MATTER

A publication of Savannah River National Laboratory

Fall 2024

ENDURING IMPACT, INSPIRED FUTURE

20 YEARS AS A NATIONAL LABORATORY

2004 - 2024

Special 20th Anniversary Issue

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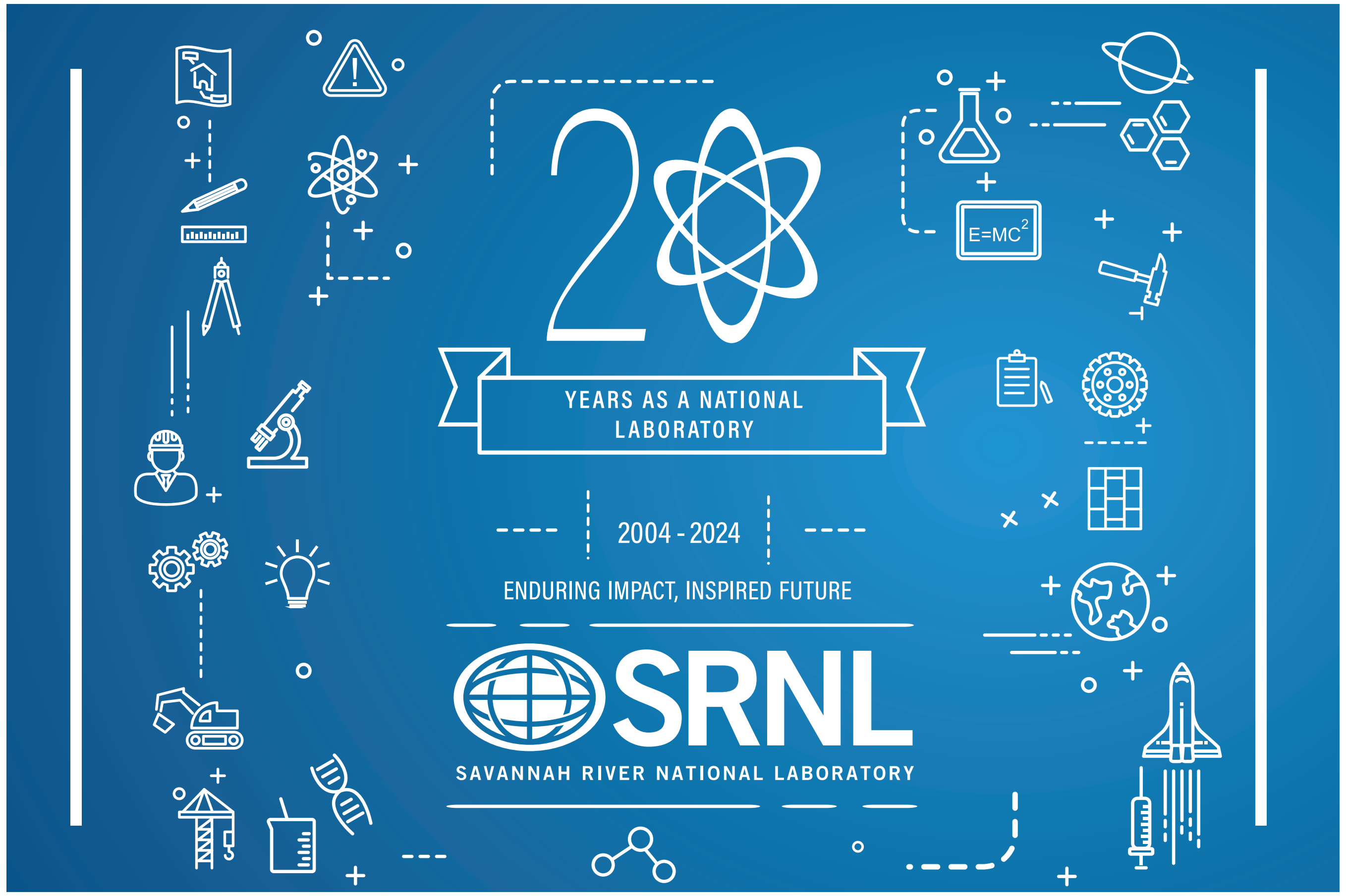
Savannah River National Laboratory®



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Savannah River National Laboratory is a United States Department of Energy multi-program research and development center that's managed and operated by Battelle Savannah River Alliance, LLC (BSRA) for the Department of Energy's Office of Environmental Management. SRNL puts science to work to protect the nation by providing practical, cost-effective solutions to the nation's environmental, nuclear security, nuclear materials management, and energy manufacturing challenges.

cover: Interns Ritwik Sharma and Olivia Belian working in the satellite lab (Brad Bohr, SRNS)

From the Director

This issue of MATTER celebrates the 20th Anniversary of SRNL's designation as a National Laboratory. This moment in our history affords us the opportunity to revisit past achievements and to boldly forge our future.

In this issue you'll find stories about our work in Space Nonproliferation, the Center for Hierarchical Waste Forms, grid security, our mobile facilities and the deployment of Advanced Long-Term Environmental Monitoring Systems beyond the Savannah River Site. In fact nearly every story in this issue highlights the global impact of SRNL's work. Our research and development and applied science achievements continue to have impacts across the DOE complex, our nation and the world.

SRNL is a DOE-EM lab and our support to the complex's most challenging cleanup and monitoring problems remains steadfast as the NNSA becomes the Savannah River Site landlord. SRNL has a long history of providing solutions to NNSA's toughest challenges and we look forward to building upon this foundation of achievement as NNSA increases its footprint in the Central Savannah River Area.

After reading this issue I know you, too, will understand why it is indeed a great time to be part of SRNL where we put science to work to protect our environment, serve our national defense, secure our clean energy future and reduce emerging nuclear threats.

Vahid Majidi
Director, Savannah River National Laboratory

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SRNL's Storied Past, Vibrant Present and Limitless Future

ENDURING IMPACT, INSPIRED FUTURE
20 YEARS AS A NATIONAL LABORATORY
2004 - 2024

by Kent Cubbage

In 2021, the Battelle Savannah River Alliance team began management and operations of the country's premier environmental, energy, and national security research facility – the Savannah River National Laboratory. This marked an important transition of SRNL into an independent, national technical resource that is delivering excellence in science and technology, operations, and community engagement.

This newfound autonomy gave SRNL the feel of a start-up company, but it belied the fact that the lab had a storied, 70-year history. In the early 1950s, as the need for SRS became apparent to expand the nation's nuclear deterrent, the Atomic Energy Commission recognized the importance of a stand-alone, dedicated laboratory to support SRS operations. The DuPont company, which President Harry Truman asked to run the new plant, agreed with this assessment and requested the proposed lab not be included in the national laboratory system. The lab was given the title of Savannah River Laboratory.

Nuclear science for both defense and commercial applications was in its infancy. The processes for producing plutonium and tritium for nuclear weapons, especially on a large scale, were still being created. SRL's talented engineers, chemists and nuclear scientists, some of whom had been part of the Manhattan Project, made great strides developing and improving them.

The 1950s and 1960s saw increased production of nuclear materials at SRS and significant advancements in the science behind it. SRL was at the heart of these primary mission activities. Nonetheless, while still not a national laboratory, SRL's innovations and discoveries rivalled those from the national laboratory complex. SRL scientists supported the discovery of the neutrino by Clyde Cowan and Frederick Reines in 1956. During these years, SRL scientists also conducted groundbreaking work with rare elements (e.g., curium, californium) and played a major role in isotope science for the U.S. space program.

SRL continued to push the boundaries of nuclear science in the 1970s and 1980s, as well as develop novel processes for the treatment and storage of legacy waste from nuclear material production. Nuclear fuels were processed in the separations canyons. Advances and discoveries continued to be made in both fundamental research and advanced engineering and chemistry. In the late 1980s, recognizing the growing capabilities and evolving missions at SRL, the name was changed to Savannah River Technology Center. This reflected a greater emphasis on expanding the lab's reach beyond the SRS boundaries.

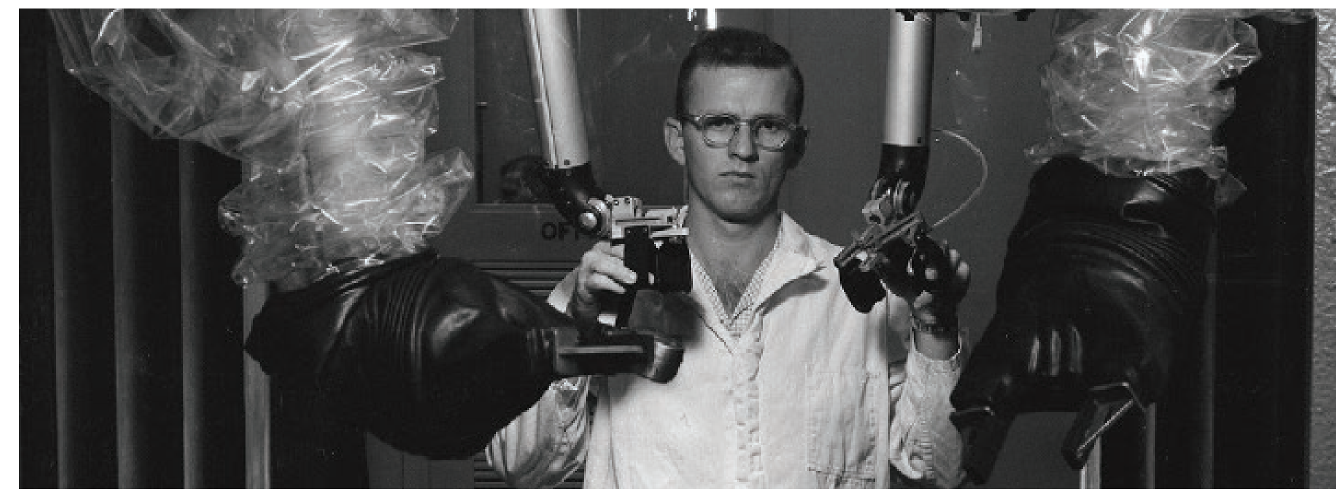
And in 2004, SRTC's title changed to reflect a much more prestigious designation. According to "Hot Labs/Cold War," a 2022 history of SRNL:

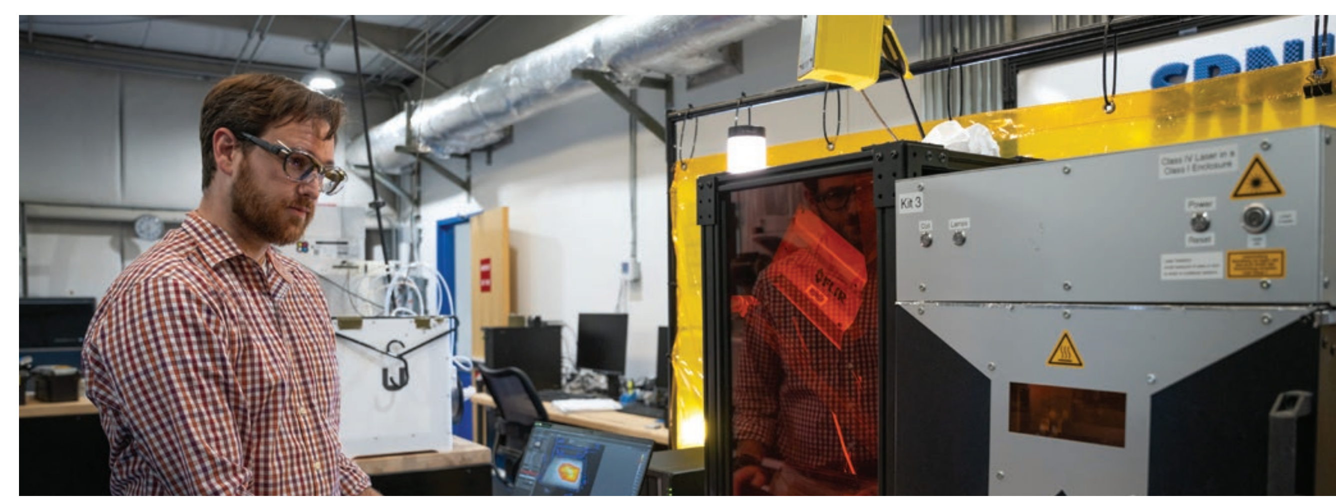
> The DOE recognized the core competencies of the SRTC in hydrogen technology, environmental remediation, non-proliferation and national security, and nuclear material stabilization. Acknowledging the importance of these areas to the nation, the SRTC was designated as a National Laboratory on May 7, 2004, and renamed the Savannah River National Laboratory (SRNL). This achievement was the culmination of the work of thousands of scientists, engineers, and technicians who innovated for over a half-century at the SRS and a recognition of the research potential of the Savannah River National Laboratory in nuclear stockpile, nuclear materials, and environmental stewardship.

