College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

FALL 2023 NEWSLETTER

NUCLEAR ENGINEERING AND ENGINEERING PHYSICS

ELITE FACULTY

Leading groundbreaking research in reactor safety analysis

Greetings from Madison!

Conversations about nuclear energy—fission and fusion—are on the rise around the country, including here in Wisconsin. As national leaders in nuclear engineering, we have a valuable role to play in these conversations, whether joining in directly or connecting groups to our networks of experts.

In March 2023, as the chair of the Nuclear Engineering Department Heads Organization (NEDHO), I participated in a series of events in Washington, D.C., along with Assistant Professor Stephanie Diem, to clarify the importance of both fission and fusion energy in the nation's energy mix. In addition to meeting with legislative staff as part of the NEDHO Hill Day and the Fusion Day on the Hill, we teamed up to provide a lunchtime keynote on recent advances in fusion energy for the UW Day on the Hill.

In April, the Customers First Coalition chose "Exploring the role of nuclear power in Wisconsin's energy generation mix" as the theme for its "power breakfast." In addition to joining a panel that included policymakers, utilities and non-governmental organizations, I helped to connect the coalition to the U.S. Department of Energy (DOE) and Nuclear Energy Institute (NEI) to share their perspectives. DOE provided an update on federal policy and how it is supporting a new generation of nuclear power plants, while NEI described the unprecedented level of activity happening in state legislatures around the country.

In June, I was honored to be elected fellow of the American Nuclear Society, the organization's highest membership status.

In July, Professor Chris Hegna (Type One Energy) joined alumnus Ross Radel (Shine Technologies) and affiliate Professor Cary Forest (Realta) on a panel for the Wisconsin Technology Council to discuss the emerging fusion industry in southeast Wisconsin and the roles for their companies in seeing it come to fruition. Tech council President Tom Still started this conversation by reaching out to our department, and he published an opinion piece in the *Wisconsin State Journal* highlighting Wisconsin's role in leading the development of fusion energy technologies.

Also in July, the conversation about nuclear energy took me to an unlikely place: the Midwest Renewable Energy Association's Energy Fair in Custer, Wisconsin. I was invited to appear on the "Rise Up" podcast series hosted and produced by the group's executive director. Both the podcast and the live appearances allowed a conversation about how small nuclear energy systems can better fit into a more decentralized energy system of the future.

In addition, we have been working to increase access to the UW Nuclear Reactor as a focal point of community interest. In addition to monthly open houses for the UW-Madison campus community and frequent tours for outside groups, it was the centerpiece of a visit from Wisconsin legislators wanting to know more about the university's role in an expanded nuclear energy future.

Finally, behind the scenes, Professor Oliver Schmitz has been leading the Clean Energy Community Initiative, which aims to better understand how the College of Engineering can directly support the clean energy transitions of urban, rural and tribal communities around Wisconsin. With support from the Department of Life Sciences Communications and the Nelson Institute for Environmental Studies, this initiative will build enduring partnerships with communities, providing enhanced expertise and resources to assist in making future energy decisions, while better informing our researchers about the near-term needs and priorities of communities.

The Wisconsin Idea is alive and well in our department. On, Wisconsin!

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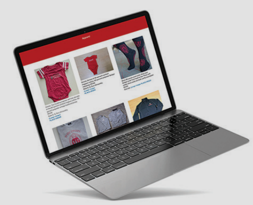

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Researchers are now using the Pegasus-III fusion experiment to study innovative plasma startup techniques. Pictured above, Assistant Professor Stephanie Diem (left) discusses an experiment with graduate students Louise Ferris, Carolyn Schaefer and Tim Tierney. Photo: Joel Hallberg.

New Pegasus-III fusion experiment off to a flying start

After years of work that involved assembling tens of thousands of components, construction of the new Pegasus-III fusion experiment at UW-Madison is finished, and researchers have begun experiments that will advance the field of fusion energy.

Supported by the U.S. Department of Energy's Office of Fusion Energy Sciences, the new Pegasus-III experiment provides a dedicated domestic platform to study innovative techniques for starting a plasma, the ultra-hot ionized gas that releases energy in a fusion reactor.

The ultimate goal of this research is to advance plasma science and understanding of fusion energy to help reduce the cost and complexity of future fusion energy systems, which could provide an abundant source of clean energy by harnessing the process that powers our sun.

"In essence, we're working to develop an innovative spark plug to light the fusion fire in future fusion energy systems," says Assistant Professor Stephanie Diem, who leads Pegasus-III.

