U.S. Department of Energy

Innovative Nuclear Research Highlights

The conduct of irradiation tests in the PULSTAR reactor's pool in support of the Naval Reactor's program.

INNOVATIVE NUCLEAR RESEARCH

Overview

Innovative Nuclear Research (INR) houses the competitively funded programs administered by the U.S. Department of Energy, Office of Nuclear Energy (DOE-NE). INR provides a consolidated vision and peer review process to DOE-NE research and development programs and dedicates support for training the next generation of nuclear scientists through multiple student opportunities.

Through the Consolidated Innovative Nuclear Research Funding Opportunity Announcement, NE conducts crosscutting nuclear energy research and development (R&D) and associated infrastructure support activities to develop innovative technologies that offer the promise of dramatically improved performance for its mission needs, while maximizing the impact of DOE resources.

Through the Integrated University Program (IUP), DOE-NE ensures an adequate number of high-quality nuclear science and engineering (NS&E) students will (1) support the need for qualified personnel to develop and maintain the nation's nuclear power technology, (2) enhance educational institutions' capabilities to perform nuclear energy-related RD&D, and (3) meet DOE's and the national laboratories' needs for highly trained scientists and engineers in support of DOE-NE programs.

DOE-NE conducts Several programs fall under the INR umbrella:

Nuclear Energy University Program (NEUP) - University research integrated with overall DOE-NE program priorities

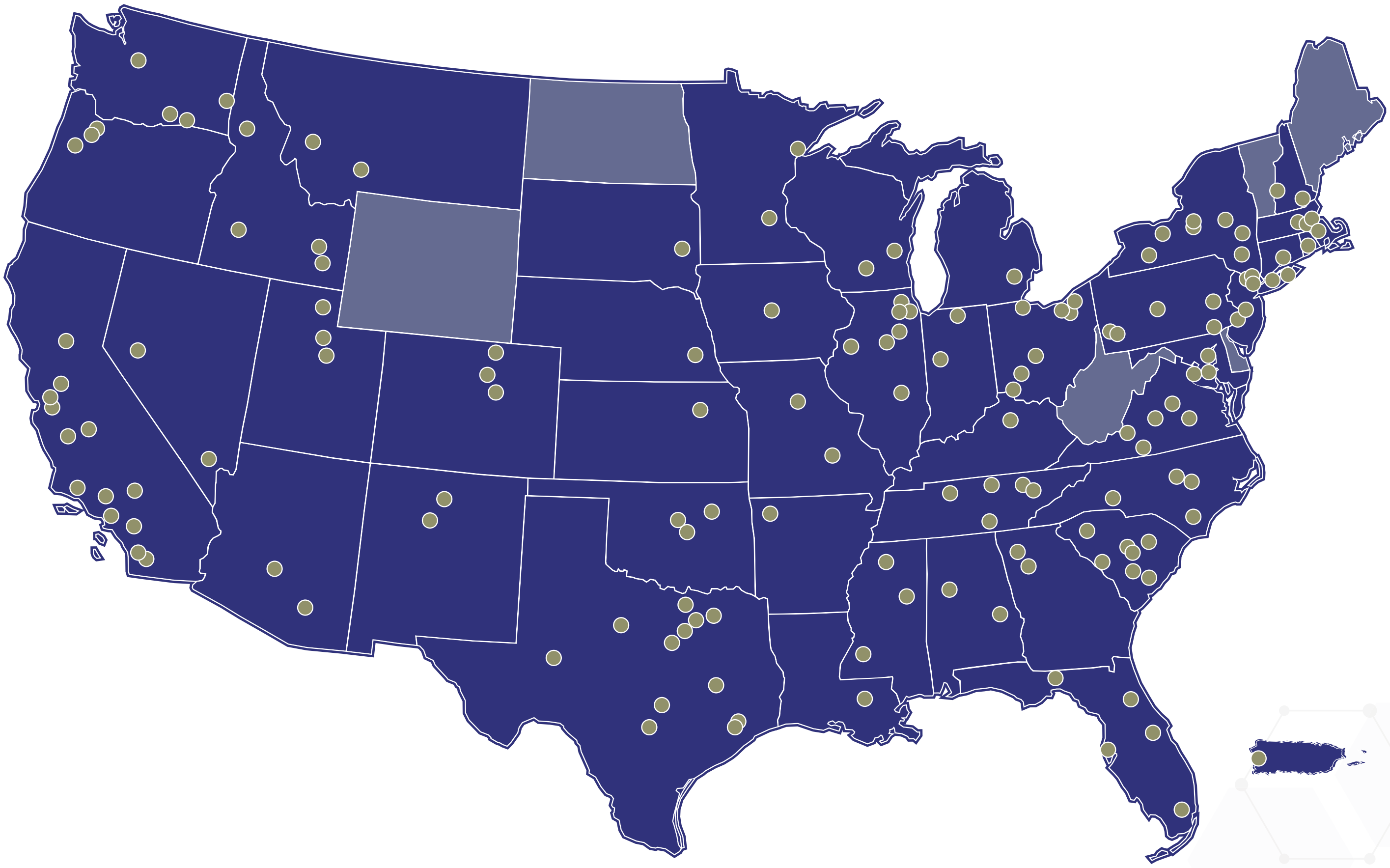
Integrated University Program (IUP) - Student educational support to train the next generation nuclear energy workforce

Nuclear Energy Enabling Technologies Crosscutting Technology Development (NEET-CTD) - Technology development focused on applicability to multiple reactor designs

Nuclear Science User Facilities (NSUF) - Unique capability access to enhance university and industry research projects

Award Recipients

Through the Consolidated Innovative Nuclear Research (CINR) Funding Opportunity Announcements (FOAs) and the Integrated University Program (IUP), $869 million has been awarded to 132 U.S. colleges and universities, 7 national laboratories, and 11 industry/utilities in 42 states, the District of Columbia, and one U.S. territory.



$869,687,091
TOTAL AWARDED THROUGH CINR & IUP

Research & Development
810 Projects
$581,342,078
Total R&D Funding

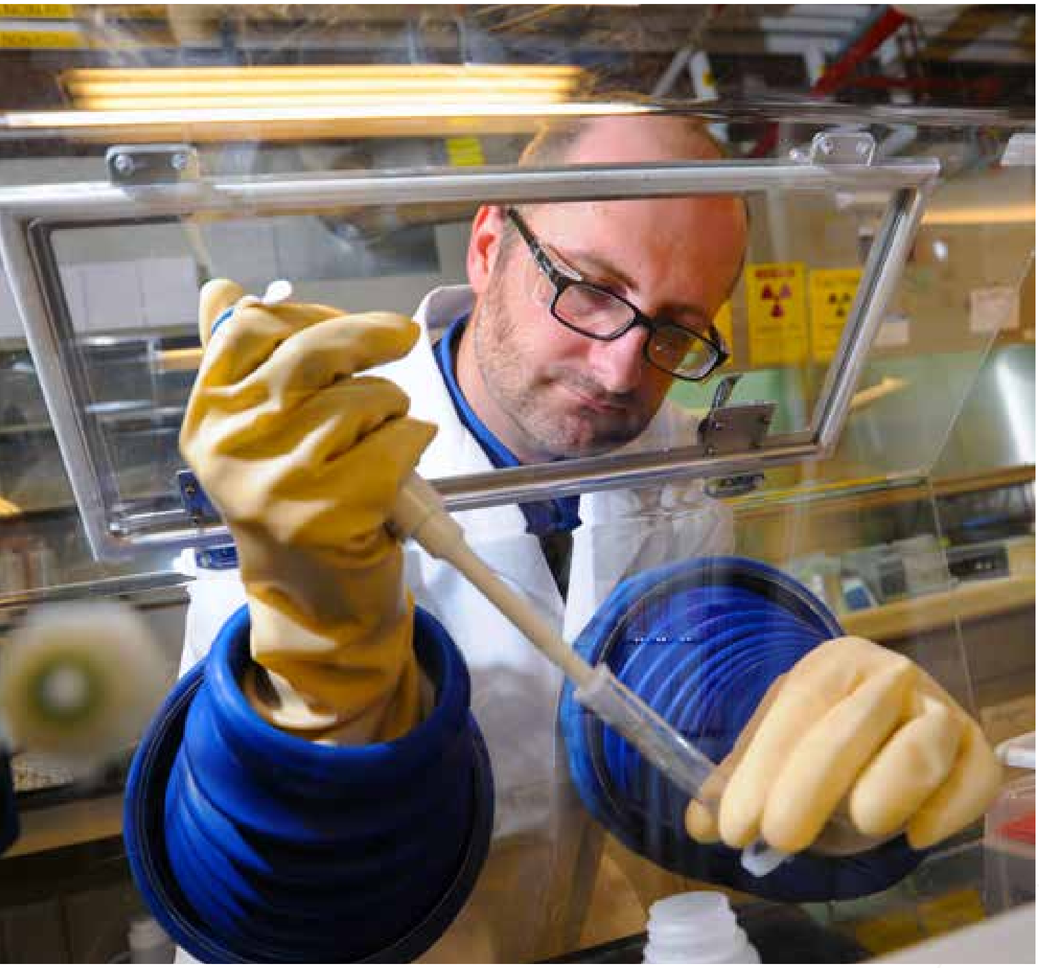
Integrated Research Projects
25 Projects
$99,809,625
Total IRP Funding

Infrastructure
286 Projects
$76,359,120
Total Infrastructure Funding

Integrated University Program
928 Projects
$55,793,999
Total IUP Funding

Nuclear Research & Development

The Consolidated Innovative Nuclear Research (CINR) Funding Opportunity Announcement (FOA) consists of three research and development (R&D) components that align with the U.S. Department of Energy's Office of Nuclear Energy (DOE-NE) mission and goals.



Scientist preparing experimental solution mixtures under nitrogen atmosphere.

The Nuclear Energy University Program (NEUP) awards competitively funded research and development opportunities in two main areas—fuel cycle and reactor concepts. The Nuclear Energy Enabling Technologies (NEET) Crosscutting Technology Development (CTD) program funds research that complements NEUP R&D. Programs partner with the Nuclear Science User Facilities (NSUF) program to provide R&D funds with access to one-of-a-kind facilities to enable research not typically available to university and industry researchers.

All applications undergo a rigorous multistage review process, including an independent peer review, to ensure projects are funded based on technical merit and relevance to DOE-NE's mission. Awardees are required to submit progress reports and meet specific milestones.

Nuclear Energy University Program: University research integrated with overall DOE-NE program priorities

Fuel Cycle: Evolving sustainable fuel cycle technologies that improve energy generation, enhance safety, limit proliferation risk, and reduce waste generation and resource consumption.

Reactor Concepts: Preserving the remaining commercial light water reactors as well as improving emerging advanced designs, such as small modular reactors, liquid-metal-cooled fast reactors, and gas- or liquid-salt-cooled high-temperature reactors.

Nuclear Energy Enabling Technologies: Technology development focused on applicability to multiple reactor designs

Advanced Manufacturing: Fabrication and repair techniques to increase viability of existing reactors or improve speed of manufacturing for new nuclear plants.

Advanced Sensors and Instrumentation: Demonstration of new sensor, instrumentation or controls technologies that enhance the operations of nuclear facilities.

NEUP	NEET	NSUF
689 Projects	80 Projects	54 Projects
102 Insitutions	33 Insitutions	29 Insitutions
53 Awards/year	8 Awards/year	4 Awards/year
$800K PROJECTS	$1M PROJECTS	$500K PROJECTS*
Average # of pre-apps 559 Average # of full apps 228	3 TECHNICAL AREAS: Advanced Manufacturing, Sensors & Instrumentation, Materials	$6.5 million in NSUF facility access/year
$498.5M Total R&D Funding: 2009-2021	$71.3M Total R&D Funding: 2012-2021	$46.1M Total R&D Funding: 2016-2021

** $500K NSUF R&D projects funded by NEUP and NEET.*

Nuclear Science User Facilities: Unique capability access to enhance university and industry research projects

Joint R&D and NSUF research projects: NEUP and NEET project funds are combined with NSUF access to enhance research projects with one-of-a-kind testing capabilities.

NSUF Access Only projects: Allows industry leads to access NSUF facilities for large ion irradiations, neutron irradiations or post-irradiation examination work to enhance industry-funded research projects.

Since 2009, the NEUP and CINR opportunities have received almost 8,000 pre-applications and over 3,000 full applications. From those applications, DOE-NE has awarded 689 research and development projects to 151 different academic, national laboratory and industry research institutions.

These projects have resulted in support for more than 2,500 students, more than 1,800 scientific publications and more than 20,000 citations in other scientific works.

PROGRAM HIGHLIGHT

Test Facility Ushers in Small Modular Reactor Revolution

by Eric Williams for DOE's Nuclear Energy University Program

The world's first small module reactor control room simulator in Corvallis, OR.

When Jose Reyes looks back to the genesis of the NuScale nuclear reactor, it's something of a time warp.

"In some respects, it seems like a long time ago, yet it also seems like yesterday," Reyes says, remembering the progress made possible 20 years ago by a novel thermal hydraulics facility at Oregon State University. "It was one of the first Nuclear Energy Research Initiative awards. The Department of Energy was looking to rejuvenate the nuclear program. Bill Richardson was Secretary of Energy. At Oregon State, we were finishing up our work on the AP600 and the AP1000."

Reyes is more enthusiastic than ever, as the efforts and investments of the Department of Energy (DOE) and private companies like Fluor move the United States ever closer to the next generation of nuclear power.

Citing numerous studies, including those from the Massachusetts Institute of Technology (MIT), Energy and Environmental Economics (E3), and others, Reyes notes "If you want to go to clean energy, you need to include nuclear."

Indeed, carbon reduction has been a pillar of NERI and related programs since the beginning. NERI was the U.S. DOE Nuclear Energy Research Initiative program that began in 1999 to foster innovative public research, with specific focus on what were termed ultra-small and ultra-safe reactors. NERI was one of the key programs consolidated in 2009 into DOE's Nuclear Energy University Program (NEUP), which is managed by the Office of Nuclear Energy.

At the heart of developing the next generation of nuclear power is that novel test facility Reyes and others have used to advance several projects. Known as the MASLWR, or Multi-Application Small Light Water Reactor, it is located on the campus of Oregon State University (OSU) in Corvallis. The MASLWR is but one of numerous initialisms interwoven in the fabric of OSU's School of Nuclear Science, housed in the College of Engineering. The AP600 and AP1000 Reyes mentioned, of course, are the Westinghouse-branded reactors.

Qiao Wu, professor of nuclear science & engineering at Oregon State, points to a 2003 report that notes the fundamental objectives of the MASLWR project were to "develop the conceptual design for a safe and economic small, natural circulation light water reactor, to address the economic and safety attributes of the concept, and to demonstrate the technical feasibility by testing in an integral test facility."

Also in 2003, while the original work done on the MASLWR test facility was concluded, the OSU team continued working on the design. Then, in 2007, NuScale Power was founded by Reyes and others. OSU conferred exclusive rights to the design to the newly formed company, and the MASLWR facility was repurposed to represent the NuScale design.

Undergraduate student Harrison Liu (left), Qiao Wu (center), professor of nuclear engineering, and unknown (right) make adjustments to the NuScale Integral System Test facility at Oregon State University. Wu leads Oregon State's NuScale-related research and testing.

Today, as NuScale nears the finish line of the arduous licensing process, OSU's objectives become ever-more real. In December 2019, the Nuclear Regulatory Commission (NRC) completed the fourth phase of review of the design certification application (DCA) of the NuScale Power Module. Soon after, in January 2020, the company submitted its pre-licensing vendor design review to the Canadian Nuclear Safety Commission.

The first deployment of the NuScale, 60-MW power module is planned in the United States later this decade. Like every previous step in the development of the NuScale plants, this is a multi-participant collaboration: a dozen modules will be planted at the Idaho National Laboratory, with the Utah Associated Municipal Power Systems (UAMPS) as the utility and Energy Northwest, which runs the Columbia Generating Station in Washington, as the operator.

Oregon State is just one example of how the transition from NERI to NEUP exhibits DOE's commitment to both continuity and steady progress; though the names have changed and organizational charts tweaked, DOE and its university partners have kept their mutual focus on "investing in the next generation of nuclear energy leaders and advancing university-led nuclear innovation" while maximizing the use of taxpayer dollars.

"That program was really innovative," says Reyes, "allowing universities to team up with industry and government in productive ways."

