2019
CASE STUDY

Slowing Down Nuclear Simulations

Oregon State University researchers use Phantom high-speed cameras to observe what happens to radioactive fuel in simulated nuclear accidents.

To prevent nuclear accidents, sometimes you have to simulate them. That's exactly what Professor Wade Marcum does at Oregon State University's School of Nuclear Science and Engineering, which seeks to drive the development of nuclear science through engineering and health physics.

Marcum specializes in nuclear energy-based research. His goal is to learn how to make current nuclear reactors safer and more economical, in addition to developing new plant concepts. To accomplish his goals, Marcum and his team of researchers design and simulate nuclear accidents—an experimental process that involves two things: seeing inside a nuclear reactor and slowing down fuel assembly failure using two high-speed Phantom cameras.

A LAB OF WHAT-IFS

"Our goal is to 'see' what's going on inside a nuclear reactor when it's operating—which is impossible," Marcum said. "Reactors operate at very high pressures and fluid temperatures. The conditions are extremely hazardous."

Since going inside a reactor was out of the question, Marcum and his team constructed a mock reactor, which operates at much lower pressures in a laboratory setting. The setup allows the researchers to visualize some of the conditions that a real nuclear reactor experiences during operation. It also allows them to simulate and observe what happens if something goes wrong. "Essentially, we're trying to answer the what-if questions," Marcum said. "What if the plant malfunctions? More specifically, what if a fuel element breaks?"

That's where the mock reactor comes in—a small, benchtop-scale loop with water flowing through it, simulating a Pressurized Water Reactor (PWR). Marcum and his team constructed a small section of a typical PWR fuel assembly, housed in a quartz cylinder. Its central rod consists of a stainless-steel tube with an outside diameter of 0.375 inches. The 24 outer fuel rods, comprising the 12-inch-long fuel-bundle section, are made of acrylic and have the same diameter as the central rod. The central rod is connected to a regulator on a nitrogen tank via a pressure line, allowing the researchers to quickly pump in nitrogen at high pressures.

"Between the acrylic and the quartz, we wanted to build a fuel element using transparent materials, which would let us see into the structure," Marcum said. "That way, during our experiments, we can simulate the fuel element breaking and then observe what happens to the fuel."

HOW PWRS WORK

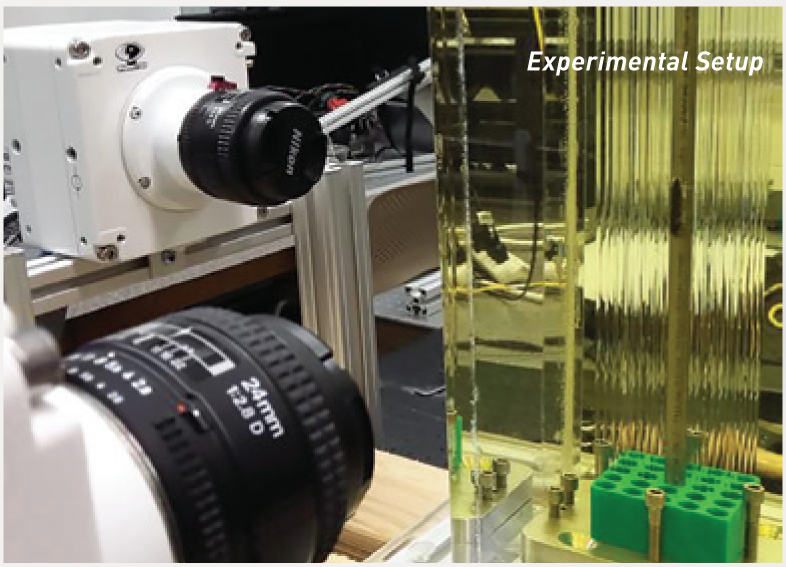
Pressurized water reactors (PWRs) make up most of the world's nuclear power plants. In this kind of system, water is pumped under high pressure to the reactor core, where it is heated by the energy released by nuclear fission. The heated water then flows to a steam generator, where it transfers its thermal energy to a secondary steam-generating system. The pressurized steam is then fed through a steam turbine, which drives an electrical generator.

