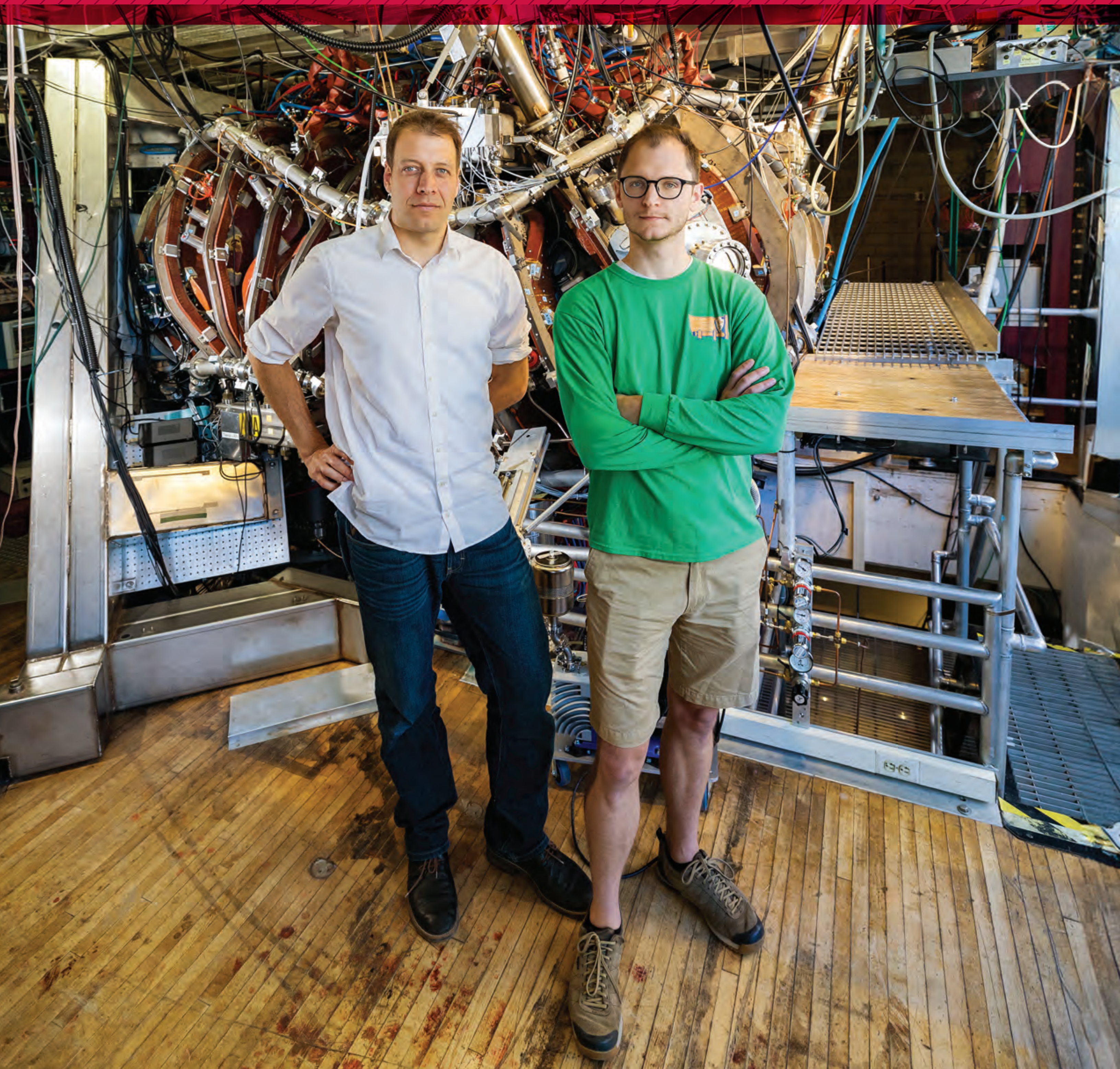
College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

FALL 2024 NEWSLETTER

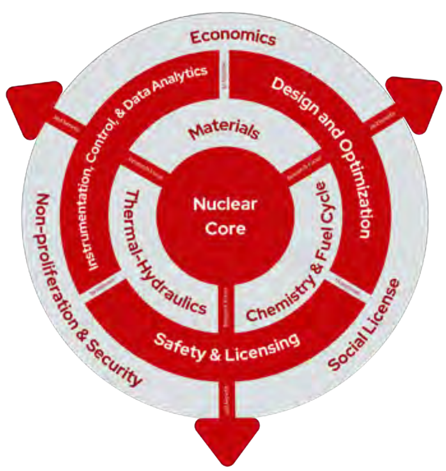
DEPARTMENT OF
NUCLEAR ENGINEERING AND ENGINEERING PHYSICS



Greetings from Madison!

