the new university reactors is based on the above components. However, these components will vary by university and reactor. The O&M component (item 2 above) of this cost should be covered by the university. As with current reactors, items 3 and 4 should be covered by existing federal funding programs. In addition, a successful new university reactor should establish a utilization and development program that is capable of generating annual external funding support.

The advanced reactors proposed to be deployed for research missions are typically based on well-understood nuclear technologies but in highly specialized configurations that exploit decades of innovation in design for passive safety. Because of the novelty of what amounts to the packaging and support systems, the cost models remain unvalidated and uncertain. However, some cost relationships can be stated with confidence. Because research reactors are much smaller than larger scale designs, such as those currently funded through the Advanced Reactor Demonstration Program, their costs will be dramatically less. Further the cost of a research reactor will depend on the specific research mission. Facilities that require access to core radiation will likely cost more per unit power, for instance.

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