UNIVERSITY OF WISCONSIN–MADISON
COLLEGE OF ENGINEERING

FALL 2021 NEWSLETTER

ENGINEERING PHYSICS

BRINGING NEW ENERGY
to fusion research

Standing in front of a class of eager (and masked) nuclear engineering seniors. Lunch with colleagues at the tables in front of Engineering Hall that were installed in spring 2020 and are a fabulous addition to our outdoor space. The return of the American Nuclear Society's Wednesday morning coffee and doughnuts, set up on our Engineering Research Building patio. A gathering of EP faculty, staff and graduate students at a nearby park.

These are just some of the pleasures that I've enjoyed since the semester began, all a balance between the caution required by the COVID pandemic and the exuberance of beginning a new academic year.

Another theme of the last few weeks has been infrastructure, as our nation's policymakers debate the size and scope of investment in a variety of themes, including important advances in clean energy. Our department looks forward to contributing to a clean energy future with efforts across its many disciplines.

- There is growing support for a continued role for nuclear energy, including excitement about micro-scale reactors that could change the conversation about nuclear energy (see: **go.wisc.edu/eap-microreactors**). In a recent study, EP researchers considered ways that the U.S. government could kick-start the deployment of these new technologies.
- Wind energy is one of the fastest growing sources of electricity in the country, and Assistant Professor Jen Franck's research may shed new light on the design of wind turbine towers by adopting ideas borrowed from seal whiskers!
- Late last year, the U.S. DOE Fusion Energy Sciences Advisory Committee" to clarify that this is a federal advisory committee recommended a pivot to a more energy-focused program, while also recognizing a need to recruit a more diverse workforce to achieve that aim. Graduate student Carolyn Schaefer has formed a new student organization, Solis, designed to recruit more women and gender minorities in the plasma physics fields at UW-Madison and better support them as they develop into the next generation of fusion scientists and engineers.

There have also been somber moments at the beginning of this semester. Late in the summer, Professor Emeritus Max Carbon passed away. He founded and led the nuclear engineering department for 34 years and built an enduring legacy both within the department and throughout the nuclear engineering community. More recently, we learned that alumna Mary Baker (BSEMA '66), a visionary and inspirational leader in aerospace engineering, also passed away in early September. She was a longtime member of our Industrial Liaison Committee and always had important insight and wisdom to share. At the time of her death, Baker was a technical director and board chairman at ATA Engineering, a San Diego testing and analysis company she co-founded in 2000. Her work influenced the design of the International Space Station, and she oversaw ATA's involvement in the testing, analysis and design of two generations of Mars rovers developed by NASA's Jet Propulsion Laboratory. ATA's efforts helped ensure the successful Mars landings of the Curiosity rover in 2012 and the Perseverance rover in 2021. Read more about Baker's life: **go.wisc.edu/mary-baker-obituary**.

Fall in Wisconsin offers many good reasons to return to Madison and visit campus, whether you are interested in Badger football, corn mazes and pumpkin patches, or taking in the leaves as they change color. If you find yourself in Madison, we hope you'll stop in and visit us, too.

On, Wisconsin!

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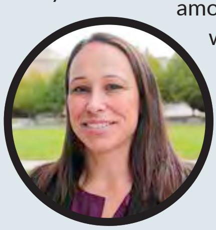
ENGINEERING
FORWARD

How seal whiskers can help engineers design innovative technology

Seals have an incredible ability to track their prey underwater thanks to the unique geometry of their whiskers.

Unlike the smooth whiskers of cats and dogs, seal whiskers have wavy surfaces that help them detect disturbances in the water caused by their prey.

"Seal whiskers have what we call an undulated cylinder geometry, and research has shown that this geometry significantly reduces forces and vibrations that result from interactions with fluids, making it attractive for many potential engineering applications," says Assistant Professor Jennifer Franck (right).



Franck is leading a National Science Foundation-funded research project to study the interactions between fluid flow and undulated cylindrical structures.

"Ultimately, we want to understand how the fluid moves across these complex surfaces, and how changes in the surface's geometry will affect the flow response around it," Franck says.

The research has applications in a variety of areas. For example, it could aid in building cheaper flow sensors for unmanned underwater vehicles that could monitor currents and detect disturbances in the water.

Findings from the research could also help reduce the cost of building wind turbine towers. With tall wind turbines, the towers themselves produce a significant amount of drag. And a strong flow of wind around a tower can cause it to vibrate.