This fall semester is definitely a season of change. The department has nearly 70 new undergraduates and nearly 30 new graduate students. The engineering campus has become a large construction site, beginning with utility work necessary to support the long-awaited new engineering building. Dean Ian Robertson announced that he would be stepping down and we have begun a search for his successor. Two of our faculty have retired and we are launching a search for three new faculty colleagues. As you can see, there is a lot going on.

It has now been a full year in our new configuration as the Department of Nuclear Engineering and Engineering Physics, and we continue to settle into our new identity and bring focus to our mission. Like any nuclear engineering department, much of our research covers a broad set of technologies that support the development of nuclear energy beyond the core topic (pun-intended!) of reactor physics. Most closely related are topics of thermal-hydraulics, materials and the chemistry of fuel cycles, but those lead to systems engineering domains including design and optimization, safety and licensing, and instrumentation, control and data analytics. Finally, in ways that are sometimes unique to nuclear energy, are the interfaces with society: techno-economics, nuclear security and non-proliferation, and social license.



What sets us apart from our peers, however, is that we consider two different types of cores equally at the center of this nuclear energy map: fission and fusion. Combining our department's history of excellence in nuclear engineering and our campus legacy of leadership in plasma physics and fusion, we are uniquely positioned to bridge the technology gap between fission and fusion systems. This unique balance will inform our search for three new faculty members over the coming year, growing by 25%.

Some of the motivation for this hiring is bittersweet: We waved goodbye to Wendy Crone and Carl Sovinec this summer; both decided to retire and enrich their lives beyond their academic pursuits. Wendy's engineering mechanics research program was one of the first to connect to nuclear engineering applications in the early years of the engineering physics program, but in recent years has focused on mechanics of human tissue in support of cardiovascular research. She has been a longtime leader in our department, including three years as the associate dean and then interim dean of the Graduate School. Closer to home, she was a driving force behind the design and administration of our engineering physics undergraduate program, including authoring a book that offers an introduction to engineering research. Carl Sovinec (who started on the same day as I did 23 years ago) has pursued a research effort in theoretical and computational magneto-hydrodynamics, specifically phenomena that led to rearrangement of magnetic configurations, including disruptions that are expected to be a challenge for tokamak devices. He also held a vital role as our associate chair for graduate studies for many years and was the director of the UW Officer Training Program, providing faculty oversight to the departments of Military Science, Naval Science, and Air Force aerospace studies. On a personal note, both have provided me with valuable insights and advice throughout my career and especially as department chair for the last five years. We will miss their scholarship, wisdom and service to our department, but wish them many years of happy retirement.

If you find yourself in Madison and want to see our changing campus in person, feel free to stop by … but you may want to park elsewhere and walk over to view the construction progress.

On, Wisconsin!

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On the cover: Engineers have uncovered ways to reduce turbulence in the HSX experiment by modifying the three-dimensional magnetic field geometry. Assistant Professor Benedikt Geiger (left) and PhD student Michael Gerard are pictured with HSX. Photo: Joel Hallberg.

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FOCUS ON NEW FACULTY

Charles Hirst enables better materials for fission and fusion reactors

While studying materials science at the University of Oxford in the United Kingdom, Charles Hirst had an a-ha moment that led him on a path to investigating nuclear materials for both fission and fusion reactors.

"In my materials science training, we learned a lot about the aerospace industry and alloys used inside jet engines," he says. "But if you put one of these specialized alloys into a nuclear reactor, the neutron radiation would rearrange the atoms inside the material and turn the exquisitely designed microstructure into scrambled eggs. That material couldn't survive such a demanding radiation environment. And I thought, 'Wow, that's the ultimate challenge,' which is why I'm a nuclear materials scientist."