In the 20 years since the designation SRNL has seen tremendous growth, with a goal of significantly expanding programs such as nonproliferation and tritium science. The Advanced Manufacturing Collaborative will soon open on the campus of the University of South Carolina at Aiken. Plans are also being made for a workforce development center.

In addition to work in nonproliferation, weapons production technology and environmental and legacy management, SRNL scientists are making new discoveries in clean energy. Applications for advancements in all these areas are plentiful throughout the nation and worldwide. Opportunities abound for technology transfer from SRNL research, and the number of patents and SRNL publications continues to grow each year.

SRNL is putting science to work and will continue to do so. As it protects our environment, secures our clean energy future, serves our national defense and reduces emerging nuclear threats, SRNL has a limitless future.





Top: The High Level Caves (Shielded Cells) in the early 1960s. (SRS Archives DPSPF-8297-12)
Bottom: The Additive Manufacturing Lab in 2023. SRNL (Laura Russo, SRNS)

A Laboratory Timeline

Cold War Years

1951
Savannah River Laboratory is created to support the Savannah River Site

1980
Invention of TCAP (Thermal Cycling Absorption Process) by Myung Lee

1982
Federal Government selects glass as preferred waste form for High Level Waste; SRNL led the team providing technical data to support the decision.

1983
Construction begins on the Underground Counting Facility

1985
786-A expanded to provide flow testing for reactor cooling systems; SRNL Underground Counting Facility begins operations.

1989
Westinghouse takes over operations at SRS from DuPont.

Post-Cold War Years

1992
SRL is rebranded Savannah River Technology Center

1994
April - SRNL-developed technology TCAP started in the SRS Tritium Facilities for production operation.

July - Susan Wood named Director of SRTC

1996
Defense Waste Processing Facility starts operations based on SRNL developed glass formulations and equipment design.

1999
Washington Group International acquires the government services business of Westinghouse, changing the Westinghouse Savannah River Company name to Washington Savannah River Company.

2002
G. Todd Wright named Director of SRTC

National Laboratory

2004
SRNL becomes the 17th national laboratory

2006
REALS (Radioactive Evidence Analysis Lab Suite) completed to support FBI Forensics; TNX closure completed.

2007
Deputy Laboratory Director Cheryl Cabbil appointed Acting Laboratory Director, taking over from Todd Wright.

2008
SRNS takes over management of SRNL from Washington Savannah River Company, installing Samit K. "Sam" Bhattacharyya as director

2009
NMO and SRNL increased life span of hydrogen getters in plutonium storage

2010
June - Expanded the FBI's Radiological Evidence Examination Facility to six times its original size in one wing of SRNL's main building

August - Terry Michalske named laboratory director

2014
SRNL appointed to manage the Department of Energy Office of Environmental Management Minority Serving Institutions Partnership Program.

2016
SRNL qualified to the International Atomic Energy Agency Network of Analytical Laboratories for Nuclear Materials Analysis.

2018
March - DOE Office of Legacy Management and Office of Environmental Management collaboration with SRNL, SRS to enhance legacy cleanup and long-term stewardship

- Vahid Majidi named laboratory director

2021
Battelle Savannah River Alliance takes over management of SRNL

2023
SRNL qualified to the International Atomic Energy Agency Network of Analytical Laboratories for the production of Reference Materials.

2024
SRNL celebrates its 20th anniversary as a national laboratory

SRNL Develops Technologies for the Emerging Advanced & Small Modular Reactor Fuel Cycle

by Chris O'Neil, APR

The nuclear energy landscape is changing. Public attitudes toward nuclear clean energy have shifted, with a majority of Americans (57 percent) indicating they favor nuclear power plants for electricity generation – an increase of 14 percent since 2020[1]. The look of nuclear power for electricity generation is similarly changing, as conversation in the industry increasingly centers more on the advantages of advanced small modular reactors to deliver safer and more secure nuclear energy, and less on the traditional large nuclear power plants. While those conversations are largely focused on how and where advanced small modular reactors can be used, Savannah River National Laboratory is leading conversations about solving fuel cycle challenges with focus on the "backend" or waste disposition for these small reactors.

As a multidisciplined, federally funded research and development center, Savannah River National Laboratory continuously seeks to understand technology gaps that emerge as new processes and industries develop. SRNL leverages its decades of applied science and technology expertise in spent nuclear fuel and waste disposition technologies to address these emerging gaps.

According to the Department of Energy, advanced small modular reactors are a key part of the Department's goal to develop safe, clean and affordable nuclear power options ranging in size from tens of megawatts up to hundreds of megawatts, offering many advantages over larger nuclear plants including smaller physical footprints, lower capital investment, siting in locations not possible with larger plants, and provisions for incremental power additions.[2]

As the U.S. moves to keep up with international competitors, SRNL is leading discussions to keep the nation from falling behind in fuel cycle and demobilization efforts surrounding small modular reactors.

"Our experience is with development and application of modular approaches to nuclear materials processing. The ability to provide right-sized process capabilities is very applicable to the emerging fuel cycles associated with advanced small modular reactors," said Bill Bates, SRNL's deputy associate

[1]Pew Research Center survey, May 30-June 4, 2023, as reported in "Growing share of Americans favor more nuclear power," Rebecca Leppert, Brian Kennedy, Aug 18, 2023, https://www.pewresearch.org/short-reads/2023/08/18/growing-share-of-americans-favor-more-nuclear-power/
[2]https://www.energy.gov/ne/advanced-small-modular-reactors-smrs

Opposite Page: Illustration: SMR fuel ecosystem (Susanna King, SRNL). (NuScale_Power_Module_1_-_JPG.jpg, Oregon State University, CC BY-SA 2.0, via Wikimedia Commons) (Cross-section_of_TRISO_fuel_pellet.jpg, DOE, Public Domain, via Wikimedia Commons) (Illustration: UO2 lattice, SRNL) (Yellowcake_(03010301).jpg, IAEA Imagebank, CC BY-SA 2.0, via Wikimedia Commons) (Illustration: cask cutaway, SRNL) (Photo: spent fuel, Steve Ashe, SRNS)

Conversations about small modular reactor deployment need to include discussion about the fuel cycle and backend.

laboratory director, Environmental and Legacy Management. Bates is quick to point out that discussions about advanced small modular reactors can't stop with the reactor deployment; rather he says, those conversations need to include discussion about the fuel cycle.

"It's more than just the new reactor, it's about the fuel, it's about how you deal with the reactor itself when you're done and it's about how you deal with the spent nuclear fuel. SRNL has experience in all of that," said Bates.

There are challenges that come with the deployment (and demobilization) of an advanced small modular reactor (or microreactor) to a battlefield or to a location impacted by a natural disaster like a hurricane or earthquake. "Here, we're talking about having to move spent nuclear fuel and highly irradiated material, and very likely the reactor itself," said Bates. It is those backend process challenges that Bates believes are only starting to get attention, and for which SRNL is well-positioned and uniquely qualified to address.

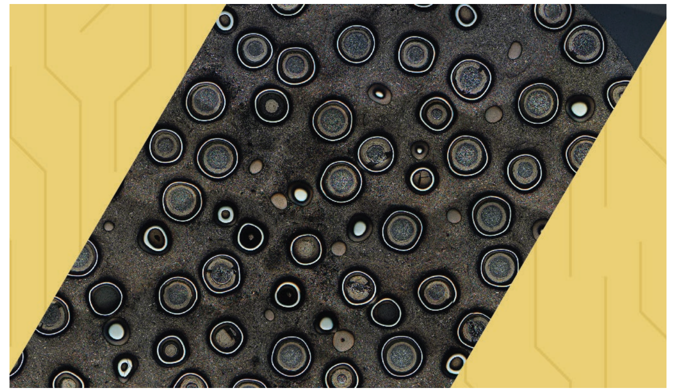
"You can preserve the spent fuel to reuse it, in which case it would be packaged and kept intact for potential future use or isotope recovery, or you can stabilize it intact or process it into a waste form, and then package it for storage as a high-level waste," said Bates.

SRNL's capabilities in highly regulated modular system deployments allow the laboratory to serve as trusted advisors and science and technology experts in support of the fuel cycle and backend aspects for these reactors.

Bates points to five specific examples of SRNL's relevant efforts in advanced small modular reactor fuel cycle technologies.

- TriStructural Isotropic fuel processing.
- Reprocessing technologies.
- Fuel optimization.
- High-Assay Low-Enriched Uranium feedstock.
- Packaging and transportation technologies.

Multiple companies plan to use TRISO fuel in small modular reactors or microreactors.

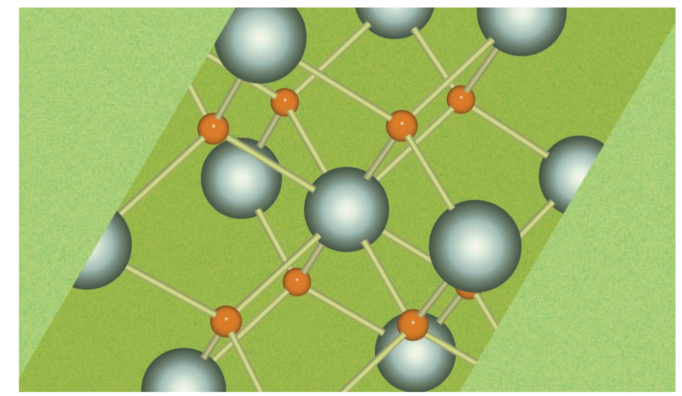


"TRISO fuel uses graphite as its cladding and moderator and SRNL has several patents on a technology for removal of that graphite," said Bates. "We're working to optimize that technology to allow for modular processing for recovery of HALEU from fresh fuel scrap during fuel fabrication or for treatment of spent nuclear fuel. SRNL was recently awarded a DOE Office of Technology Transitions project in which SRNL is partnering with the University of South Carolina.

"The removal of the graphite from the spent TRISO fuel enables either the reprocessing of the spent fuel or a reduction of the volume of high-level waste requiring packaging, storage, transport and disposal. This is possible because SRNL's process technology removes more than 90 percent of the fuel volume. In the processing, some neutron poison material is added back in but the final overall volume reduction of material is about 60 percent."