It's been that way from the start. In May of 1999, Charles A. Thompson of the Office of Nuclear Energy, Science and Technology made a presentation to a committee of the International Atomic Energy Agency (IAEA). Thompson's report explained how NERI was in no small part initiated as a result of the work of the President's Council of Advisors on Science and Technology (PCAST), under President Bill Clinton.

Thompson's presentation noted the observations made by PCAST, which today seem almost prescient:

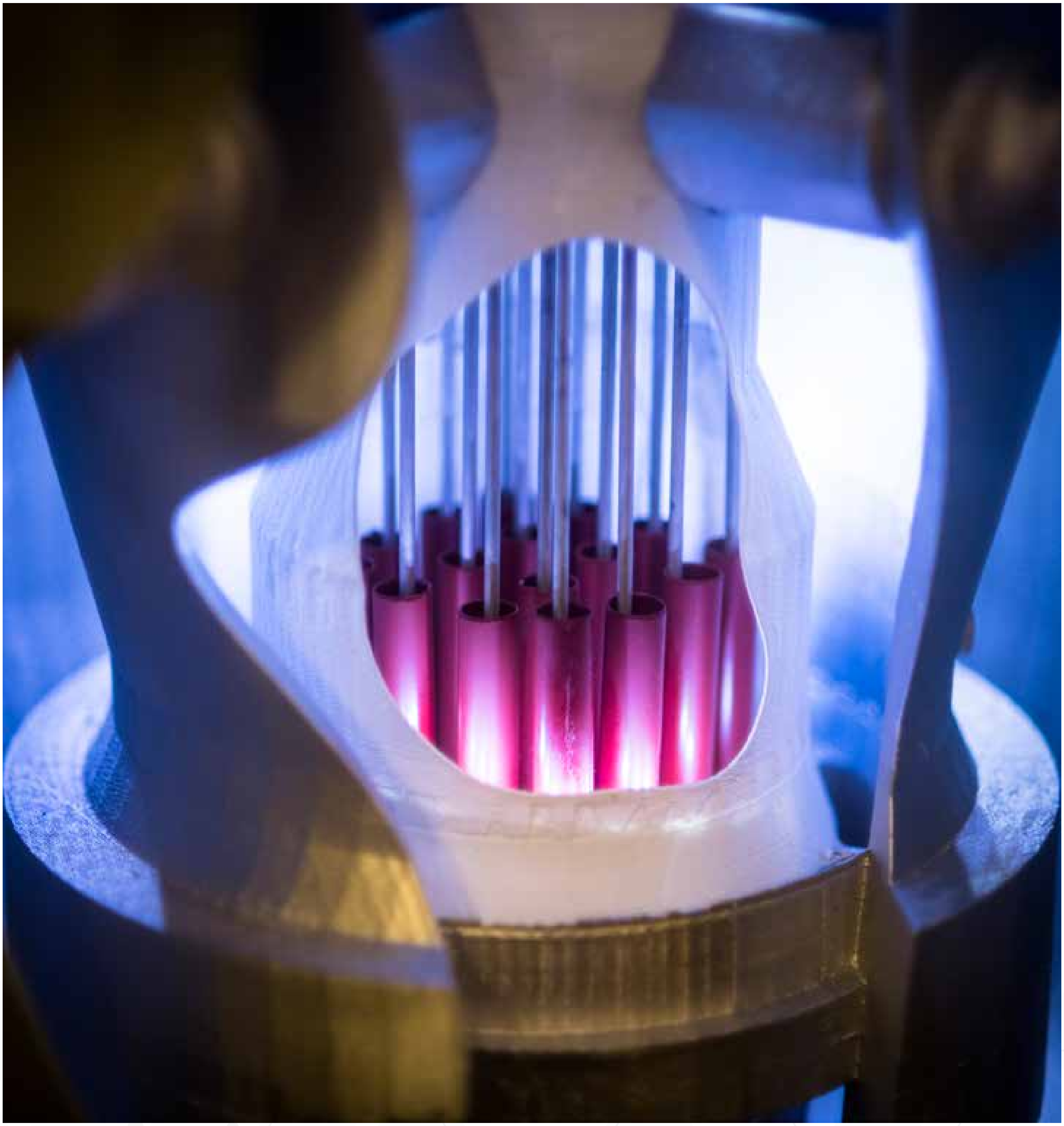
- Potential benefits of expanded contribution from fission in helping address CO_2 challenges warrant the modest research initiative.
- "To write off fission now as some have suggested ... would be imprudent in energy terms and would risk losing much U.S. influence over the safety and proliferation resistance of energy activities in other countries."
- Fission belongs in the R&D portfolio.
- Building on those observations, the PCAST recommendations were:
- Foster innovation and new ideas through investigator-initiated R&D proposals.
- Enhance cooperation among universities, DOE laboratories, and industry.

NuScale Chief Technology Officer and Co-founder, Dr. Jose Reyes, describes NuScale's SMR technology by using a model of the NuScale Power Module™ .

- Establish a new program to address the key issues affecting the future of fission energy, including:
  - Proliferation-resistant reactors and fuel cycles
  - New reactor designs with higher efficiency, lower cost, and improved safety to compete in the global market
  - Lower-output reactors for use in settings where large reactors are not attractive
  - New techniques for on-site and surface storage and for permanent disposal of nuclear waste
- Establish an R&D program to address continued operation of existing reactors to assist the U.S. in meeting greenhouse gas emission goals.

Also important, Reyes says, is the DOE support for first-of-a-kind tools. "When doing something for a first-of-a-kind design, for first-of-a-kind test programs, there's always an extra expense," he says. "The role of government is key because it reduces that risk."

In the mid-2000s, there was a great team with "lots of ideas on how to move the MSLWR design to the NuScale design," according to Reyes. Also, during that time, they not only took critical steps in the design of the NuScale reactor, but also began to make the business case. "There were three basic patents, which became the IP (intellectual property) for the company," he said. Today, NuScale has more than 400 patents granted or pending in 19 countries.



A close-up view of the nuclear core inside a model of the NuScale Power Module™ located in NuScale's Corvallis, OR office.

“We reached the point of being investment-ready, and in January 2008 we received the first private investments,” Reyes said. He credited Oregon State University’s support as key “to us getting through the valley of death.” He added, “Going from academia to private business, well, there are sharks. Like on the TV show, they do exist. Then Fluor did come in, did its due diligence, and to their credit invested big time, even after Fukushima.”

The tsunami-caused meltdown at the Fukushima Japan nuclear plant in 2011 (which caused no fatalities), raised the profile of Oregon State University’s nuclear work, mostly in a positive way. “After Fukushima, I got a lot of calls from the Oregonian (the state’s largest-circulation newspaper), Wu recalled. “They said, ‘We understand you are looking at what this SMR could do. When reporters and others in the state began to become more educated on the MASLWR-enhanced design, “people started thinking more rationally.”

NEUP balances the competitiveness between universities — and between national laboratories — with those very same institutions’ shared appreciation for collaboration. As an example, Wu notes several collaborating entities and their respective leaders, including:

- Idaho National Laboratory, Dr. Shannon Bragg-Sitton
- University of Wisconsin, Prof. Michael Corradini
- Texas A&M, Prof. Yassin Hassan
- University of Idaho, Prof. Richard Christensen
- Purdue University, Prof. Mamoru Ishii
- International Atomic Energy Agency

In designing the NuScale Power Module™ and power plant, NuScale has achieved a paradigm shift in the level of safety of a nuclear power plant facility.

"Integrated and collaborative research is at the very heart of what we do through NEUP. We want to make sure that the work funded under the Office of Nuclear Energy has a real impact on the future of nuclear energy. The NEUP projects bring together the expertise of U.S. universities, industry, national laboratories, and the government to deliver meaningful results." – Alice Caponiti, Deputy Assistant Secretary for Reactor Fleet and Advanced Reactor Deployment

For Oregon State University, the DOE partnership is much broader and deeper than just having test facilities on campus. There are numerous "knock-on effects," as noted by Kathryn Higley, Head of the School of Nuclear Science and Engineering at OSU. Pointing to the MASLWR, as well as the Advanced Plant Experimentation Test Facility (known as APEX and key to licensing the Westinghouse AP1000), Higley says, "Success in these programs contributed to our ability to hire additional faculty. Those top-flight faculty then got key opportunities … which led to additional research, and a new building with amazing capabilities, which brings in more students interested in the field and sets us apart from our peer institutions. There's a cumulative impact."

The partnerships have enhanced Oregon State's College of Engineering's already strong position of fulfilling higher education's core mission – preparing students for the real-world companies and institutions who employ engineers.

"It's really opened up the market for our students, both graduate and undergraduate," says Wu. "We'll get calls from recruiters, saying, 'Hey, I want this student,' and when we let them know that student is a semester away from graduating, they say, 'No, I want them now!'"

In 2009, OSU student Alexei Soldatov won the prestigious Mark Mills Award, given by the American Nuclear Society for the best original technical paper by a graduate student; his paper evaluated various scenarios for optimizing fuel performance in the MASLWR.

Wu added, "Many of our students are now at the national labs, at Westinghouse, Areva, TerraPower – and NuScale, of course." Further, he says the 300 NuScale employees at its office in Corvallis, a community of 58,000 residents, have a major positive impact on the economy. He said OSU estimates NuScale's presence adds approximately $150 million to the economy annually.

"About 40 percent of our company is under the age of 40, adds Reyes. "That brings a lot of innovation, and that spirit of innovation is what we've brought from Oregon State."

That student development has also been an objective since early on.

"University involvement in NERI-funded research has been particularly important in renewing student interest in pursuing degrees in nuclear engineering and related sciences and enabling educational institutions across the country to stay at the forefront of nuclear science research," William Magwood IV, then director of the Office of Nuclear Energy, wrote in the 2003 NERI Annual Report. Magwood is now director general of the Paris-based Nuclear Energy Agency.

That 2003 report highlighted 10 NERI research projects, including "Testing of Passive Safety System Performance for Higher Power Advanced Reactors," in which Westinghouse Electric Company, LLC, was the collaborator. Who was the principal investigator? Jose Reyes of Oregon State University.

1994

The Integral Fast Reactor (IFR) project cancelled

1997

President Clinton orders Committee of Advisors on Science and Technology to review the national energy portfolio.

1999

The Department of Energy initiates NERI, the Nuclear Energy Research Initiative, to foster innovative public research. INEEL (Idaho National Engineering and Environmental Laboratory, now the Idaho National Laboratory) and Argonne National Laboratory tabbed as leads for the Department of Energy's nuclear reactor technology work.

2000

The Multi-Application Small Light Water Reactor (MASLWR) project is launched, consisting of a team representing Oregon State University (OSU), INEEL, and Nexant (a Bechtel subsidiary).

2003

MASLWR funding ends. OSU scientists continue work on design of a small modular reactor (SMR).

2007

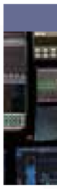
OSU confers exclusive rights to the nuclear power plant design and continued use of the test facility to the newly formed NuScale, under a technology transfer agreement.

2008

NuScale informs the Nuclear Regulatory Commission (NRC) of its intention to develop a 45-MWe power module.

2011

Fluor becomes NuScale's primary investor.



2012

NuScale's twelve-
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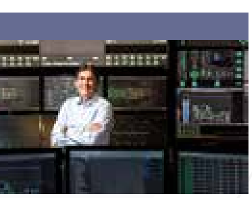
simulator becomes
perational for human
factors engineering
development.



2013

DOE announces selection of NuScale to receive up to $226 million in matching funds to support further design develop-ment and secure NRC design certification. Also, Rolls Royce joins Fluor as a backer of NuScale.

2014

The power module's output is raised from 45 MWe to 50 MWe.

2015

NuScale Power awarded $16.6M for the preparation of a combined Construction and Operating License Application (COLA) for the first customer, the Utah Associated Municipal Power Systems' (UAMPS). Also, Fabrication and assembly of a full-scale, upper-module mockup of NuScale Power Module™ completed.

2016

NuScale is the first to submit a design certification application (DCA) to the NRC.

2018

The NRC completes the first phase of the NuScale Power Module™ DCA, making it the first SMR application to undergo NRC review. Also, the DOE Office of Nuclear Energy awards NuScale $40 million in cost-sharing financial assistance under its U.S. Industry Opportunities for Advanced Nuclear Technology Development program. Further, NuScale announces the power module's output increased from 50 MWe to 60 MWe (gross).

2019

NuScale has more than 350 employees across seven offices, including one in the United Kingdom. Approx-imately 300 are in Corvallis, home of Oregon State University.

2020

NuScale makes first submittal of its pre-licensing vendor design review (VDR) to the Canadian Nuclear Safety Commission (CNSC). To date, more than $900 million has been invested in NuScale, with the DOE contributing approximately $340 million of that through cost agreements.

PROGRAM HIGHLIGHT

Staying Ahead of the Curve: Argonne, INL Collaborate on Software to Aid Power Plant Operators

by Paul Menser for DOE's Nuclear Energy University Program

The Human Systems Simulation Laboratory (HSSL) at Idaho National Laboratory is a full-scale test facility for performing human factors experiments with control room operators.

If one word could sum up the guiding principle behind the operation of a commercial nuclear power plant, it might be "anticipation."

"Plant situational awareness" is a term any control room operator is familiar with. With complex mechanical systems and massive amounts of energy involved, it's not only desirable but necessary to be in front of any plant issue that has the potential to grow into trouble. The greatest danger operators face is falling behind the curve due to the countless little tasks their jobs involve.

Researchers at Argonne National Laboratory (ANL) and Idaho National Laboratory (INL) have recognized that the answer is not to replace control room operators with computers, but to provide them with a computerized operator support system (COSS), a collection of capabilities that helps them monitor plant performance and make timely, informed decisions.

The U.S. Department of Energy established the Nuclear Energy Enabling Technologies (NEET) Program to help address nuclear technology development challenges through innovative research. Under NEET, the Advanced Sensors and Instrumentation (ASI) technology area coordinates instrumentation and controls (I&C) research, such as this one, to support the nuclear industry.

In a collaboration that stretches back nearly ten years, Argonne and INL have developed competencies that complement each other. Argonne has done extensive research into equipment fault diagnosis. Its PRO-AID software for diagnosing component faults in nuclear power and process industry plants dates back to the 1990s. One goal—made possible by today's advances in software development tools—was to modernize PRO-AID so that its automated reasoning (AR) capability would be more maintainable and extensible. This essentially required a rewrite of the software using current generation AR coding techniques. On its side of the partnership, INL is home to the Human Systems Simulation Laboratory (HSSL), a high-fidelity, digitized control room simulation environment where four light water reactor (LWR) plant models can be used for assessment of human performance in a highly realistic setting.

Since 2015, the progress has been toward software that can manage and distill the enormous amount of information an operator must process to maintain awareness of a plant's condition, particularly in nascent off-normal situations.

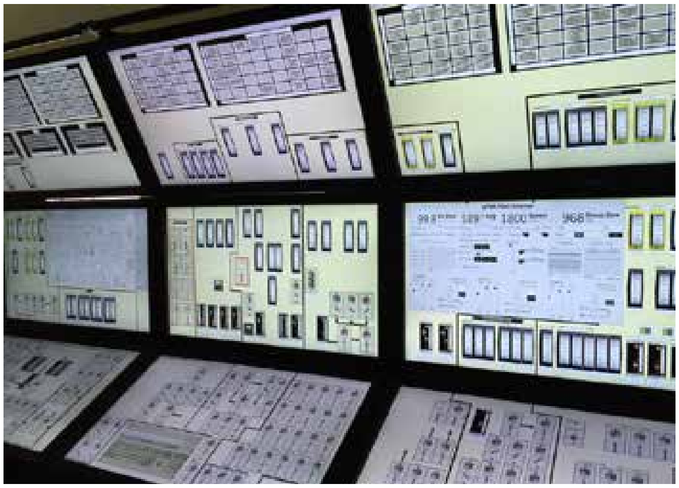
"It doesn't encroach on their functions as much as it brings to their attention conditions that might become actionable," said Ken Thomas of INL, who collaborated on the project with Ron Boring, a distinguished human factors scientist at INL, and with Richard Vilim, the principal investigator from Argonne. "It's not some black box. It's an engine that reasons just like an operator would reason," adds Vilim.

Human performance assessment with Palo Verde operators was done to simulate fault injection to gauge operator performance for PRO-AID assisted and non-PRO-AID-assisted scenarios.

The reasoning process is designed to be transparent and familiar to operators. It is based on nearly the same qualitative reasoning process by which they, given sufficient time and access to instrument readings, would make a fault diagnosis.

"It's engineered to be deployable," Vilim said. "It doesn't need a subject matter expert. It runs very quickly in real time. It looks at all the components in a system and uses this information to almost double the number of available process variables for improved awareness."