Hirst joined the department as an assistant professor in August 2024.

In his research, Hirst explores the interplay between radiation damage, temperature and stress to determine how materials will behave in harsh irradiation environments. He uses various microscopy and characterization techniques to understand what's happening inside a material at the atomic level and to investigate how defects in the material evolve as a function of time, temperature and applied load. "Once we understand the mechanisms behind those processes, we can design better, more resilient materials for the next generation of fission and fusion reactors," he says. "And we can design mitigation strategies for existing materials that are currently in nuclear reactors."

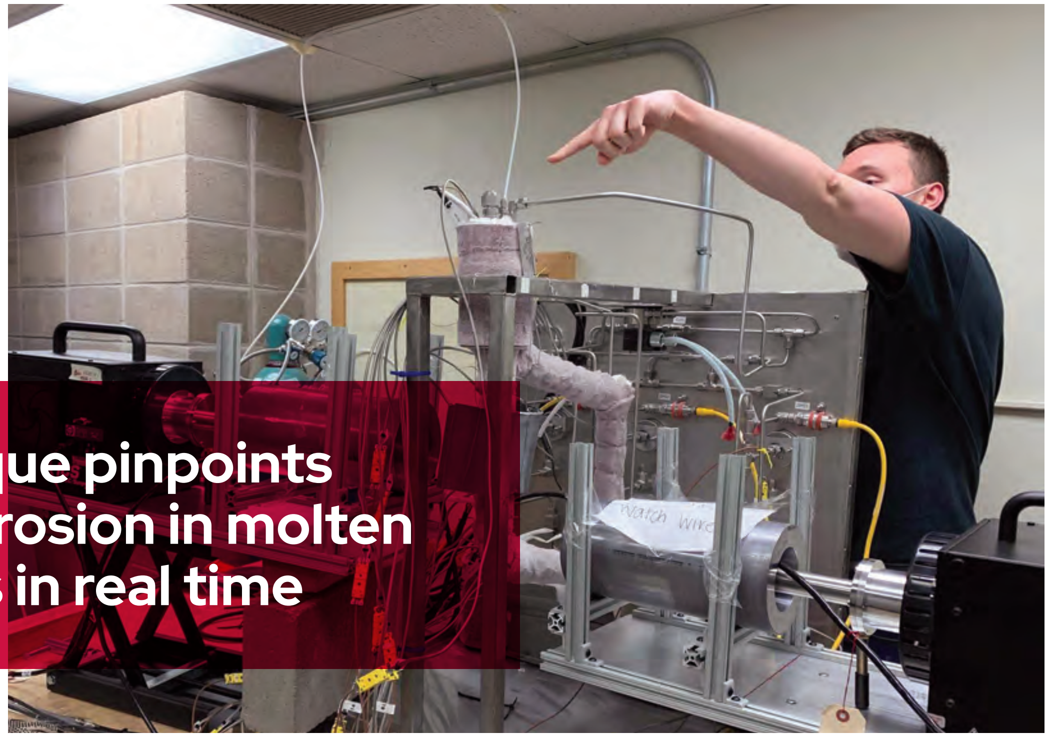
Hirst aims to create "maps" to describe the relationship between temperature and mechanical load to establish safe zones for current and future nuclear materials. "Designers could use these maps to, for instance, know that they could safely operate a reactor at a higher temperature if they reduce the mechanical load on the material," he says. "So, ultimately this materials science knowledge could inform operational practices for reactors."

Hirst will conduct research in the UW-Madison Ion Beam Laboratory, where he will lead development of several *in situ* ion irradiation experiments, including both mechanical testing and differential scanning calorimetry, to explore a wide variety of loading and annealing scenarios.

After earning his master's degree in materials science at the University of Oxford, Hirst received his PhD in nuclear science and engineering from MIT in 2022. Prior to joining UW-Madison, he was a postdoctoral research fellow in the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan. His postdoctoral research involved irradiation creep testing and developing gas implantation gradients to emulate fusion irradiation environments.

Hirst was drawn to UW-Madison because of the NEEP department's outstanding reputation, as well as the university's nuclear reactor and ion beam laboratory, both of which are used for research and education.