The Pegasus-III experiment consists of a compact donut-shaped magnetic bottle, which is called a spherical tokamak, to hold very-high-temperature plasmas. Almost every tokamak-style fusion experiment in the world relies on magnetic induction from a central magnet, called a solenoid, to drive the current that creates and heats a plasma.

However, eliminating the need for a central solenoid in a tokamak would greatly simplify the construction and reduce the cost of these devices, increasing their viability for commercial energy production. That's why the UW-Madison researchers are using Pegasus-III to investigate several solenoid-free startup techniques, including local helicity injection, coaxial helicity injection, and radio-frequency waves. Local helicity injection is a unique startup method that uses small plasma sources that look like lightsabers to inject ribbons of super-heated plasma, which are captured and confined by a magnetic field. Coaxial helicity injection is a startup method where a voltage is applied between two electrodes to create a bubble of plasma. And radio-frequency wave injection relies on injecting microwaves that are tuned to the natural frequency of charged particles rotating around the magnetic field to transfer energy to the plasma.

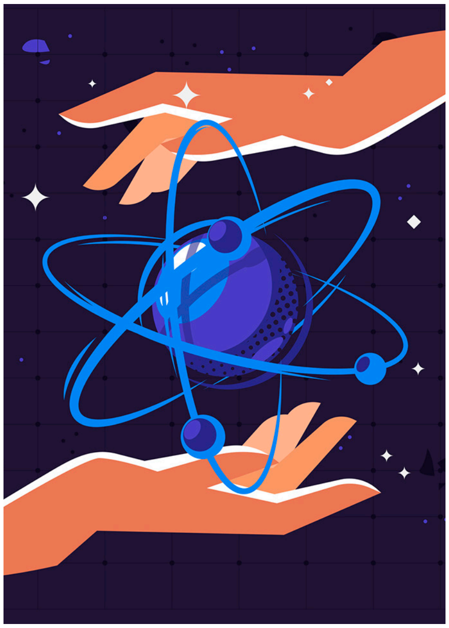
"We are in a unique space at UW-Madison where we can study all three of these methods in one device," Diem says. "Not only can we test each technique independently, but we can also investigate if one technique can enhance another. In addition, we can get our hands on the machine to design whatever experiments we want to test different theories, and this also provides a great hands-on learning opportunity for our students."

As they learn more about the fundamental plasma physics involved in these startup techniques, the researchers will develop models to scale up to larger fusion devices.

Diem says building Pegasus-III was a massive undertaking and a true team effort. "All that remains of the previous phase of the experiment is the container and a few magnetic coils," she says. "We've built all new power supplies and a new, higher-power toroidal magnetic field to confine the plasma, so this is a brand-new facility."

The construction project began in 2020 as the COVID-19 pandemic emerged, which caused additional challenges. Diem credits the research team's flexibility, hard work and dedication for the project's success.

"We have a great and supportive research team, and everyone has been amazing with all the work they put into this," Diem says. "It wasn't easy to build a new facility during a pandemic and while also dealing with supply-chain issues, so I'm really proud of everyone on the team and very excited that Pegasus-III is running."



UW–Madison continues to excel in earning DOE nuclear research awards

The U.S. Department of Energy has awarded more than $41.2 million through its Nuclear Energy University Program (NEUP) to support university-led nuclear energy research and development projects. Of that, a total of $4.6 million went to transdisciplinary projects led by UW-Madison engineers.

Mark Anderson, Consolidated Papers Associate Professor in mechanical engineering, received $1 million for a project to experimentally investigate the thermal-hydraulics performance of silicon carbide compared to other accident tolerant fuel cladding materials under accident scenarios. The project will advance the understanding of the operation and optimization of heat pipes for advanced nuclear reactors. Tiago Moreira, a scientist in mechanical engineering, and Allison Mahvi, a mechanical engineering assistant professor, are UW-Madison collaborators on the project, along with researchers from Massachusetts Institute of Technology, Westinghouse, General Atomics, and Pacific Northwest National Laboratory.

Kaibo Liu, a professor of industrial and systems engineering, received $1 million for a research project that aims to provide technical solutions to unique cybersecurity challenges in future microreactor fleet through cyber-informed design, real-time anomaly detection, dynamic monitoring and cost-effective mitigation strategies. The efforts will significantly improve the economics and effectiveness of cybersecurity risk management in future microreactor fleets. Professor Laura Albert, the David Gustafson Department Chair of Industrial and Systems Engineering at UW-Madison, is a collaborator on the project, along with researchers from the University of Michigan, Georgia Institute of Technology and Idaho National Laboratory.