One key consideration in the development of COSS was that it not become one more thing for operators to deal with. Automated systems perform more reliably than humans at rote tasks. Humans on the other hand perform much better at system oversight, evaluating complex situations and formulating an appropriate response. The goal was to develop a computer-based operator advisory system that would improve operational reliability, improve nuclear safety, and reduce human error through seamless integration of plant measurements, the physical laws, and automated reasoning.



The COSS displays at the HSSL reflect the real-time plant parameters for normal and fault conditions. The display to the left is the operator interface panel and the display to the right is the plant systems overview.

Operator participates in simulation testing at the HSSL.

The first successful demonstration of COSS at the HSSL occurred in 2017, when human factors interactive graphics and fault diagnostics algorithms were seamlessly integrated with a full-scope simulator, providing a real-time platform for human performance tests. One test simulation involved the failure of a reactor coolant pump seal while the other involved a leak in outside containment.

In working with the nuclear industry, the labs began work with Arizona Public Service, conducting human performance tests with operators from the utility's Palo Verde Nuclear Generating Station. The workshop provided an opportunity to allow operators to interact with the COSS prototype in real time.

In order to benchmark their performance, the operators first performed a scenario using a traditional analog board layout. They then used the COSS interface displayed within the chemical and volume control system (CVCS) board. A number of different measures were collected during each scenario completion. Simulator logs, eye tracking, and audio logs were taken in real time, and following the scenario the operators completed a series of subjective questionnaires.

> *"The next logical step is to load the COSS interface onto a power plant's computer for a test case. There has been interest from utilities, but the main hurdle will be validating to regulators that it will not be a distraction to operators."*
>
> *– Richard Vilim*

Operator using COSS at the INL Human Systems Simulation Laboratory.

"They really engaged and liked the idea of it," Thomas said. "I think they really did see this as something that could help them."

Argonne is currently working with industry on applications of PRO-AID methods and software to improve efficiency of operations and maintenance activities at U.S. nuclear plants. The lab has partnered with an energy service company and nuclear utilities to deploy the software for improved situational awareness. In one application, PRO-AID provides a real-time estimate of equipment condition and serves as a basis for improved maintenance and optimization to reduce costs. In another, it is used to analyze the installed sensor set at a nuclear plant, recommending how it should be augmented to better meet the information needs of a prospective monitoring and diagnostics center. The software is also a candidate building block in the operations technology that is being developed for achieving a long-term goal of near autonomous operation of a nuclear plant.

The next logical step is to load the COSS interface onto a power plant's computer for a test case. There has been interest from utilities, but the main hurdle will be validating to regulators that it will not be a distraction to operators.

From there, "Adopting this from one plant to another would not be a great jump," Thomas said.

Operator support technology includes simulated diagnostic technology, an operator alarm display, and the fault scenario.

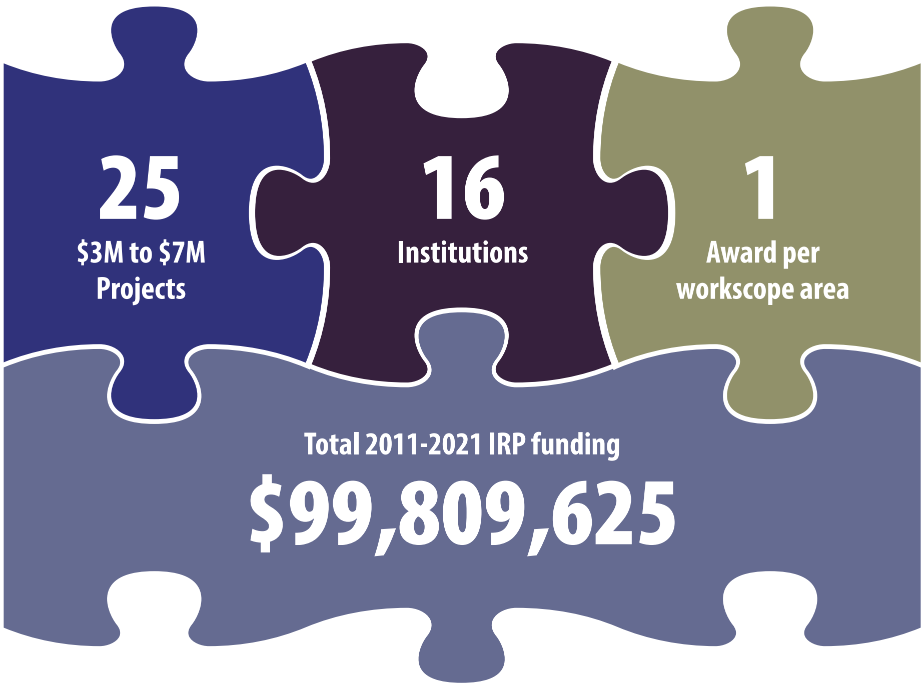
Integrated Research Projects

Integrated Research Projects (IRPs) comprise a significant element of the Department of Energy's (DOE) innovative nuclear research objectives and represent the Program Directed (PD) component of the Office of Nuclear Energy (NE) strategy to provide research and development (R&D) solutions most directly relevant to the near-term, significant needs of the NE R&D programs.

Graduate student Shaun Aakre standing next to a sCO_2 test rig connected to a molten salt loop getting ready to test a PCHE between salt and sCO_2 for the first time.

IRPs are significant projects within specific research areas. IRPs are intended to develop a capability within each area to address specific needs, problems, or capability gaps identified and defined by NE. These projects are multidisciplinary and require multi-institutional partners. IRPs may include a combination of evaluation capability development, research program development, experimental work, and computer simulations. Past areas include:

- Advanced reactor design;
- Used fuel disposal and transportation;
- Accident tolerant fuel development;
- Materials irradiation techniques;
- Transient test reactor instrumentation and fuel testing;
- Used fuel cask inspection and repair techniques;
- Compact heat exchangers development; and
- Modeling and simulation.



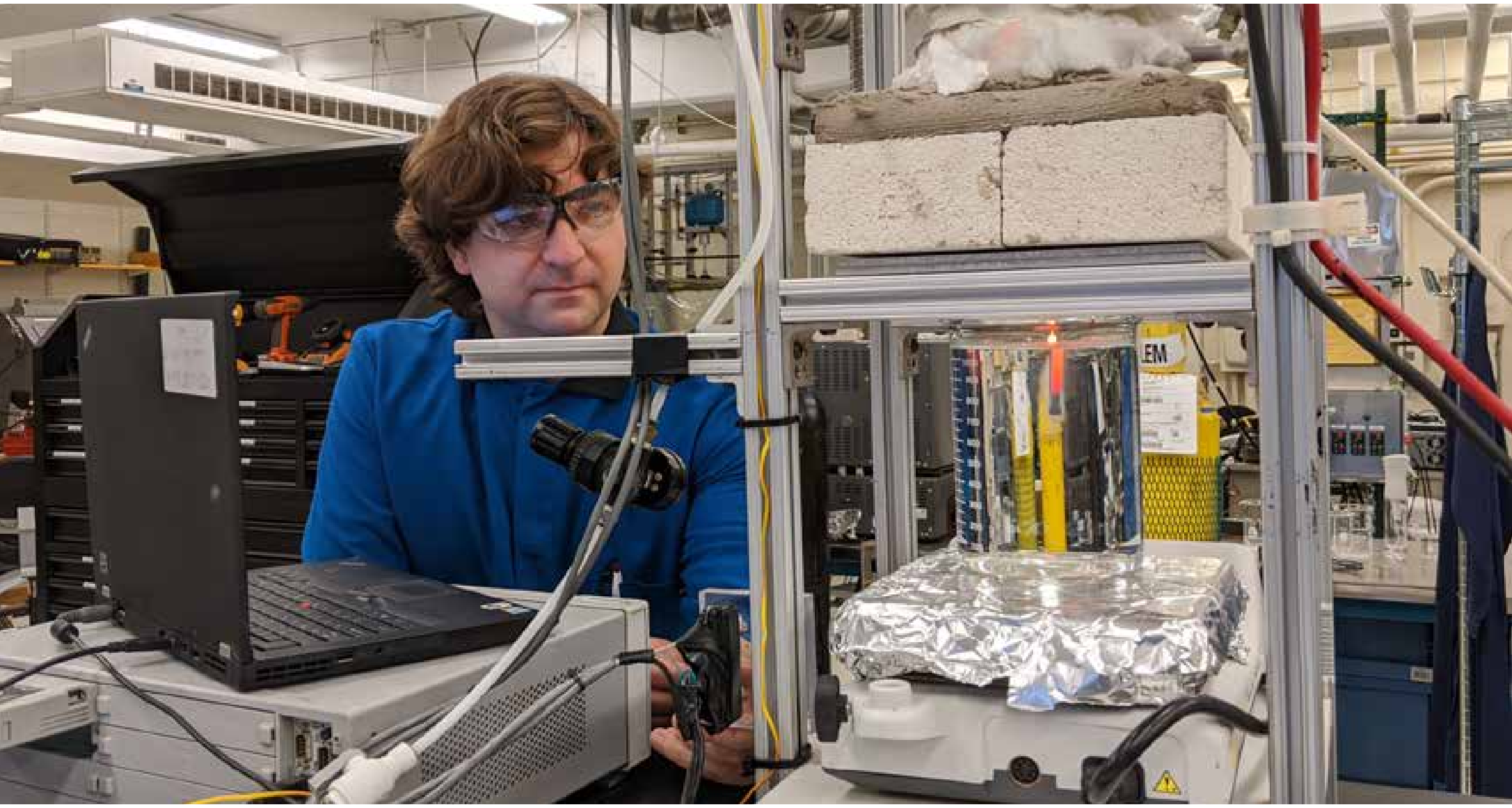
IRPs are intended to integrate several disciplinary skills in order to present solutions to complex systems design problems that cannot be addressed by a less comprehensive team.

Although a proposing team must be led by a university principal investigator and include at least one additional university collaborator, the proposed project team may include multiple universities and non-university partners (e.g., industry/utility, minority-serving institution, national laboratory, underrepresented group, and international).

PROGRAM HIGHLIGHT

Nuclear Energy University Program IRP Results Lead to Important Recommendations for the Nuclear Industry

by Eric Williams for DOE's Nuclear Energy University Program



Research scientist Dr. Bren Philips performing high temperature quench experiments on coated cladding concept to understand mechanical and thermal-hydraulic performance.

Koroush Shirvan isn't a zoologist, but he's well acquainted with moose, bison, cobras, and falcons, to name a few.

Like anyone working in the world of advanced research on nuclear power, this assistant professor in the Massachusetts Institute of Technology's (MIT) Nuclear Science & Engineering department deals daily in initialisms and acronyms, which for Shirvan include MOOSE, BISON, COBRA, FALCON, and dozens more.

One of Shirvan's areas of expertise is accident-tolerant fuels (ATF), and he served as the executive director of an Integrated Research Project (IRP) titled, Development of Accident Tolerant Fuel Options For Near-Term Applications. The multi-institution project was funded by the Department of Energy's Nuclear Energy University Program (NEUP).

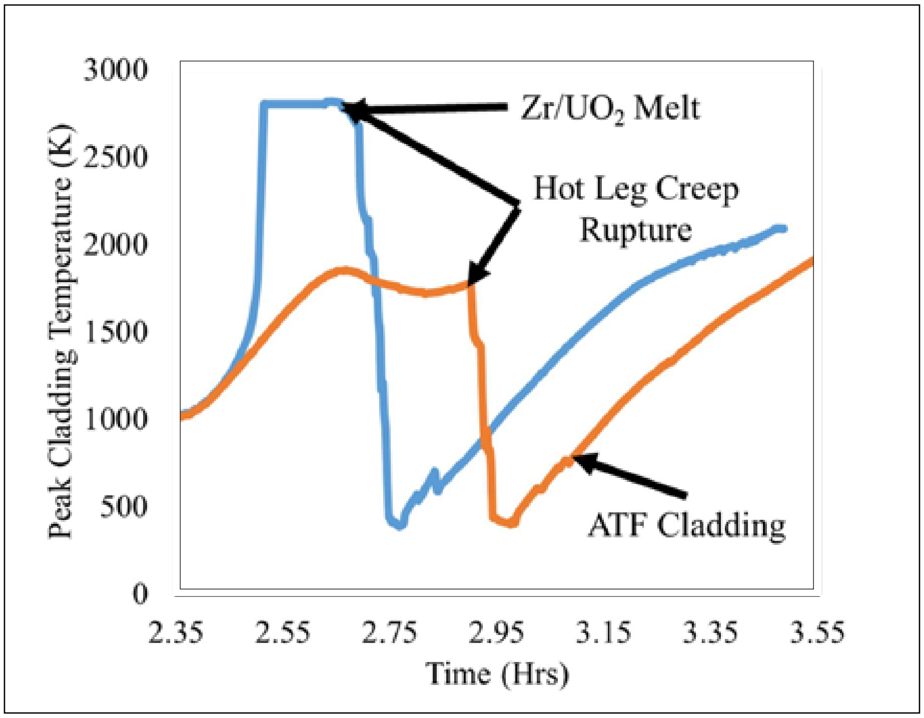
At the outset, the project was framed with a clear understanding that it wasn't intended to find one magical answer about which ATF concept was the best. Rather, the objective was to take the necessary, practical step of understanding the different ATF concepts, develop computational tools, and set out a pathway that leads to a down-select process.

"In 2015 when we started, the (broader) ATF program had really been expanded to all countries with major nuclear programs," Shirvan recalled. "So, we had a very good foundation to draw on. We decided to focus on near-term concepts that would see commercializing sooner … we were really focused on finding an economic benefit."

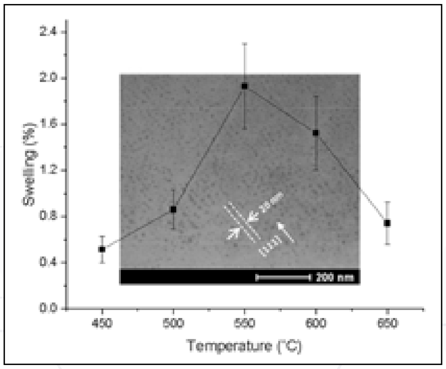
When Shirvan says "we," he means it. The IRP team included experts from Texas A&M University, the University of Florida (UF), and the University of Wisconsin at Madison (UW) as well as Idaho National Laboratory (INL) and private industry representatives with Structural Integrity Associates, Inc. and Framatome. Also high on Shirvan's "we" list is Frank Goldner, the longest-tenured employee at the Department of Energy, and the one who provided Federal oversight for the project.

Goldner, in turn, has high praise for Shirvan, the "powerhouse" universities on the team, and Framatome's role in providing the base material for coatings. "If you are looking for a poster child of something that has worked well, this one is it," Goldner said.

Indeed, Framatome's involvement was vital and required high levels of trust and cooperation in navigating the process, technical and legal considerations. This excerpt from the report exemplifies how creativity overcame the interwoven complexities:



UW utilized MELCOR and MIT used Enhanced TRACE (results shown) to perform PWR Station Blackout Analysis for Zircaloy and ATF claddings. Analysis results showed ATF cladding can prolong time to fuel melt by a noticeable but modest length of time.



TAMU performed ion irradiation of Chromium to investigate its radiation stability. The graph shows the void swelling of pure Cr irradiated to 50 peak dpa, as a function of irradiation temperature and TEM image of a grain in <111> orientation, showing development of void alignment.

IRP TEAM

MIT's accident-tolerant fuel IRP team included four universities, two industry partners, and one national laboratory (INL).

The feasibility of modeling the chromia doped fuel behavior under normal operation in BISON [the nuclear fuel performance code] was confirmed based on Halden [Norway research reactor] data … The available validation data from Halden did not include power ramps, the key benefit of doped fuel and the FRAMATOME power ramp database is proprietary. Therefore, a unique collaboration mechanism was arranged. MIT, in collaboration with INL, optimized the BISON settings for simulation of doped fuel. Then MIT turned in the BISON input files to FRAMATOME which has the BISON license through the CASL program. FRAMATOME then modified the input file with their proprietary boundary conditions for 3 different tests involving a power ramp. The result indicated a 15% underestimation of FGR by BISON, which is within the uncertainty of the code. In such way, we gained confidence in code prediction and capability for use in future projects while FRAMATOME kept the intellectual rights of its data.