"Having a nuclear reactor on campus is fantastic because we can put materials into the core and expose them to neutrons," Hirst says. "Also in the Ion Beam Lab, ion accelerators can be used to emulate neutron irradiation by shooting ions into materials. So, at UW-Madison we can do both kinds of tests and compare the results, which is super interesting. I'm very excited to leverage the facilities at UW-Madison. It's a pretty unique place, as there aren't many universities with both a nuclear reactor and an accelerator lab on campus."



Harnessing gamma ray spectrometry, the new method enables researchers to acquire crucial data for designing sustainable energy systems. Paper co-author Cody Falconer (MSMSE '20, PhDMSE '22) is pictured with the team's experimental setup. Photo courtesy of Adrien Couet.

New technique pinpoints material corrosion in molten salt systems in real time

A team of UW-Madison engineers has developed a new technique that allows them, for the first time, to see how materials corrode directly within a high-temperature flowing molten salt system.

Researchers can use the technique to acquire crucial data that can inform the design of sustainable energy systems, including next-generation nuclear reactors, thermal energy storage, and concentrated solar power plants. The team detailed its method in a paper published in April 2024 in the journal *Nature Communications.*

Molten, or liquid, salt is attractive for solar energy because it can store the sun's heat for later use. Advanced nuclear reactors could use molten salt as a coolant, making them potentially smaller, safer and more economical than current nuclear power plants.

However, there's a major challenge with molten salt: It's highly corrosive, so metals in contact with the salt will wear away.

"The metal will dissolve into the salt, and a big question is how fast the material will dissolve," says Professor Adrien Couet, who led the research. "Will the amount of material lost be about the thickness of a human hair in one year, or more like the thickness of a finger? There hasn't been a way to measure the rate at which the material dissolves in a complex molten salt system with much precision."

In addition, researchers don't know where that dissolved material will end up in the system. That's important information, because the material could end up traveling into the heat exchanger and clogging it, affecting the system's performance.

Couet says it has been very difficult to answer these questions due to challenges with monitoring a dynamic, high-temperature environment with flowing molten salt. And because exposure to air can make the salt sticky, similar to what happens with table salt, it needs to be studied in an oxygen-free environment.

To overcome these challenges, the researchers' technique harnesses gamma ray spectrometry. First, they irradiated a piece of stainless steel by blasting it with high-energy particles, which produces radionuclides in the material. Then, the researchers welded the steel piece to their molten salt test loop. As the radionuclides decay, they emit gamma rays, which are detected by spectrometers positioned in multiple locations around the test loop. Since gamma rays have specific energy signatures, the researchers can use the spectrometers to precisely track the material corrosion and transport throughout the system.

Using their technique, the researchers measured the recession rate of the stainless steel and also discovered that the material mostly corroded in a manner that wasn't expected from more classic corrosion studies without in-situ trackers.

"Applying this technique to such a high-temperature system had never been done before, and we didn't know if it would work," Couet says. "It was very exciting to show that it works and that researchers can use it to acquire important data that we couldn't get before. This data is really useful for helping designers plan energy systems using molten salt that can accommodate the material corrosion, as well as for designing and testing materials that corrode less."

First plasma marks major milestone in UW–Madison fusion energy research

A UW-Madison fusion device generated plasma for the first time on July 15, 2024, opening a door to making the highly anticipated, carbon-free energy source a reality.

Over the past four years, physicists and engineers have been constructing and testing the fusion energy device, known as WHAM (Wisconsin HTS Axisymmetric Mirror) in the Physical Sciences Lab in Stoughton, Wisconsin. It has now transitioned to operations mode, marking a major milestone for the yearslong research project that's received support from the U.S. Department of Energy.

WHAM started in 2020 as a partnership between UW-Madison, MIT and the company Commonwealth Fusion Systems. Now, WHAM will operate as a public-private partnership between UW-Madison and spinoff company Realta Fusion Inc., positioning it as major force for fusion research advances at the university. Professor Oliver Schmitz and Assistant Professor Ben Lindley are co-founders and technical advisors for Realta.

"Not only is WHAM already breaking plasma physics records, for example in magnetic field strength for a magnetically confined plasma, but it provides an ideal platform for development of fusion technology going forward, which has long been a strength of the NEEP department," Lindley says.