Bates notes that the elimination of the graphite yields carbon dioxide, but the work the lab is doing with the University of South Carolina aims to capture the CO2 and convert it into a solid form allowing it to be disposed of as low level waste. "Our solution is an elegant way to process spent TRISO fuel, compared to many other approaches that have numerous challenges including grinding, burning, and cutting of graphite," he said.

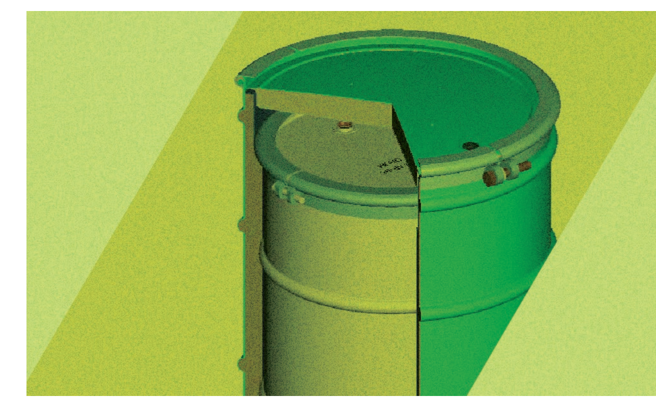
Bates' next example is work SRNL is doing in collaboration with Metatomic Inc., following the award of a Gateway for Accelerated Innovation in Nuclear project where the lab is working with Metatomic to scale up their technology to take spent civilian nuclear fuel (such as spent fuel from a traditional nuclear power plant), remove the cladding and make it all (the isotopes are not separated) into a salt that can be used as fuel in an a molten salt reactor, one of several types of advanced small modular reactors. SRNL's work here is on the backend of the commercial nuclear fuel cycle, but it's the front end for a molten salt reactor. SRNL has completed the initial experiments converting uranium dioxide to uranium chloride, but much more work is ahead.



A DOE Advanced Research Projects Agency - Energy project is Bates' third example. In this collaboration with TerraPower, uranium from used nuclear fuel is separated by a chloride-based volatility process designed to reduce waste volumes by recovering the uranium. The chloride-based volatility process uses the principle of fractional distillation to recover different chloride salts at selectively different temperatures. The process can be applied to metallic- and oxide-based reactor fuels with a goal to also adapt it to salt-based reactor fuel.

SRNL's work with HALEU fuel feedstock is Bates' fourth example. Here SRNL performs – for DOE's Office of Nuclear Energy – detailed radiochemical analysis of all the high-enriched uranium cleaned up from the Savannah River Site's H-Canyon facility, to support an advanced reactor fuel fabricator's specifications once blended down to high assay low enriched uranium (Low Enriched Uranium consisting of the clean, highly enriched uranium from the Savannah River Site's H-Canyon, blended with low enriched uranium or natural uranium to between 5 and 19.75% U-235 enrichment). "Our packaging and transportation group is also working with Orano (under the same scope) on licensing a shipping package to be able to ship the HALEU in a liquid form to the fuel fabricator who will use this high-assay low enriched uranium to produce fresh reactor fuel," Bates said. "The project demonstrates our expertise in packaging and analytical capabilities to support the initial feedstock for advanced small modular reactors of the near future," he said.

Finally, SRNL's expertise in packaging and transportation continues to drive innovation as demonstrated by SRNL's development of a new shipping package and the expansion of SRNL's existing packaging licenses to include fuel for modular reactors, such as TRISO, to be certified by the Nuclear Regulatory Commission for commercial use. This will enable the safe transport of unique unirradiated fuel from fabrication to future locations where the modular reactors will be used.



Bates notes SRNL also has other lines of work supporting the DOE Office of Nuclear Energy's Nuclear Fuel Cycle (NE-4) and Spent Fuel & High-Level Waste Disposition (NE-8).

Seeking to solve the fuel cycle and "backend" challenges of small modular reactor deployment is another example of SRNL leveraging its 70 years of experience to provide solutions to tomorrow's complex challenges.

From Nuclear Production to Grid Support

How SRNL's Legacy Helps Ensure Grid Security

by Federica Staton

Our world is becoming increasingly interconnected and, now more than ever, the security of our power grid is paramount. As we become more interconnected the emergence of cyber threats is also a growing concern. Savannah River National Laboratory's Global Security Directorate supports the U.S. national security communities by focusing efforts on power grid security, electronic warfare and wireless test and evaluation processes.

Energy security, according to The Department of Energy's Office of Energy Efficiency and Renewable Energy, is having enough energy to meet demand and having a power system and infrastructure that are protected against physical and cyber threats.

However, according to SRNL's Director of Cyber Security Strategy, Glenn Fink, it is as simple as, "When someone switches on the light-switch, the light turns on, and they are afforded the ability to never question whether or not the light will in fact turn on."

Ensuring that everyone's lights remain on is achieved through safeguarding both critical cyber and physical infrastructure. SRNL supports that safeguarding effort through extensive and innovative testing.

Unique Testing Ground

In the 1950's Savannah River Site was home to five nuclear reactors that produced the fissile materials used in nuclear weapons. All of the reactors were shut down by 1989, which now makes those areas usable to help protect our grid's future.

SRS had a vast electrical network that serviced nuclear reactors and related facilities. With the reactors no longer running, there are 17 miles of transmission line that are surplus to the site's needs. SRNL is partnering with Federal and South Carolina State departments and agencies, SRS stakeholders, industry and other national labs to refurbish those transmission lines to form a testbed for voltages from 115kV to 230kV. This testbed is substantially isolated from the remainder of SRS's transmission lines and the surrounding commercial power grid.

SRNL's testbed will allow grid components to be tested in

Opposite: SRNL substation on the Savannah River Site (SRNS Photo) a complex integrated system to better understand how they interact and may negatively affect each other. Power companies are conservative in adopting new technology because their only place to test interactions is on the actual power grid where failure of the new technology can negatively affect consumers, and data collection could harm consumer privacy. SRNL's testbed will enable grid operators and equipment manufacturers to test and gain confidence in a low-risk environment.

Another initiative that SRNL is working on is Threat Hunting Representations for Embedded Anomaly Tracking. THREAT helps cyber threat hunters understand data within their systems. This means that SRNL is developing the ability to help power companies learn what to look for when analyzing computer communication to determine what normal communication flows look like. Fink says that this is key for power companies because, while they ensure that the physical grid is ready and resilient, they may not have the bandwidth to recognize and analyze future threats.

Beyond prevention, SRNL also focuses on enhancing grid resilience. Examining cyber electromagnetic issues gives SRNL a better understanding of the potential threats and how to mitigate them. Introducing new equipment, such as transformers, to the grid prematurely can lead to potential blackouts, but the test bed allows new equipment to be tested on a self-contained grid to mitigate risk.

SRNL also has simulators, which include control modules from real equipment, that are used for training and helping power plants with their resiliency efforts. These simulations allow groups like the National Nuclear Security Administration, the Department of Defense and other agencies to learn how to defend the electrical grid from cyber attackers.

Looking to the Future

"One of our main roles as a national lab is to think ahead two-to-five-years and find out how we're going to meet challenges that we expect to have before they become really popular," says Fink. To help achieve this, his group is working on a solution using Artificial Intelligence.

One project Fink's group is working on in collaboration with our partners, uses technology to help align safety, safeguards and security information from small modular nuclear reactors using AI to try to enhance security for the nation.

When it comes to cyber security, network engineers who have sizable networks rarely know everything that's on it. Fink's goal with AI is to characterize what is normal on networks where there are some unknown components. He wants to use these characterizations to help operators understand when their network deviates from normal status and what those deviations mean.

SRNL power substation. (SRNS Photo)

Grid security is a collaborative effort, and SRNL actively engages in partnerships with government agencies, energy providers, industry and sibling DOE National Laboratories to share knowledge to coordinate an approach to grid vulnerabilities and how to counteract them.

While protecting the grid is a multifaceted, ever evolving task, SRNL has a stake in preparing the world for future threats to come. From nuclear reactors of the past to our 17 miles of disconnected transmission line, SRNL's unique role in ensuring grid security allows us to leverage the infrastructure of the past to create the grid of the future.

SRNL Explores Treating and Re-purposing Heavy Water Stockpile

by Kent Cubbage

SRS personnel with a shipment of heavy water bound for Sweden in 1969 (SRS Archives).

Five nuclear reactors were constructed at Savannah River Site in the early 1950s to produce plutonium and tritium for nuclear weapons. However, none of the reactors could produce these materials, or even enter the initial start-up process, until the 400/D area at SRS came online. The massive 400/D area, one of the first production areas completed at SRS, was constructed for the sole purpose of supplying the reactors with heavy water.

Light water is the typical form of water, consisting of one oxygen atom and two hydrogen atoms known as protium, both containing one proton in their nucleus. In heavy water, the two protium atoms are replaced with deuterium, an isotope of hydrogen that also contains a neutron in its nucleus.

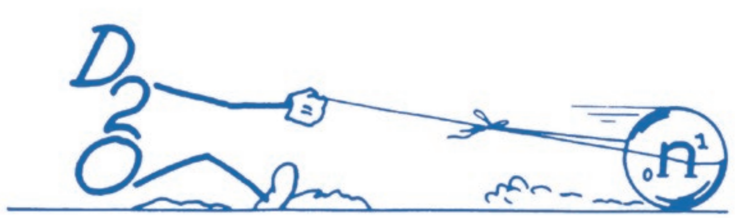
The reactors at SRS were unlike the reactors at the Hanford Site in Washington state that produced plutonium for the Trinity test and the atomic bomb dropped on Nagasaki. Those reactors were "moderated" with graphite, which meant they used that form of carbon to slow down to a controllable level the neutrons released from uranium atoms splitting apart.

SRS reactors were heavy water moderated. Heavy water is much better than graphite at moderating neutrons during the fission process, but it can also cool the reactors. Completion of the reactors at SRS was staggered so they could be brought online as 400/D produced the amount of heavy water they each required.

Cartoon from the SRL Promotional booklet, *Nucleonics of Tomorrow in the Making Here Today* (undated) representing the United States selling heavy water to the rest of the world.

Heavy water operations at SRS were fully ceased by 1982, having produced what was needed plus a sizeable surplus. Most was used in SRS reactors or otherwise domestically, while much was sold to other countries. By 1989 all of the reactors were shut down, further adding to the heavy water stockpile. Thus, nearly 450,000 gallons of heavy water are sitting idle at SRS, awaiting some form of disposition. Much of it contains tritium, a radioactive isotope of hydrogen, along with other contaminants.

The heavy water can be disposed of by immobilizing it in grout, but this is expensive and labor intensive. The Hydrogen Processing Group at Savannah River National Laboratory was approached by the Department of Energy Office of Science to explore ways of removing the tritium from the heavy water so it can gain new life.



Cartoon from the SRL promotional booklet *Nucleonics of Tomorrow in the Making Here Today* (undated) depicting heavy water slowing down a neutron.

SRNL's Dave Babineau is the project lead, and Lucas Angelette is the technical lead. Angelette says that the demand for heavy water and deuterium is gaining steam, with new uses emerging each year. Other countries use heavy water moderated reactors for power generation, including Canada, but that country does not currently produce heavy water.