PHANTOM-FAST RECORDING SPEEDS

Being able to see inside the fuel assembly was just one piece of the puzzle, however. Marcum and his team also had to figure out a way to slow their simulations down. "Fuel assembly breaks occur in hundreds of microseconds," Marcum said. "So we needed to record around 10 times that duration—somewhere on the order of 10 microseconds." To accomplish that, the researchers utilized two high-speed Phantom VEO 340L cameras, which can record up to 800 frames per second (fps) at 2,560 x 1,600 resolution and over 1,400 fps at 1,080p HD.

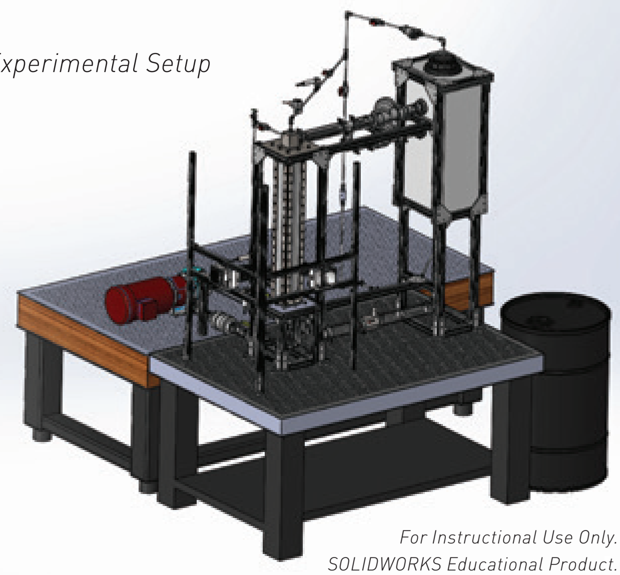
Ideal for scientific imaging especially in university settings, the Phantom VEO 340L includes a 4-megapixel sensor and high data throughput (3 gigapixels/second)—allowing researchers and scientists to record phenomena at low frame rates while still achieving very high resolution. In addition, the camera features an Image-Based Auto Trigger feature, which—in this case example—allowed Marcum to trigger the recording process at the precise instant the fuel cell broke. This capability, coupled with the camera's high internal memory, provided the nuclear team with fast, uninterrupted footage of the entire explosion process.

"We break the cladding, then use the cameras under high-speed conditions to understand what happens to the fuel element," Marcum said. "Does the fuel move all over the place? Does it bend and bow?"