The axisymmetric mirror technology is an attractive option for future power plants due to its simpler geometry, which will enable modular and cost-effective design.

"We are looking forward to collaborating with our colleagues in the College of Letters & Science and in Realta Fusion on bridging the gap between record-breaking plasma physics and a viable power plant to produce secure, low-carbon heat and electricity, tackling the science and engineering challenges along the way," Lindley says. "We are already seeing the benefits of partnering with private industry to perform cutting-edge research inspired by real-life end use cases."

Engineers land DOE nuclear research awards

The U.S. Department of Energy awarded more than $44 million through its Nuclear Energy University Program (NEUP) in 2024 to support university-led nuclear energy research and development projects, including a total of $4.6 million for projects led by UW-Madison engineers.

Assistant Professor Juliana Pacheco Duarte received $1.1 million for a project that will demonstrate that power uprates higher than the current state of operation can be reached using accident tolerant fuels in light water reactors while not exceeding reactor safety margins during normal operation and accidents.

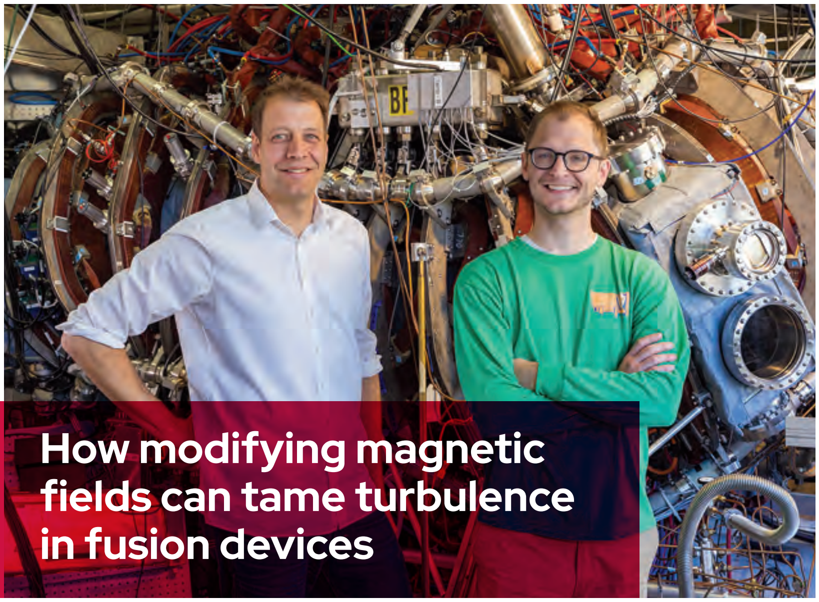
Assistant scientist WooHyun Jung received $1 million for a project that will focus on investigating the impact of chromium coating on the SiC-SiCf composite (silicon carbide fiber in a silicon carbide matrix) cladding of various architectures under normal operating and accident conditions in light water reactors and advanced reactors for the safe and economic deployment of silicon carbide cladding.

Assistant Professor Juliana Pacheco Duarte (right) discusses research with undergraduates Briunna Smith (left) and Aria Murphy (center). Credit: Joel Hallberg.

Assistant Professor Yongfeng Zhang received $1 million for a project studying iron-chromium-aluminum alloys, which are promising materials for nuclear fuel claddings that make current fuels more tolerant to accidents. These alloys, however, suffer from embrittlement caused by the formation of chromium-rich precipitates called α'. While molybdenum is often added into these alloys to improve the high-temperature mechanical strength, its impact on α' precipitation is unclear. This project aims at developing a mechanistic understanding on the effects of molybdenum on α' precipitation and dislocation loop formation in iron-chromium-aluminum alloys in thermal and irradiation conditions.

Zhang also received a $533,333 continuation award for research that complements and enhances ongoing NEUP research. This project will establish an irradiation-microstructure-property-performance correlation that links initial buffer microstructure with fracture initiation in buffer and progression to the silicon carbide layer in TRISO particles.