"The idea is that having some undulations and carefully designed shapes on these tall towers could reduce the drag and vibrations and make them less expensive to build," Franck says.

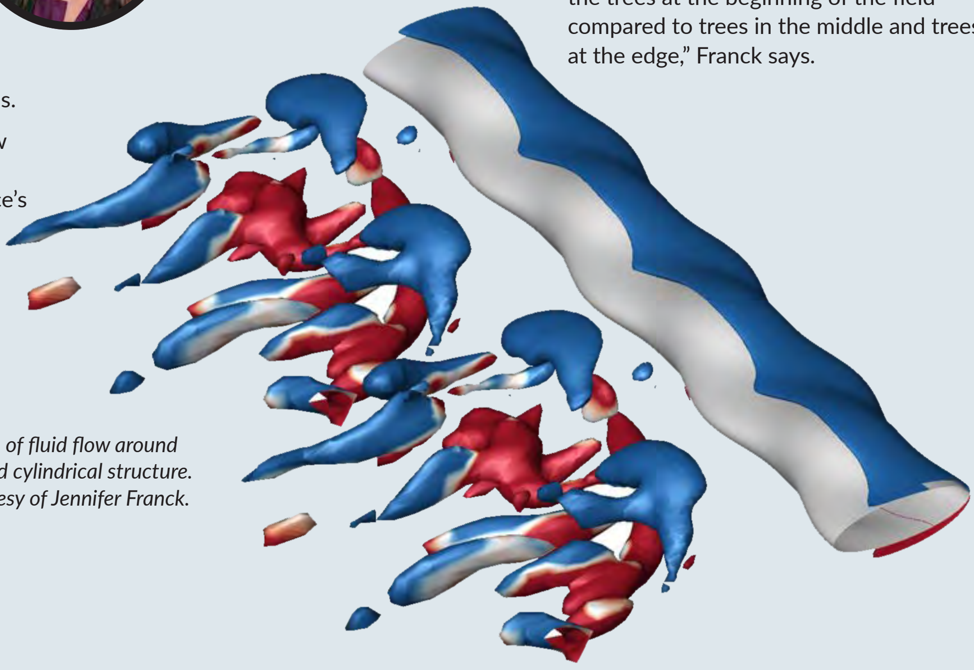
In this interdisciplinary project, Franck is leveraging her expertise using computational simulations to investigate fluid mechanics. She is collaborating with Raúl Bayoán Cal, a Portland State University mechanical and materials engineering professor who is conducting wind tunnel experiments, and Christin Murphy, who runs the Bio-Inspired Research and Development Laboratory at the Naval Undersea Warfare Center in Newport, Rhode Island.

Franck and her collaborators are also conducting simulations and experiments to investigate how an array of seal whiskers, which are packed close to one another, functions as a system.

For example, Franck says the flow that happens in the wake of the first whisker will influence the flow interaction with the second whisker, which will then influence the next whisker in the group and so on.

This research could also improve understanding of ecological systems, such as how weather systems interact with forests.

"In forests, trees—which are kind of shaped like undulated cylinders—are packed close together in arrays. When a strange weather pattern comes through, how will it affect the flora and fauna that live in this ecosystem? We could develop models to look at how the wind patterns will affect the trees at the beginning of the field compared to trees in the middle and trees at the edge," Franck says.



A simulation of fluid flow around an undulated cylindrical structure. Image courtesy of Jennifer Franck.

Tapping innovative balance of power, microreactors could enhance energy resilience

Deploying micro-scale nuclear reactors—microreactors—for on-site power generation at select U.S. government facilities could enhance their ability to recover during a power grid outage, according to a new study by UW-Madison engineers.

Several U.S. companies are developing microreactors that will be dramatically smaller than the large, centralized nuclear reactors operating today. Small enough to transport by truck, these compact reactors will generate power in the range of 1 to 10 megawatts—or, enough to power 1,000 to 10,000 homes for a year.

Because of their smaller size and technical features, microreactors could take on unique roles in future energy systems.

In the new study conducted by the Institute for Nuclear Energy Systems for the U.S. Department of Energy, the UW-Madison team set out to determine the potential role of microreactors in enhancing the energy resilience of federal government facilities. Resilience refers to the ability of a facility to continue operating when the external source of utility power becomes unavailable.

