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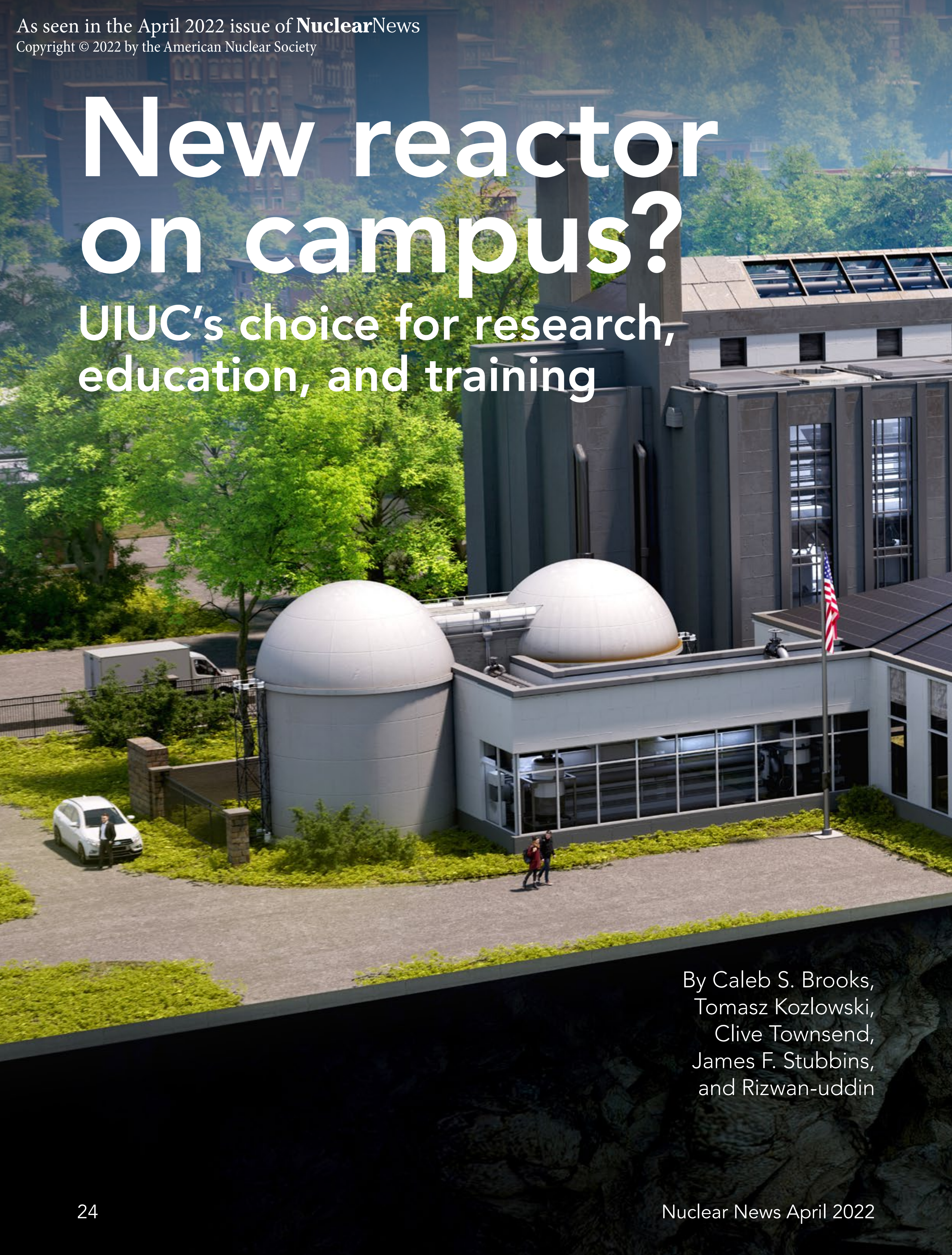
New reactor on campus?