Notably, the project overcame the untimely deaths of two key team members, Principal Investigator Mujid Kazimi and Collaborator Thomas McKrell, both of MIT and both leaders in nuclear research and mentoring. Also integral to the project's success, Goldner noted, was the appropriate level of cooperation the IRP team had with the Nuclear Regulatory Commission (NRC). In simple terms, the project deployed models the NRC was using – including, specifically, the TRAC/RELAP Advanced Computational Engine (TRACE) and the integrated safety analysis code known as MELCOR.

Here's how the team's report described the situation this IRP addresses:

Following the Fukushima disaster in 2011, US Congress mandated the Department of Energy to start an R&D program on accident-tolerant fuel (ATF) concepts for the existing light water reactor fleet. By 2015, the start date of this IRP, several ATF concepts were being pursued by various entities. In general, the ATF concepts were divided into two categories: near-term and long-term. The near-term concepts included coated

Zircaloy clad, fuels with additives and dopants, and FeCrAl/steel-based claddings. The long-term concepts included SiC composite cladding, high density fuels (U_3Si_2, UN), and TRISO type fuel forms (e.g., FCM).

This particular NEUP project focused on those near-term concepts; it made specific recommendations in ten areas:

- Mo/FeCrAl coating testing outcome
- Cr coating testing outcome
- Ion irradiation testing outcome
- Quench heat transfer behavior testing outcome
- Reactor physics simulation
- Thermal-hydraulic system modeling and simulation
- Normal and AOO fuel-performance simulations of near-term ATFs
- Transient and accident fuel performance simulations of near-term ATFs
- Economics and cost analysis
- Time-to-fuel-failure analysis

A key objective of the ATF research, of course, is to buy time; when things don't go as planned and operators need to make adjustments, minutes are precious. Both Goldner and Shirvan are optimists, and both were somewhat disappointed in the research findings. According to the report:

Recommended NEUP Direction on ATF

Part and parcel of the final report (Development of Accident Tolerant Fuel Options For Near-Term Applications) were recommendations for future work. The recommendations are presented in three areas:

NEUP Areas Bucketed in Industrial ATF Concepts:

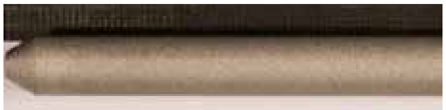
- Coated cladding
- Doped fuel
- Silicon carbide fiber in silicon carbide (SiC/SiC) matrix composites
- High-density fuels
- Fuel performance for beyond design basis
- Post-critical heat flux (CHF) and fuel rod survival after CHF

Other Recommended Future Work:

- Coated cladding experimental testing
- Improvement in ATF value proposition including application to high burnup
- Improvement of the NEAMS fuel performance tool BISON for Transients and Design Basis Accidents
- Improvement of the TRACE severe accident simulations

Recommended Work Not Accomplished by the IRP:

- Fuel performance during a severe accident, specifically through a structural mechanics framework
- Atomistic and mesoscale modeling of the corrosion and interlayer interaction for coated cladding
- Pairing Nuclear Energy Advanced Modeling and Simulation (NEAMS) Multiphysics Object Oriented Simulation Environment (MOOSE) tools to perform the multiphysics analysis of concepts
- Pursuit of new MAX-phase (layered material system) alloys as a coating
- Code-to-code comparison of Fuel Analysis and Licensing Code such as FALCON to BISON for near-term ATF concepts



Pressure Tube Sample

CRUD Ring Sample

4-Point Bend Fatigue Sample

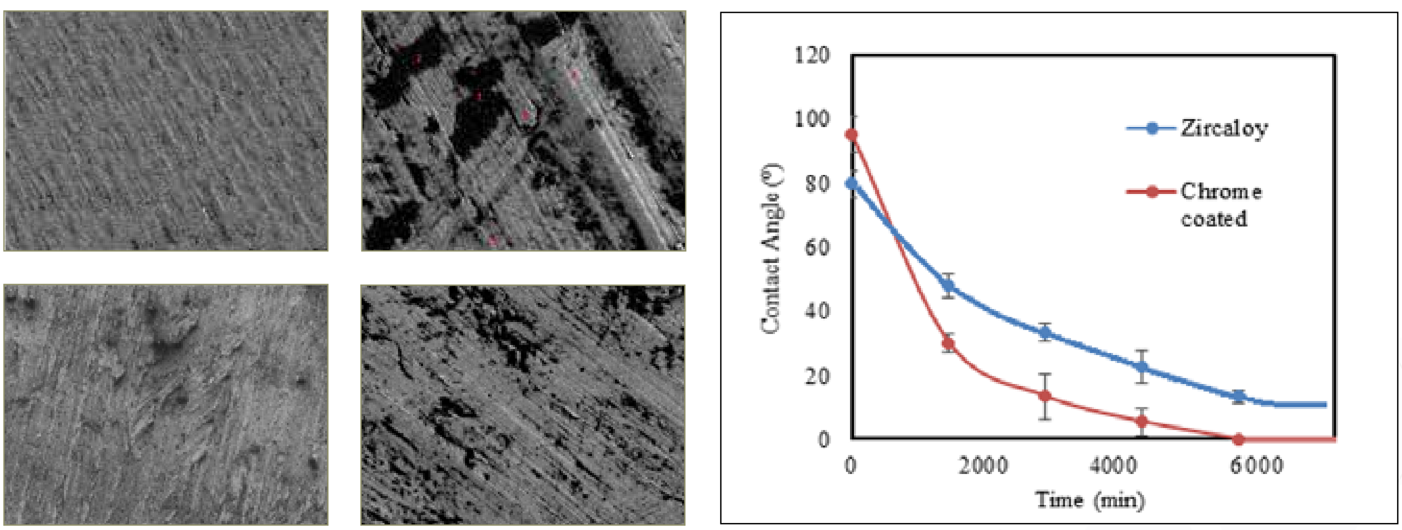
Steam Oxidation Sample (Tested)

Hydraulic Quench Sample

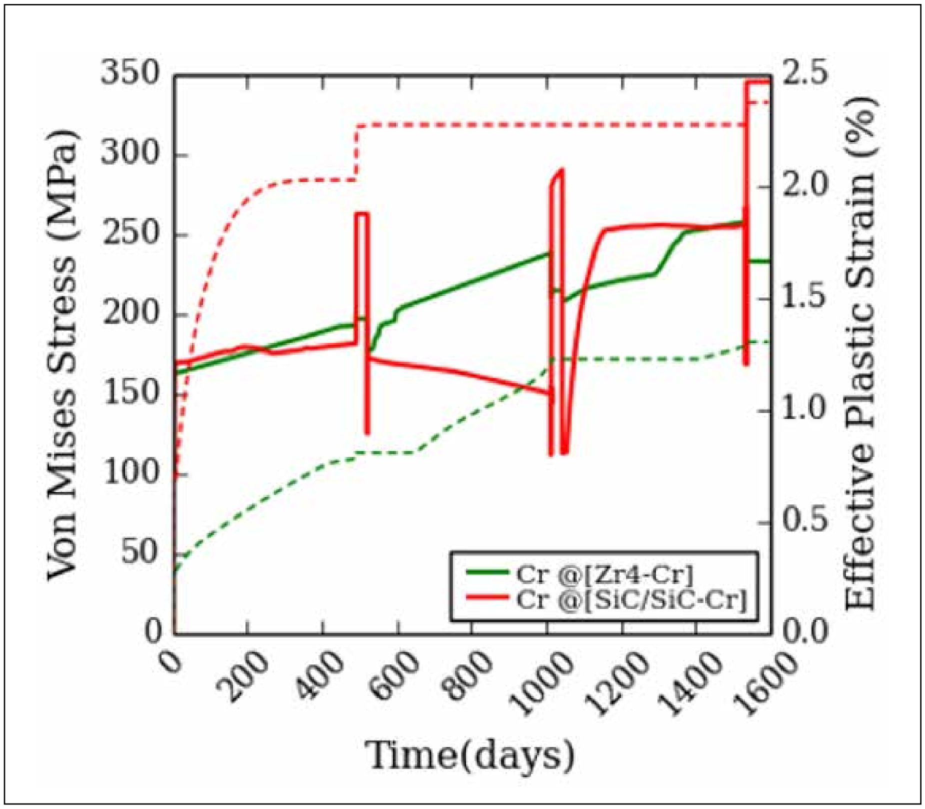
Fabricated Cold-Spray Cr coating sample-types for testing; a unique approach of the IRP was to start with test samples that can cover a large set of separate-effect test conditions to decipher coated clad failure modes as opposed to initially testing small coupons.

In this IRP, the system code TRACE predicts up to 20 minutes added coping time while MELCOR simulations predict up to 2 hours for station blackout type scenarios. In either case, the capacity to provide additional core cooling as an alternative severe accident mitigation strategy is deemed to be more effective for existing plants.

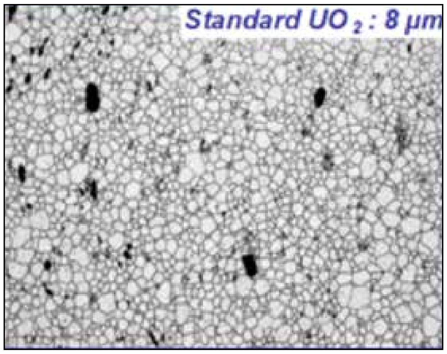
Shirvan explained that "some analysis was being done that said, if you employ these cladding concepts, you can gain several hours" before the core's integrity becomes problematic. There were even predictions that the cladding concepts could provide a cushion of a few days, but the research determined that's not the case. As the research continues, "we initially found it to be five minutes, and now it's up to forty minutes," he said.

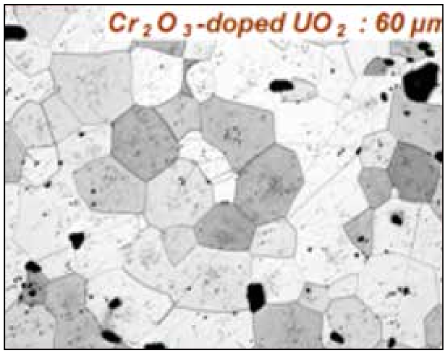


Mechanism of surface induced hydrophilicity (lowering of contact angle) due to gamma irradiation was found to be due to formation of surface oxides as shown in black (top middle photo) after sample gamma irradiation. The surface undergoes hydrophobic recovery due to surface contamination of the formed oxide as shown in SEM after 24 hours of irradiation (bottom left photo) but the contamination is removed upon heating (bottom middle photo) and the benefits of increase in hydrophilicity due to gamma radiation is present during accident conditions.



IRP for first time modeled Cr coating for Zircaloy and SiC cladding with MOOSE/BISON during normal operation, power ramps, load following, and loss of coolant and rod ejection accidents. Figure above shows while Cr coating is compatible with Zircaloy and SiC, some plasticity (dotted lines) is expected to occur even during normal operation.





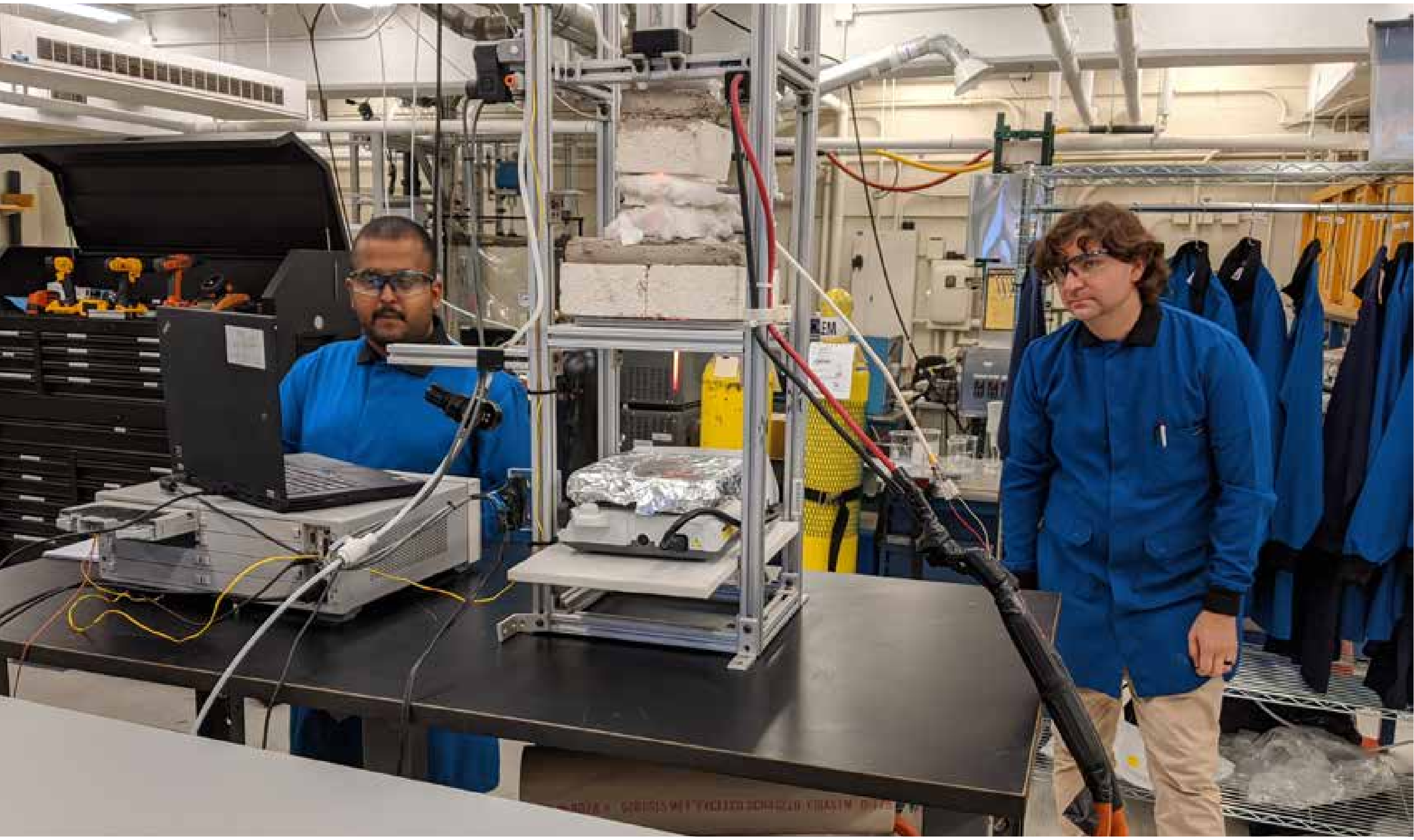
Unique team structure was formed to investigate the fission gas release of doped UO_2 fuel within the IRP. MIT performed model development with guidance of INL and INL's HPC resources. Then the model in BISON was transmitted to Framatome to be used for validation purposes. On average, the predicted fission gas release for doped UO_2 after a power ramp was less than 20% compared to Framatome's proprietary database. The findings were also used to confirm LANL diffusivity calculations after the IRP. Photo courtesy of Framatome.

Along with being optimists, Shirvan and Goldner are also realists. As Goldner put it, "the results didn't give me my dream answers, but they did give the system some additional time, when minutes are crucial." They agreed that it's far better to know the answers rather than relying on overly enthusiastic estimates and to subscribe to the adage put forth by America's greatest inventor: "Negative results are just what I want," Thomas Edison said. "They're just as valuable to me as positive results. I can never find the thing that does the job best until I find the ones that don't."

Moreover, like many ATF researchers, Shirvan's team is also on the lookout for other attributes the advanced fuels can provide.

As explained in the report:

However, outside of their modest coping time improvements, ATFs do present other safety and economic opportunities in [the] form of more resilient fuel for normal operation and design basis accidents and have potential to enable higher fuel burnups. In order to realize such benefits, significant R&D is needed



Team members graduate student Arunkumar Seshadri and research scientist Dr. Bren Philips performing high temperature quench experiments on coated cladding concept to understand mechanical and thermal-hydraulic performance.

to address new failure modes and build the safety and commercial case. These challenges can be overcome through a public-private partnership between the DOE and industry.

“The most important thing is that nuclear is a blessing. That is my elevator speech,” Goldner said.

And, he added, “we’re trying to make sure a Fukushima doesn’t happen again. We’re working to enhance the safety of nuclear reactor[s] and at the same time ensure they’re economically competitive.”

Completing a project of this scope, in a university environment and in the compressed three-year timeframe allowed by the IRP program, is full of potential pitfalls. Despite those challenges, by using an integrated modeling and testing approach Shirvan and the team not only solidified the understanding of the additional time that ATFs provide in crucial moments, they also provided much-needed clarity to inform the next steps in research.