"The main finding of our study is that if microreactor vendors can reach their goals for total costs, and if they rely on low-interest government financing rather than private financing, then microreactors could be economically competitive against natural gas and increase the energy resilience of certain government facilities." says Grainger Professor of Nuclear Engineering Paul Wilson, who led the study.

For the study, the researchers started with a list of approximately 1,800 U.S. government-owned facilities—which include hospitals, data centers, rocket launch facilities, biology laboratories and nuclear accelerators—around the country and narrowed it down to 211 facilities that consume an amount of energy large enough to make them good candidates for microreactors.

Currently, the utility power grid provides most of the electricity for those 211 facilities.

"Given the number of severe power outages that have occurred around the country over the past few years, from outages caused by wildfires in California to the winter storm in February 2021 that crippled the power grid in Texas and left millions without electricity, it's important for these facilities to have robust on-site generators for backup in the event of a power grid failure," Wilson says.

Currently, government facilities have on-site diesel or natural gas generators that are typically held in standby and used only for emergencies. In their analysis, the researchers examined whether a microreactor could effectively take over the role of these backup generators.

However, because even the much smaller microreactors are very expensive to build, using one merely as a backup generator wouldn't be economically viable, Wilson says. So, the UW-Madison researchers developed an innovative dual-source configuration that leverages the strengths of microreactors—and, importantly, shifts the paradigm for backup power generation.

The approach involves placing microreactors at each of the government facilities, where they would run continuously and provide enough power to meet the facility's critical power demand. In addition, each facility would buy electricity from the utility to meet its remaining power demand for non-critical uses. If the utility has an outage, the facility would only lose power for nonessential uses. Meanwhile, the microreactors would continue running uninterrupted, providing on-site "backup" power for critical needs.

Conversely, if the microreactor needs to refuel or if it shuts down, then power from the utility can serve as the backup. Wilson says a key assumption of the study is that facilities would implement this configuration, enabled by a microgrid to distribute this power around the facility.

Another benefit of microreactors is that they could run for months or even years before needing to refuel—which would provide the resilience required for operating during long-term power outages. On the other hand, relying on diesel or natural gas generators as backup could affect a facility's resilience during major outages since the generators rely on a finite supply of readily available diesel or on a continuous supply of natural gas.

For comparison in their study, the researchers also modeled building a "green scenario," a resilient, carbon-free energy system that excludes fossil fuels, including natural gas.

Image: Third Way Think Tank/flickr.com

However, they found that relying entirely on renewable energy sources like wind and solar, coupled with battery storage, would require overbuilding the components of the renewable energy system to ensure adequate resilience—ultimately resulting in a more expensive system.

"To build a carbon-free energy system, our analysis shows that you'll likely need something other than just wind, solar and batteries to make it cost-effective. You need to include a source of clean energy that's reliable and dispatchable—and we focused on microreactors as a solution," Wilson says. "In our study, we showed that even using expensive microreactors is actually cheaper overall than a system that consisted of only solar and batteries—by about a factor of two, for the particular set of circumstances in our model. These results are similar to findings by other researchers."

Because microreactors don't emit greenhouse gases, they could also make a broader environmental contribution. "While an analysis of the potential climate impact of adopting microreactors was outside the scope of this study, it's important to consider carbon emissions when making decisions about future energy systems," Wilson says. "The Biden administration has recently announced plans to sharply reduce emissions, and this commitment could further tip the balance toward nuclear energy over natural gas."

