December 2018

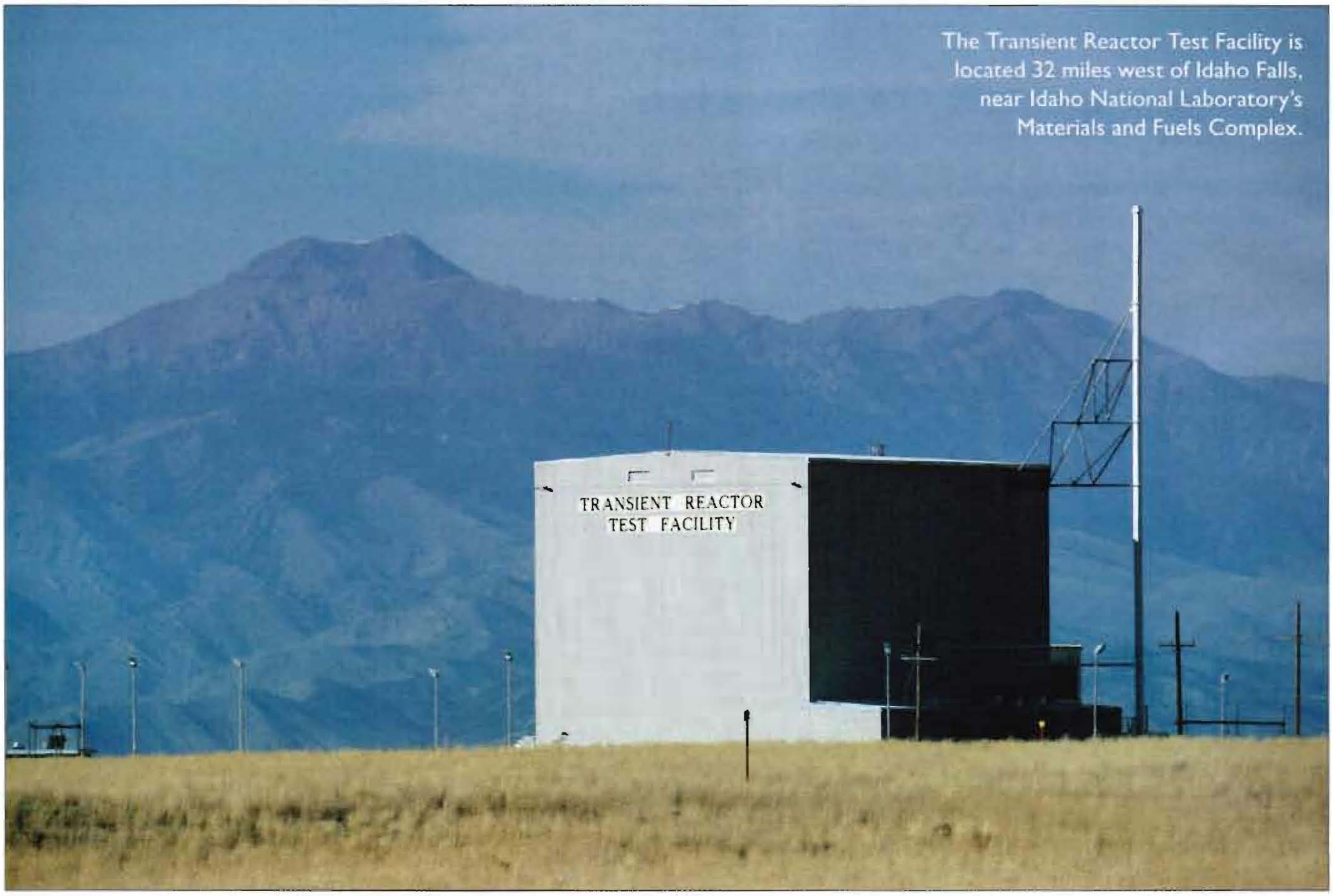
Nuclear News

Fuel Special Section | 43

A diamond in Dogpatch: The 75th anniversary of the Graphite Reactor—Part 2: The Postwar Years | 28

Author interview: Robert Mayo on *Introduction to Nuclear Concepts for Engineers* | 32

ANS



The Transient Reactor Test Facility is located 32 miles west of Idaho Falls, near Idaho National Laboratory's Materials and Fuels Complex.