Assistant Professor Yongfeng Zhang received $1 million for a project that aims to gain a fundamental understanding of the impact of moisture and salt chemistry on corrosion of nickel-chromium alloys in molten chloride salts. The researchers will design a novel approach coupling multiscale simulations and experiments to determine salt acidity, its dependence on salt composition, and its effects on the transport of water and chromium ions and the corrosion kinetics of nickel-chromium alloys in chloride salt. UW-Madison collaborators include Kumar Sridharan, Grainger Professor in nuclear engineering and engineering physics and materials science and engineering, and Associate Professor Adrien Couet, along with researchers from the University of Florida, Los Alamos National Laboratory and TerraPower.

Mike Wagner, an assistant professor in mechanical engineering, received $1 million for a research project that aims to develop an integrated nuclear system that would use electricity and waste heat to operate a desalination and mining process from adjacent seawater. The desalination approach targets zero-liquid discharge with multiple marketable minerals extracted. Because the ability of nuclear facilities to load follow is increasingly important, the researchers will incorporate a cold thermal storage system. The team will experimentally validate the desalination and mineral extraction process at lab scale. UW-Madison collaborators include Assistant Professor Ben Lindley, mechanical engineering faculty Mark Anderson and Luca Mastropasqua, and Mohan Qin, an assistant professor in the Department of Civil and Environmental Engineering, along with researchers from Idaho National Laboratory and Westinghouse.

In addition, Assistant Professor Juliana Pacheco Duarte received a U.S. Department of Energy distinguished early career program award for $625,000. (See story on page 5).

Graduate student lands UNLP fellowship

PhD student Kailee Buttice has received a University Nuclear Leadership Program fellowship from the U.S. Department of Energy. Buttice is a member of Associate Professor Adrien Couet's research group. Broadly, the group studies the degradation and corrosion of materials in advanced reactor environments. Buttice will be focusing her PhD research on the basicity of molten fluoride salts to better understand how it affects the corrosion of structural alloy elements in a nuclear reactor. By measuring the free fluoride ions in the molten salts using spectroscopy, the goal of Buttice's research is to generate a basicity scale, similar to that of the standard pH scale. The scale can then be used to measure how aggressively the molten salt will corrode metal alloys.

The fellowship provides Buttice with a stipend and pays for her tuition. She will also have funding to travel to conferences, where she can share her research and network. As a requirement of accepting the fellowship, Buttice will also complete an internship with a national lab.

Among nation's elite, Duarte eyes machine learning to improve nuclear safety

Assistant Professor Juliana Pacheco Duarte has received a U.S. Department of Energy distinguished early career program award.

Duarte is one of only five faculty in the United States to receive the award in 2023. The program invests in the innovative research and education programs of outstanding early-career university faculty poised to pave new lines of inquiry and advance mission-critical research directions in nuclear energy. Duarte's award is for $625,000 over five years.

With the award, Duarte is conducting experiments and harnessing machine learning techniques to answer crucial questions about transient critical heat flux in light water reactors.

"Critical heat flux is a phenomenon that is very important to understand for the thermal design and safety of nuclear reactors that are cooled by water," Duarte says. "We're trying to better understand these transient scenarios where there's a very fast power increase in the reactor."