Engineers receive $3.6M in DOE nuclear research awards

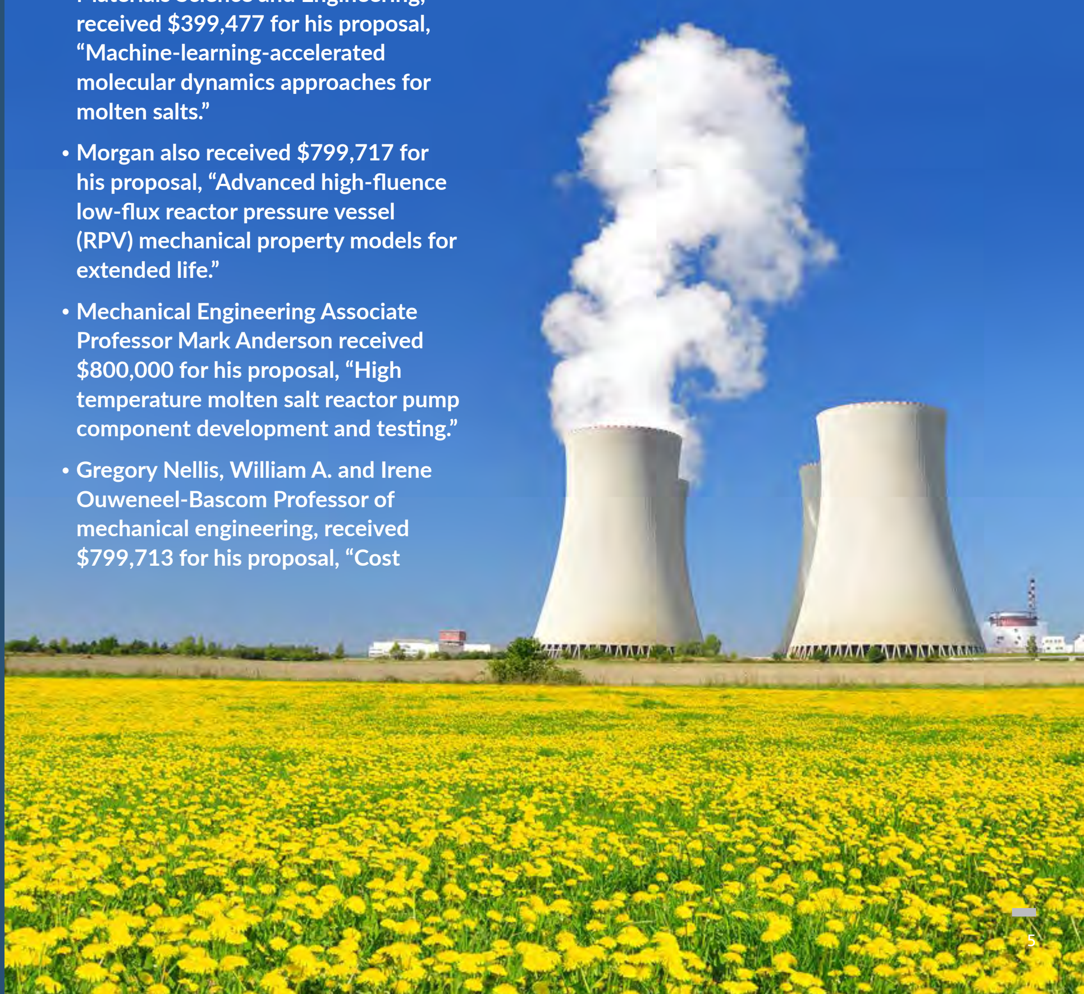
The U.S. Department of Energy recently awarded more than $48.8 million through its Nuclear Energy University Program (NEUP) to support university-led nuclear energy research and development projects, including a total of about $3.6 million awarded for projects led by UW-Madison engineers.