Software:

MOOSE - A Multiphysics Object Oriented Simulation Environment that allows nuclear fuels and materials scientists to develop numerous applications that predict the behavior of fuels and materials under operating and accident conditions.

BISON - A Finite Element-Based Nuclear Fuel Permormance code applicable to a variety of fuel forms including light water reactor fuel rods, TRISO particle fuel, and metallic rod and plate fuel.

COBRA - Class of code systems for thermal-hydraulic transient analysis of light water reactor fuel assemblies and core. One class, CTF has been adopted for use in the CASL VERA toolset.

MARMOT - Mesoscale fuel performance code with the purpose to predict the coevolution of microstructure and material properties of nuclear fuels and claddings due to stress, temperature, and irradiation damage.

Exposure of three coated pressure tubes to 1200°C steam for 90 minutes and two new severe accident failure modes were identified: Cr coating survived in all three tests, zipping due to presence of manufacturing coating defect took place in top two figures (top fresh, middle post-creep), ductile bending or buckling due to lack of thick oxide layer took place in bottom figure.

PROGRAM HIGHLIGHT

Used Fuel Drying at the University of South Carolina

by Eric Williams for DOE's Nuclear Energy University Program

Dr. Travis Knight, Integrated Research Project (IRP) principal investigator with test chamber and insulation on right.

Deep, highly technical science sometimes leads researchers to facts that bend our notion of logic.

Like the idea that water – tucked alongside spent nuclear fuel in a triple-lined container located in South Carolina – would freeze. Freeze solid.

Of course, that's not the only thing Travis Knight and his co-workers at the University of South Carolina (UofSC) found in their project funded through the Department of Energy's Nuclear Energy University Program (NEUP). But it certainly was the most counter-intuitive.

The project is titled, "Experimental Determination and Modeling of Used Fuel Drying by Vacuum and Gas Circulation for Dry Cask Storage." UofSC leads a project team that includes the University of Florida and South Carolina State University, as well as industry collaborators Orano and Framatome. Notably, the core team includes graduate students, undergraduate researchers, and post-doctoral staff. Research and current industry storage practices show that, while some water may remain in casks during storage, the amount is so small it does not pose a danger to human health or the environment.

"It's something that sounds a bit weird, when you say you are drying spent nuclear fuel," acknowledged Knight, professor and director of UofSC's Nuclear Engineering Programs. "Your neighbor's going to imagine you getting out a towel."

Of course, it's more complex than that. But at its core, dry cask storage is best and safest when it's, well, dry. Or as dry as possible.

Nationwide, the U.S. nuclear fleet generates about 2,000 tons of spent fuel annually, and there are approximately 80,000 tons safely stored – mostly on-site at power plants – awaiting a long-term storage solution. "Eventually, it will go into a geologic repository, or be recycled," Knight said.

"I'm told, round numbers, storage is costing about a million dollars a cask," Knight said. Each cannister holds some 32 pressurized water reactor fuel assemblies, or 68 boiling water reactor assemblies. "There are three vendors putting spent fuel into storage. It's a business, and we shouldn't lose sight of that." Providing accurate data is of the upmost importance to these vendors to prove the efficacy of the techniques.

"There's no such thing as zero in our business," said Rod McCullum, senior director of fuel and decommissioning at the Nuclear Energy Institute (NEI), an advocacy group representing the interests of the nuclear industry. "Really, the question is the 'How much?' An extremely small amount of water is not going to be enough to threaten the integrity of the fuel inside the cask, but a relatively large amount might. The work that Travis and his team have done is critical to having a better understanding of these situations, demonstrating that the amount of water trapped in the sublimation process is small."

View of open test chamber showing installation of mock fuel assembly.

Matthew Shalloo, UofSC graduate student, working with the desiccators.

Shannon Henry, undergraduate research assistant, inserting interchangeable test rod at corner location. Possible test rods include simulated failed fuel rod, BWR water rod, PWR guide tube with dashpot, ordinary fuel rod (in this case with depleted uranium). Rods sticking out of the top of the chamber are the 12 heater rods.

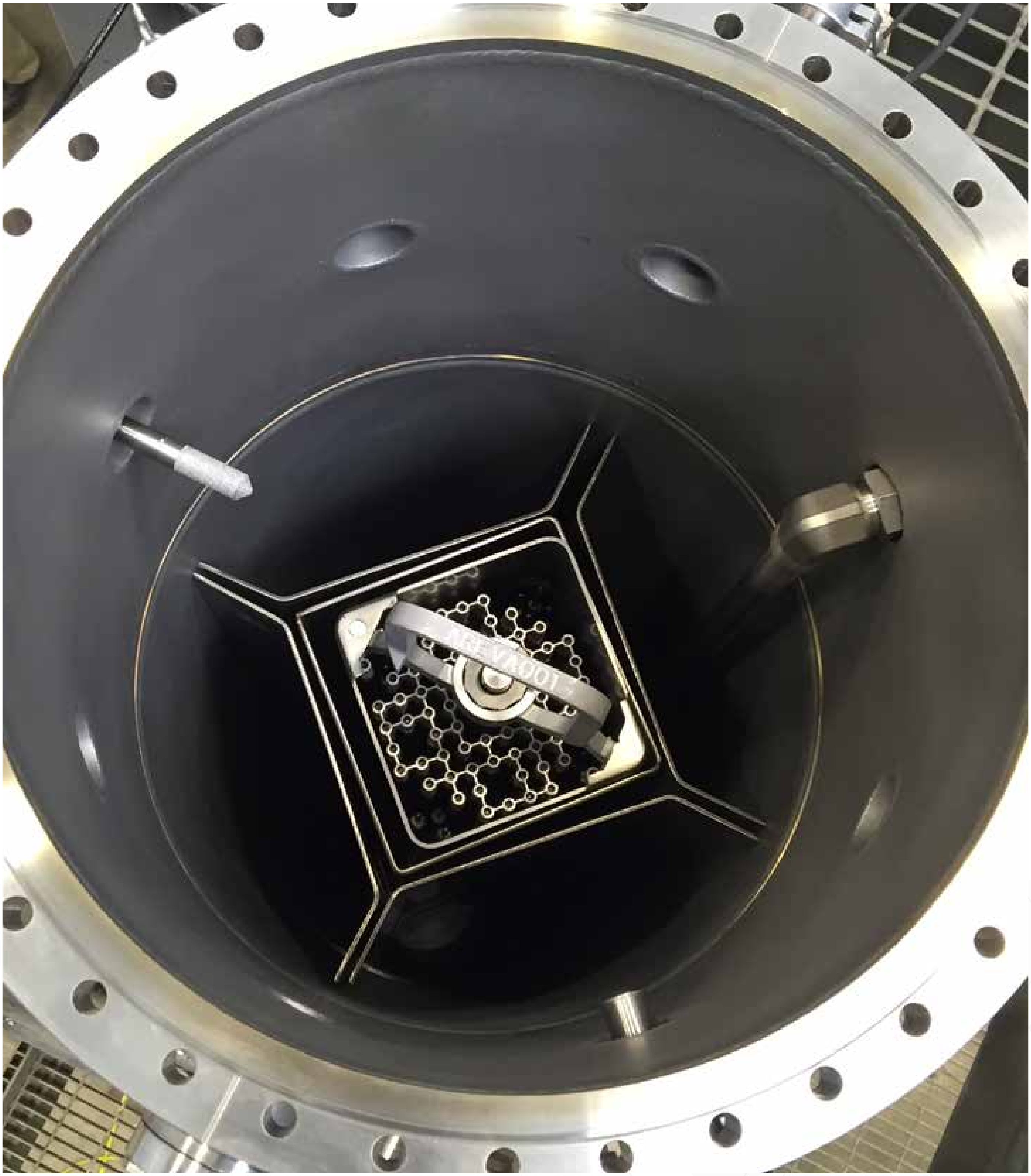
That better understanding concluded that the most likely crevice where water might remain is in a failed fuel rod, though even that amount is extremely small. What water is there is due to the fact used fuel rods are cooled in specially designed pools for approximately five years before being moved to casks.

Water itself isn't the main problem; rather, the concern is that over time, water sealed in a cask will be taken up as corrosion and produce hydrogen gas. Thus, to McCullum's point, you want the 'how much' to be both very little and well-known.

The moment at which pent up hydrogen gas would be the most dangerous is when a cask is opened up. And if in the future spent nuclear fuel is going to be recycled, casks would need to be opened to retrieve it – and the Nuclear Regulatory Commission (NRC) regulations specify that used fuel must be "retrievable."

As the research project title indicates, there are two main methods of extracting water out of a spent fuel cask. One is forced gas dehydration (often described as forced helium drying), and the other is vacuum drying. When you're using a

View of the chamber; third level: Shannon Henry and Jonathan Perry; second level: Matthew Shalloo and Travis Knight.



Top view of open chamber showing mock fuel assembly with basket and rails.

specialized vacuum designed to pull water out of tiny gaps and crevices, freezing is a big problem. Vacuum systems configured to remove liquid water don't do well with ice.

"There's a tube that goes into the cannister, to the bottom, which during some drying scenarios could result in freezing," Knight explained. The bottom of the fuel assembly is colder, due to heat transfer and other factors. "If you are dealing with older, colder fuel, and you try to do things too quickly, you could freeze the tube, giving you a false report of drying."

As with all things in the nuclear energy realm, companies must meet NRC standards regarding water content. "So the question proposed is, 'What is sufficiently dry?'" Knight posited. The answer is determined by measuring vapor pressure inside the cask. "If you evacuate the water from the canister, and it holds the pressure level for 30 minutes, then your canister is sufficiently dry."

Getting the tests to that point, however, takes considerable planning, preparation, and execution. So how did the researchers go about it? Well, first they built a replica to use for testing. Then, as the official project abstract explains, "More than 120 drying tests were conducted using a mock fuel assembly with depleted uranium rods and heater rods to simulate decay heat. These tests followed standard industry practice for vacuum and forced helium drying (FHD)."

Plus, as Knight pointed out, "We instrumented the heck out of it," including everything from relative humidity probes to sophisticated optical emissions monitors, to spectroscopy. The chamber was constructed with six view ports for observation during the tests. Also, in line with the nuclear power industry's safety-first ethic, ceria pellets were used as surrogates for uranium.

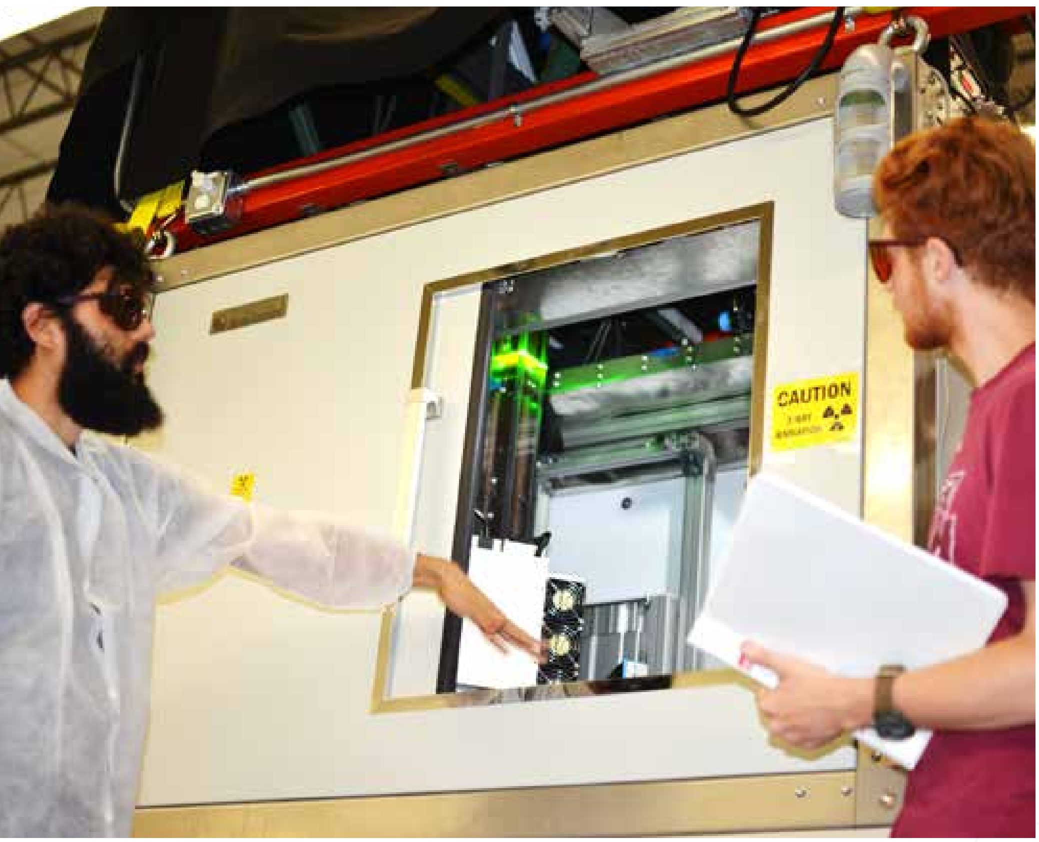
McCullum also praised NEUP and the collaboration and intellectual horsepower it harnesses. He visited the UofSC campus to see the project in person and was impressed.

"I graduated in 1985 {from the University of Cincinnati} and hadn't been on a college campus in years," McCullum said. "I was thoroughly impressed with the level of sophistication, the measuring capabilities, and especially the tremendous human resources involved in this project. Enabling and enhancing programs like nuclear engineering at UofSC allows them to build and maintain their capabilities, and the nation is better off, thanks to that."

NEI's McCullum said the multi-test, as well as considering numerous possible factors, is one of the strengths of the UofSC-led approach. He said the tests "demonstrated that the amount of water that gets trapped in the sublimation process is relatively small," and actually miniscule enough to convince McCullum of its safety.

Infrastructure

Through the Nuclear Energy University Program (NEUP), NE integrates university-led innovation into its technical missions by way of a competitive grant process. Established in 2009, NEUP funds two types of grants: Research and Development (R&D) and Infrastructure. Infrastructure grants have been integral in strengthening the nuclear energy research capabilities of universities across the country.



Students and the experimental system at the Thermal Hydraulic Research Lab (Texas A&M University). The system was awarded by NEUP Infrastructure for high-resolution multiscale measurements of single and multiphase flows featuring X-ray tomography, optical sensors and laser-diagnostics.

This support is often in the form of laboratory equipment. DOE funds two types of NEUP Infrastructure grants: General Scientific Infrastructure (GSI) support and research Reactor Upgrades. The typical amount awarded by the government for a GSI grant is $250,000 (may include cost match). Universities can receive up to $1.5 million for reactor upgrades.

To date, the Department of Energy (DOE) has funded 286 Infrastructure grants at 69 institutions at a value of more than $73 million. Split between two focus areas, GSI and Reactor Upgrades, DOE has funded projects such as a nuclear power plant simulator at The Ohio State University and the replacement of cooling system components at Oregon State University's TRIGA reactor. All 25 university research reactors in the United States have been supported through NE Infrastructure grants,

$73,056,154*

in NEUP infrastructure grants since 2009

	Awards	Universities
General Scientific Infrastructure	**176** awards	**69** different universities
Reactor Upgrade	**103** awards	**24** universities *(out of 24 eligible institutions)*

boosting universities' capabilities for cutting-edge research and for educating the next generation of the nuclear workforce.