Photos: Idaho National Laboratory

TREAT: A look at its past, present, and future

After nearly a quarter-century in standby mode, the Transient Reactor Test Facility at Idaho National Laboratory is once again conducting experiments.

By Hank Hogan

The revival of the Transient Reactor Test Facility (TREAT), which on September 18 conducted its first experiment in over 20 years, marked the return of a critical testing capability in the United States that will benefit the nuclear industry. The test reactor is expected to play a key role in quantifying fuel safety margins for the current fleet of power reactors as well as for the advanced reactors now under development. Both missions require data to improve fuel performance, and TREAT is well-suited to provide that data.

Hank Hogan is a freelance science and technology writer.

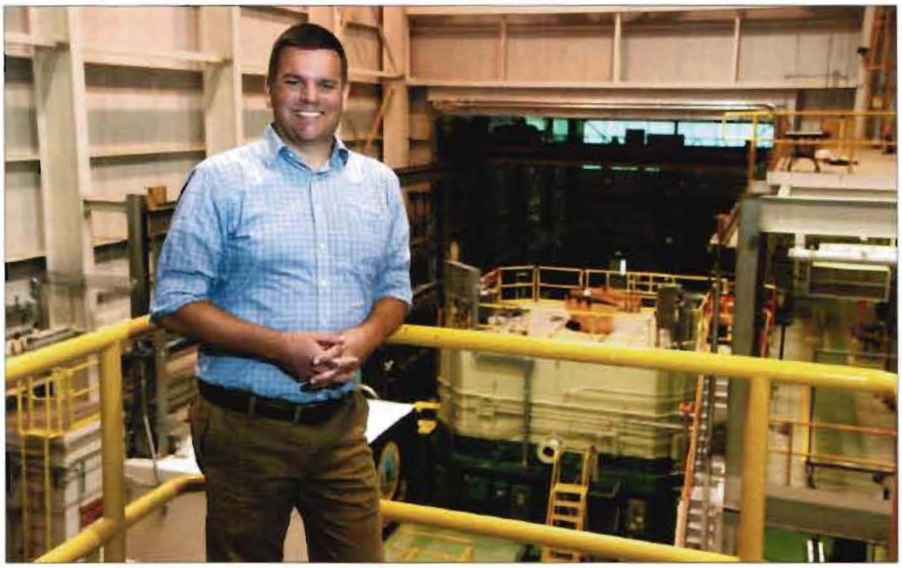
"The TREAT reactor is a necessary piece of scientific infrastructure for developing nuclear fuels that can withstand extreme conditions," said Daniel Wachs, the national technical lead for fuel safety research at INL. "Some researchers use microscopes or chemistry labs to gather necessary data. We use specifically designed nuclear reactors like TREAT."

"Crash testing" nuclear fuel

Air-cooled and graphite-moderated, TREAT is designed to simulate excursions—uncontrolled increases in power level, such as transient overpower and undercooling—that can occur in many different types of reactors. TREAT has an extremely flexible core design and a unique reactor control system that allows it to mimic an array of reactor operating conditions.

The rapid movement of TREAT's control rods, achieved through a computer control system, allows for a wide range of transients. The reactor's control rod drive system can hydraulically move rods in and out of the core at speeds of up to 356 cm/sec, and rod travel can be programmed to follow a specific plan or to occur in response to a trigger signal from an instrument. Transients produced in TREAT range from pulses as short as a few milliseconds to complex-shaped transients that last several minutes.

A key component in TREAT tests is the experimental capsule, which is loaded with the fuel being studied and the equipment needed to simulate an appro-



Left: Dan Wachs and his team at INL have designed an initial series of TREAT experiments that will lay the foundation for researchers to test accident-tolerant fuels for the current fleet of nuclear reactors.