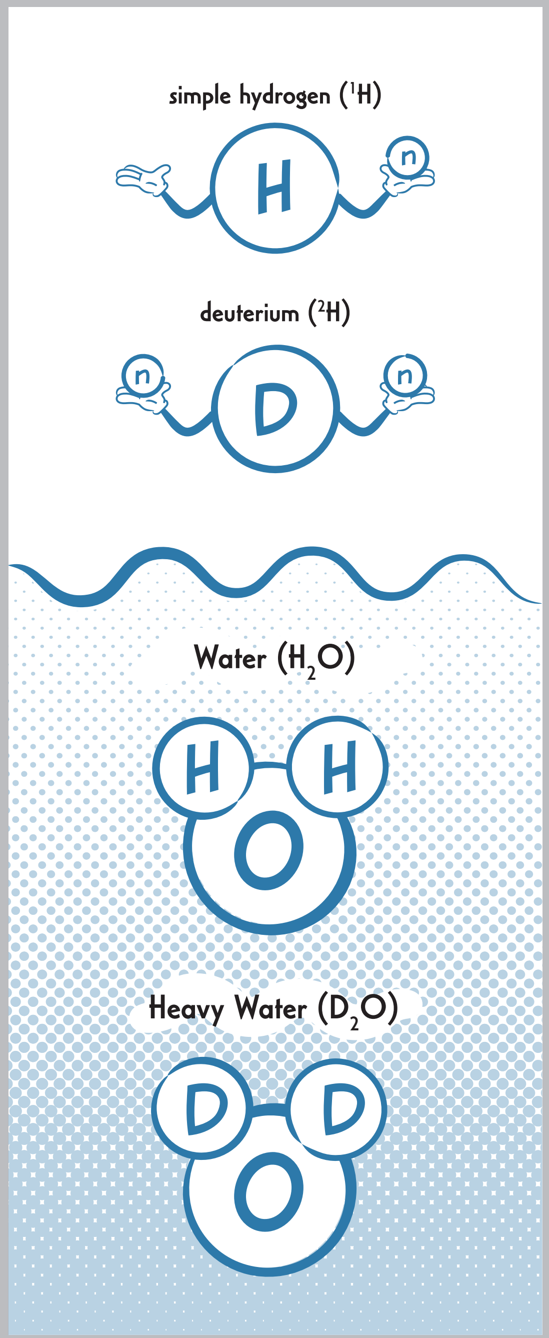
Deuterium is used in semiconductor production and in the medical industry. "There are more [uses for deuterium] coming for cancer-targeting drugs," said Angelette. "Literature has shown that the deuterium concentration can actually accelerate or inhibit cancer growth. The cancer cells have a deuterium preference."

While not all of the heavy water stockpile is highly impure, much of it will require significant treatment. That's where SRNL's unique expertise with tritium comes to bear. The Hydrogen Processing Group has investigated the existing methods for tritium removal, including simple distillation, combined electrolysis catalytic exchange and cryogenic distillation. All of these methods have pros and cons.

The group favors an approach that incorporates all three methods. "Putting them altogether, we can treat 100% of the water, get back 100% of the heavy water, and get tritium gas that DOE can sell," said Angelette. "[the tritium] can be used by fusion companies, for self-illuminating exit signs, and for night sights for firearms."

Moreover, the heavy water contains rare and valuable isotopes of oxygen that, like deuterium, are useful in medicine. One of these isotopes is used in PET scans and can be worth thousands of dollars.

The group is putting together cost estimates for both a pilot scale system and full production facility. Some funds are already available for purchasing capital equipment for the pilot system. In addition, the National Nuclear Security Administration has shown interest in the project. Hopefully in the near future this liability from yesterday can be reborn as today's asset.



Light water is the typical form of water, consisting of one oxygen atom and two hydrogen atoms known as protium, both containing one proton in their nucleus. In heavy water, the two protium atoms are replaced with deuterium, an isotope of hydrogen that also contains a neutron in its nucleus.

(Illustration: Susanna King, SRNL)

The Future of ALTEMIS

by Chris O'Neil, APR

Research conducted by Savannah River National Laboratory has impacts far beyond the perimeter of the Savannah River Site in Aiken, S.C., where the laboratory has been addressing the nation's most complex environmental and legacy management challenges for more than 70 years. The Advanced Long-Term Environmental Monitoring Systems Program is an example of innovative technical approach developed by SRNL at SRS and is now being applied in other U.S. locations and internationally to improve groundwater monitoring of long-lived radiological contaminants.

ALTEMIS uses sensors to capture and deliver data that are analyzed using machine learning to predict future contaminant flux by tracking master variables in real time to predict contaminant concentrations and provide early warning of unexpected contaminant plume migration. By measuring the controlling chemical variables (e.g., pH levels, moisture, and other key geochemical changes) that cause contaminants to be released into groundwater, ALTEMIS can predict contaminant movement before it happens.

Since the development and deployment of this innovative strategy at the Savannah River Site's F-Area, demand for deployment of the technology, in an array of environments, has increased. Each deployment of ALTEMIS beyond the Savannah River Site demonstrates the technology's ability to drive down monitoring costs and accelerate site closure of groundwater contamination sites. It is estimated that Department Of Energy is currently responsible for $520 billion of the government's $620 billion (roughly 83 percent) in environmental and disposal liability. ALTEMIS has the potential to reduce the associated long term monitoring costs by an estimated 50 to 80 percent.

Aerial image of Sellafield Ltd. located in Cumbria, England, a new location where ALTEMIS is being installed. (Sellafield Ltd. Photo)

Internationally, ALTEMIS is demonstrating its value through projects located in Canada and England.

Project lead Carol Eddy-Dilek said the Canadian Nuclear Laboratories sought ALTEMIS assistance with their strategy for handling a strontium-90 plume at the Chalk River site in Ottawa. Eddy-Dilek said that a beaver dam break sent water toward the plume and diverted the plume away from the existing treatment system and toward the Ottawa River. The monitoring regimen in place at that time led to a significant delay in recognizing the change. At Chalk River the controlling variable is water level, and by monitoring the water level, any changes in groundwater flow direction can be predicted. She said the ALTEMIS team is developing a plan for the Canadian Nuclear Laboratories to put in a sensor network to better monitor the flow of groundwater.

Another member of the ALTEMIS team, Haruko Wainwright, from Lawrence Berkeley National Laboratory (now at MIT), presented the ALTEMIS capabilities at the 2023 Geological Society of London Conference and visited the Sellafield nuclear site near Cumbria, England. That visit led to the upcoming deployment of ALTEMIS to analyze the controlling variables at Sellafield. Unlike F-Area, where the controlling variable is pH, the Sellafield site's controlling variable is total dissolved solids. "We're working on a plan to help them monitor for those total dissolved solids to locate any leaks from buried waste," said Eddy-Dilek.

According to Eddy-Dilek, there are nine complex plumes across the DOE complex located at:

- Hanford, Washington
- Los Alamos, New Mexico
- Oak Ridge, Tennessee
- Savannah River Site, South Carolina

- West Valley, New York
- Paducah, Kentucky
- Moab, Utah

Of those major plumes, four are located in arid areas. For arid sites, Eddy-Dilek says ALTEMIS work is still about the monitoring of the controlling variables, but it is also about the tools selected for the monitoring. For example, unmanned aerial vehicles can be used instead of using hand-held monitoring devices, lowering potential workplace hazards due to lack of dense vegetation. This allows the use of a wide range of geophysical, chemical, and spectral methods that provide a complete map of the surface variations. Eddy-Dilek said the Moab site provides an excellent opportunity to further demonstrate the value of ALTEMIS and its applicability in arid climates.

"I selected Moab for the arid site deployment because the site is scheduled for transition to LM [Legacy Management] in three years," said Eddy-Dilek. "Secondly, Moab doesn't have a remediation system in place, so they don't have a long-term monitoring system in place, which means I don't have to replace an existing one." Separate from the ALTEMIS work, SRNL is also providing technical assistance to Moab, designing the remediation and regulatory strategies and making recommendations for the long term monitoring.

Legacy Management's acceptance of the Moab site transfer hinges, in part, on having a Groundwater Corrective Action Plan, which includes having an approved monitoring system. Successful use of ALTEMIS at Moab has the potential to pave the way for future deployment at other arid climate sites.

While much of ALTEMIS's "beyond-the-fence line" work has been driven by personal interaction, program managers recognize there must be a way for customers to access information electronically. This knowledge transfer capability is the next challenge for ALTEMIS. The question becomes how to create a portal where a customer can input site and contaminant characteristics and receive back a plan specific to that site, including the types of tools to use to monitor and an indication of what remediation and monitoring approach to use.

A Florida International University member of the ALTEMIS team is taking best practices from a system he built for Deactivation and Decommissioning and working to apply them to an electronic portal for ALTEMIS. Eddy-Dilek and other team members are working on the portal's design. Creation of the portal will allow sharing of the ALTEMIS approach to monitoring and groundwater contamination remediation.

The ATLEMIS approach flipped a switch in remediation and monitoring work, moving from a reactive process to a proactive process. Developing an online portal will similarly transform the remediation and monitoring landscape, empowering even greater time and cost savings while better protecting the environment.

Haruko Wainwright (right) of the Massachusetts Institute of Technology represents the ALTEMIS project at Sellafield Ltd. (Sellafield Ltd. staff photo)

SRNL's ALTEMIS Sensors Make International Impact at Sellafield

by Catelyn Folkert

The Advanced Long-Term Environmental Monitoring Systems project funded by the Department of Energy – Environmental Management Office of Technology Development is an ongoing effort at Savannah River National Laboratory (SRNL) with the overarching goal of improving the monitoring of groundwater contaminant plumes. ALTEMIS allows for a more affordable and proactive approach to monitoring groundwater contaminants while leveraging Artificial Intelligence and Machine Learning to predict the location and migration of contaminant concentrations.

During an ALTEMIS project presentation at the Waste Management Symposium in February of 2023 , a representative from Sellafield Ltd. approached Will Jolin of SRNL regarding ALTEMIS sensors as a potential solution for a groundwater contamination monitoring issue at their site.

Sellafield is located near Seascale on the coast of Cumbria, England. This site stores high level radioactive waste in cylinders that rest roughly 75 feet in the ground. One of these cylinders developed a leak that was first discovered in 2019, resulting in a contaminated groundwater plume, however, the Sellafield team was unable to determine the location of the leak due to the dense subsurface infrastructure

"Groundwater plumes can be thought of as complex geochemical systems," said Carol Eddy-Dilek, program manager for ALTEMIS at SRNL. "Tracking the plume with sensor measurement of controlling variables instead of periodic sampling of contaminant concentrations allows for proactive management of the plume, so that unexpected contaminant migration can be predicted and addressed. This proactive approach puts us in a much better position to understand and manage the contaminants 10-20 years in the future."

Haruko Wainwright, project co-lead from the Massachusetts Institute of Technology, represented the ALTEMIS team during her visit to the Sellafield site in May 2023. Wainwright and other members of the team worked with Sellafield to develop a mitigation strategy. SRNL created AI/ML models based on the strategy to support the plan before its implementation.

After SRNL provided analysis, Sellafield purchased sensors and began the approval process for their installation within existing wells on the site. Once the sensors are installed, they'll collect data that will be provided to SRNL for analysis. SRNL will use these data to confirm the effectiveness using controlling variables. This will allow Sellafield to differentiate the underlying groundwater plume from where the contaminants are originating so they can locate and stop the leak.