Mark Anderson, Consolidated Papers professor in mechanical engineering, received $1 million for a project that aims to experimentally investigate the thermal-hydraulics performance of liquid sodium heat pipes applied to microreactors, with a focus on exploring different design parameters, effects of different parameters on operating performance and understanding the evolution and impact of different failure modes.



How modifying magnetic fields can tame turbulence in fusion devices

In magnetic confinement fusion devices, an unruly plasma is a big obstacle to harnessing fusion as a clean energy source.

This turbulence in the plasma, which isn't fully understood, causes heat and particles to flow out of the plasma and prevents the ionized gas from reaching the extremely hot temperatures necessary for fusion reactions to occur.

Now, using numerical simulations, UW-Madison engineers have uncovered ways to reduce turbulence in the Helically Symmetric eXperiment, or HSX, at UW-Madison by modifying the three-dimensional magnetic field geometry.

The researchers detailed their findings in a paper published in May 2024 in the journal *Physics of Plasmas*.

"These exciting results are relevant not only for the HSX experiment but also for other fusion devices as we've obtained new insight on turbulence and the underlying instabilities through this research," says Assistant Professor Benedikt Geiger, who led the research.

HSX is a stellarator-type fusion device housed in the NEEP department. It uses electromagnetic coils to create three-dimensional magnetic fields that confine the high-temperature plasma inside a vacuum chamber. The researchers discovered that altering the electrical currents in individual coils allowed them to change the geometry of the magnetic field, and this new geometry reduced a particular instability that is a main driver of turbulence.

"We were able to develop a solid understanding of how this stabilization was occurring in the plasma and how it relates back to the geometry of the magnetic field," says Michael Gerard, a NEEP PhD student and first author on the paper. "These new insights will be useful when considering the design of future fusion devices."

Gerard says a key insight from this research is that the way individual particles drift in the plasma is a major driver of the instability. The researchers plan to conduct experiments to validate their simulations.

With HSX, the researchers had to work with the experiment's existing coil set, which limited how much they were able to modify the magnetic field geometry. "It will be interesting to see how our findings could further enhance the plasma stability in future fusion devices where there's a lot more design freedom to shape the magnetic field geometry," Gerard says.

Alum honored at Engineers' Day

NEEP honored alum Ken Petersen (BSNE '87, BS Physics '87) as part of the college's annual Engineers' Day festivities.

Petersen, the immediate past president of the American Nuclear Society, received the Distinguished Achievement Award for his success as nuclear engineer with unique expertise in the nuances of the technical and business aspects of the global nuclear fuel cycle.

Petersen has spent his entire career in the nuclear energy industry, and while the industry has had its share of ups and downs over the years, he says the future looks bright for nuclear, as it offers a vital source of reliable, carbon-free energy for addressing climate change. And as the 2023-2024 president of ANS, Petersen played a significant role in advancing nuclear.

"It has been an exciting opportunity with the very positive recent developments for nuclear, including supportive legislation and the growing support from environmentalists," he says. "So, it was a great time to be ANS president and to be able to help move various aspects of nuclear forward—not just power plants but also nuclear in space and isotopes for medical applications."

He served as vice president of nuclear fuels for Exelon—the largest nuclear utility in the United States—from 2009 to 2021. In this role, he led Exelon's fuel purchasing, nuclear core design and related safety analyses and spent fuel management. He oversaw Exelon's $1 billion annual budget for nuclear fuel procurement and managed a nuclear fuel contract portfolio valued at more than $5 billion, while reducing overall fuel costs by 20%.

UW-Madison engineers part of consortium to support nuclear security and nonproliferation

Six UW-Madison faculty members are part of a consortium of 12 universities and 12 national labs to support the basic science that underlies the U.S. Department of Energy National Nuclear Security Administration's nuclear security and nonproliferation missions.

The Consortium for Enabling Technologies and Innovation (ETI) 2.0 is led by Georgia Tech and funded by a $25 million award from NNSA.

The technical mission of the ETI 2.0 team is to advance technologies across three core disciplines: data science and digital technologies in nuclear security and nonproliferation, precision environmental analysis for enhanced nuclear nonproliferation vigilance and emergency response, and emerging technologies. They will be advanced by research projects in novel radiation detectors, algorithms, testbeds and digital twins.