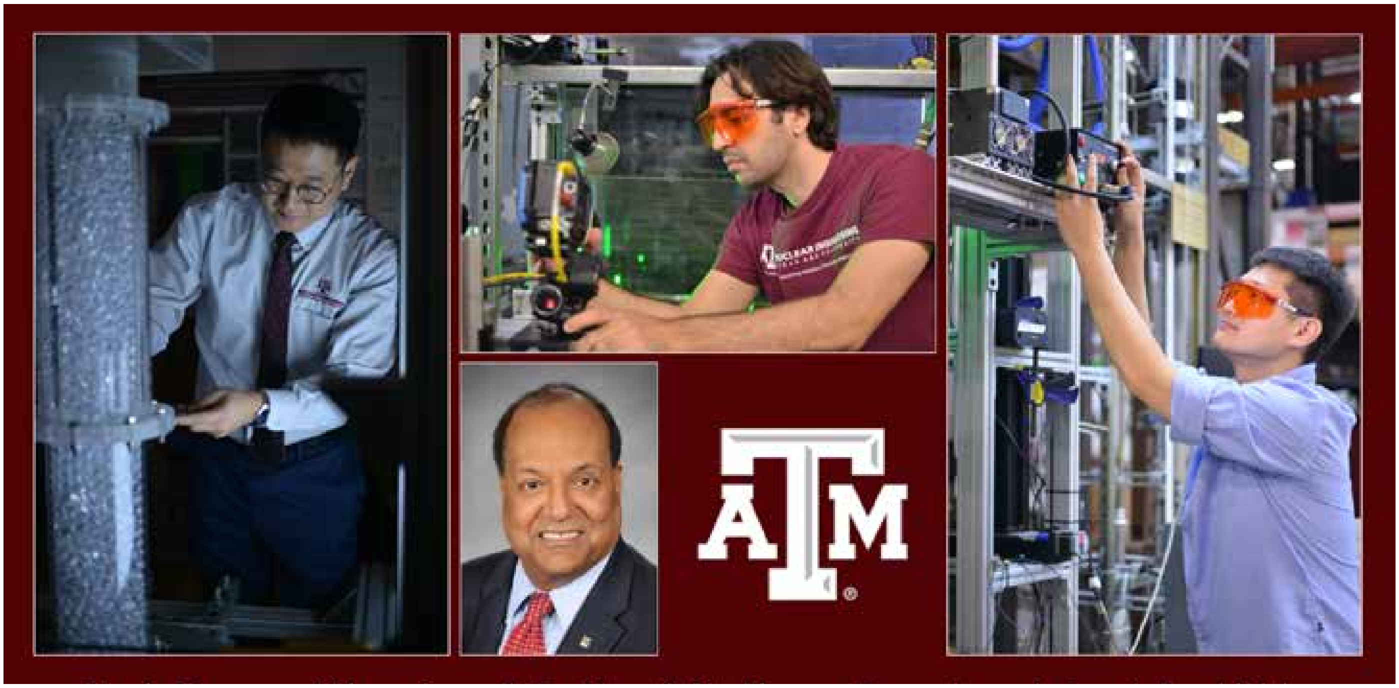
Infrastructure upgrades often develop or strengthen a unique capability beneficial to researchers from more than just the university at which the capability resides. Historically managed by NEUP, the Infrastructure grant process now resides with the Nuclear Science User Facilities (NSUF). NSUF, another program housed under NE, offers free access to NSUF facilities found at universities and national laboratories around the world. Through NSUF's separate competitive peer-reviewed processes, researchers can gain access to NSUF facilities for zero cost. These include the partner facilities found at universities enhanced through NEUP grants.

* $64,649,176 including 7 NEET national laboratory infrastructure projects (2014-2016)

PROGRAM HIGHLIGHT

Nothing to Sneeze at: Nuclear Engineers Do Their Part in the Fight Against Coronavirus

by Paul Menser for DOE's Nuclear Energy University Program



Dr. Yassin Hassan and his students at Texas A&M University: Se Ro Yang (left), Giacomo Busco (top center), and Joseph Seo (right).

When Giacomo Busco got a Saturday night call in spring 2020 from his professor, Dr. Yassin A. Hassan, he was expecting a conversation about thermal hydraulics, computational fluid dynamics, or multiphase flow. For a nuclear engineering student at Texas A&M University, these are what you typically talk about with your professor.

He did not anticipate the question to be, "What do you know about sneezing?"

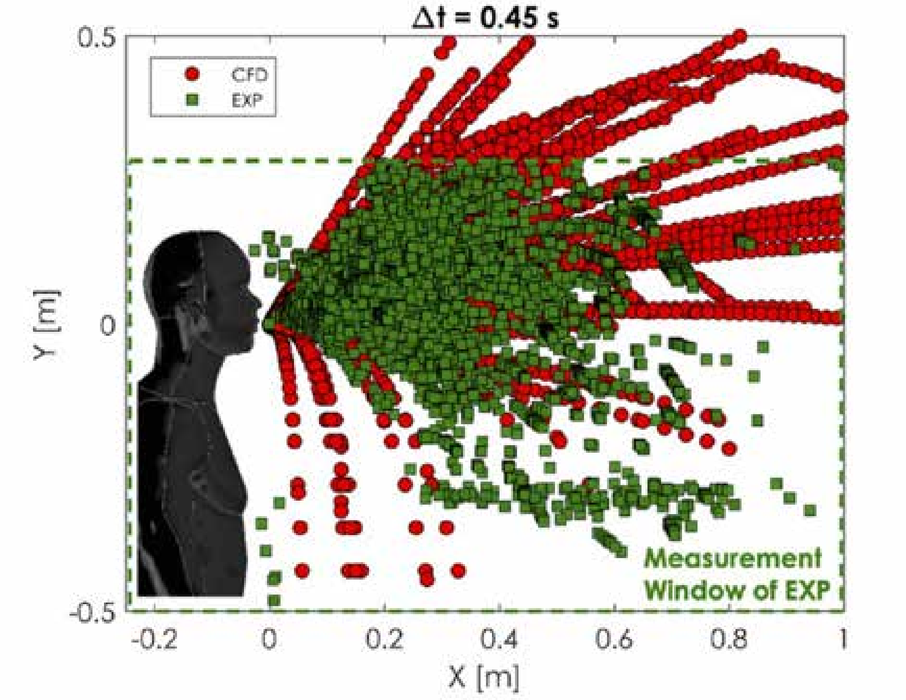
But Hassan, whose honors include membership in the National Academy of Engineering and the American Nuclear Society's Seaborg Medal, had coronavirus on his mind. Because his research interests include fluid mechanics, turbulence and laser velocimetry, and imaging techniques, he thought it might be timely to pursue research into the mechanics of an everyday ah-choo!

More than coughing, a sneeze from an asymptomatic COVID-19 patient has the potential to disperse infected droplets and aerosol particles over a wide pattern. How widely in various conditions—hot, cold, dry, humid, smoggy—was what intrigued Hassan.

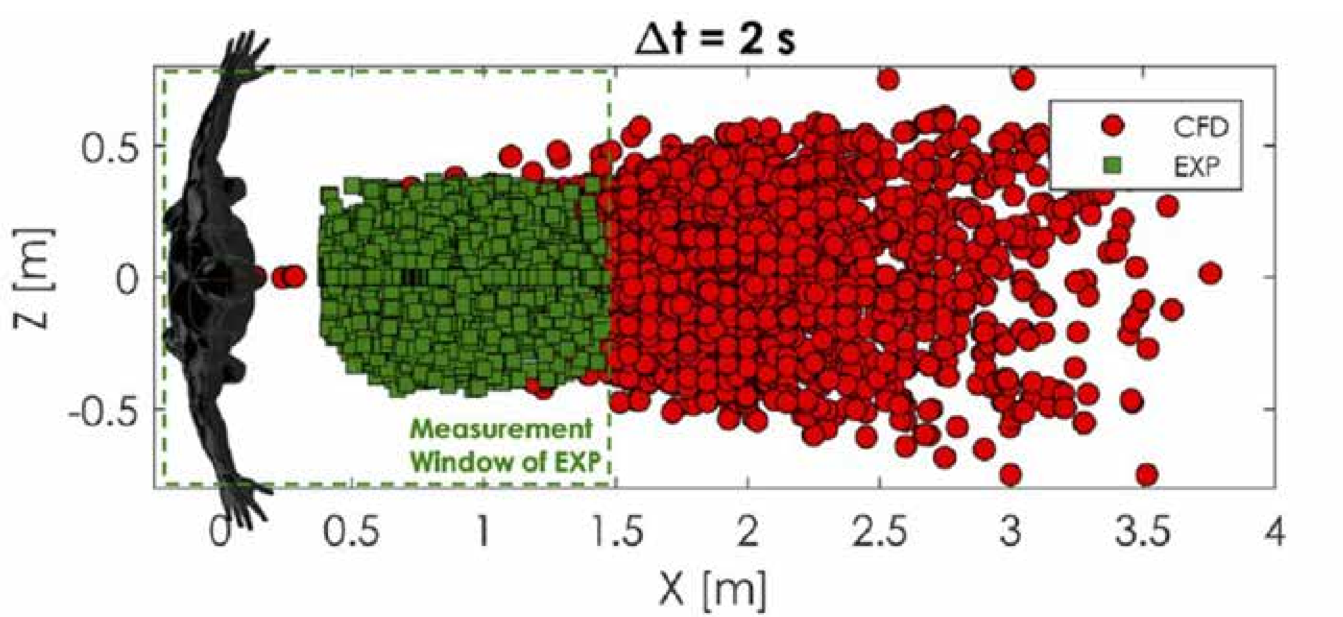
This curiosity resulted in a peer-reviewed article in Physics of Fluids, “Sneezing and Asymptomatic Virus Transmission.” In addition to Busco, the main author, and Hassan, Se Ro Yang and Joseph Seo, also nuclear engineering students at Texas A&M, contributed. Since its publication in mid-July 2020, it has had more than 6,400 views and been cited 22 times. Hassan has received calls from the National Institutes of Health and international organizations.

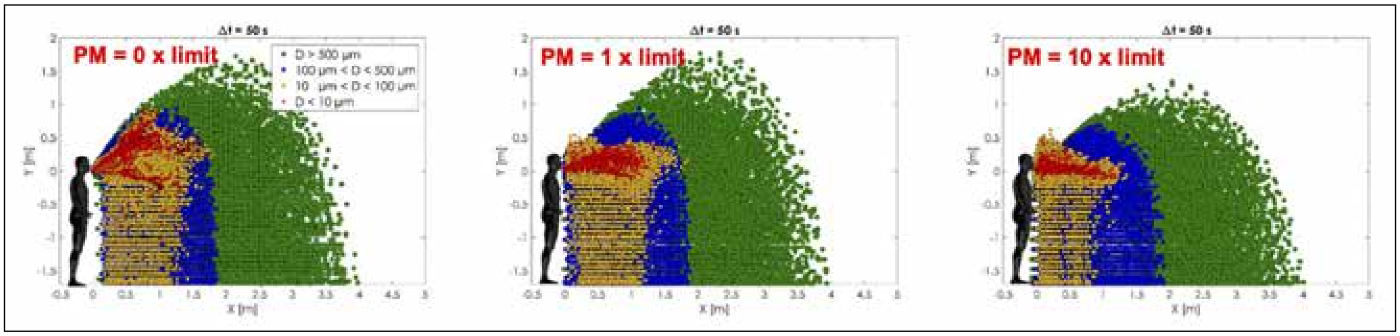
“The reception is unlike anything I’ve ever seen with one of my papers,” said Hassan.

To accomplish this research, the team had the resources of Texas A&M’s Thermal-Hydraulic Research Laboratory, which contains



Comparison of cumulative time distribution of the sneezing droplets. Front view (photo 1) and top view (photo 2). Measurement window of the experiment (EXP) is the dashed line.





It is clearly seen that the air pollution simulated by particulate matter (PM) affects the droplets and aerosol spreading dynamics. Increased PM causes more drag and reduces the spread of the sneeze cloud. The above figures show the increase of pathogen concentration with PM10 & PM2.5. Direct transmission from the droplets and indirect transmission due to deposition of droplets to surfaces should be considered more seriously under the air pollution.

equipment funded through the U.S. Department of Energy's Nuclear Energy University Program. With state-of-the-art high-speed cameras and an infrared camera, they were able to use laser-diagnostics techniques, including particle image velocimetry and particle tracking velocimetry, to characterize flow dynamics of the sneeze.

The team's efforts were aided immeasurably by Yang and his rhinitis. While the journal Rhinology reported in 2002 that a normal person sneezes on average less than four times a day, Yang lets loose around 30 times a day. During the experiments, only Yang was allowed to be in the room. All surfaces were cleaned thoroughly with disinfectant after each sneeze.

Before their paper, existing models for studying sneezes treated the head as stationary and rigid, without any motion or individual variations affecting the predicted dynamics and spatial region covered by the sneeze. By including head motion, Yang and the team developed a more realistic sneezing model for studying complex coronavirus transmission scenarios.

A combination of experimental and computational techniques allowed the group to create a dynamic model that captured the flow characteristics of sneezes a healthy adult might produce. Human factors—specifically head motion and changes in pressure—were incorporated while treating the sneeze as a momentum source.

As they analyzed the cloud spread of a sneeze, they found that one cloud could cover twice as much space as what had been previously thought. The authors also used the technique to factor in humidity, temperature, and air pollution.

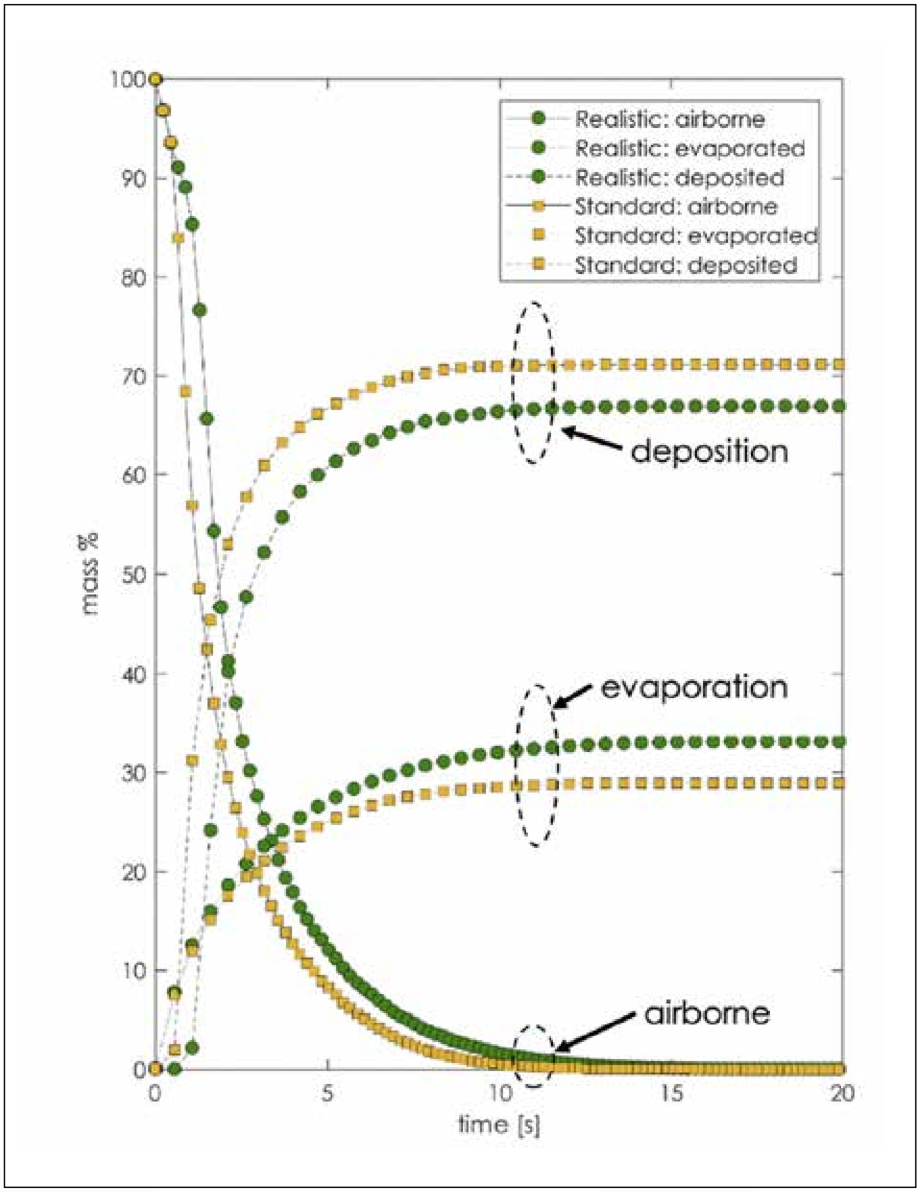
"Is it safer to sneeze in a hot, humid, and polluted city or in a cold, dry, and unpolluted suburb?" asked Busco. "Our study can answer this question."

Busco said he was interested in learning why industrialized northern Italy, where he lives, suffered more from COVID-19 than rural Sicily, at the southern end of Italy. Pollution could be one factor, which strengthened his belief that nuclear power can offer cleaner air and better health for everyone.

By customizing computational conditions to alter flow pattern like air circulation, the sneeze cloud model can be adapted to specific settings, such as a particular office or factory. The group is currently using their model to optimize some of their university classroom setups in anticipation of reopening, in addition to aiding the rail transport industry to manage seating.

Whether it's studying turbulent flow in a reactor or droplets and aerosols dispersed in a sneeze, the physical phenomena and the validations of the models through experimentation have similarities, Busco said. "Human factors are critical in nuclear operations and the spread of coronavirus. The physics are similar."