The benefits of utilizing sensors for monitors include significant cost savings and the ability to place the sensors in the positions to best monitor the system. Several Department of Energy sites are currently using or planning to use ALTEMIS sensors, including the Moab site in Utah and the Oak Ridge Reservation in Tennessee, as well as a non-DOE facility, the Canadian Nuclear Laboratories. The ALTEMIS team, which also includes Lawerence Berkley National Laboratory, Pacific Northwest National Laboratory and Florida International University continue to present at a variety of conferences to educate the industry on the capabilities of the sensors and secure additional opportunities for ALTEMIS implementation.

Cementing Nanotechnology in History

by Fateish Graham

Simona Murph (right) monitoring controlled release of hydrogen isotopes from magnetic-hydride nanomaterials. (SRNS staff photo)

Simona Murph, SRNL's 2023 Inventor of the Year, is widely recognized for her research in nanoscience and nanotechnology. She holds 20 patents and patent applications including her most recent one for nano-additive manufacturing, the science that enables scientists to create, assemble and print nanoscale materials.

Nanotechnology enables innovations across every sector of science and industry, including plasmonics electronics, catalysis, sensing, environmental remediation and biomedicine. Nanomaterials have the ability to advance clean energy technologies and industrial decarbonization processes through process intensification in manufacturing processes. The research into nano-additive manufacturing also helps support SRNL's missions through reduced use of energy and materials, efficient use of resources, and enhanced performance and function. The promise of nanomaterials as components of new technologies is due to their unique properties that arise at the small length scales of 1-100 nm. As material size decreases into the nano size regime, novel properties arise that are different from their molecular and bulk counterparts. Due to the size and shape effects in this regime, a nanoparticle's morphology has a profound effect on its properties.

"We developed nano-additive manufacturing, a state-of-the-art nano-scale material production technology, that can, for a fraction of the cost of current methods, rapidly and continuously form high quality products with tunable dimensions, geometries and compositions," said Murph. "An added benefit of this technology is that it generates nanomaterials with high product yield. Nanomaterials can be subsequently printed in organized architectures through defined control of the boundary conditions."

Her research proves that shape-selective hybrid nano-antennas (like gold-iron oxide), an inexpensive and abundant material with magnetic functionalities, can photothermally heat aqueous solutions as efficiently as pure gold nanoparticles to transduce light into heat and significantly increase catalytic reaction rates. Remote separation and methodical manipulation of 'payloads' in the form of hydrogen isotopes has been successfully demonstrated using hydride-magnetic storage nanomaterials. These innovations expand the DOE's energy security, fusion, and defense missions. Bio-medical applications of the technology are also being explored for chemotherapy drug delivery, nano-thermometer probes, tracking drugs inside the body and magnetic resonance imaging platforms.

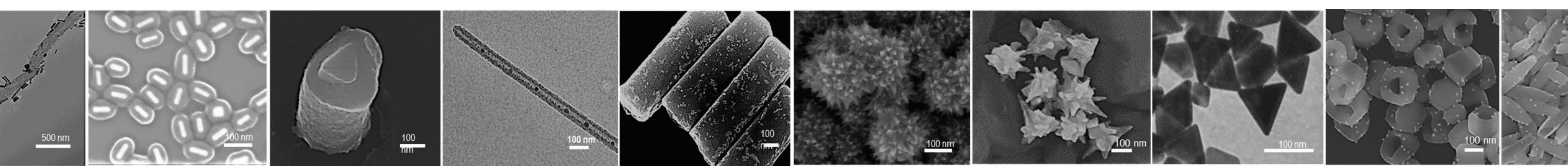
> "By enabling the development of these unique nanotechnologies, new businesses, products, and industries could be created."
>
> - Simona Murph

Her next goal is to find ways to incorporate nanomaterials into devices on a commercial scale and transfer of nano-additive manufacturing technology to the marketplace. "By enabling the development of these unique nanotechnologies, new businesses, products, and industries could be created, promoting the economy, and creating jobs," said Murph. "Patenting our work increases company valuation and portfolio-attracting investors, increasing our credibility and reputation in the scientific field and in various industries."

In addition to being named Inventor of the Year, Murph is a Brimacombe Medal winner and the first SRNL employee to be appointed to serve at the national level as a committee member of the DOE Office of Science, Fusion Energy Sciences Advisory Committee. She has mentored and supported 54 collegiate students, postdoctoral researchers and visiting faculty members at SRNL.

Benefits of nano-additive manufacturing

- High throughput
- Fast physico-chemical processes
- Flexibility in tailoring/creation of complex compositions, functionalities, and structures
- High quality products with higher yield
- Reduced chemical consumption and waste
- Online quality control analytical tools
- Continuous printing and patterning on/in 2D and/or 3D platforms
- Applicable for syntheses that involve challenging reactions



ENVIRONMENTAL & LEGACY MANAGEMENT

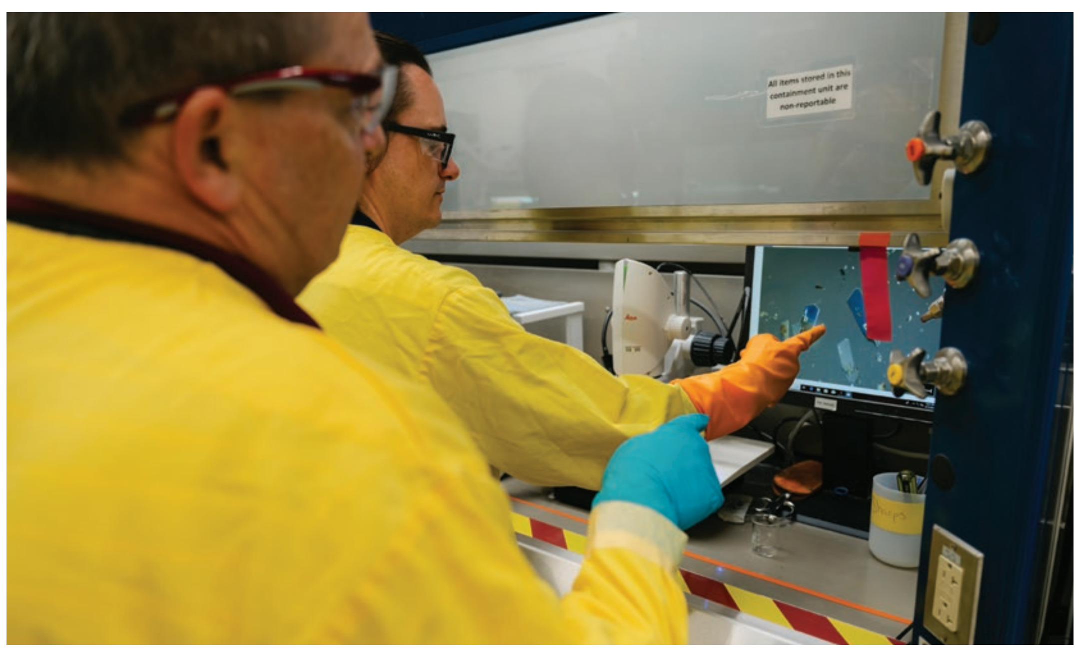
Discovering, Making, Testing New Materials: Center for Hierarchical Waste Form Materials

by Chris O'Neil, APR

Savannah River National Laboratory researchers are building on the laboratory's legacy of cutting-edge science to effectively immobilize nuclear waste in innovative ways. As part of the Center for Hierarchical Waste Form Materials, SRNL is leveraging its depth of experience in radiological waste management to explore new frontiers in the industry.

About a decade ago the Department of Energy Office of Science began a program called Energy Frontier Research Centers to address some of the basic research needs for Environmental Management. These Energy Frontier Research Centers are intended to realize the synergy from each center's mixture of institutions that together can achieve research goals not possible without that symbiotic collaboration.

"The multi-institutional Center for Hierarchical Waste Form Materials was founded about eight years ago as an EFRC on developing the basic science of hierarchical waste forms that could lead to waste form solutions and waste form type materials," said Jake Amoroso, Principal Investigator, in SRNL's Glass, Cement and Ceramic Sciences Group. "We're not producing or engineering a final waste form per se, instead we're doing the basic science to help understand how we would create and design novel waste form materials to perform in a predictable way. Along the way we end up discovering, making and testing new materials," he said.



Travis Deason, a senior scientist in the Nuclear and Chemical Processing Division of Savannah River National Laboratory's Environmental and Legacy Management Directorate, demonstrates for David Diprete, a Lab Fellow in SRNL's Environmental and Legacy Management Directorate, the search for appropriate crystals of novel actinide materials using a microscope located in a radiological containment unit. (SRNS photo by Lj Gay)

Led by the University of South Carolina, and working with its partner institutions including SRNL, Pacific Northwest National Laboratory, Clemson University, University of Michigan, University of Florida and Commissariat à l'énergie atomique et aux énergies alternatives (CEA) in France, the Center for Hierarchical Waste Form Materials is providing insights into fundamental behaviors of radiological elements that have use in applications across the the Department of Energy and the industry.

"Over the last 40 or 50 years, there's been an overwhelming amount of research into vitrification – glassy waste forms – it is the recognized standard across the world," said Amoroso. "But glasses can't do everything, it's recognized that there are applications where glasses may not be the best waste form material. But now there is a knowledge gap, a gap in our understanding of the full potential of these alternative waste form materials." Amoroso said closing this knowledge gap is the purpose behind the Center for Hierarchical Waste Form Materials, "there just hasn't been comparatively much research in the past 30 or 40 years."

> SRNL is developing new transuranic materials that incorporate americium, neptunium, and plutonium.

In its role as a member of the center, SRNL is developing new transuranic materials that incorporate americium, neptunium, and plutonium, including the recently developed plutonium (V) borate structure. "That structure (Pu (V) borate) was one of the recent new structures we developed, about a year ago," said David Diprete, a Lab Fellow in SRNL's Environmental and Legacy Management Directorate. "The center's made unique materials like the americium borate, plutonium borate, plutonium silicates, neptunium fluorides, and plutonium fluorides," said Diprete. "We're in the process now of characterizing these materials further," said Amoroso, "we've published some results and are working on more papers every day."

"Some of the elements we are focusing on include plutonium, uranium, cesium, americium, neptunium and curium," said Amoroso. "The transuranic elements are of particular interest to us because they have interesting properties, there is not a lot of research out there on them, and SRNL is one of only a few places that can safely handle them. What's more, SRNL is helping to develop a capable and skilled workforce through collaborative research under the CHWM."

According to Amoroso waste forms are all about how well they hold on to the radioactive element(s). By building compounds like americium borate, the center isn't targeting development in the dark, rather, the center builds stable crystalline materials that it can presume will stay relatively stable in the chemical environment. That allows for measurement, using leach studies as an example, to measure the degree to which the radioactive elements do or do not come out of the waste form. This helps the Center understand what would or would not make a good waste form.

Diprete said the center is one big collaboration where the universities lead the theoretical modeling and analog development of materials and because of SRNL's capabilities, the lab can work with the radioactive elements and make and test those materials.

"We're learning more about the chemistry of these materials," said Diprete. "No one has made these before, so beyond just holding the element in the waste form, we're figuring out what materials can actually be made from these elements. What we're doing hasn't been done before, we're gaining a lot of basic science knowledge," he said.

While SRNL is well known for its excellence in applied science, its role in the center is aligned more with basic science. Amoroso said the goal of the Center isn't about making the newest waste form, rather, the goal is to close the gap in knowledge and better understand the science behind making alternative waste forms.

The work of the Center for Hierarchical Waste Form Materials and SRNL continues to expand our understanding of hierarchical waste forms and to drive innovation that will ensure the continued safe disposition of nuclear waste.