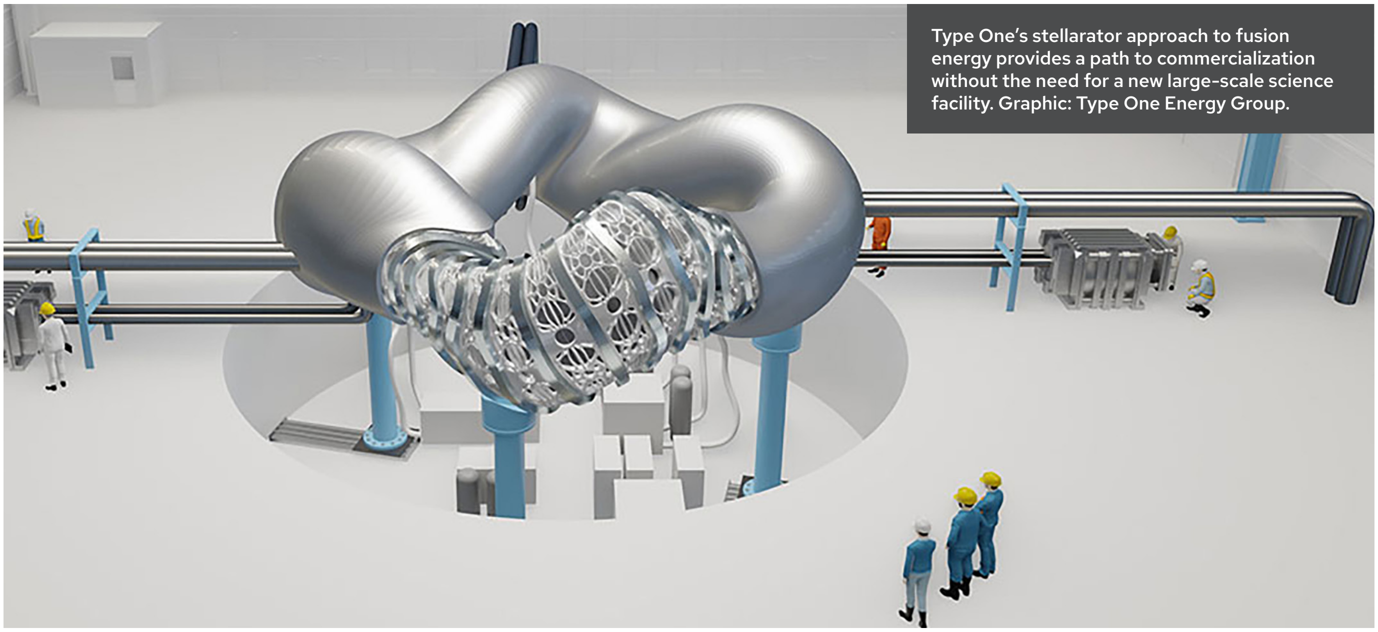
There's a lack of reliable experimental data about this transient heat transfer phenomenon in reactors, causing uncertainty in the computational models used for reactor safety analysis. In this research project, Duarte will help fill that data gap using an experimental setup in her lab. She is using optical fibers to measure the temperature in a nuclear fuel rod simulator at prototypical light water reactor conditions. Duarte will conduct experiments using different cladding materials and under various transient scenarios.

"We will be getting unique, very-high-resolution data with these experiments," Duarte says. "While previously there have been many experiments conducted at lower pressures that show these phenomena change with different cladding materials, I will be one of the first researchers performing these kinds of experiments at high pressure and at reactor conditions. With this unique data, I will use machine learning to improve the models that are used for safety analysis of nuclear reactors."

In addition, Duarte seeks to better understand how different nuclear fuels, including new accident-tolerant fuels, affect transient critical heat flux and post-critical heat flux. Her findings should be very useful for aiding the regulatory licensing process that's needed for upgrading existing nuclear plants to use accident-tolerant fuels.

With her award, Duarte is also working to build more inclusive learning environments in class and in the lab for both undergraduate and graduate students in nuclear science, technology and engineering, with an emphasis on thermal hydraulics and reactor safety analysis. She will develop active-learning-based educational materials for her NE 411: *Nuclear Reactor Engineering* course.

Assistant Professor Juliana Pacheco Duarte is conducting experiments and harnessing machine learning techniques to answer crucial questions about transient critical heat flux in light water reactors. Pictured above, Duarte (right) discusses her experimental setup for the DOE distinguished early career award project with undergraduates Briunna Smith (left) and Aria Murphy (center), both members of Duarte's Heat Transfer and Safety Analysis Laboratory at UW-Madison. Photo: Joel Hallberg.



Type One's stellarator approach to fusion energy provides a path to commercialization without the need for a new large-scale science facility. Graphic: Type One Energy Group.

Funding for startups highlights our leading role in fusion energy

Two startups based on technologies pioneered at UW-Madison have received large federal grants to support their efforts to develop clean energy through fusion.

Realta Fusion and Type One Energy Group, both based in the Madison area, were two of eight ventures from across the nation that the U.S. Department of Energy selected for public-private-partnership grants of several million dollars to support research and development of fusion energy technologies. Both companies are pursuing potentially simpler and more cost-effective paths to commercializing fusion energy. Earth-based fusion energy, which seeks to mimic the nuclear fusion that powers the stars, could someday provide a source of clean, safe and virtually limitless power and heat.

This federal investment reflects UW-Madison's leading role in fusion research as the United States strives to reduce its reliance on fossil fuels.