Below: TREAT can mimic an array of reactor operating conditions because its control rod drive system can hydraulically move rods at speeds of up to 356 cm/sec.

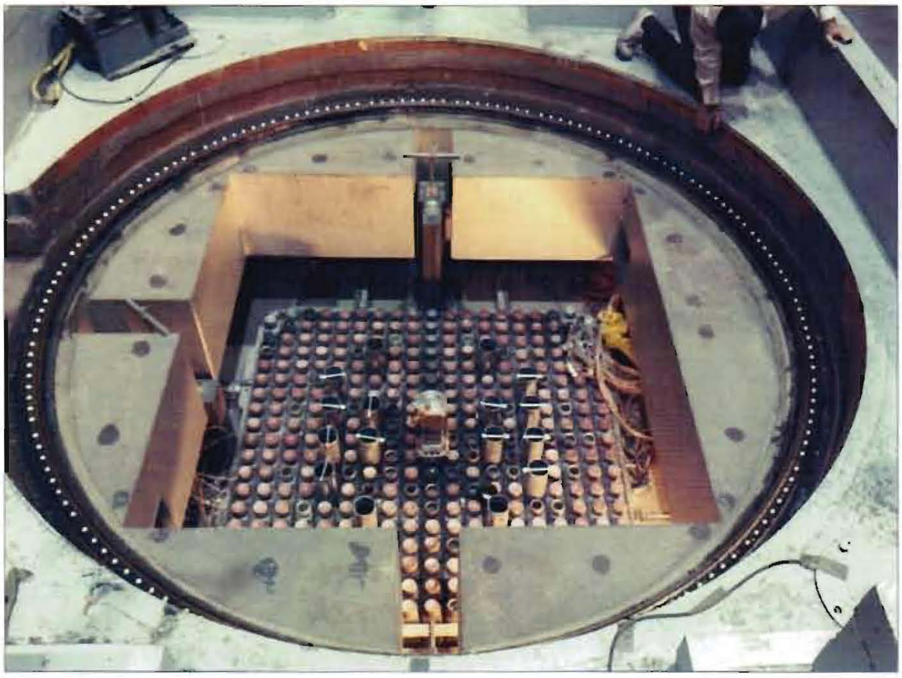
priate reactor environment. A capsule is typically less than 10 inches in diameter and 10 feet long, and it must contain instrumentation for monitoring the experiment, which presents a challenge. A test in a pressurized water system, for example, requires that pressurizers, pumps, and instruments all fit within the allowable capsule volume.

"Mechanical engineers designing these devices think of them more like Swiss watches than big power plants," Wachs said. "All of the pieces have to fit carefully into place." The capsules typically last for a few experimental runs and are then discarded.

Researchers generally look at three tiers of testing. The first is for expected or usual operational occurrences, such as normal startups and shutdowns, or power level adjustments. "This is a clearly defined operational space," Wachs said, "and any fuel must be able to withstand this without a problem."

The second testing tier is for design-basis accidents. An example might be loss of coolant or an overpower for a short period of time. What's key is that these types of accidents are deemed likely enough that a facility may encounter them, and the system must be designed to overcome an accident of this magnitude. Design-basis accidents are the focus of the accident-tolerant fuel research and development program being funded by the U.S. Department of Energy that Wachs, in his role at INL, is helping to lead. Beyond those, researchers can look at extraordinary events, the types of accidents that make it into the international news and the history books. "When things go really bad, what can happen?" Wachs said. "We call those the severe accident family."

After the 2011 accident at Japan's Fukushima Daiichi nuclear power plant, the DOE saw an opportunity to improve light-water reactor fuel—which all of the



TREAT's core is air-cooled and graphite-moderated.

98 power reactors operating in the United States utilize—and began pushing for the development of new accident-tolerant fuels. But to do that, the DOE needed a testing facility capable of simulating high-impact scenarios—the nuclear version of car crash testing. After carefully considering its options, the DOE made the decision in 2014 to restart TREAT.