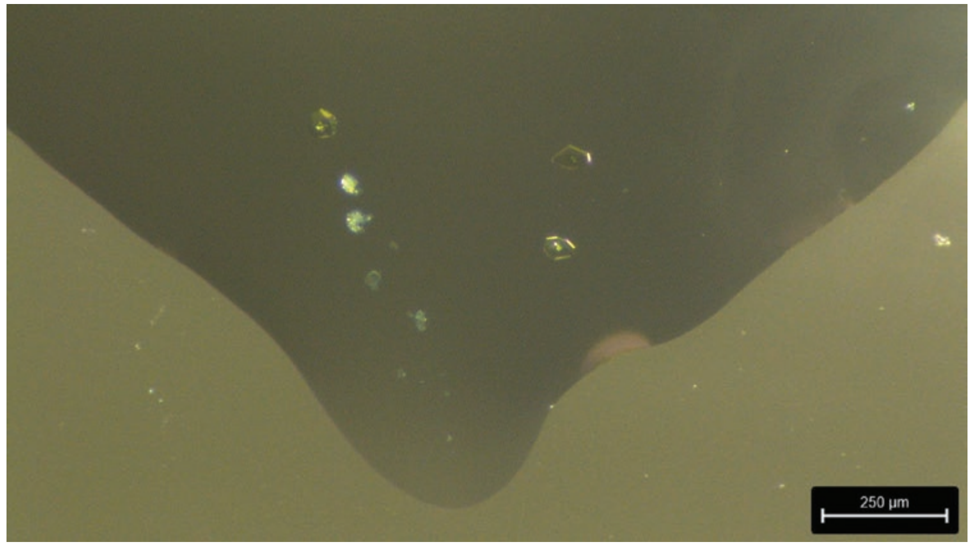


Image of radioactive $Cs_2NiNp_3F_{16}$ crystals grown in the SRNL radiological laboratories. (SRNL Image)

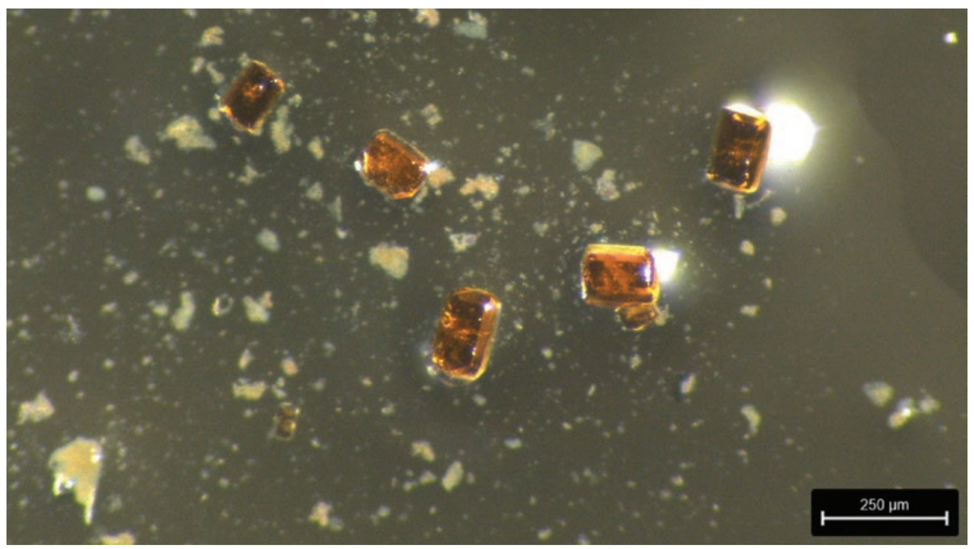


Image of radioactive $Na_3GaPu_6F_{30}$ crystals grown in the SRNL radiological laboratories. (SRNL Image)

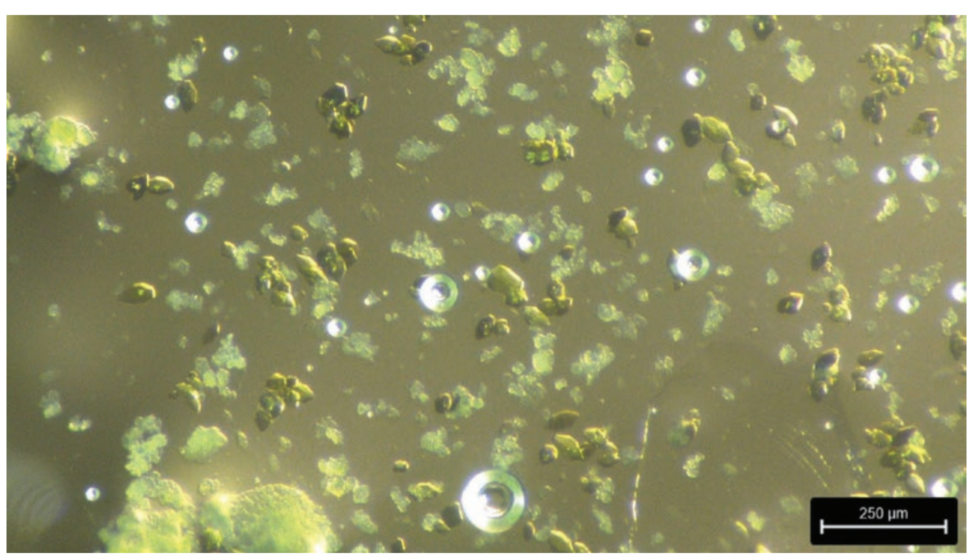
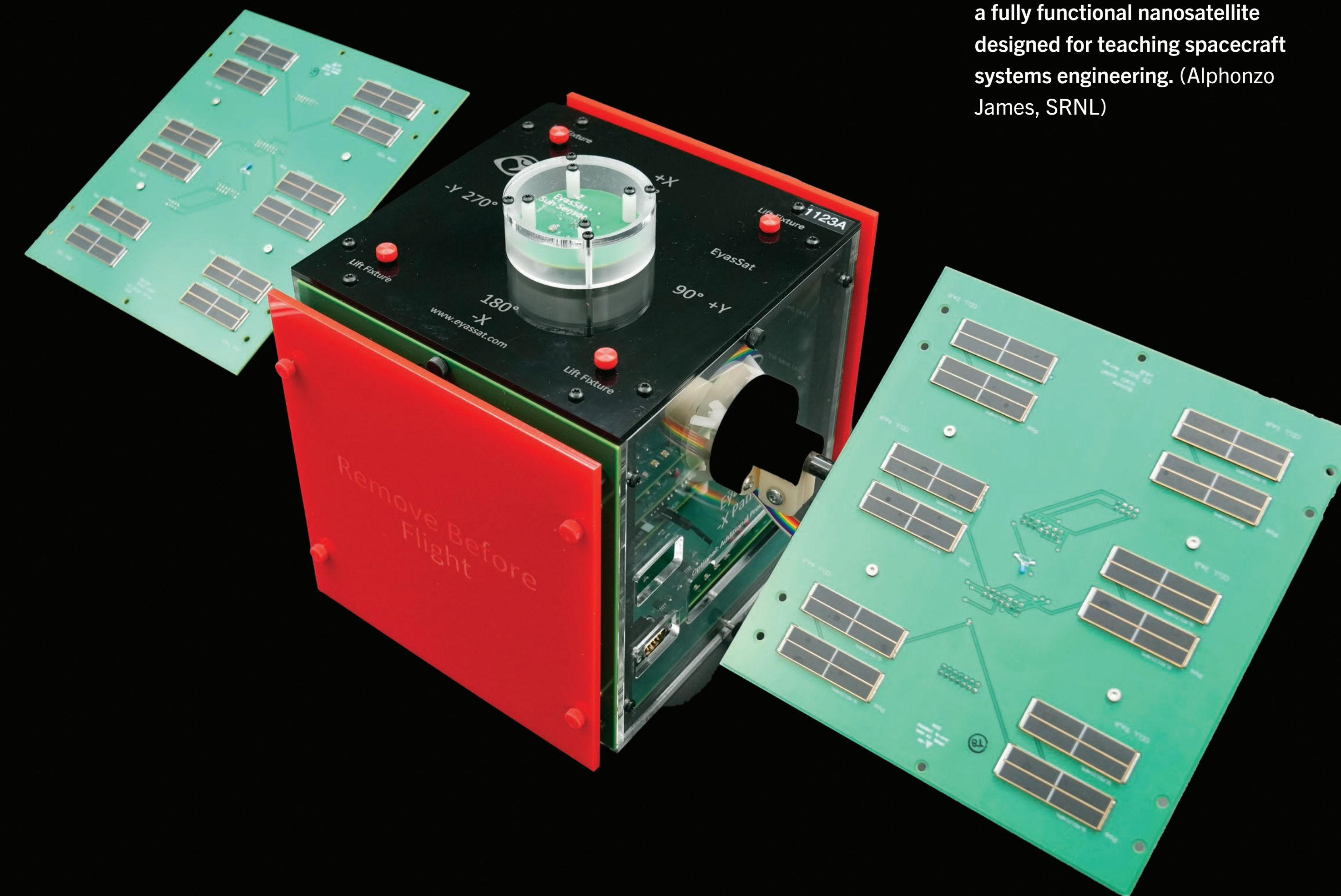


Image of radioactive $Cs_2NiNp_3F_{16}$ crystals grown in the SRNL radiological laboratories. (SRNL Image)



EyasSat Classroom Satellite, a fully functional nanosatellite designed for teaching spacecraft systems engineering. (Alphonzo James, SRNL)

Beyond Earth's Bounds

SRNL Explores Innovations in Space Mission Power and Cyber Defense

by Charnita Mack

Necessity for Nuclear Power

You may know that Sputnik was the first satellite in space and that Neil Armstrong was the first man on the moon. Those facts are common knowledge for many, but the facts on another space-related milestone is not as well known: the name of the first nuclear powered satellite launched into space. While the answer is more obscure, the technology behind this bit of space trivia became an integral piece of future space exploration missions and discoveries.

When the United States Navy launched Transit 4A in June of 1961, it became the first satellite powered by a radioisotope thermoelectric generator. An RTG is one of two types of radioisotope power systems that the Department of Energy manufactures, tests, and analyzes for space exploration and security missions. The fuel that powered the RTG used for Transit 4A came from an isotope known as plutonium-238 (Pu-238). The discovery of Pu-238's usefulness in space exploration made way for the Savannah River Site, then known as the Savannah River Plant, to put its expertise to use.

> NASA is now turning to CubeSats for the exploration of deep space because of the cost effectiveness.

The former U.S. Atomic Energy Commission looked to SRP to produce Pu-238 for space exploration because of its extensive experience with plutonium isotopes. Scientists at the Savannah River Laboratory, now known as the Savannah River National Laboratory, referenced prior methods used with other isotopes and successfully completed its first production of Pu-238 in 1959. SRP then provided that Pu-238 to power Transit 4A's RTG. To effectively explore deep space, missions that extend past Earth and the moon, the National Aeronautics and Space Administration must ensure that all spacecrafts and space instruments have a reliable, long-lasting power system to provide electricity and heat, and Pu-238 became vital to providing that.

RTGs produce energy by converting heat from the natural decay of Pu-238 into electricity. Pu-238 has a half-life of about 88 years, which means it would take nearly that long for just half of the Pu-238 to decay. Therefore, it can act as an energy source for decades.

