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

Used Fuel Drying at the University of South Carolina

by Eric Williams for DOE's Nuclear Energy University Program

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."

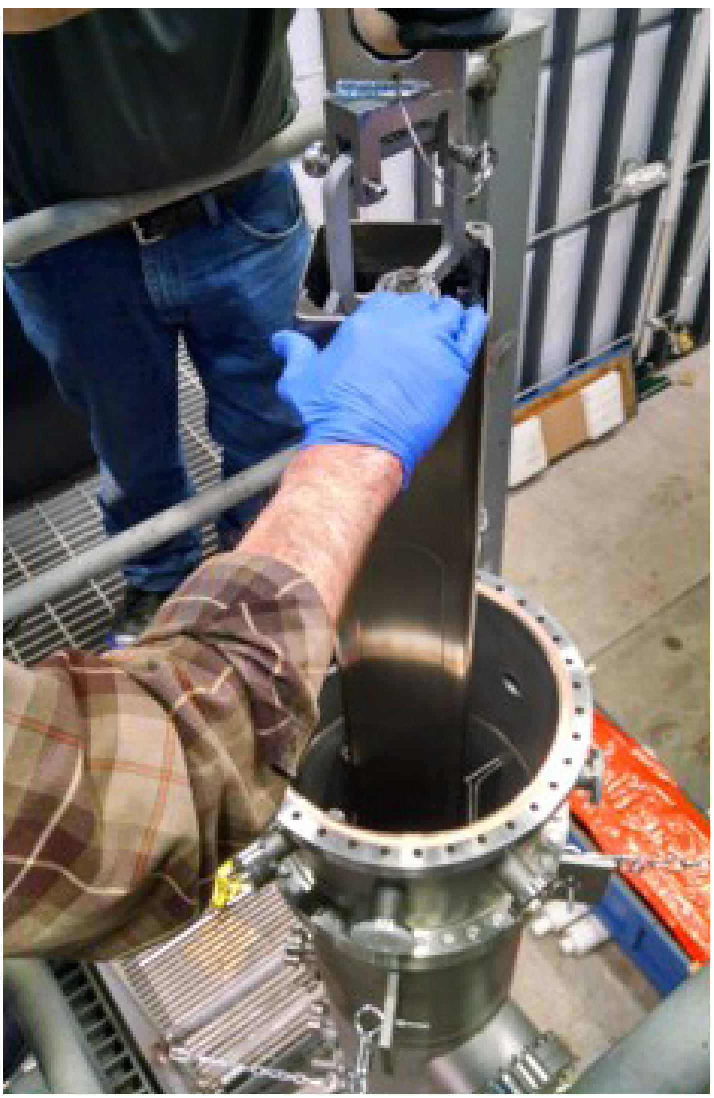
That better understanding concluded that the most likely crevice where water might remain is in a failed fuel rod, though even that amount is extremely small. What water is there is due to the fact used fuel rods are cooled in specially designed pools for approximately five years before being moved to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

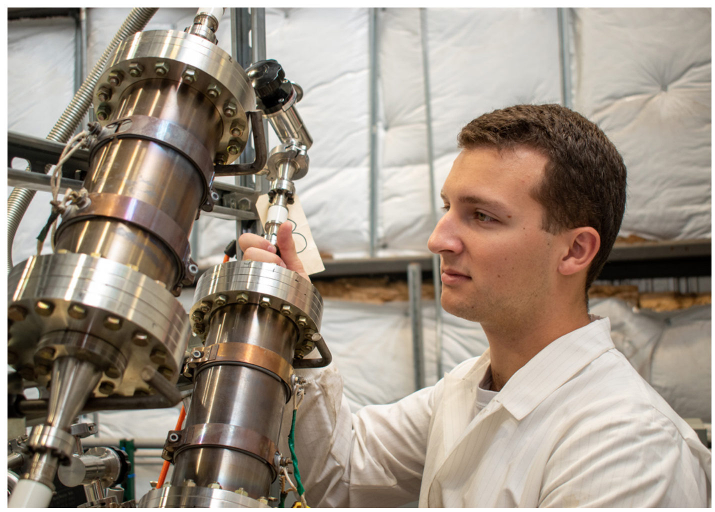
The moment at which pent up hydrogen gas would be the most dangerous is when a cask is opened up. And if in the future spent nuclear fuel is going to be recycled, casks would need to be opened to retrieve it – and the Nuclear Regulatory Commission (NRC) regulations specify that used fuel must be "retrievable."

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 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



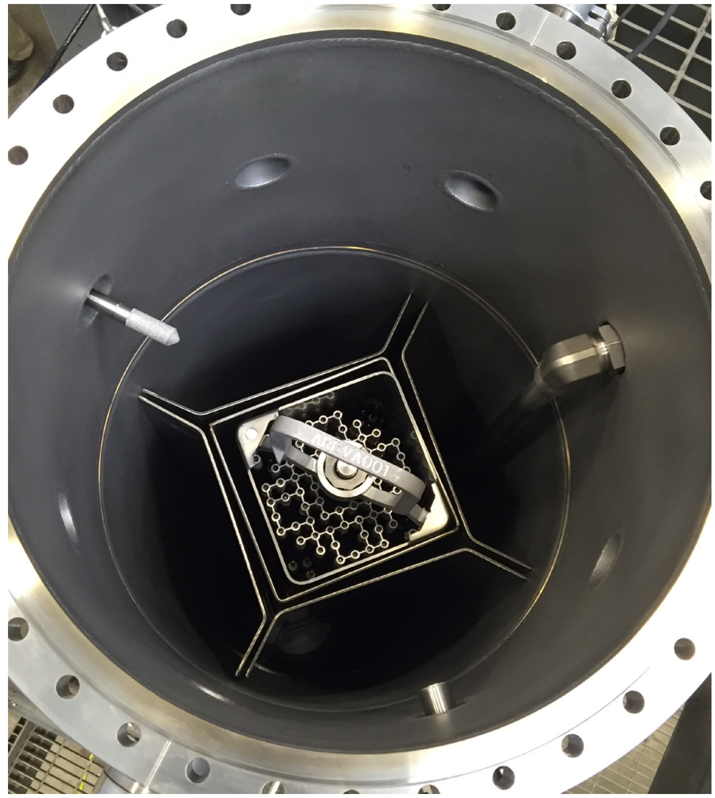
View of open test chamber showing installation of mock fuel assembly.



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.

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.

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.