Looking back to the future

TREAT operated from 1959 until 1994, performing thousands of transient tests in a wide array of fuel safety studies for LWRs and fast breeder reactors. The facility's focus in the 1960s was on the former, which make up the bulk of the commercial nuclear fleet worldwide. In the 1970s, TREAT's research emphasis shifted to sodium-cooled fast breeder reactor fuels.

In the early 1980s, TREAT's scientific mission changed once again, this time to oxide fuels for fast reactors. That prompted a refurbishment, completed in the late 1980s, which included the replacement of several key components.

"When the plant was restarted in 1988, it was fully refurbished," said John Bumgardner, who guided the restart of TREAT as INL's director for the resumption of transient testing.

From 1988 to 1994, researchers used TREAT for various fuel safety experiments. In the 1990s, however, the DOE began shutting down reactors. TREAT's shift to standby mode was an exception. It remained fueled, but its control rods were electrically disabled. The previous refurbishment provided some important benefits to Bumgardner and the INL team. When considering what it would take to restart TREAT, the INL team had a relatively clean slate, with technology and equipment that was up-to-date when the reactor entered standby mode. "Indeed, this fact likely played a role in TREAT rising to the top in terms of options when fuel testing resumed," Bumgardner said.

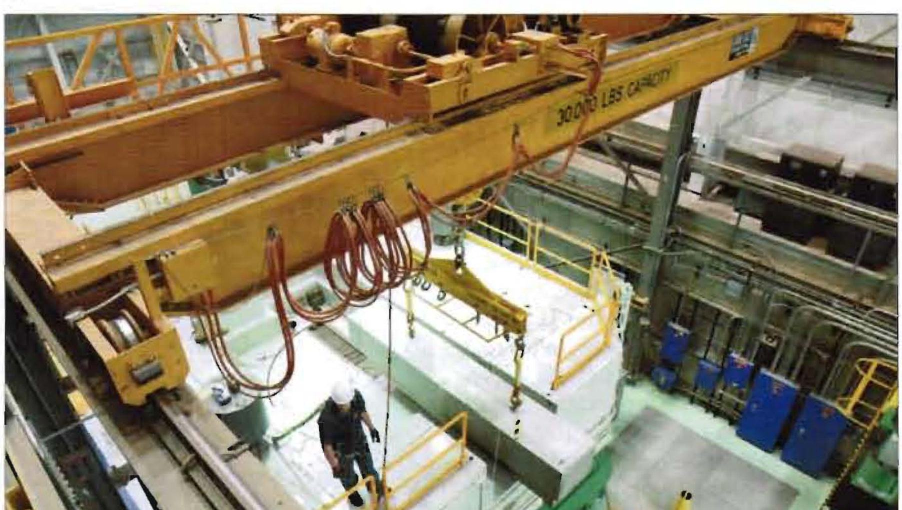
Because TREAT was in standby, the reactor went untouched for over two decades. That was not the case for nonreactor areas of the facility. For instance, a high-bay structure was repurposed for other programs. Another building was constructed within it, and by the time the restart effort began, the high-bay building was crammed with gear and material, Bumgardner recalled.

INL maintained some of the TREAT facility's nonreactor components, such as air handlers and diesel generators. Some of these rotating pieces of equipment were periodically run for a short while, greased, and then returned to standby. For this equipment, the problem discovered during restart was not one of neglect but rather of too much maintenance. "There was an excessive amount of grease inside of them," Bumgardner said. "We had to disassemble them and remove the grease."

In the reactor control room, however, nothing had been touched. Inspections conducted before and after the decision to restart, for instance, showed that chart recorders still contained paper documenting the last time the reactor operated. There had been some losses in the control room, however. Time—and mice—had destroyed documents inside. That information, unfortunately, was gone, but there was plenty of other available data that would prove useful.

First, the team had to devise a strategy to approach the restart process. In a running reactor, upgrades and updates keep technology current and ensure that the facility meets changing fire protection codes and similar standards. Also, seals and other components in an operating reactor facility are regularly replaced to avoid problems with age-related degradation.