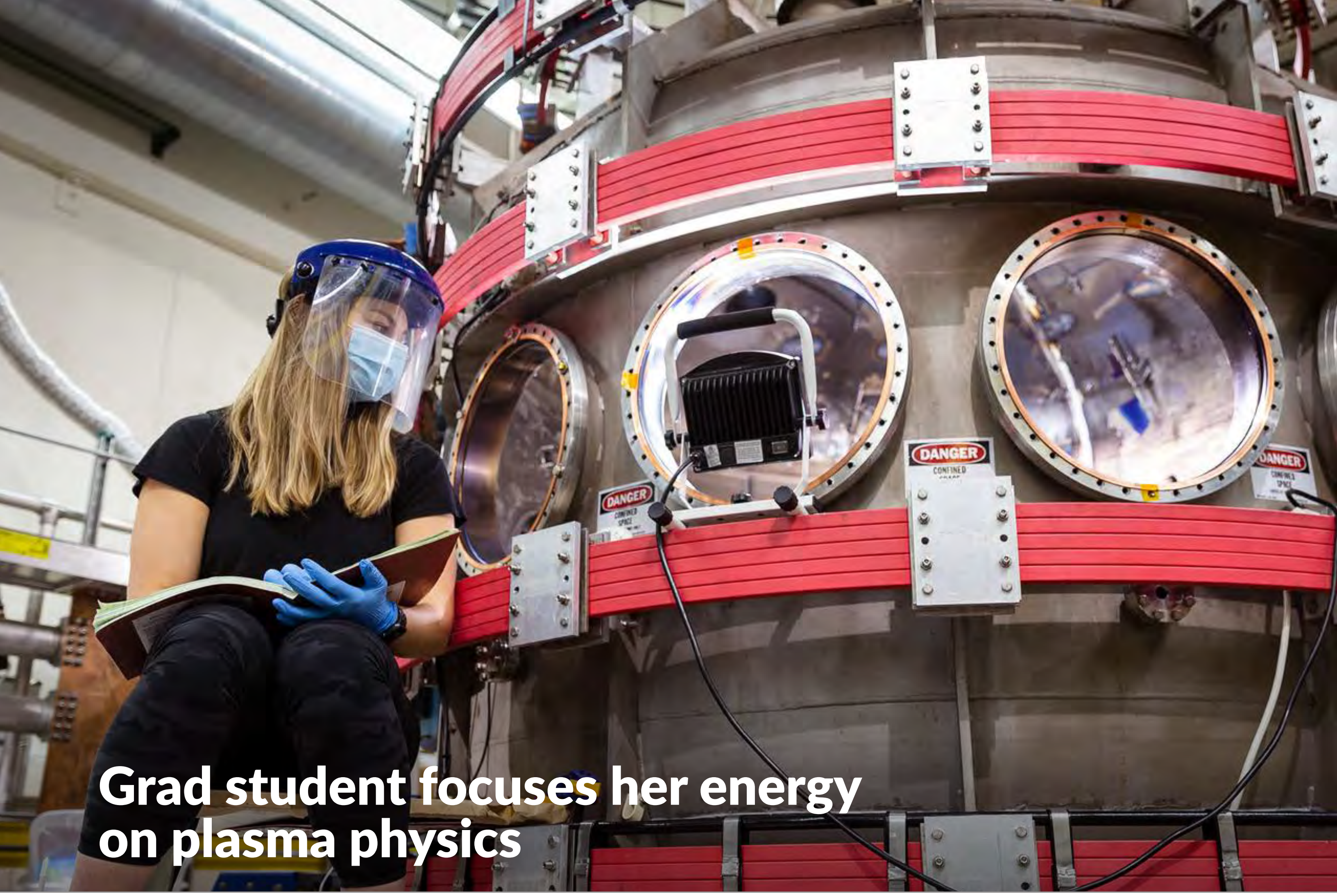
NEUP seeks to maintain U.S. leadership in nuclear research across the country by providing top science and engineering faculty and their students with opportunities to develop innovative technologies and solutions for civil nuclear capabilities.

UW-Madison engineers are principal investigators on five NEUP projects:

- Associate Scientist Hwasung Yeom received $800,000 for his proposal, "Post-DNB thermo-mechanical behavior of near-term accident tolerant fuel (ATF) designs in simulated transient conditions."
- Dane Morgan, Harvey D. Spangler Professor in the Department of Materials Science and Engineering, received $399,477 for his proposal, "Machine-learning-accelerated molecular dynamics approaches for molten salts."
- Morgan also received $799,717 for his proposal, "Advanced high-fluence low-flux reactor pressure vessel (RPV) mechanical property models for extended life."
- Mechanical Engineering Associate Professor Mark Anderson received $800,000 for his proposal, "High temperature molten salt reactor pump component development and testing."
- Gregory Nellis, William A. and Irene Ouweneel-Bascom Professor of mechanical engineering, received $799,713 for his proposal, "Cost reduction of advanced integration heat exchanger technology for micro-reactors."

UW-Madison also received one of the 24 awards for research reactor and infrastructure improvements under the NEUP infrastructure program. UW Nuclear Reactor Director Robert Agasie received $222,294 for the project, "Development of neutron tomography at the UWNR." This project will enhance nuclear energy-related research and development at the University of Wisconsin Nuclear Reactor (UWNR) and associated Characterization Laboratory for Irradiated Materials (CLIM). The researchers aim to enhance the neutron radiography capabilities at the reactor by acquiring a high-resolution detector, rotation stage, visualization software and a high-performance computer. Assistant Faculty Associate Andrea Strzelec, program director for UW-Madison's Master of Engineering in Engine Systems, is a collaborator on the project.





Grad student focuses her energy on plasma physics

"For my research, I'm doing what I do because I want a carbon-free energy future," says Carolyn Schaefer. "That's why I got into it and the world really needs it right now."

A fifth-year PhD student, Schaefer chose UW-Madison for her graduate education because, she says, it's the best for hands-on experimental work on a fusion experiment. "There's a big fusion community and a ton of plasma classes," she says. "I knew I wanted to be here. I visited for a few hours the week before I decided to come. I wanted experimental, and I wanted to be part of a group of grad students."

