MATTER

Summer 2023

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Savannah River National Laboratory®

An aerial view of Savannah River National Laboratory. photo: Savannah River Site Photography

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From the Director

MATTER magazine is designed to provide you a window into the exciting projects at Savannah River National Laboratory (SRNL).

As a multipurpose national laboratory, we work on challenging research across a wide spectrum of science and engineering problems. SRNL is the only national lab sponsored by the Department of Energy's Office of Environmental Management (EM).

In this issue, we highlight several EM projects, including ALTEMIS, Tank Waste Disposal and the Regulatory Center of Excellence, that underscore the significance of advanced technologies and a sound regulatory framework. This issue also previews the EM-sponsored Advanced Manufacturing Collaborative, describing some of the work we look forward to doing with our partners in industry and academia.

This issue of MATTER magazine also outlines our commitment to clean energy by showing the research and engineering development projects on the fusion fuel cycle, ITER and hydrogen fuel cells.

We'll also feature our initiatives in nonproliferation that help make our world a safer place by reducing emerging nuclear threats.

Our lab is growing, and we continue to put science to work to help protect our environment, secure our clean energy future, serve our national defense and reduce emerging nuclear threats.

Vahid Majidi
Director, Savannah River National Laboratory

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Also in this issue

Fusion Fuel Cycle Research

by Scott Shaw

For a commercially viable fusion energy plant, research, design and development is needed to create an efficient, continuously operational fuel cycle. That's where SRNL's expertise comes in.

Savannah River National Laboratory is working to advance technologies, materials, and process efficiencies to help realize fusion energy commercialization. Initial commercialization of fusion energy expects to use a deuterium-tritium fuel cycle. SRNL is the nation's leading laboratory in tritium science and engineering, with more than 60 years of success in supporting the National Nuclear Safety Administration (NNSA) Defense Program mission for tritium supply. SRNL is currently focused on five tritium research topics relating to the fusion fuel cycle:

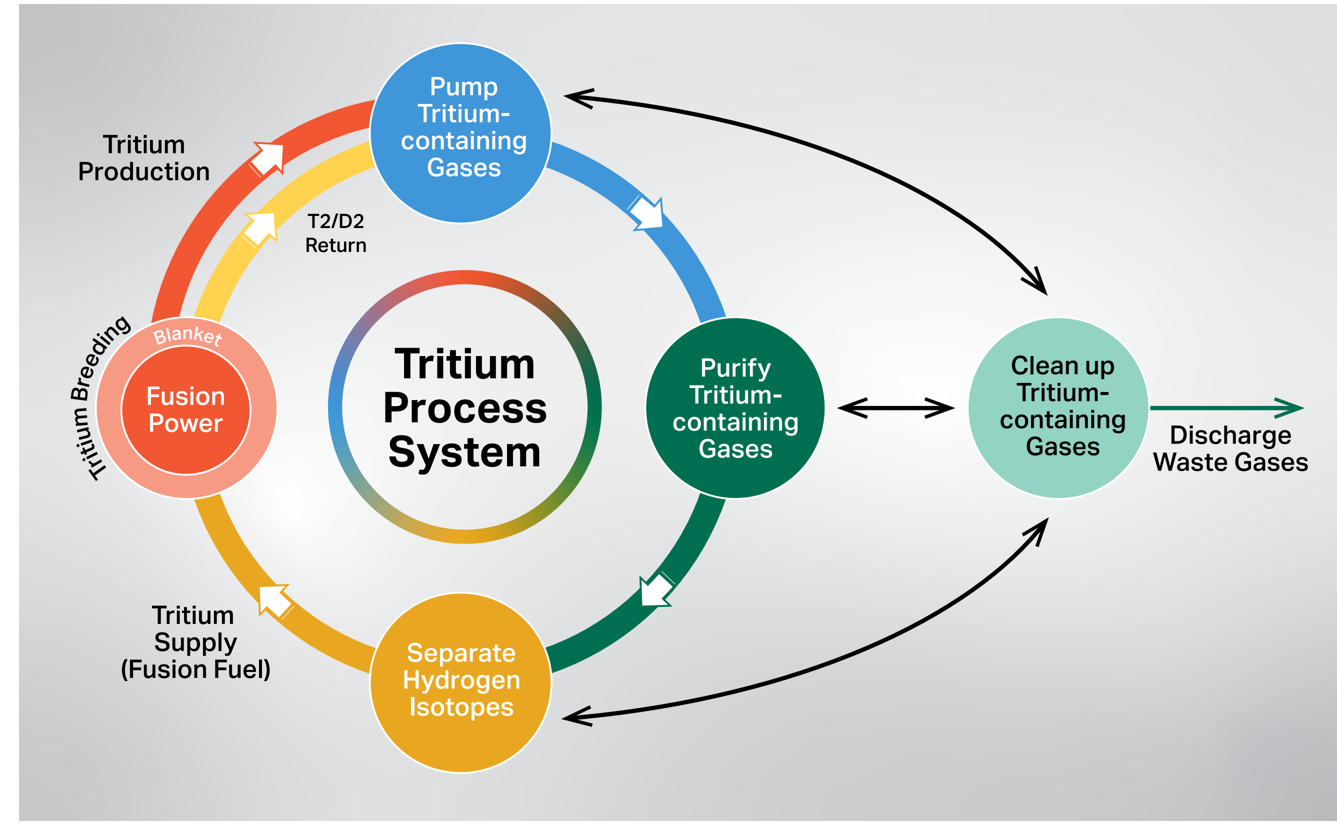
1. **Process Modeling, Process Control and Simulation**
   Defining models to advance and optimize system design, monitor operation, control the process and simulate performance during operation.