In contrast, resuming operations at TREAT required leapfrogging 20-plus years of technological changes and component aging. Given this situation, the team decided to follow the restart recipe found in reactor outage management processes, but with a twist, Bumgardner said. "We used those standard reactor outage management processes, but we modified them to have a focus on age-related degradation and changing standards, because those are the things that would be different after a 20-year shutdown period," he said.



TREAT operated from 1959 until 1994, performing thousands of transient tests in a wide array of fuel safety studies for light-water reactors and fast breeder reactors.

In September, INL operators prepared to run the first fueled experiment in TREAT in more than 20 years.

Keys to a successful restart

The next phase of the restart required an extensive walk-through of the facility to assess any damage and determine which areas needed work. The INL team noted and documented problems, such as missing or degraded parts. That produced an initial punch list of corrective maintenance activities.

"We wanted to renew the plant to its original operating configuration, but we did not want to extensively modify it because it's much easier to get authorization to restart if you can point to previous operating experience," Bumgardner said.

The team also evaluated the state of the technology, sometimes opting to replace old equipment and sometimes not. Among the equipment to be replaced were the chart recorders. At the time the reactor went into standby, instrument and other data were captured on paper. The chart recorders were replaced with modern electronic equivalents, in part because they were not an essential or mission-critical part of the reactor control system.

That was not the case for the Automatic Reactor Control System (ARCS), an Intel multibus system with 8,086 microprocessors. New when it was installed in the mid-1980s, ARCS was definitely a critical component. Versions of the same Intel system are still in use today, so spare parts are available from vendors equipped to support and service the computer. Changing it out would have increased the risk of the project and could have caused difficulty in getting certification from regulators and authorization to restart, so the team opted to refurbish, rather than replace, the computer.

That decision also posed a challenge. The ARCS software controlling the rod movement in TREAT was written in a mix of FORTRAN and assembly language, which even in the 1990s was becoming increasingly rare. By the time the TREAT restart was launched more than two decades later, this programming skill set was nearly unheard of. Fortunately, INL had one employee, Kurt Fielding, who was capable of handling the task. He recovered the latest version of the software from 8-inch floppy disks.

Much of the success of the restart relied on people who had once worked at the facility. Although a few were still on staff at INL, many more live in surrounding communities. The INL team contacted as many former operators, engineers, and managers as possible and even organized a meet-and-greet luncheon. One of the goals was to find those with specific expertise in the operation of the reactor.

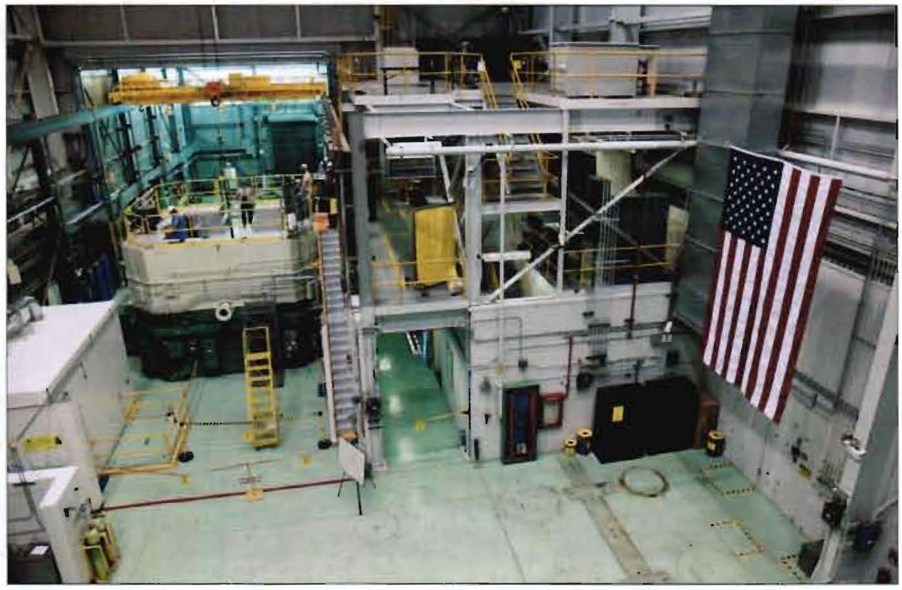
Eventually, INL rehired five individuals who had once worked at TREAT: a plant manager, a training manager, a systems engineer, a nuclear safety analyst, and a reactor facility foreman who had experience in maintenance and training as a reactor operator.