She got both: Schaefer is among approximately 20 students and scientists working on Pegasus-III, a longstanding and internationally respected fusion experiment that's currently undergoing a major U.S. Department of Energy-funded upgrade. "Not many people get to be part of a tokamak being put together," she says. "You may be part of the operations, but not actually be part of the construction, so that's pretty unique."

Among other aspects, the upgrade centers around the team's ability to test techniques it pioneered for actually starting the experiment and producing a plasma, which fuses atoms to make energy. Most tokamaks use a solenoid to start the plasma via magnetic induction; Pegasus-III will be a dedicated U.S. "proving ground" for studying innovative noninductive startup techniques.

Schaefer not only is helping with the experiment's physical renovation, but in her research, she has been modeling the unique distribution of currents in the plasma, given the team's noninductive method for starting the plasma. One aspect of the Pegasus-III upgrade is vastly improved diagnostics, which will enable her and others to develop improved models that see beyond just a moment in time and focus on how the plasma develops over time. That's key, she says, because one of the team's main startup techniques creates an atypical plasma with a main current stream as well as one at the plasma's edge. "Understanding how this system evolves in time could answer many outstanding questions. The question I'm trying to answer is whether the main plasma is still OK," she says. "Is the confinement still good despite the streams at the edge? We want to ultimately be able to say we can use this advantageous technique and have a plasma that looks like that produced in traditional tokamaks."

A native of Cold Spring, New York, Schaefer attended the Massachusetts Institute of Technology as an undergraduate, majoring in nuclear science and engineering with a minor in energy studies. Like many future engineers, she excelled at physics and math in high school and says she chose to pursue an engineering degree because it could open a variety of opportunities for her future.

During her undergraduate career at MIT, she also took advantage of several opportunities to conduct research, including work in MIT Plasma Science and Fusion Center and an internship in the DIII-D National Fusion Facility at General Atomics in San Diego, California. "I got more exposure being there and got to get into the field, learn and meet people," she says.

Nuclear engineering research and education pioneer Max Carbon passes away

Nuclear Engineering Professor Emeritus Max W. Carbon passed away on June 23, 2021, at age 99. Renowned for advances in nuclear reactor safety and heat transfer, he was founding chair of the UW-Madison Department of Nuclear Engineering.

A native of Monon, Indiana, Carbon attended Purdue University, where he earned his bachelor's degree in mechanical engineering in August 1943. After completing his undergraduate education, he joined the U.S. Army in 1943 as a corporal, and served in the ordnance department in New Guinea, the Philippines, and Japan. He retired to the U.S. Army Reserve in 1946 as a captain.

Following World War II, Carbon returned to Purdue to earn his master's degree in 1947 and a PhD in 1949. While a graduate student, he held the DuPont Fellowship in mechanical engineering.

From February 1949 until September 1955, he worked at the General Electric Company's Hanford Works in Richland, Washington, producing plutonium for atomic and hydrogen bombs for national defense. His primary duty was as head of the heat transfer group, which was responsible for the safety analysis, operating limits and cooling technology that allowed for increased plutonium production and extended reactor lifetimes. As group head, he played a significant role in increasing production by a factor of four over design. Subsequently, he joined the Avco Manufacturing Corp. as head of its thermodynamics section, successfully designing the nose cone for the Titan Intercontinental Ballistic Missile.

In 1958, he came to UW-Madison to establish a nuclear engineering program as part of a growing postwar research emphasis on designing better, more efficient nuclear power plants for generating electricity. In 1961, as the program grew, he became first chair of the Department of Nuclear Engineering; at second or third, its academic programs in nuclear engineering consistently ranked among the nation's highest. During his tenure as chair, he led the department in establishing bachelor's, master's and PhD curricula, and he strongly supported the practice of "research teaching" (in which students learn research techniques and methods and how to study and work independently of an advisor) as a necessary complement to formal classroom instruction. He was one of the key advisors for undergraduates in nuclear engineering, and also supervised more than a dozen master's and PhD students.

Carbon also recruited, hired and mentored top staff and faculty—among them, James Callen, Robert Conn, Raymond Fonck, Harold Forsen and Gerald Kulcinski, all of whom ultimately were named fellows of the National Academy of Engineering. Carbon also oversaw construction of the university's research and training nuclear reactor, which achieved initial criticality in early 1961. He served as chair for 34 years until his retirement in 1992, as the department added plasma physics and engineering mechanics components to become today's Department of Engineering Physics.