2. **Tritium Inventory Reduction and Improved Process Technologies**
   Improving tritium processing to reduce the inventory needed and lower the radioactive source term.

3. **Isotope Supply, Tritium Breeding, and Tritium Extraction**
   Defining tritium/isotope supply source and processing, ensuring the tritium breeding ratio is achievable, and minimizing captive inventory.

4. **Tritium Confinement to Reduce Emissions and Support Safety Basis**
   Developing advanced tritium wetted materials and confinement barriers, understanding and mitigating tritium effects on plasma-facing components, and improving tritium removal and recovery from secondary/tertiary confinements and effluent streams.

5. **Tritium Accountability and Tritium Analytical/Diagnostic Capabilities**
   Developing rapid, high-accuracy/precise accountability measurement instruments and techniques to measure tritium and account for it in different parts of the system.



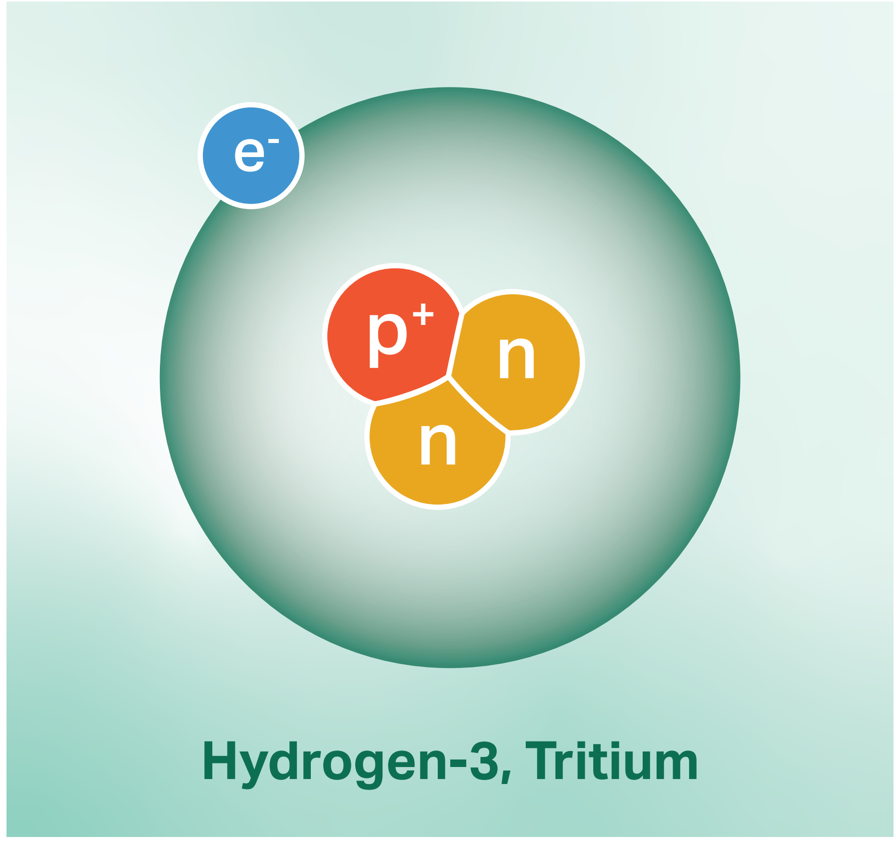
An overview of SRNL's vision for the fusion fuel cycle. The fuel cycle breeds new tritium and recovers unburned tritium, purifies it, and prepares it to be fed back into the reactor, creating a safer, more efficient fuel cycle.
graphic: Savannah River National Laboratory

SRNL is applying its tritium expertise to advance fusion energy projects and research and development investigations with ITER (formerly known as International Thermonuclear Experimental Reactor) and other Fusion Energy Sciences (FES) and Advanced Research Projects Agency - Energy (ARPA-E) programs.