The site's Pu-238 research through SRL and production at SRP continued to be the fuel source for a number of additional missions, including NASA's Cassini-Huygens. The spacecraft launched in 1997, reached Saturn in 2004, and explored Saturn's moons for more than two decades. The Pu-238 produced and provided by SRP played a critical role in its longevity. Cassini was one of the last missions that used the Pu-238 from SRP, as production concluded in the late 1980s.

SRNL Interns Ritwik Sharma and Olivia Belian work with CubeSats. (Brad Bohr, SRNS)

A New Outlook

SRNL didn't let its important role in space research disappear with the end of Pu-238 production. Space Science and Cybersecurity Analyst Rachel Jones mentored SRNL intern Olivia Belian in 2023 during her redesigning of CubeSat structure for space research. CubeSats are essentially mini satellites that were initially created to be used in education settings for students to study spacecraft design and development. The design landed Belian's work in the AMSAT Journal, a bi-monthly digital magazine published by the Radio Amateur Satellite Corporation. Belian is back at SRNL as an intern, advancing the lab's research on alternative power and propulsion systems for interplanetary deep space missions with CubeSats.

NASA is now turning to CubeSats for the exploration of deep space because of the cost effectiveness, but the longevity of the current propulsion systems and electronics used for CubeSats isn't sufficient for the lengthy type of research desired.

"The electronics have a death date of 25 years, so it is a race against time," Belian said. "I've been looking at everything from batteries and solar power to things like RTGs and nuclear thermal propulsion. Long-term power solutions are essential for any exploration past Jupiter."

Belian indicated that there has only been one interplanetary CubeSat mission to date, the Mars Cube One, or MarCo, launched by NASA's Jet Propulsion Laboratory in 2018.

"Nuclear power is consistent, and we know it's going to work. It is almost a necessity when having to maintain human life according to most academic literature out now," Jones added. "[Other countries] are looking at placing nuclear reactors on the south pole of the moon, and there are other industries looking for nuclear propulsion to get us to Mars sooner."

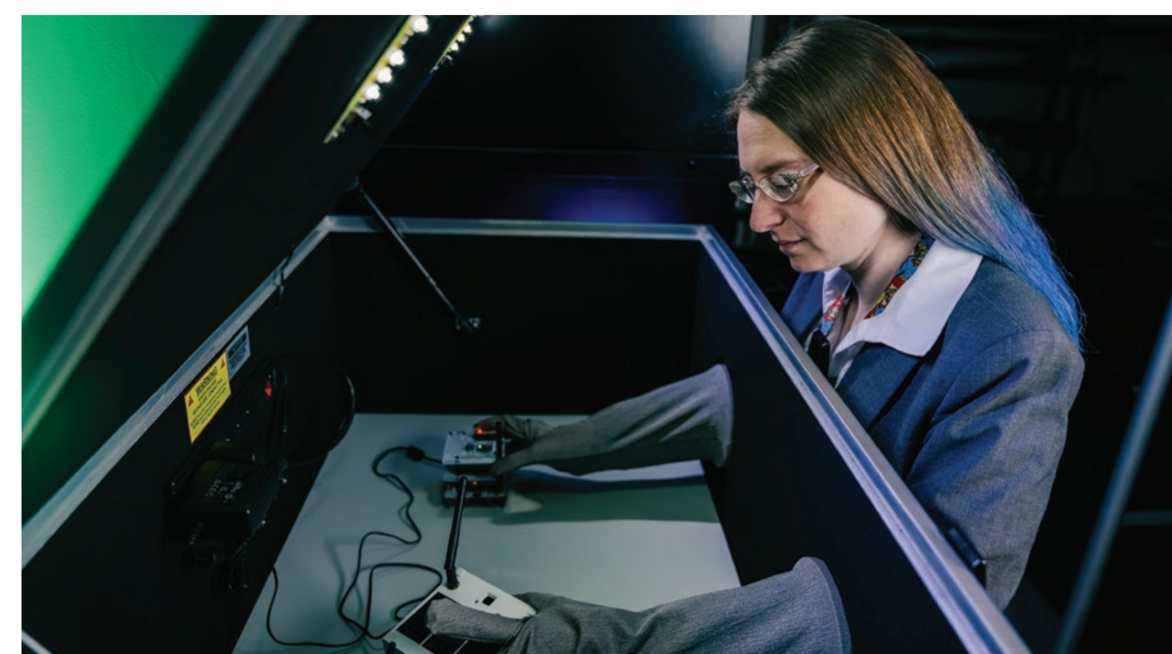
Although Pu-238 nuclear propulsion has traditionally been the method of choice, Jones said there are alternatives. For instance, the European Space Agency is currently gearing up to use americium-241 (Am-241) to help power its first Mars Rover, named Rosalind Franklin.

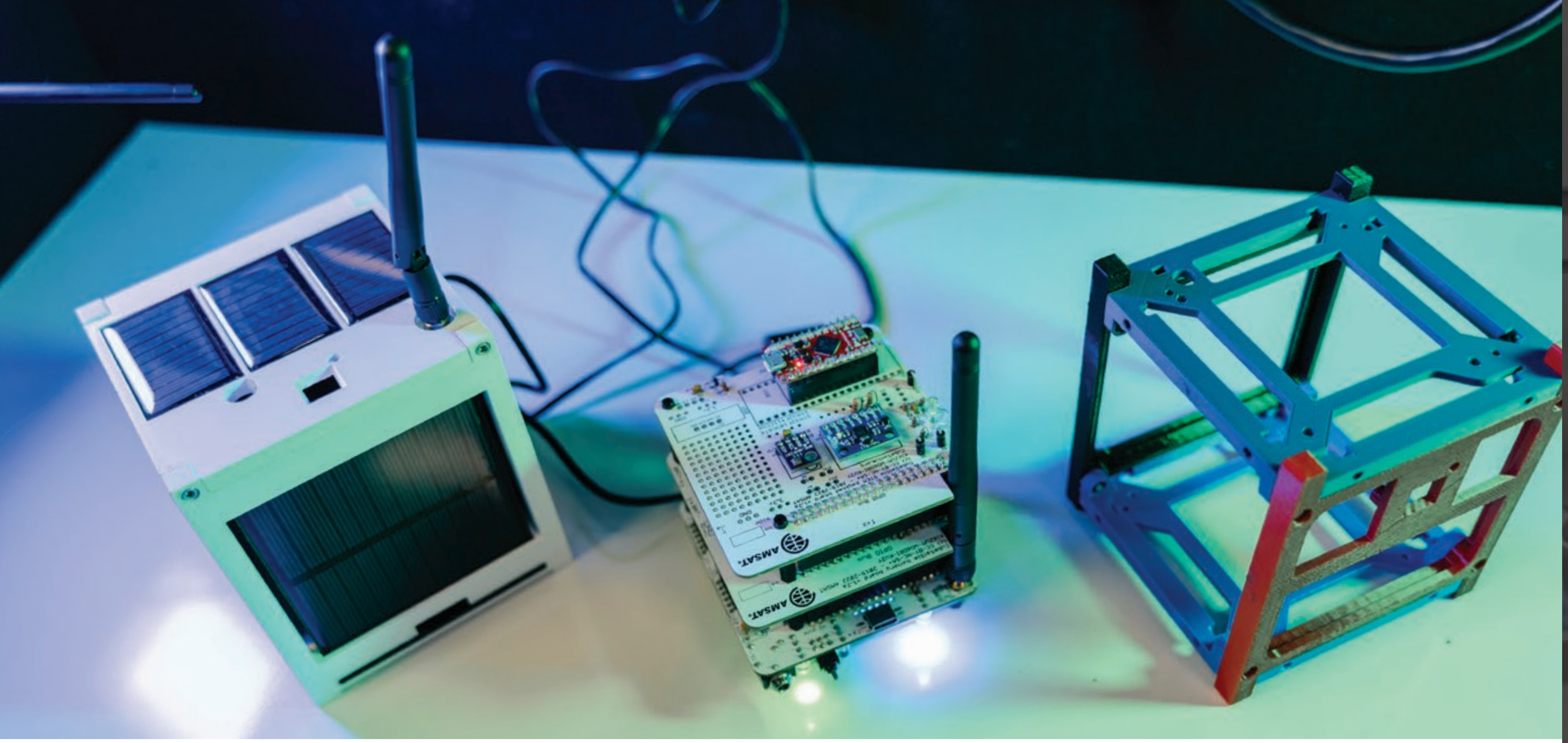
"SRNL has a great resource and ability to help drive this science for the future," said Jones.

Safeguarding Satellites

In addition to deep space exploration research, Jones is using her cybersecurity expertise to drive her study of small commercial satellites. The SRNL Laboratory Directed Research and Development program is allowing Jones to make strides in her findings on satellite cyberattacks.

Space Science and Cybersecurity Analyst Rachel Jones works with the terrestrial-based satellite test bed in the space research lab at SRNL. (Brad Bohr, SRNS)





CubeSats like the ones pictured are being researched and restructured to aid in deep space exploration. (Brad Bohr, SRNS)

"My LDRD [project] looks at the data integrity of small satellites," she said. "We're focusing on them because there is a growing need for literature, standards, and guidance for teams who build these small satellites to build in cybersecurity – to build in assurance that they aren't going to get hacked."

One of her main goals is to disseminate information, communicate the vulnerabilities that exist, and lay out ways to mitigate those vulnerabilities. Jones believes that is key for small satellite success.

Jones, Belian, and another SRNL intern under Jones' mentorship, Chase Hyman, are using a terrestrial-based satellite test bed to further the research. The STB uses a radio frequency glove box where Jones and her team can simulate cyberattacks on satellites where stored information or provided information is altered.

"We're working to see if we can prevent hackers before they get to a certain point of intrusion through radio frequency signatures," Hyman said. "This technology would help commercial vendors to identify attacks on their small satellites."

Hyman is also a member of the Army National Guard where he serves as a member of the Critical Infrastructure Team of the 135th Cyber Security Company, the only such company in the Guard. His unique experience with a team that specializes in industrial control systems has proven useful in his research at SRNL.

"We really go in depth into the defense of internet connected devices, and that's closely related to space satellites because they suffer from many of the same problems," Hyman said.

As Jones and her team explore and uncover new knowledge about cybersecurity in space, they are confident their research will contribute to a safer planet.

"We are working to make our world a better place, and I think some of the research that my team is going to put together is really going to work toward improving tomorrow," she said.

Hyman echoed Jones' sentiments, adding, "The better we can inform people of what's out there, the better security in space will be in the future."

Focusing on the Future

Jones is hopeful the research will affect major change and decisions when it comes alternative power for space missions and cybersecurity efforts in space.

"I would like us to be a supporter of future actions when it comes to space nuclear, power and propulsion," she said. "I also want us to continue to help commercial partners and be able to provide that background and feedback for space cybersecurity. Right now, I don't believe that other labs are looking into this issue, so if we continue in this space, we'd be one of the first national labs to provide this kind of support.".