Hiring these contractors was a key element of the restart program's success, according to plant manager David Broussard. "They had extensive knowledge of some of the undocumented information," he said.

Finding former TREAT staff proved beneficial in many ways. For instance, a significant portion of the legacy procedures and data for TREAT were available only in hard copy. The contractors helped sift through mountains of paper, as well as electronic documents, and provided advice on which documents were relevant to a particular topic. An hour of their time working on historical research activities sometimes saved current staff several days of frustration.

Legacy staff also helped develop a training program. Since TREAT does not have a simulator that can be used to train new operators, reactor operators had to be qualified "provisionally," without actual experience operating the reactor. Part of the solution involved picking the brains of the historical contractors, as well as developing a team of expert instructors with extensive experience in reactor operations.

The INL team hired the first wave of operators early in the restart process, which enabled them to gain expertise in maintaining and repairing the plant systems, operating the reactor control systems (in a shutdown mode), and assisting with integrated system testing.



On November 14, 2017, TREAT went critical for the first time since being placed in standby mode in 1994. The first fueled experiment was performed 10 months later.

A key activity that provided the final missing component for training and integrated system testing was replacing 16 fuel assemblies in the core with boron assemblies, temporarily poisoning it. This kept the reactor from going critical no matter how the control rod system was manipulated. That allowed the control rods to be safely refurbished, critical systems to be updated or repaired, integrated plant testing to occur, and, ultimately, training to take place. In essence, the reactor became its own simulator, with the important provision that excess boron would keep it subcritical.

Part of the restart involved a complete update of the reactor's safety analysis report and technical specifications, which had to be in place before TREAT could operate again. Although difficult, the update was completed without slowing down the restart, thanks to a high level of interaction between the TREAT staff and the regulators approving the safety analysis report. "Because the DOE regulator was available for real-time feedback, we were able to move through the entire process in a very timely manner," Bumgardner said.

First experiments and beyond

On November 14, 2017, TREAT went critical for the first time in more than 20 years. The entire restart effort cost about $20 million less than the baseline estimate and was completed about a year ahead of schedule.

After a low-power shakedown and testing phase, TREAT staff conducted the first experiment in September. The reactor pulsed for a few seconds, subjecting a small capsule of LWR fuel to radiation and heat.

The current test plan is replicating work done more than two decades ago. Getting the same results today as in the past proves that the reactor function has not changed and will allow future testing to build upon past results.

The future of TREAT includes support for the existing commercial nuclear fleet through efforts such as the testing of accident-tolerant fuels, but it will also involve new projects, Wachs said. For instance, after the TREAT restart was already under way, the government of Norway announced the closing of its Halden test reactor, which supported LWR testing for a broad base of international customers. TREAT's current mission overlaps with some of the Halden work and could potentially contribute to filling the void left by the closure of that test reactor.

New fuels and reactor concepts will need to be tested for the next generation of reactors, including micro-reactors producing less than a megawatt of power. Moving these new reactor concepts from the drawing board to reality depends on data from TREAT or a similar facility.

"Basically, every time you have a new technology, it's going to require significant safety testing," Wachs said. "We're going to have to do that for any new reactor technology that comes out."

What the test reactor will do in the future beyond these and other known projects is still being defined. Future experiments will come from industry and government, arising from the needs of each. For Wachs, it's ultimately a question of how best to use one-of-a-kind scientific infrastructure. NN