Within the U.S. ITER program, SRNL is leading the design, construction, and testing of the Tokamak Exhaust Processing system. For a commercially viable fusion energy plant, research, design and development is needed to create an efficient, continuously operational fuel cycle that can breed and extract tritium; exhaust byproduct helium; remove and exhaust impurities; separate and rebalance hydrogen isotope mixtures; and provide fuel to the fusion machine.

The deuterium-tritium fusion fuel cycle applies to both magnetically confined fusion energy (MFE) and inertially confined fusion energy (IFE) concepts. Both magnetically and inertially confined fusion energy require structural and process system materials that are durable in extreme environments. Current and near-future research, design and development investigations at SRNL include:

- Exploring methods to implement direct internal recycling of hydrogen isotopes with an MFE system.
- Improving all fuel cycle stages (tritium extraction, impurity removal, isotope separation, and fueling) to have higher throughput with lower tritium inventory.
- Developing and characterizing durable materials exposed to hydrogen, deuterium and tritium.
- Improving pumping technologies for hydrogen isotopes and helium.
- Process modeling with gap analysis to identify technology needs and optimize process design including minimizing tritium inventory.
- Developing technologies to minimize environmental release of tritium through permeation barriers, water detritiation, and other methods of tritium containment and recovery.



INFUSE Awards – Public-Private Partnerships

SRNL works with the Department of Energy (DOE) to support fusion commercialization through partnerships with companies that are developing fusion plants and implementing fusion fuel cycles. SRNL also has capabilities to support fusion device design-build with technologies for fabricating system components by advanced manufacturing; robotics for remote maintenance; system modeling and control using artificial intelligence; and other areas needed for developing a functional fusion plant. SRNL engages companies through public-private partnership (PPP) programs such as INFUSE that will help solve technology challenges and enable the commercialization of fusion energy.

Sponsored by the Fusion Energy Sciences (FES) program office within DOE's Office of Science, Innovation Network for Fusion Energy, the INFUSE program focuses on accelerating fusion energy development through public-private research partnerships. SRNL received two Department of Energy (DOE) INFUSE awards with General Atomics and General Fusion to further advance the fusion fuel cycle and development of a commercial fusion power plant.

"These two new INFUSE awards continue SRNL's efforts to deepen industry engagement through public/private partnerships that help industry develop their technologies into viable commercial solutions," said SRNL Fusion Energy Research Program Manager Brenda Garcia-Diaz. "The projects with General Atomics and General Fusion will leverage SRNL's expertise in fusion fuel cycle technologies in unique ways to help design and implement improved systems in significantly different fusion concepts."

General Atomics is developing a modeling workflow for fusion pilot plant (FPP) integrated design and optimization, and needs verified and validated models for the tritium fuel cycle. SRNL will develop two models for General Atomics' use: a reduced model for tritium processing, which will be utilized by General Atomics' FPP systems code, as well as comprehensive Aspen fuel cycle simulations to assess the significance of design decisions. General Atomics and SRNL will perform FPP optimizations with these tools and SRNL will supply a relative, initial cost analysis for the tritium processing facilities. General Atomics Principal Investigator David Weisberg and SRNL scientist Holly Flynn are leading this project.

"One of the most attractive aspects of a fusion power plant is the environmentally friendly hydrogen fuel, which doesn't require any harmful mining or drilling activities," explains David Weisberg. "But we also need to perfect the way we recycle fuel inside the power plant, and SRNL has expertise to advance the technological readiness of that system."

With General Fusion, SRNL will work to model the total inventory of tritium in General Fusion's future commercial pilot plant (CPP) design. Understanding tritium inventory is a necessary step to design, license, construct, and operate larger and increasingly integrated fusion machines. SRNL will apply its expertise to quantify and streamline tritium processing in the CPP to support General Fusion's pilot plant development to deliver clean, safe, and on-demand fusion power at commercial scale. General Fusion Chief Technology Officer Ryan Guerrero and SRNL Scientist George Larsen are leading this project.

"General Fusion's practical Magnetized Target Fusion technology is designed with a low start-up tritium fuel requirement and an advantageous breeding ratio to produce sufficient quantities of tritium fuel to sustain the fusion process," said General Fusion Chief Technology Officer Ryan Guerrero.

A third INFUSE award has SRNL partnering with Commonwealth Fusion Systems to investigate molten salt as a novel blanket material for its fusion tokamak. But molten salt made from a mixture of lithium fluoride (LiF) and beryllium fluoride (BeF2) FL:Be is known to cause significant degradation to structural materials. Use of FL:