As members of the engineering research community, the team saw its role as an important one, developing tools and engineering solutions that might aid humanity in its defense against a deadly pandemic. "It is extremely important to create a modern, reliable computational framework that is able to simulate different scenarios while containing as much physics as possible," the article said.



Evaporation, deposition, and residual airborne percentage of the initial ejected mass. Comparison of the conventional (standard) model with the present (realistic) model.

PROGRAM HIGHLIGHT

Online College Benefits from NEUP Grant: Funds allow Excelsior to offer degrees to people in industry and military

by Paul Menser for DOE's Nuclear Energy University Program

Michael Johnson, currently adjunct faculty at Excelsior College.

While the COVID-19 pandemic has accelerated the trend, online learning and nuclear engineering have been moving toward each other for more than a decade. One of the leaders has been Excelsior College, an online school based in Albany, New York.

In 2018, Excelsior was able to purchase a generic pressurized-water reactor simulator through a $245,000 grant from the U.S. Department of Energy's Nuclear Energy University Program (NEUP). Used in five required courses in the online bachelor's program, the simulator is an essential tool in helping students understand both basic and advanced concepts.

Michael Johnson, former associate dean of technology in the School of Business & Technology, led the effort for online learning at Excelsior. "When I was in the nuclear navy, Admiral (Hyman) Rickover never believed in simulations," Johnson said. "Students were to run equations." He doubts Rickover would approve even now, but Johnson believes running equations and checking them against simulation results provides valuable information and aids critical thinking.

Johnson has a unique background in that he is a two-time Excelsior graduate himself. His experience dates back to when he was in the Navy, serving as a nuclear limited duty officer in Norfolk and attending night school. Through the base's education office, he discovered that Regents College (Excelsior's original name) would allow him to take exams that would earn him the upper-level credits he needed for a bachelor's degree in sociology.

Once he earned his bachelor's, he stayed in the Navy, refueling reactors aboard the U.S.S. Enterprise while studying for a master's in management at the Florida Institute of Technology's satellite campus in Norfolk. He followed up by earning—online—a doctorate in organizational leadership, but he realized that to get ahead in a technical field he needed a technical degree.

That was when he enrolled in Excelsior's nuclear engineering technology program, earning his bachelor's. The experience was so positive that he stayed connected with Excelsior. While working at a commercial nuclear power plant, he became the school's subject matter expert for thermodynamics and also taught the capstone course in the technology program.

Johnson became Excelsior's faculty program director for energy management in 2014. For three years, he applied his nuclear industry experience to the school's curriculum. Recognizing the industry's demands for structure and attention to detail, he revised the program's capstone course. And, at a conference in 2017, he was able to observe how North Dakota's Bismarck State College was using a simulator. He approached Excelsior's leadership about buying one and was told to go ahead—if he could find the money.

He found the NEUP online. Established in 2009, NEUP funds nuclear energy research and equipment upgrades at colleges and universities across the United States. The infrastructure grant to Excelsior in 2018 was one of nine grants totaling $1.96 million. At the time of the award, Johnson called it "an incredible success" for the college, pointing out that other awardees included Massachusetts Institute of Technology, Pennsylvania State, and the University of Florida.

"(This) is indicative of the unrivaled reputation that Excelsior has achieved," he said. "With faculty that have extensive industry experience and now the opportunity to build a world-class online simulator, this puts Excelsior College in the front rank of global centers of excellence in nuclear technology."

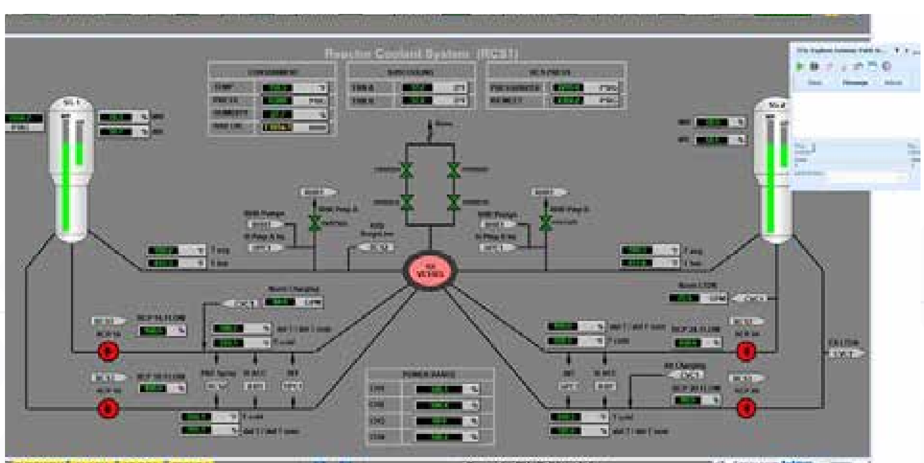
Overview page of a Westinghouse pressurized water reactor illustrating the major systems in the plant. Students are able to monitor system parameters and have a better understanding of system interrelations (left). Graphical representation of reactor plant response during a reactor scram. Students observe the system response and explain why certain parameters change (right).

Johnson estimates that between 300 and 400 students enroll in the Energy Management Program each year. The college has partnered with the non-profit Energy Providers Coalition of Education (EPCE), as well as energy industry giants such as Exelon Corporation. Since Exelon joined the EPCE and began offering employees the opportunity to earn a degree from Excelsior, more than 2,200 students have earned a bachelor's in nuclear engineering technology.

ABET accreditation (Accreditation Board for Engineering and Technology) means a national non-governmental organization has reviewed the program and found that it meets certain standards for successfully preparing graduates for jobs in engineering and technology fields. For Excelsior, the hardest part of gaining accreditation was convincing the ABET panel that the online learning platform is valid, Johnson said. "We demonstrated to them that online students get more attention and feedback from instructors than they do at brick-and-mortar schools."

Johnson has a special affinity for military service members balancing work with education, especially online learners. "I was in their shoes. I walked in their path to get to where I am," he said. Even as he heads into semi-retirement, he plans to keep a hand in teaching. With so many people retiring from the nuclear industry, there is a definite need for young engineers to fill the ranks.

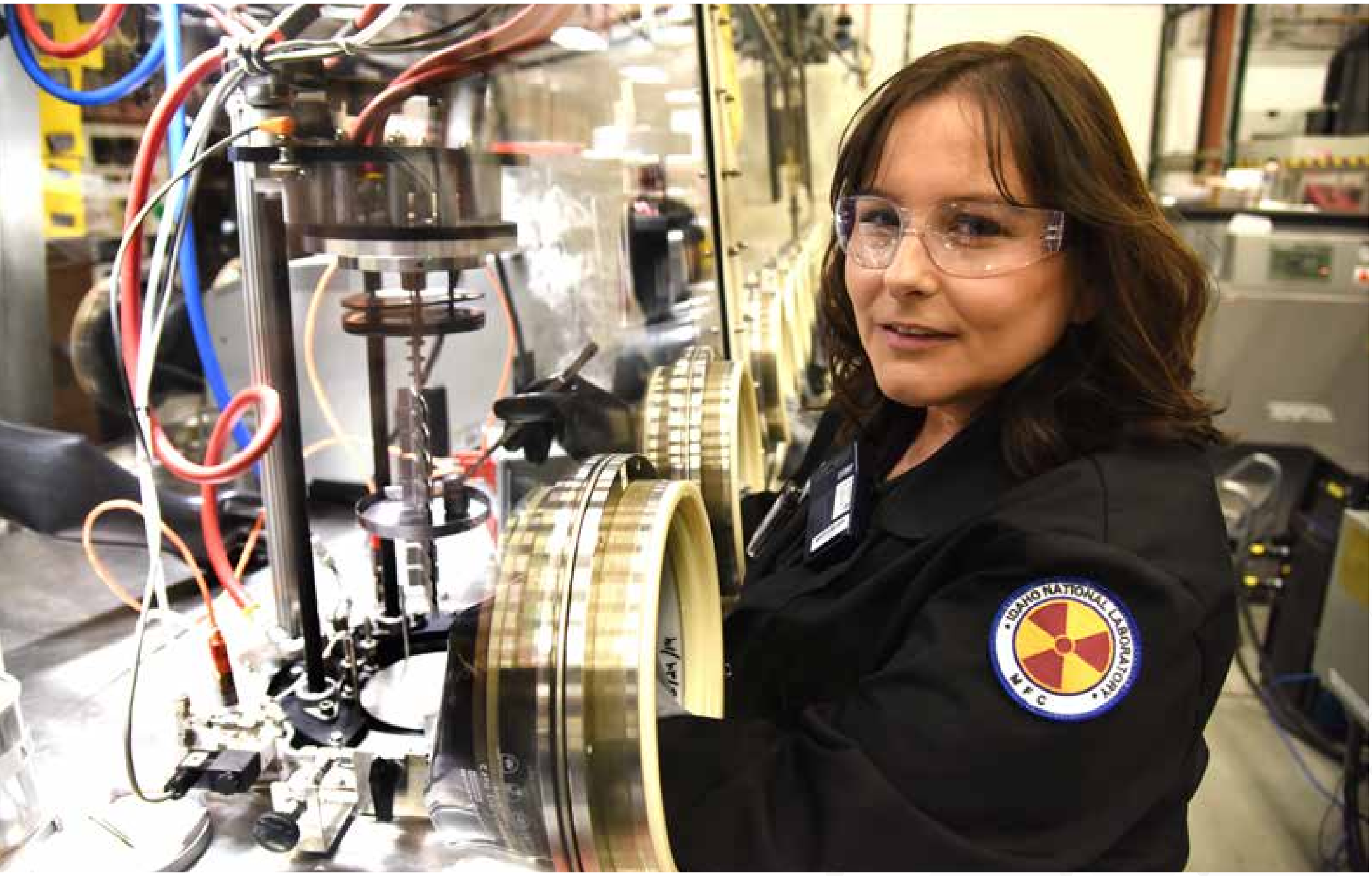
"I expect it to grow," he said. "I'm keeping an eye on the small modular reactor programs. To me, that's the path."



Reactor coolant system for a Westinghouse pressurized water reactor. Students can monitor system parameters and observe how the system responds to various transients.

Student Support

The Office of Nuclear Energy's (NE) Integrated University Program (IUP) funds undergraduate scholarship and graduate fellowships as part of the U.S. Department of Energy's (DOE) ongoing commitment to educating the next generation of nuclear scientists and engineers. NEUP research projects also support research roles for students ranging from undergraduates to post-doctoral researchers.



Jennifer Watkins, 2018 IUP Fellow from Boise State University, loading fuel into the refractory metal sintering furnace located inside the high density fuels glovebox at the Idaho National Laboratory.

IUP and NEUP have supported more than 2,500 undergraduate and graduate level students in obtaining science, technology, engineering or math (STEM) degrees.

The vast majority of IUP Fellows have gone on to start their own companies, work in industry, become faculty members at distinguished universities or researchers at national laboratories. Students funded by NEUP on research and development (R&D) projects are not tracked past graduation, but many of these students are active in the nuclear academic, national laboratory and industry communities.

929
IUP Scholarship & Fellowship Recipients

341 Fellows

588 Scholars

Nuclear Energy Graduate Fellowship Program

4-Year Colleges/Universities

$161,000 over 3 years

- Enrolled in an UNLP-approved college or university
- GPA of 3.5 or higher at both the undergraduate and graduate levels
- Entering their first or second year of overall graduate study
- U.S. citizens or legal permanent residents
- Studying nuclear science or engineering, or a related field

Undergraduate Scholarship Programs:

4-Year College/ University Scholarship Program

$10,000 for 1 year

- Enrolled in an UNLP-approved college or university
- Minimum 3.0 GPA
- Completed at least one semester of undergraduate study to apply
- U.S. citizens or legal permanent residents
- Studying nuclear science or engineering, or a related field

2-Year Trade School & Community College Scholarship Program

$5,000 for 1 year

- Enrolled in an UNLP-approved trade school or community college
- Minimum 3.0 GPA
- Entering first or second year of undergraduate study to apply
- U.S. citizens or legal permanent residents
- Studying nuclear science or engineering, or a related field

PROGRAM HIGHLIGHT

IUP Fellow Dr. Kathryn Metzger: The Art of Engineering

by Eric Williams for DOE's Nuclear Energy University Program

Particle Spray (sculpting gel, acrylic, gold leaf on canvas): Based on the particle spray resulting from the reaction of 32S+ 197Au at 6.4 TeV (Stable sulfur isotope with 16 neutrons incident on a heavy and stable gold nucleus with a comparable 118 neutrons). Painted by Kathryn Metzger and included in her undergraduate thesis.

When the physics majors at the University of South Carolina (UofSC) handed in their honors theses in 2009, one stood out.

"I think our professor intended for them to be research papers," Kathryn "Kallie" Metzger recently recalled. "But I noticed my friends in the arts were having more fun than we were." As a result, her thesis included 13 of her original paintings, ranging from the helix nebula (oil on canvas) to a particle spray (sculpting gel, acrylic, and gold leaf on canvas).

Today Metzger is the advanced fuels development lead for Westinghouse Electric Company, bringing a broad-spectrum, creative approach to the field. "There is a nice parallel between painting a new image and making a new product," she said. "If you're developing a new material, in the commercial world, research and development is an iterative process, the same as painting on canvas."

Since her undergrad days at UofSC, Metzger has developed strong technical chops by excelling in the academic, national laboratory, and private-sector worlds. A South Carolina native, she earned her masters and PhD in nuclear engineering from UofSC; as an Integrated University Program (IUP) Fellow, her doctoral work focused on accident tolerant fuels (ATF) and cladding systems, including material testing, characterization, and fuel performance modeling and simulation.

"If I hadn't had the fellowship, I don't know if I would have had the opportunity to go from a master's to a PhD," she said. "I do know I wouldn't have been able to go to conferences and attend other meetings that help build strong relationships in the nuclear community." Those ties, in turn, are invaluable when working across multiple public and private platforms.

After her schooling, Metzger worked in nuclear materials at both Savannah River National Laboratory and Idaho National Laboratory, deepening her expertise in irradiation testing, microstructural characterization, and fuel performance modeling. She has also carved out time to volunteer, having served on the Advanced Test Reactor-National Scientific User Organization's executive committee, and currently as chair of the American Nuclear Society's Materials Science and Technology Division. In addition, she represents Westinghouse on the Nuclear Energy Advanced Modeling and Simulation (NEAMS) Light Water Reactor and Advanced Reactor Industry Councils.

Above left to right: Jeff Leong (Westinghouse), Adrian Wagner (Idaho National Laboratory), Tom Morello (Exelon), and Kallie Metzger (Westinghouse). Westinghouse and its partners have developed EnCore® Fuel as part of the U.S. Department of Energy's (DOE) Accident Tolerant Fuel Program. The Westinghouse-Exelon EnCore® Fuel Lead Test Rod (LTR) Program marked the first insertion of EnCore® Fuel rod assemblies into a commercial nuclear power plant. These two lead test assemblies contain chromium-coated zirconium cladding for enhanced oxidation and corrosion resistance, higher density ADOPT™ pellets for improved fuel economics, and uranium silicide pellets. Photograp

"My focus is the pellets inside the fuel rod," she said recently. "I have an appreciation for all materials within the fuel cycle, but I get nerdy about the fuel pellets."

Indeed, Metzger relishes getting nerdy when delving into the benefits of advanced fuel materials like uranium nitride (UN) and uranium silicide (U_3Si_2). In 2016, for example, she completed her doctoral thesis, Analysis Of Pellet Cladding Interaction and Creep of U_3Si_2 Fuel for Use in Light Water Reactors, under advisors Travis Knight and Elwyn Roberts.

Metzger's dissertation noted advanced and high-density fuel pellets offer "a number of advantageous thermophysical properties, including high density, high thermal conductivity at room temperature, and a high melting point." These properties support goals of accident tolerance while higher uranium density is capable of supporting uprates to the Light Water Reactor (LWR) fleet.

"Too often physics is dismissed as complex, intimidating, or even boring. The aim of my senior art exhibit was to dispel these misconceptions through art. An interdisciplinary art exhibition allowed individuals from all walks of life to experience and learn about physics in a lecture-free format. Brochures were available at the art exhibit to clarify physics terminology and to enhance the viewer's understanding of the relationship between physics and art."