UIUC's choice for research, education, and training



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The University of Illinois at Urbana-Champaign formed a partnership with Ultra Safe Nuclear Corporation to deploy an advanced research reactor on campus, based on a microreactor design that improves upon well-established high-temperature, gas-cooled reactor (HTGR) technology. Unlike traditional research reactors, our focus at UIUC is not on a laboratory tool to study radiation interactions with matter, or even on the production of radioisotopes. Instead, we will build a research, education, and training facility intended to help advanced reactor technology become a widely deployable, marketable, economic, safe, and reliable option for a clean energy future. If successful, the USNC-designed Micro Modular Reactor (MMR)[a] would operate on UIUC's campus with the capability to advance critical and enabling technologies required for advanced reactors to realize their full potential, while educating and training the workforce as a key step toward delivering on the technology's promise. Microreactors can become a transformative distributed energy technology and revolutionize energy infrastructure worldwide.

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Image: USNC

[a]MMR is a registered trademark of USNC.

Nuclear technology has a rich legacy in Illinois, beginning with the world's first nuclear reactor at the University of Chicago in 1942. Soon after came the 1946 founding of Argonne National Laboratory near Chicago, a lead organization in reactor design and testing. The first privately funded nuclear power plant came on line in Morris, Illinois, in 1960. Today Illinois remains the largest producer of nuclear power in the country, with the majority of the state's electricity generation coming from nuclear. Fission-based power is increasingly being recognized as an essential asset for a clean energy future, nuclear power's importance for Illinois being emphasized by the state's large reinvestment in September 2021 to prevent the premature closure of four plants across the state.[1]

UIUC is charged by our state to "enhance the lives of citizens in Illinois, across the nation, and around the world through our leadership in learning, discovery, engagement, and economic development." As a land-grant university, it is UIUC's responsibility to support the critical industries of the state through this mission. The university's nuclear engineering department first began as an interdisciplinary program in 1958 and has a rich history of pioneering nuclear research. One of the early TRIGA reactors operated in the heart of campus from August 1960 until 1998, with a design power level of 1 MW (and 6,000-MW pulse).[2] The site, now an American Nuclear Society Historical Landmark, serves as a reminder of the lean years of nuclear and the critical need for nuclear advocacy, public engagement, and dialogue. To this end, and in alignment with UIUC's clean energy goals, the MMR project has the strong support of UIUC leadership and Illinois's congressional delegation.[3]

The advanced microreactor opportunity

The UIUC effort to revive its education, research, and outreach capability via a new university research reactor began in late 2018 with a series of discussions between university, industry, and federal stakeholders. From the outset, the university's goal was to partner with a microreactor developer to envision a next-generation research reactor that could address the pressing issues facing advanced