As a faculty member, Carbon helped to define, advance and champion the field of reactor safety and heat transfer, not only among the technical community, but also by educating members of the public about the importance of nuclear power.

Carbon's many honors include being elected to the National Academy of Engineering in 2012 for his pioneering work in establishing engineering educational programs for nuclear reactor design and safety.

Thevamaran earns Outstanding New Mechanics Educator Award from ASEE

Assistant Professor Ramathasan Thevamaran has received the 2021 Ferdinand P. Beer and E. Russel Johnston, Jr., Outstanding New Mechanics Educator Award from the American Society for Engineering Education (ASEE).

This award is given annually by the ASEE Mechanics Division to recognize early-career faculty who demonstrate a strong commitment to teaching with evidence of exceptional contributions to engineering mechanics education.

Since joining UW-Madison in fall 2017, Thevamaran has been teaching three courses—EMA 405: *Practicum in Finite Elements* (undergraduate-level), EMA/EP 615: *Micro- and Nanoscale Mechanics* (undergraduate/graduate-level), and EMA 700: *Theory of Elasticity* (graduate-level)—which are now being taken by students from several departments.

He designed the EMA/EP 615 and EMA 700 courses from the ground up under existing titles. In addition, he introduced several modules to EMA 405 to incorporate interesting topics varying from modeling nonlinear plastic behavior of metals to random structural vibrations.

Thevamaran integrates contemporary research with examples from his own research lab to illustrate the role of basic mechanics principles in enabling research and engineering applications—from metamaterials to microballistics. "This approach allows me to intrigue the students first, which motivates them to learn the fundamental mechanics concepts effectively," Thevamaran says.

Thevamaran embraces opportunities to hone his skills as an educator, including participating in the Madison Teaching and Learning Excellence (MTLE) program as a fellow.

"This program was a fantastic opportunity for us to learn and experiment with various evidence-based teaching approaches, facilitated by professionals in education," he says. "There is immense support and encouragement at UW-Madison for us to excel in scholarship in addition to research. I expect this trend to grow as we strive to provide a holistic student-centered engineering education."

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Diem selected for NASEM New Voices program

Assistant Professor Stephanie Diem has been selected as a member of the New Voices in Science, Engineering and Medicine Program's 2021-2023 cohort of 22 early-career leaders from academia, industry, government and nonprofit organizations.

The new members are rising stars in their fields and were selected through a competitive review process out of nearly 300 applicants.

The New Voices program was launched by the National Academies of Sciences, Engineering and Medicine (NASEM) in 2018 as an initiative to bring diverse perspectives from early-career U.S. leaders to important dialogues around how science, engineering and medicine are shaping the global future.

With support from the Gordon and Betty Moore Foundation, the new cohort will gather over a two-year period with a senior advisory committee to discuss key emerging challenges in science, engineering and medicine, engage nationally with a wider group of young leaders from diverse groups, and attend international events on science policy.

At UW-Madison, Diem's experimental plasma physics research focuses on using microwaves to heat and drive current in magnetically confined, high-temperature plasmas for fusion energy development. Diem is the principal investigator of the Pegasus-III experiment, a new magnetic confinement fusion experiment funded by the U.S. Department of Energy studying innovative plasma startup techniques in an effort to reduce the cost and complexity of future fusion reactors. Prior to joining the faculty at UW-Madison, she was a staff scientist in the Fusion Energy Division at Oak Ridge National Laboratory on long-term assignment at the DIII-D National Fusion Facility in San Diego, California.

Diem currently serves on the American Physical Society Division of Plasma Physics (APS-DPP) Executive Committee and the APS-DPP Committee for Women in Plasma Physics. She created the APS-DPP-sponsored annual Visual Science Communication Award and is co-leader of the U.S. Fusion Outreach Team, a grassroots organization focused on reducing barriers to outreach efforts. Additionally, she was one of the organizers of the Early Career Fusion Scientists (ECFS) forum, a grassroots organization that initiated discussions and polling among the early-career community to provide input to the NASEM committee on a strategic plan for U.S. burning plasma research. She also is the faculty advisor of the new APS-sponsored student organization Solis, which is designed to support and create community among women and gender minorities in plasma physics fields at UW-Madison.