"The Bubble Chamber and Particle Series is inspired by actual bubble chamber images. I selected a transparent cyanic blue for many of the bubble chamber images because it reminded me of Cherenkov radiation and emphasized the liquid background of the bubble chamber traces. The colors in the Bubble Chamber series are bright and vibrant to suggest the energy movement and activity of particles in a detector. The galaxy and nebula series is an investigation into the origins of cosmic rays using images from the Hubble telescope. Cosmic rays are energetic particles from outer space that rain down on the Earth's atmosphere and can be observed through a variety of particle detectors. The relationship between the far reaches of the galaxy and particle traces observed in man-made bubble chambers was something I attempted to portray through the artwork. In total, 15 pieces of art were shown."

Dr. Kathryn Metzger,
undergraduate honors thesis

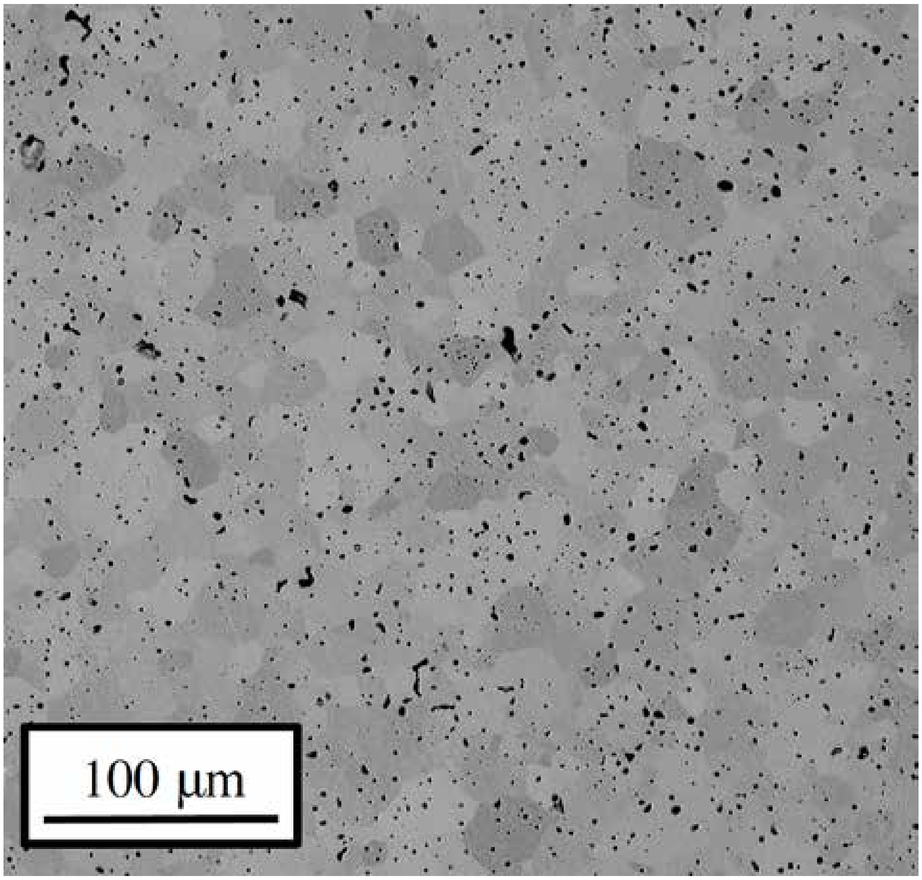


Image shows high density microstructure of Uranium Nitride fuel pellet, produced by Los Alamos National Laboratory (LANL). Image provided courtesy of Josh White, LANL. Dr. White is leading both UN fuel fabrication and thermal mechanical testing in support of the Westinghouse ATF program.

Energy density is one of the attributes she finds especially important. And she has a way of merging her understanding of the complex with her ability to frame things in simple terms. "If you have more uranium atoms in there, that ultimately dictates how much power you'll get from the fuel pellet – it's an economic benefit to the plant," she said, adding "Everyone recognizes we have a need for reliable, energy dense, power. We already have it in nuclear. As developing countries grow and commercialize and want the amenities afforded by electricity, nuclear is a critical part of the solution."

In an abbreviated description of its ATF fuel products, Westinghouse says "chromia (Cr_2O_3) and alumina (Al_2O_3) doped UO_2 pellet, known as our ADOPT™ pellet, will be enhanced for the first phase of the EnCore® Fuel Program. The improved ADOPT™ pellet design achieves greater uranium efficiency" through attributes such as a higher creep rate, higher thermal stability and, of course, density. Higher density fuels like nitrides and silicides provide the opportunity for significant improvements to uranium density and fuel cycle economics.

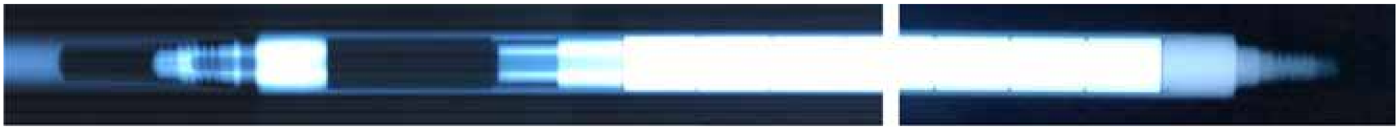


Image shows U_3Si_2 rodlet loaded in Byron Unit 2 as part of Encore® LTR program. Two ATF LTRs were inserted in April 2019. LTRs contained chromium-coated cladding, ADOPT™ doped UO_2 pellets, and U_3Si_2. $U_3Si_2$was inserted in the form ~12 inch rodlets as shown in figure below. First cycle ATF materials are due to be removed in fall 2020. Photo courtesy of Westinghouse Electric Company, LLC.

Two lead test fuel assemblies from Westinghouse-Exelon EnCore® Fuel Lead Test Rod (LTR) Program. The assemblies contained chromium-coated zirconium cladding for enhanced oxidation and corrosion resistance, higher density ADOPT™ pellets for improved fuel economics, and uranium silicide pellets. Photo courtesy of Westinghouse Electric Company, LLC.

Image taken from panel discussion on Accelerated Fuel Qualification (AFQ), as part of Atomic Wings Lunch and Learn Series. Left to right: Kallie Metzger (Westinghouse), Chris Stanek, (Los Alamos National Laboratory) Adam DeMella (Professional Staff Senate Appropriations Committee), Ron Faibish, (General Atomics), U.S. Representative Chuck Fleischmann (House Appropriations Committee), Andy Griffith (DOE-NE), Michelle Harstine (DOE), and John Monninger (NRC).

Westinghouse fuels benefits from a number of collaborations with universities and national laboratories via the DOE Accident Tolerant Fuel Program. In December of 2018, Idaho National Laboratory (INL) announced U_3Si_2 pellets had been manufactured in the lab, noting "The new pellets use a mixture of uranium and silicon instead of uranium and oxygen, to achieve a higher density of uranium atoms per pellet – leading to longer operation times, increased power outputs and higher burnups."

Today Kallie plays a key role on the Westinghouse team advancing fuels, including leading the uranium nitride development and testing. "We're among the first to look at the uranium nitride potential for LWRs. We're asking, 'How will it perform in a reactor?' "Working with our collaborators, we are able to make slight changes to the fuel microstructure and composition with the end goal of improving uranium nitride performance and

Bubble Chamber II (oil on canvas): Based on particle traces produced in CERN's first liquid hydrogen bubble chamber. Painted by Kathryn Metzger and included in her undergraduate thesis.

behavior. Such advancements ensure that the fuel remains suitable and compatible with its environment during both normal operation and off-normal events."

Finding suitability and compatibility is at the core of science and engineering, in nuclear power and myriad other fields. Viewing things from an atypical perspective is an inborn trait for Metzger.

"I admit I approach problems abstractly," she said. "I'm ok asking the weird questions and thinking outside the box."

Kallie is a strong believer in the benefit of non-traditional approaches. One might not think to put experimentalists and modelers in a room and get them talking but it makes natural sense to her. She is a strong champion of integrated experiments and modeling-simulation. "When we use a continuous loop of modeling-informed experimentation, we accelerate our material development and commercialization timelines. This process, referred to as Accelerated Fuel Qualification (AFQ), aims to reduce lengthy fuel development and licensing timelines."

One might conclude that her jam-packed schedule today would preclude Metzger from creating new art, but that's not the case. "I still paint," she said. "Just smaller and usually watercolor. These allow me to complete a small doodle in an afternoon."

Kallie Metzger, PhD (Advanced Fuels Development Lead, Accident Tolerant Fuels, Westinghouse), and Chris Stanek, PhD (Joint Modeling and Simulation Program National Technical Directory, Los Alamos National Laboratory). Photo taken during Atomic Wings Lunch and Learn Series on 'Accelerating Qualification of New Nuclear Fuel'. Stanek and Metzger were panelists supporting the combined use of advanced experimental techniques and modeling and simulation.

Left to right: Jeff Leong and Kallie Metzger (Westinghouse). Westinghouse and its partners have developed EnCore® Fuel as part of the U.S. Department of Energy's (DOE) Accident Tolerant Fuel Program. The Westinghouse-Exelon EnCore® Fuel Lead Test Rod (LTR) Program marked the first insertion of EnCore® Fuel rod assemblies into a commercial nuclear power plant. These two lead test assemblies contain chromium-coated zirconium cladding for enhanced oxidation and corrosion resistance, higher density ADOPT™ pellets for improved fuel economics, and uranium silicide pellets. Photograph shows inspection of U_3Si_2 pellets prior to loading in segmented rod. Photo courtesy of Westinghouse Electric Company, LLC.

PROGRAM HIGHLIGHT

CEO Credits IUP Support for Freedom in Innovation

by Paul Menser for DOE's Nuclear Energy University Program

Dr. William Sames with former Secretary of Energy Rick Perry and HTS IC employee Dale Lawhorn, giving the Texas A&M (TAMU) "Gig 'em." (Sames and Perry are both former TAMU students.) Photo taken at the InnovationXLab℠ Advanced Manufacturing Summit event sponsored by the Office of Technology Transitions in May 2019 at Oak Ridge National Laboratory.

As CEO of a company involved in additive manufacturing and diffusion bonding, William Sames recognizes he's traveled a different road from most PhD researchers who've received help from the Department of Energy's Integrated University Program (IUP). What's most striking, however, is the path of commerce has gone full circle, back to his nuclear roots. "I went into business," said Sames, who heads HTS International Corporation (IC). "Commercializing technology is a challenge I like."

HTS IC operates sales and research and development (R&D) for HTS IC d.o.o. of Slovenia and provides engineered thermal management solutions for tooling components in the injection molding and die casting industries.

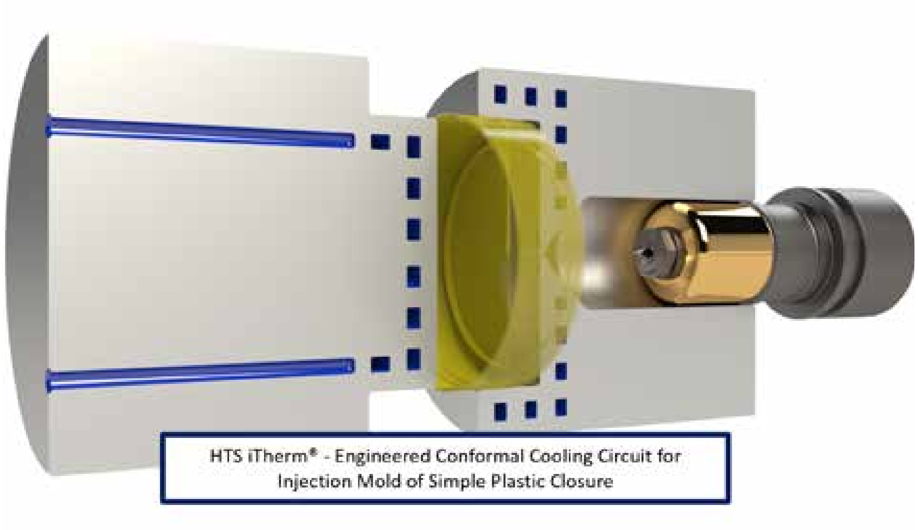
Today, after doing business with automotive, packaging, and medical device manufacturers, Sames and his company are manufacturing vessel components for Oak Ridge National Laboratory's (ORNL) Transformational Challenge Reactor (TCR), a program to dramatically change how reactors are designed and constructed.

Sames received both an IUP Scholarship while an undergraduate at Texas A&M University, and an IUP Fellowship in 2012 to pursue his doctorate in nuclear engineering. In 2009, the undergraduate scholarship afforded him the freedom to be patient. "I was able to wait for the right research job on campus," he said. "It gave me some flexibility to get involved with the research I wanted to do."

As for the fellowship, it wasn't a sure bet. His application was initially passed over, and he had gone to an internship with Westinghouse's Nuclear Fuels Group in Pennsylvania when he got word that someone had dropped out and it was available after all.

"I had a plan for what I wanted to do with it," he said. His dissertation research focused on the development of Inconel Alloy 718 as a production material for use in the Arcam EBM® electron beam melting additive manufacturing process. Inconel 718 is a high-strength, corrosion-resistant nickel chromium material that can be readily fabricated.

Sames said he had an ally at Texas A&M in Sean McDevitt, director of the Nuclear Science Center and head of the university's materials group. "He was very supportive of me," he said. As he became more focused on metal additive manufacturing, IUP funding gave him the freedom to explore what resources were available within DOE's national lab system.



iTherm® conformal cooling, which is produced by HTS IC's MFT™ DBAM.

In 2011, the possibilities of 3D printing were only starting to be realized. With IUP funding in hand, Sames reached out to ORNL and Ryan DeHoff, the laboratory's metal additive manufacturing lead in the Manufacturing Demonstration Facility (MDF). Sames became a visiting research fellow at MDF, which allowed him to gain extensive metallurgy training and improve his professional network.

After earning his doctorate in 2015, Sames founded Additerra, a small company in Knoxville focused on additive manufacturing with metals and polymers. The following year he became CEO of HTS IC.

He maintained his ties with ORNL, as HTS IC and the national laboratory signed an agreement to collaborate on advanced manufacturing research in 2017. This was when HTS IC was

"The Department of Energy invested in our education as IUP Fellows. It is our duty to work hard to give our country a return on investment. For me, that means trying to do the hard things like commercialize technology and create technology-based jobs that didn't exist before."

– Dr. William Sames

HTS IC's part is the shiny one, front right. This is a header for the TCR reactor vessel, which makes use of HTS IC's technology to embed sensors and thermal insulation, in addition to complex fluid passageways for reactor coolant. HTS IC's Metal Fusion Technology (MFT™) is a type of diffusion bonding additive manufacturing (DBAM) and was used to produce the component in coordination with the ORNL TCR team.

preparing to launch a series of products under its iTherm® brand. Establishing a collaboration with ORNL to test and validate the iTherm® tool plates and inserts was the first step toward the standardization of conformal cooling for the injection molding industry. Through the collaboration, HTS IC managed to cut molding cycle times by more than 50%, enabling parts to be produced at twice the usual rate and eliminating scrap that can be caused by uneven temperature distribution, polymer warpage, casting porosity, and soldering.

Using diffusion bonding to fabricate heat exchangers offers strength far superior to brazing. "It has no weak areas," Sames said. "The bond is no longer the weak point. Instead, it's the material. You can make very big pieces, and to me that is very exciting."

HTS IC's involvement with the TCR project began in 2019, when the company won the opportunity to manufacture vessel components with advanced additive manufacturing technology. In addition to fabricating complex fluid passageways for reactor coolant, the work involves embedding sensors and thermal insulation.

William Sames holding Inconel 718 fabricated by Arcam EBM® electron beam melting additive manufacturing, standing next to the machines at the ORNL MDF, where the DOE IUP-funded research was completed.

With the COVID-19 pandemic affecting HTS IC's sales to the automotive sector, TCR also has proved to be something of a lifeline. "We have been able to refocus on other R&D projects as a business," Sames said.

Although he recognizes that many of his PhD peers are more comfortable at universities and in laboratories, as a person in business, Sames would like to see more people with his mindset take advantage of the Nuclear Energy University Program and IUP Scholarships and Fellowships.

"DOE invested in us, in our education as IUP Fellows," he said. "It is our duty to work hard to give our country a return on investment. For me, that means trying to do the hard things, commercializing technology, and creating technology-based jobs that didn't exist before."

"I see both ends of it," he said. "I think these programs are so important. I want to see things that get the best and the brightest out into industry."

"Participating on the TCR project was a career moment for me. I started my studies in nuclear engineering and then researched metal additive manufacturing at the ORNL Manufacturing Demonstration Facility during my IUP Fellowship. Bringing HTS IC's novel technology to the project felt like coming full-circle in my career as this is just the start of the synergy between advanced manufacturing processes and the development of next generation small and microreactors."

– Dr. William Sames

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