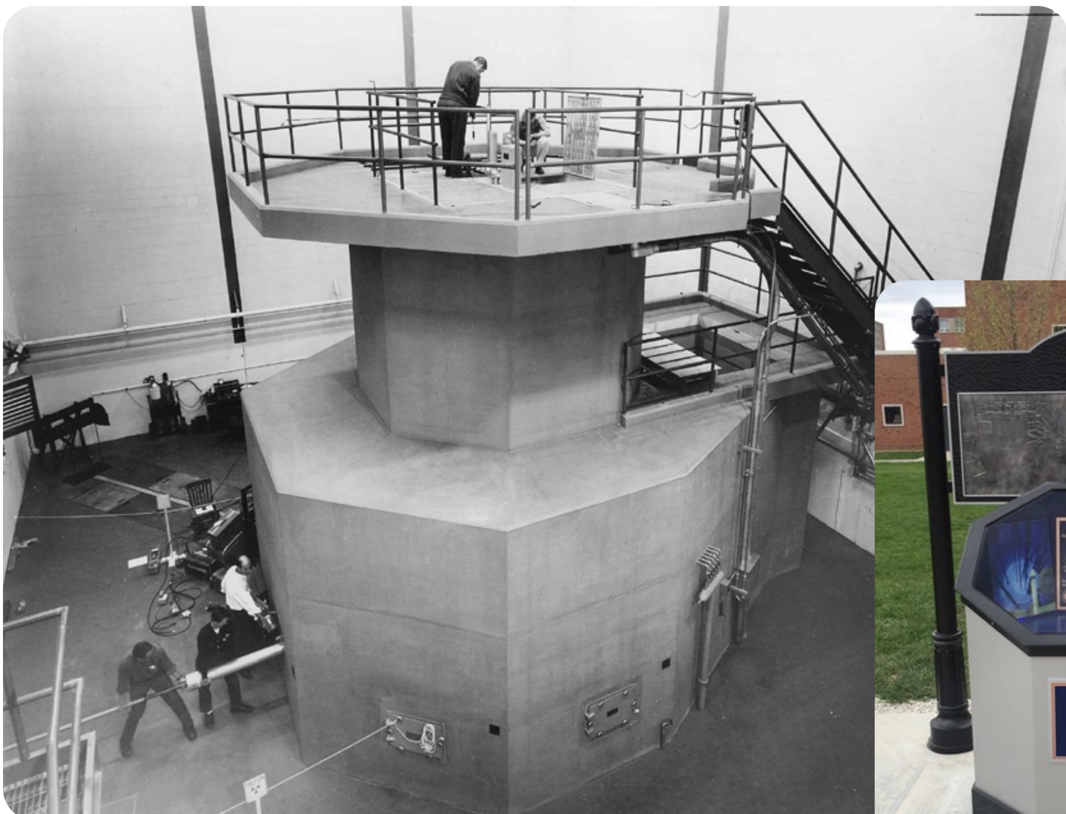

Fig. 1. The TRIGA reactor (left) that operated for 38 years in the heart of the UIUC campus. The site is now an ANS Historical Landmark (right). (Photos: UIUC)

reactor deployment and operation. This led to collaboration with USNC and the MMR technology. The MMR is an inert-gas-cooled, graphite-moderated microreactor that will operate at 15 MWt with a core lifetime of 20 years (Fig. 2). Established tristructural isotropic (TRISO) fuel particle designs that have been evaluated for safety by the Nuclear Regulatory Commission[4] are further encapsulated into silicon carbide pellets (instead of carbonaceous pellets, as with legacy HTGRs) to form the fully ceramic microencapsulated (FCM)[b] fuel (Fig. 3). The MMR builds on the long legacy of gas-cooled reactor technology to provide additional defense-in-depth features such as ceramic encapsulation, complete underground siting, and low power density. This suite of technology gives both inherent and intrinsic safety. The heat exchanger from the gas coolant interfaces with an intermediate molten salt thermal storage loop. This storage system provides flexibility in the dispatch of energy to coupled conversion systems. In the case of UIUC, the heat stored in the molten salt loop will interface with a steam generator and connect into the main steam header of the colocated Abbott Power Plant.

Abbott Power Plant is a hybrid natural gas and coal facility that serves the university owned and operated electrical and steam distribution system. Its primary responsibility is to supply 100 percent of the steam requirement for campus, which peaks at 550,000 lb/hr of steam production, while the plant has a 1,025,000 lb/hr capacity.[5] As a by-product, the plant produces a significant portion of the campus's

Fig. 2. The MMR builds on legacy HTGR technology, providing 15 MWt with a 20-year core life. (Image: USNC)

[b]FCM is a registered trademark of USNC.