As a recent *TechCrunch* article notes: Wisconsin has quietly become a hotbed of fusion power startups as long-running UW-Madison research programs are transferring their technology out of the lab.

Realta is working to develop fusion for industrial heat generation. The company is building a first-of-its-kind compact neutron source, and it aims to later to produce fusion energy via a compact but powerful magnetic mirror. Realta was spun out of a research project funded by the U.S. Department of Energy's Advanced Research Projects Agency–Energy and is led by Physics Professor Cary Forest. The company is constructing its device at the UW-Madison Physical Sciences Laboratory, where it's expected to produce a first plasma in fall 2023. Assistant Professor Ben Lindley and Thomas and Suzanne Werner Professor Oliver Schmitz are two of the co-founders of Realta Fusion.

"Realta's technology is expected to simplify the fusion energy approach due to its simple form factor and the accessibility of the device," says Schmitz, who is advising the company on plasma surface interaction. "Also, it is easy to scale the device to produce the level of heat and power that are required for the customer."

UW-Madison's fusion program began in the 1960s and includes researchers in multiple departments, including physics, nuclear engineering and engineering physics, and electrical and computer engineering. Together, the departments have awarded more than 480 doctoral degrees to fusion researchers, and many of them have become the world's leaders in the field.

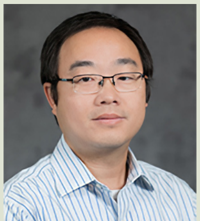
Meanwhile, Type One Energy Group is working to develop fusion energy that builds on the ECE department's long-running stellarator experiment, which also uses very strong magnets to confine plasma. Harvey D. Spangler Professor Chris Hegna and ECE Professor Emeritus David Anderson are co-founders of the startup.

"The fusion and plasma physics programs at UW-Madison are broadly acknowledged to be world leading, and Type One Energy grew out of this environment," says Hegna, the company's vice president of stellarator optimization. "The strong technical team we have at Type One Energy is a product of its close ties to the university."

The federal awards add to millions of dollars of private funding raised by both startups. Realta and Type One Energy Group aren't the only fusion companies with close ties to the NEEP department. SHINE, the Janesville, Wisconsin-based company founded by PhD alumnus Greg Piefer, is deploying and scaling fusion technology now that it hopes will one day lead to powering the world. The company has a four-phased approach that targets more immediate applications of fusion—like inspecting industrial components through neutron imaging and producing isotopes with a range of medical applications. These applications create tremendous social and economic value and are the building blocks for SHINE's future goals: recycling nuclear waste and generating on-demand, carbon-free energy through fusion.

"There is great potential for creating a fusion hub in Wisconsin that will help grow the economy and clean energy, and support workforce development," Schmitz says. "By leveraging UW-Madison's research strengths, we can benefit the state."

Understanding lattice defects can help keep fuel cool



Yongfeng Zhang

In nuclear fuel, there's a heat-related sweet spot that not only ensures the reactor operates safely, but also that it generates as much energy as it can.

"Heat transport is critical for both reactor efficiency and safety. It determines how fast the thermal energy generated from nuclear reaction can be harvested to generate electricity," says Assistant Professor Yongfeng Zhang. "In addition, if heat is not transported out efficiently, the temperature inside of the fuel can get too high and potentially cause safety issues."

In ceramic nuclear fuels, which most current nuclear reactors use, heat transport is mediated by phonons, which are units of vibrational energy that arise from atomic oscillations within a crystal. Disruptions, or lattice defects, in the orderly arrangement of atoms in crystalline solids can hinder phonon transport. Unfortunately, the intense irradiation inside nuclear fuels is perfect for creating lattice defects that hinder heat transport.

"We can picture the phonons as a wave of water in a lake; objects like rocks or floating wood can deflect and slow down the wave. The nature, size and number density of such objects all affect their ability of slowing down the wave," Zhang says. "In a similar way, the efficiency of heat transport in nuclear fuels will be dependent on the nature, size and number density of lattice defects that are generated by irradiation."

As part of the DOE Office of Science Energy Frontier Research Center for Thermal Energy Transport under Irradiation led by Idaho National Laboratory, Zhang is a member of an internationally recognized multi-institutional team of experimentalists and computational materials theorists aiming to develop a comprehensive, atom-to-mesoscale understanding of how lattice defects affect phonon and electron transport in advanced nuclear fuels.