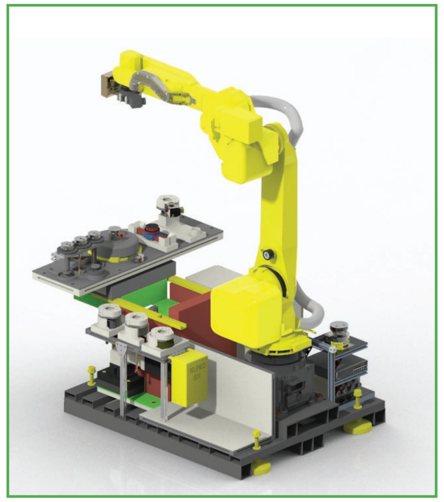
NONPROLIFERATION

Savannah River National Laboratory Advances Mk-18 Program Supporting Nuclear Nonproliferation

Bagless Transfer Packaging System designed at SRNL enables training cold runs and helps bring program closer to startup and operation

by Mike Ettlemeyer

Digital model of the Robot Packaging Skid (Kevin Hera, SRNL)



Savannah River National Laboratory has access to the only irradiated target assemblies containing a rare isotope ideal for use as a certified reference material used in nuclear forensics related applications. Called Mk-18 targets, they contain plutonium-244 — a very rare and extremely important material that can be used to support nuclear nonproliferation applications.

For decades the Savannah River Site has stored irradiated Mk-18 target assemblies, produced in nuclear reactors during the Cold War that were deactivated in the early 1990s. A National Nuclear Security Administration sponsored collaboration between SRNL and Oak Ridge National Laboratory in 2014 brought a renewed focus on the stored material as a valuable resource to benefit research and analysis in nuclear nonproliferation national defense missions. Specifically, the new NNSA Office of Environment, Safety and Health via the Nuclear Materials Integration Division is bringing the project to fruition.

Pu-244 is mostly found in outer space, which makes it hard to come by and sought after as a plutonium isotope. The U.S. supply is very low. The small quantity that remains came from Mk-18 targets that were processed to recover the rare isotope in the 1970s.

Last fall the SRNL team moved

equipment into SRNL's shielded cells, which are used for safe handling of irradiated nuclear material, for Phase I. It was a readiness phase to ensure the material could be properly removed from a pilot testing location, shipped to the lab, and moved into the shielded cells in accordance with SRNL's high safety standards.

"SRNL will do the chemical separations from these targets. We're not doing any isotopic purification; that will be done at Oak Ridge," says Chris Armstrong, Separation Sciences and Engineering, Environmental and Legacy Management.

An SRNL-designed Bagless Transfer Packaging System went through final acceptance testing and was assembled outside SRNL's shielded cells. Three cells will be used to extract material from the Mk-18 targets. The BTPS is one part of the overall system that will package americium and curium material byproducts for shipping to ORNL. Central to the BTPS is an automated induction brazing system, a process that joins metals together using induction heating, that ensures a clean seal.

"Our equipment allows the removal of radiological material from the hot cells into packages for shipment to Oak Ridge National Laboratory," says Alan Busby, Advanced Engineering, Weapons Production Technology at SRNL.

With this system, material can be taken out of a glove box or a hot cell and inserted into a can so it can be transferred safely without any external radiological contamination from inside the box or shielded cells. Ongoing cold runs ensure the system operates as intended before a hot start with the Mk-18 radiological material.

With the BTPS system, material is placed in the can and a plug, with a hollow center, is pushed into place and brazed in the desired position. The can is then cut in the center of the plug, creating a container that has never been in the hot contaminated environment to safely transfer the material for further packaging.

"Essentially, this process enables a can to be partially inserted into a hot, contaminated environment, with seals all around it. So, just the tip of the can is exposed to that environment," says Busby.

While this is a simplified description of a complex process, the bagless can or container of material goes into another special-forms container and then into the drum for shipment from SRNL to ORNL. Four drums at a time will be circulated between SRNL and ORNL for reuse.

Before the BTPS is used, the overall process starts with a unique cask or container, also designed at SRNL, initially containing simulant material -- eventually radiological material -- in a water-filled spent nuclear fuel storage basin at SRS. Then the cask is shipped to SRNL where it is moved by a crane to a cask receipt table, where the individual target is transferred from the cask into the shielded cells. The target material is cut, and chemical separations begin. Once hot startup with radiological material begins later this year, it is estimated that shipments to ORNL will occur about every eight weeks, depending on other radiological work being performed in SRNL's shielded cells.

The Mk-18 program continues to be a prime example of SRNL's ability to develop and deploy unique scientific solutions to challenging problems in processing and recovery of valuable nuclear materials.

Illustration showing the Robot Packaging Skid inserting a target into a can (Kevin Hera, SRNL)

NONPROLIFERATION

The Nuclear Paradigm Shift: SRNL Modular Systems Transform Global Security

by Charnita Mack

The MPF is the only facility in the world that can support the safe characterization, stabilization, and packaging of weapons-grade plutonium material through rapid response deployment.

In 2006, the Department of Energy sought a way to obtain excess plutonium from around the world in the safest and quickest way possible. The Savannah River Site, with more than 70 years of experience with plutonium, was the answer. Through the National Nuclear Security Administration's Office of Material Management and Minimization (NA-232), or M3 for short, DOE set out to work with partners to "minimize the need for, presence of, or production of weapons-usable nuclear material around the world." For the past 15 years, Savannah River National Laboratory, through the Global Security Directorate, has been a mainstay of this mission through deployable modular systems designs and teams.

When the DOE request reached SRNL, the lab immediately began developing a concept that would eventually become the first nine modules of the Mobile Plutonium Facility. The facility is the only one in the world that can support the safe characterization, stabilization, and packaging of weapons-grade plutonium material through rapid response deployment.

"When a country is identified by M3, the MPF will be ready to be deployed within 30 days' notice," said NA-23 Portfolio Manager Doug Lowry.

The MPF's modules contain specialized equipment, from gloveboxes, to x-ray equipment, to a standalone power grid, to successfully recover and remove the plutonium (Pu) and safely package and store it until disposition decisions can be made.

Today, the MPF team, which consists of about 30 members, has enhanced operations of the system by adding an advance Remote Recovery team that can recover small amounts of Pu materials quickly while waiting for the rest of the MPF team to arrive on site. With the acquisition of Boston Dynamics' Spot®, a four-legged robot that resembles a dog, the team now has a small, easy to deploy kit that will provide operational awareness for the MPF team. It also reduces human exposure to radiation and other hazards while the material is removed and moved to a safe location for further processing. Its autonomous operation allows the team to focus on data analyzation while Spot handles the physical inspection of the facility location.

The deployment of the MPF on several exercises sparked the idea and conception of the team's next material minimization project – the Mobile Melt Consolidate system.

Like the MPF, the MMC is a one-of-a-kind, true modular system that can be transported to different parts of the world, but this technology aims to transform highly enriched uranium to more stable LEU forms, supporting nonproliferation goals. The MMC is a collection of modules – furnace, control, pump, cooling, etc. – that melt down the spent nuclear fuel. This allows countries to store the materials in a more stable and safer configuration. It is built to fit within the bounds of a specified country's placement area and run on that country's power grid.

The current iteration of the MMC requires about 15 people for operation throughout the modules. Once each new country is identified, the team will get started on the next build based on the outlined dimensions and enhancements needed for the specific location.

A look inside the control module of the Mobile Melt Consolidate (MMC). (SRNL)

Glove boxes inside the Mobile Plutonium Facility (MPF) are used to do testing of nuclear materials on a small scale. (SRNL)

Finding the Design Sweet Spot

Both the MPF and the MMC module designs have challenged the GSD team to conduct extensive research and experiments with an array of solutions to ensure the systems performed at the highest capacities.

Unlike the MMC, which is built around the provisions of one country at a time, the MPF is designed for usage anywhere it is deemed necessary. The design of the MPF modules has gone through a series of modifications and testing to ensure its sustainability. The MPF team has tested the facility in the frigid temperatures of Alaska, the dry heat of the Nevada deserts, the dampening humidity of Key West, and the rocky waters of the Atlantic Ocean.

"Our first modules were built by Site construction, but we found out there are so many fabricators who could construct so many other types of modules," Lowry said. "For example, we learned that we could get three modules built that could replace nine modules that we had previously built."

Lowry and his team have worked with specialized manufacturers of International Standards Organization containers and modular buildings across the U.S., as well as companies that produce specialty equipment like glove boxes, nitrogen generators and automatic transfer systems. Bringing the companies together in a partnership has increased innovation and productivity.

"We've gotten a glove box built and shipped it to the module manufacturer, where a module was already built. They would then cut the roof off the module, use a crane to lower in the glove box, and then build the roof back on," Lowry said. "Now, we have a really good module to complete glove box missions within a much smaller footprint in terms of shipping, but a bigger footprint to operate in because they've designed special fold out modules."

Because the team has moved to a design build concept, it has lowered costs, which allows for elevated efficiency. All specifications of module designs are now bid out to different contractors and all factory acceptance testing is done on the vendor's site. Once complete, the modules are shipped to SRNL where team members are then trained on the module.

"[The MPF] gives us the ability and platform to go all around the world with a much lower budget than building a nuclear facility that would stay in one place. We're able to design it, get it built, and once we do it for one country, we can make some tweaks and build another for a different country. With this concept, the cost is greatly reduced, which means we can do more work, and the timeline to do it is significantly lower," Lowry added.

An aerial view of the Mobile Melt Consolidate. The system is made up of a collection of modules that work together to melt down spent nuclear fuel. (SRNL)

Convert, Remove, Dispose

The NA-23 program is executing its mission through a three-prong approach: convert, remove, and dispose. With SRNL's extensive history in nuclear materials management, there are knowledgeable teams currently working within or working toward contributing to all three mission areas.

The use of advanced small modular reactors is an integral part of providing affordable and safe nuclear power options across the world. Lowry says these reactors are a part of what they have been working on recently, trying to utilize the lessons learned in the MPF and MMC program in modular system design and shipping strategies. GSD experts are also aiming toward converting large reactors, which use HEU and turn it into LEU, into small reactors that can be deployed as needed.

"We're figuring out how to partner with organizations and take the things we've learned about setting up and shipping nuclear facilities," Lowry said. "We can share those technologies with the vendors who are designing the modular reactors."

The MPF and MMC are currently operating to fulfill the removal goal. They have been meticulously designed to be set up in a country to remove special nuclear materials and create a safer environment.

When it comes to the disposition of materials, the GSD team has been working with a group in the K Area Complex at SRS. The Site's goal is to get rid of almost 57 metric tons of plutonium materials, so they called on SRNL to help in the design of a system that can increase throughput, reduce dose rate exposure to employees, and monitor hold up in the process lines to make these processes safe for operators.

"The modules are a small footprint, so we can test things that other larger facilities can't test, such as radiation monitoring equipment or glove box processes." Lowry said. "We've been able to pilot things on a much smaller scale so the bigger facilities, like those in K Area, can benefit from them."

Uniquely Positioned

The move forward to securing new projects is intimately related to SRNL's long-term history with modular systems. The knowledge that has been generated over time and through trial and error has positioned SRNL as modular experts for other government agencies to model their potential systems after.

"We have built a core set of engineers, E&I [electrical and instrumentation maintenance] people, maintenance mechanics, operational, and RADCON [radiological control] people who have all these lessons learned from the last 15 years. So, when it's time for a new design, [our team] can say 'we learned this in the desert or in the arctic, and these are things you need to think about.' That way we can help the vendors understand our needs better, and then they have good methods to build the modules," Lowry explained.

The SRNL Packaging Technology Group is also an invaluable asset to the modular systems team. Lowry says the luxury of having specialists within the lab who understand the nuances of nuclear materials and how to safely package and transport them is what separates SRNL from commercial modular system providers.

"Our vision is to grow the modular team so we can keep a core group that retains knowledge and is continuously learning. That way, when other agencies want to take on projects, we can be on their team and share our knowledge. It'll almost be like a mentorship, and that's where we want to get," Lowry said.

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