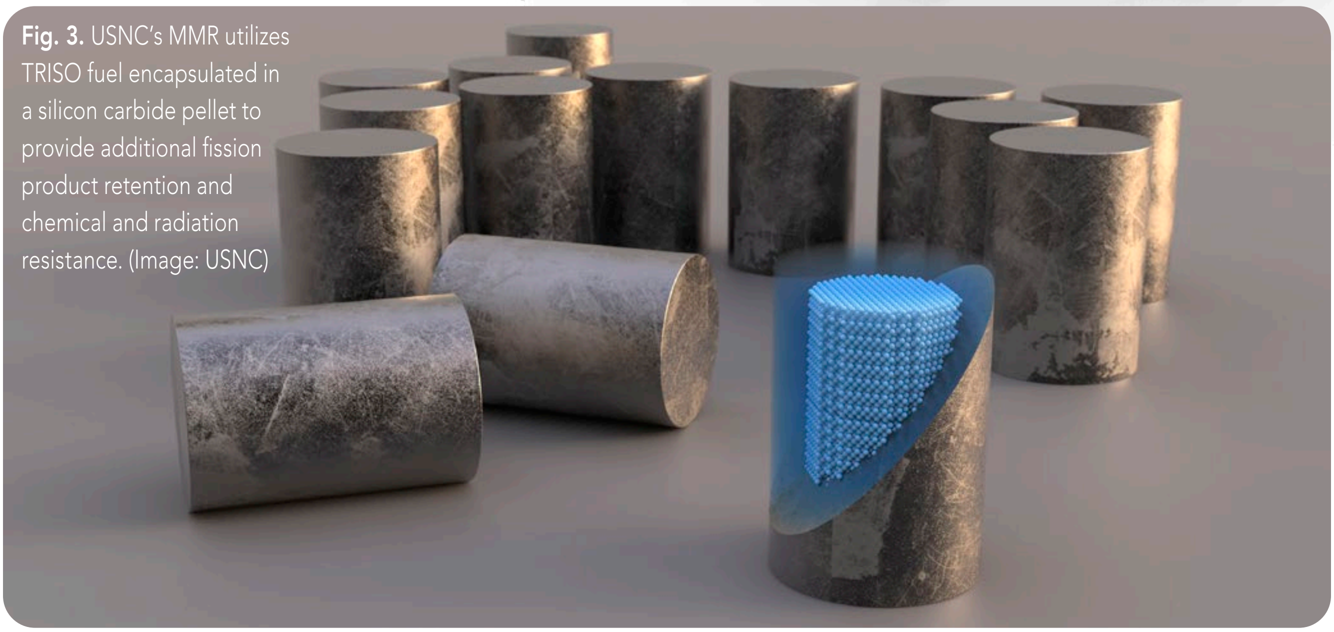

Fig. 3. USNC's MMR utilizes TRISO fuel encapsulated in a silicon carbide pellet to provide additional fission product retention and chemical and radiation resistance. (Image: USNC)

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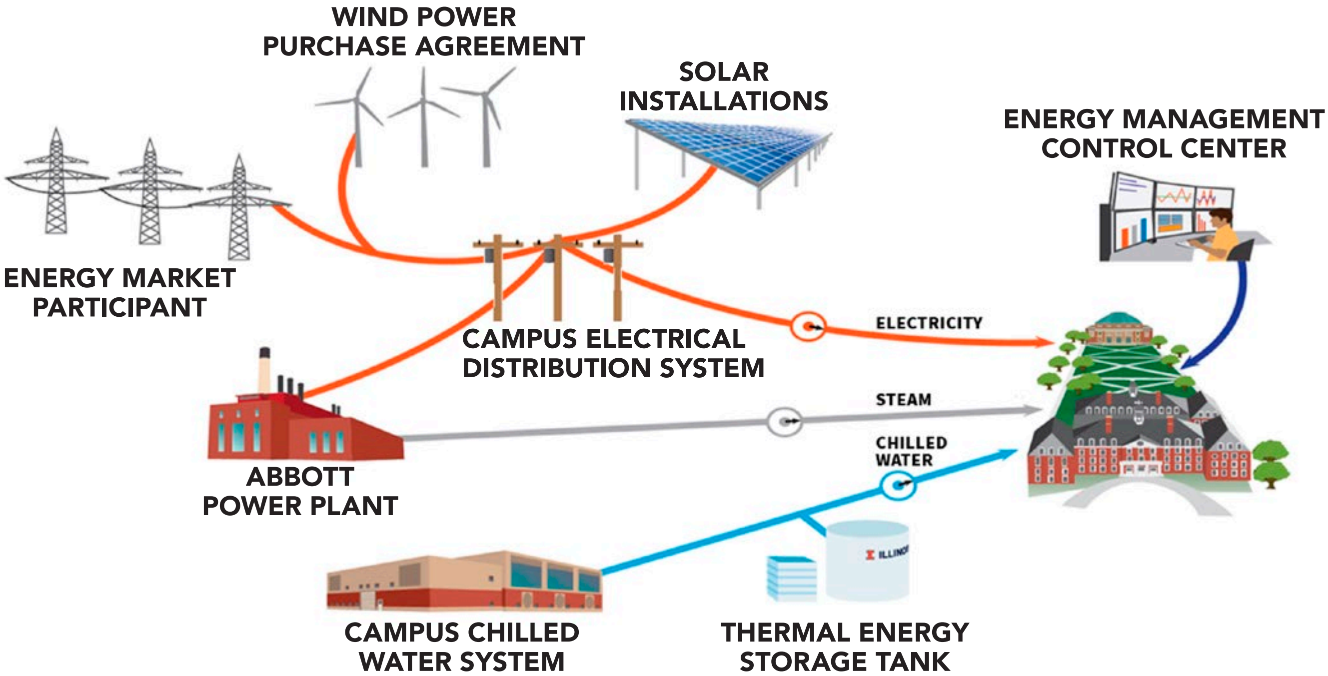