Experimental Setup

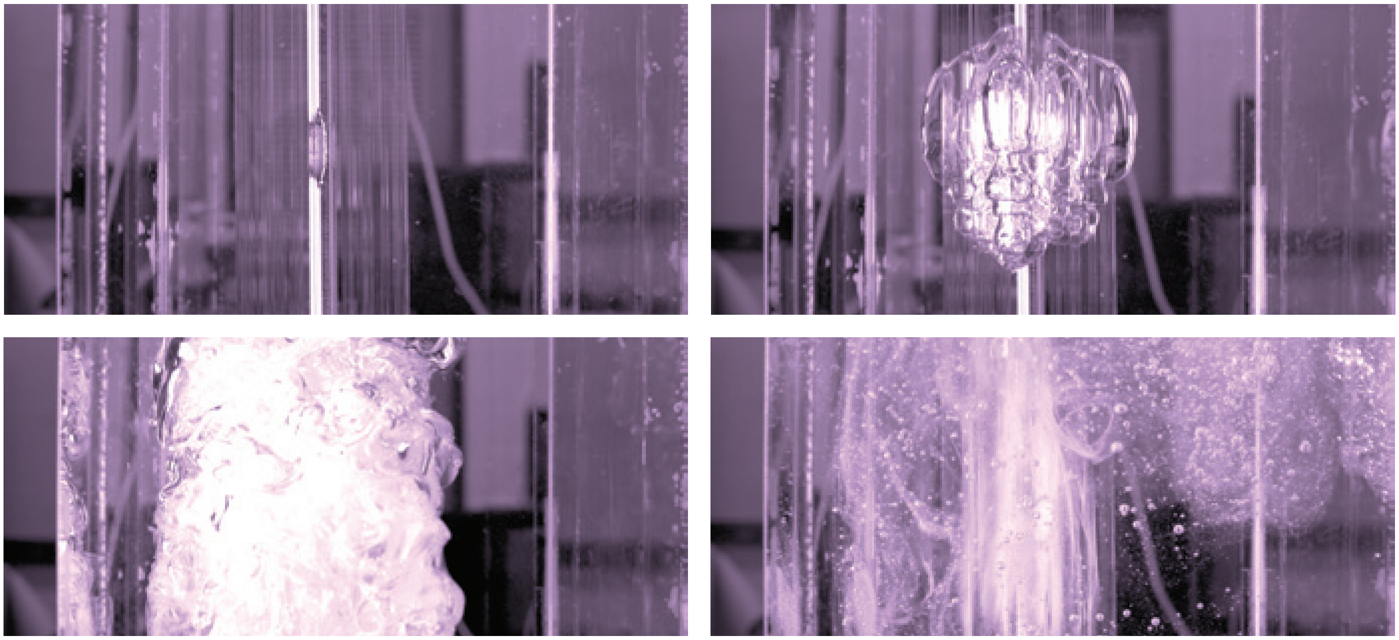
Experimental Setup



For Instructional Use Only.
SOLIDWORKS Educational Product.

BREAKING DOWN THE FUEL ASSEMBLY

A typical PWR fuel assembly weighs about half a ton and stands between 4 and 5 meters high. Fuel rods within the reactor core house the uranium dioxide, which provides the nuclear fuel. These rods are grouped together into fuel assemblies, or bundles. The outer layer of the fuel rods, known as the cladding, allows the water to be heated while also preventing radioactive fission fragments from escaping the fuel and contaminating the water.



The researchers recorded a simulated fuel element break using two Phantom VEO 340L cameras at 800 fps. Each point of analysis is 5 ms apart.

PROMISING PRELIMINARY TESTS

In a loss-of coolant (LOCA) accident, for example, a PWR's emergency core cooling system (ECCS) floods the reactor cavity, causing the cladding internal pressure to rise. This can burst the fuel element and eject a plume of fragmented oxide fuel into the coolant, causing multiple safety concerns, such as flow channel blockage or localized steam explosions.

During preliminary LOCA tests, the researchers arranged the cameras in a perpendicular configuration, focusing them on the centerline of the fuel bundle to capture the cladding rupture at different angles. Their aim was to analyze the growth of the plume in the first moments of the breach to characterize its behavior. To initiate the break, the researchers pressurized the charging line to 400 psig. They then opened the vent valve at the same instant the cameras were triggered, capturing the burst at 800 fps. Afterwards, they analyzed the progression of the plume at six different points, each one 5 ms apart.

"These experiments wouldn't be possible without the Phantom cameras," Marcum said. "They slowed the explosion down enough, allowing us to see in detail what the plume is doing at various microseconds. So far, these results are very promising."

With the help of the two cameras, Marcum and his research team have been able to visualize some of the "what-if" conditions nuclear reactors experience—enabling them to better understand and prevent these destructive phenomena from occurring. "Excitingly, this is just the beginning of a longer, three-year project," Marcum said. "Now it's about collecting more data."

PHANTOM® VISION RESEARCH AMETEK® MATERIALS ANALYSIS DIVISION