Zhang is studying how atomic-level defects form, move and grow in nuclear fuels such as uranium dioxide, thorium dioxide and uranium nitride. Specifically, he's working to characterize the size and distribution of sub-nanometer defects, which are too small to view clearly, even with highly advanced transmission electron microscopes. Instead, Zhang is developing atomistic models of the materials under irradiation. The models will allow him to simulate how tiny defects form and evolve into larger defects whose structures are better known.

State legislators learn about cutting-edge nuclear research

On June 1, 2023, a group of Wisconsin state legislators visited the engineering campus to learn about the cutting-edge research being conducted in the department and industry partnerships faculty members have throughout Wisconsin and the United States.

Tour highlights included:

- UW Nuclear Reactor with Grainger Professor of Nuclear Engineering and Chair Paul Wilson. The reactor is an invaluable tool that provides hands-on experience for nuclear engineering undergraduate students and allows for research and industry partnerships, particularly with local Wisconsin companies.
- Ion Beam Lab with Associate Professor Adrien Couet, instrumentation tech Nate Eklof and graduate students. The lab is part of a strategy for developing and testing novel materials that will improve the safety and affordability of advanced reactor concepts and is a user facility for scientists around the country.
- Cold Spray Laboratory with Grainger Professor Kumar Sridharan and graduate students, who are developing solutions to preserve materials from irradiation and corrosion in the harsh environment of a nuclear reactor.
- Pegasus-III fusion experiment with Assistant Professor Stephanie Diem and graduate students, who are working to develop novel startup techniques for future fusion power plants.
- Helically Symmetric eXperiment (HSX) with Assistant Professor Benedikt Geiger and graduate students. Researchers at HSX are exploring novel concepts for achieving fusion energy with the potential for higher performance than traditional approaches.

Representatives Donna Rozar and Patrick Snyder examining high-throughput testing plates used by researchers in the Ion Beam Laboratory.

Rep. Joy Goeben (second from left), Rep. Tom Michalski (second from right) and staff look into the UW Nuclear Reactor core with Chair Paul Wilson (right).

On tours of several facilities and laboratories, representatives and staffers expanded their understanding of the potential and challenges associated with nuclear energy and how our department is addressing those through education, research and outreach.

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Grad students shine in DOE nuclear energy research competition

UW-Madison had an especially strong showing in the U.S. Department of Energy Nuclear Energy University Program's (NEUP) 2023 Innovations in Nuclear Energy Research and Development Student Competition, with graduate students winning first and second place in the open competition fuel cycle technologies category.

The competition recognizes and awards graduate and undergraduate students for innovative nuclear energy research publications.

Recent PhD graduate Claire Griesbach received a first place award for her journal paper, "Microstructural heterogeneity of the buffer layer of TRISO nuclear fuel particles," which was published in the February 2023 edition of the *Journal of Nuclear Materials*.

In her PhD research, Griesbach collaborated with NEEP Assistant Professor Yongfeng Zhang to better understand the failure response of a protective coating in nuclear fuel particles, which is designed to


Claire Griesbach


Kyle Quillin

contain the harmful effects of radiation. She conducted research at Oak Ridge National Laboratory, where she investigated the irradiation-induced micro- and nano-structural changes in the buffer layer of AGR-2 TRISO particles. Griesbach, who earned her PhD in engineering mechanics in May 2023, was advised by ME Assistant Professor Ramathasan Thevamaran. In September 2023, she started a postdoctoral researcher position at ETH Zurich.

Kyle Quillin, a MS&E PhD student and member of Grainger Professor Kumar Sridharan's research group, earned second place for his journal paper, "Microstructural and nanomechanical studies of PVD Cr coatings on SiC for LWR fuel cladding applications," which was published in *Surface and Coatings Technology* in July 2022.

Quillin's research is focused on the development of protective coatings for silicon carbide fuel cladding in light water reactors. Silicon carbide is an accident tolerant fuel cladding material that can greatly improve the safety performance of a reactor, should a severe loss-of-coolant accident arise, like what happened at Fukushima in 2011.

However, the silicon carbide cladding requires a protective coating on its outer surface to prevent corrosion at normal operating conditions when exposed to the reactor coolant. In the journal paper, Quillin investigated chromium coatings made using six different processes, and he identified a state-of-the-art coating process called bipolar high-power impulse magnetron sputtering that produced the best-performing coating. "In this work, we identified a protective coating with a great blend of properties that furthers the development of silicon carbide fuel cladding, with the ultimate goal of improving the safety of future light water reactors," he says.

After completing his PhD, he will start a position as an R&D engineer with Fisher Barton in Watertown, Wisconsin.