Fig. 4. UIUC owns and operates its own electrical, steam, and chilled water distribution system. Deployment of a microreactor within this existing embedded grid can enable the critical research necessary for wide technology adoption and can help train the next-generation nuclear workforce. (Graphic: UIUC)

electricity demand using a series of steam turbines. Additionally, Abbott Power Plant has a pair of combustion turbines that can support the electrical needs of campus based on economic consideration of its other energy sources.

The university has committed to reducing the campus's carbon footprint as demonstrated by two solar farms (27 GW·hr annual capacity),[6] a wind power purchase agreement with a nearby wind farm obligating the university to 8.6 percent of the real-time wind generation (25 GW·hr annual capacity),[7] low-grade geothermal to support building HVAC, and a pilot biofuel project. The remainder of the electricity is purchased from the surrounding grid, to supply a total of approximately 450 GW·hr of total annual consumption (Fig. 4).[8]

Although the MMR deployment is not meant as a solution to campus 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 the Abbott Power Plant enables (1) critical research, innovation, and education in integrated energy systems; (2) education and training of operations solutions in energy-diverse grids; (3) demonstration of microreactor capability to integrate with existing power generation infrastructure; and (4) utilization of otherwise wasted energy produced while carrying out the research, education, and outreach mission of the reactor.

Research, education, and training mission

Deployment of a microreactor on a university campus as a research and training reactor can de-risk, accelerate, and optimize commercial deployment through alignment with the following critical needs.

Research: Microreactors represent a paradigm shift in nearly all aspects of nuclear power deployment and operation. In contrast to traditional nuclear power, wide adoption of microreactors will require streamlined factory fabrication, limited site preparation, long core life, minimal operations and maintenance demands, small footprint for colocation 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 also represent the technology's opportunity. With a robust, research-focused microreactor deployment on a university campus, such design constraints can be overcome. Direct research with a microreactor 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 and 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 workforces of regulatory bodies face a similar drought in human capital capable of evaluating the ever-growing backlog of construction permits and operating license 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 (CFR), 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 (Fig. 5).

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[12] 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. Of the various expert groups considered, public trust was high for university scientists and National Academy of Sciences experts and lowest for private companies. For maximum impact, microreactor demonstrations should prioritize sites where the public can witness, understand, benefit from, and recognize the case for nuclear power. A university microreactor 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 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 ensuring that the reactor receives the full