The UW-Madison faculty members in ETI 2.0 include Paul Wilson, Grainger Professor of Nuclear Engineering and NEEP department chair, and Assistant Professor Ben Lindley. Wilson and Lindley will focus on accountancy of tritium from fusion energy systems at engineering and enterprise scales.

Jennifer Choy, Dugald C. Jackson assistant professor in electrical and computer engineering, will contribute her expertise in quantum sensing technology to support nuclear nonproliferation missions. Materials Science and Engineering Professor Dan Thoma will investigate signatures of advanced manufacturing techniques for materials/structures of significance for nuclear nonproliferation.

Andreas Velten, an associate professor in biostatistics and medical informatics and electrical and computer engineering, will research quantum measurements for novel radiation detection systems. Philip Townsend, a professor of forest and wildlife ecology, will contribute his expertise in hyperspectral imaging of vegetation to detect the presence of radionuclides.

Engaging students in research in the nuclear nonproliferation field is a key part of this effort. The plan is to train more than 50 graduate students, provide internships for graduate and undergraduate students, and offer faculty-student lab visit fellowships. This pipeline aims to develop well-rounded professionals equipped with the expertise to tackle future nonproliferation challenges.

Historic gift for new engineering building

A $75 million gift will fuel construction of a much-needed new building for the College of Engineering.

With their lead gift—the largest single gift in college history—brothers and UW-Madison L&S alumni Marvin and Jeffrey Levy are honoring the memory of their brother, Phil, who passed away in 2021. Phil earned an English degree from the university in 1964; the Levy family has a long history of involvement in and support for UW-Madison.

A stunning facility that marries intentional design with future-ready engineering flexibility, the Phillip A. Levy Engineering Center will be the new centerpiece of the College of Engineering campus. The transformative facility will inspire future engineering leaders, spark collaboration and yield breakthroughs that echo across generations. Enabling work for the building already has begun.

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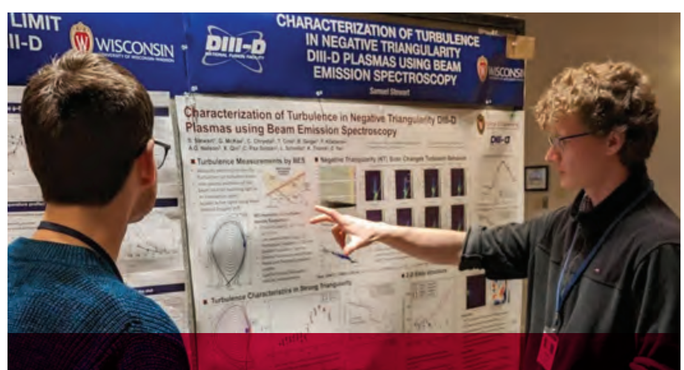
Graduate student earns best poster award

UW-Madison hosted the 2024 US-EU Transport Task Force Workshop, chaired by George McKee, a NEEP senior scientist, in Asheville, North Carolina. Eighty researchers from the United States, Germany, the United Kingdom, Italy, Norway and China gathered to present, discuss and debate the latest research in the field of turbulence and transport physics, including experiments, theory and simulation results and their performance impacts for magnetically confined fusion plasmas.

NEEP graduate student Samuel Stewart received the best student poster award for his poster, "Characterization of turbulence in negative triangularity DIII-D plasmas using beam emission spectroscopy." Stewart is a PhD student working with Assistant Professor Benedikt Geiger and McKee in the Plasma Turbulence and Spectroscopy Group.

To produce energy from fusion reactions, similar to what happens in the sun, gasses need to be heated up to millions of degrees to produce a plasma. These plasmas must be confined in magnetic "containers." However, heat from the plasma can escape the container through fast, chaotic vibrations called turbulence. Stewart's research focuses on how the shape of the container affects the turbulence and how well the plasma can be confined. The shape Stewart focuses on is a negative triangularity in donut-shaped devices called tokamaks, where the outer edge of the donut is flattened. Using a fast, camera-like detector, Stewart was able to show turbulence is reduced in the negative triangularity shape. Future fusion devices could use this shape to garner better plasma confinement and device performance.



Graduate student Samuel Stewart (right) presents his award-winning poster at the 2024 US-EU Transport Task Force Workshop. Photo courtesy of George McKee.