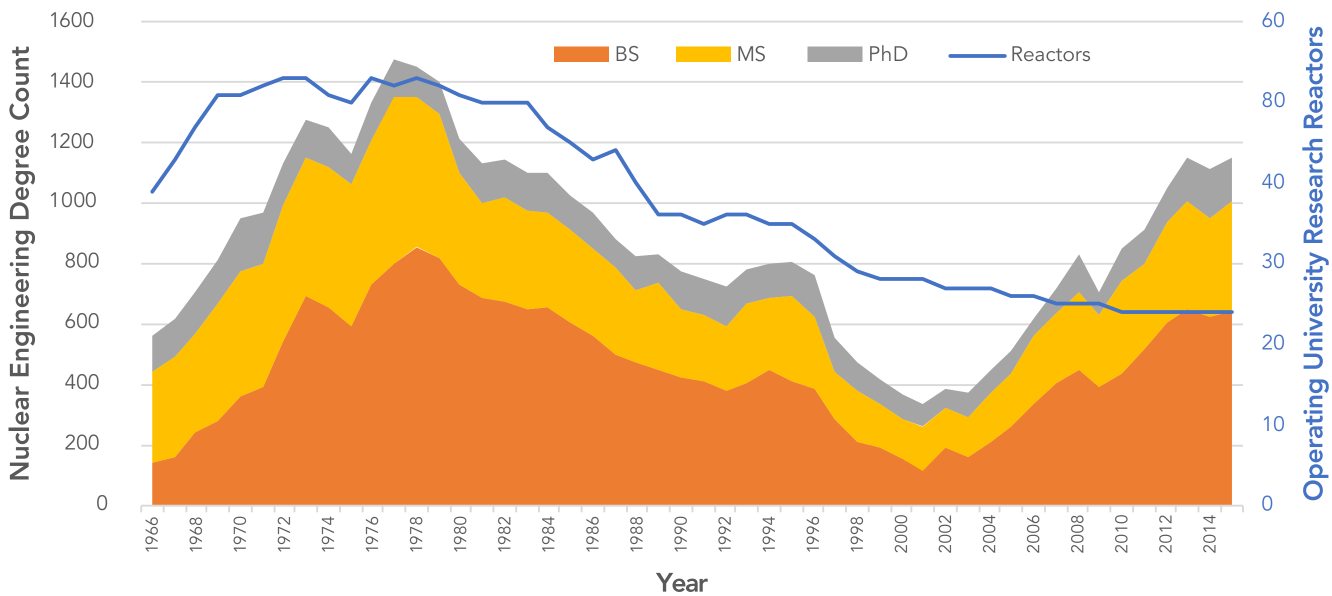

Fig. 5. Relationship between university research reactors and nuclear engineering enrollment from 1966 through 2015. The trends highlight the need for advanced research reactors to support the emerging advanced reactor workforce. Data compiled from the Oak Ridge Institute for Science and Education.[9,10,11]

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force of regulatory rigor expected from the NRC in carrying out 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 test reactor on a university campus. This need is particularly acute for microreactor operations and controls, which will require a new paradigm if there is to be widespread adoption of the technology.

Fuel: Fuel leasing agreements between universities and the DOE Research Reactor Infrastructure 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 (currently, there is no U.S. commercial fuel supply for the necessary enrichment levels of leading microreactor designs), research and test reactors at universities qualify for an existing fuel stockpile available through 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.

Microreactors are a necessary option as we look to decarbonization beyond just the centralized electric grid.

Prototype testing: Licensing next-generation commercial nuclear reactors will require next-generation test reactors. The NRC Regulatory Review Roadmap for Non-Light Water Reactors[13] clearly indicates that such prototype testing will be essential and that a class 104(c)–licensed university test reactor could safely perform tests satisfying the requirements of 10 CFR 50.43(e)(2). Subsequent class 103 licenses for *n*'th-of-a-kind deployments could then rely on those tests as a technical basis for subsequent license applications. In alignment with university educational and research missions, this testing enables faculty and students to collaborate with industry, laboratory, and regulatory stakeholders to demonstrate the performance of additional design features, to consider interdependent effects among the design features, and to ensure that sufficient data exists regarding all design features. Further, U.S. universities are vibrant centers of innovation containing diverse expertise across intersecting areas of science, technology, policy, marketing, and psychology. A university microreactor deployment can leverage this ecosystem to advance synergistic and enabling technologies toward safer, more versatile, and ultimately more economic microreactors.

Microreactor markets: As signatories of the American College and University Presidents Climate Commitment, UIUC and hundreds of campuses across the country have pledged to become carbon neutral by the year 2050.[14] 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 and test reactors, microreactors 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 microreactor performance for broadly anticipated microreactor 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 nontraditional nuclear markets. The UIUC project can provide credibility to colocation of microreactor technology with energyintensive installations and installations with minimal siting flexibility.

A clean, sustainable energy future will be made possible through safe, peaceful uses of nuclear power. Microreactors are a necessary option as we look to decarbonization beyond just the centralized electric grid. Our institutions, whose mission is focused on learning, discovery, engagement, and economic development, are perfectly aligned to support these pressing needs and deliver on this reality. This synergy is recognized by the UIUC campus commitment to demonstrating clean energy technologies, the NRC's class 104(c) licensing pathway, the DOE Research Reactor Infrastructure Program, the state of Illinois's investment in and commitment to nuclear power, the bipartisan political support for a robust nuclear workforce, and a generation of young engineers eager to dawn a new day for safe, economical, and clean nuclear power.

For more information on the UIUC project, please visit the project website, https://npre.illinois.edu/about/nuclear-powered-uiuc. More information on the USNC MMR can be found at https://usnc.com/mmr/. The project team welcomes feedback at micro-reactor@illinois.edu.

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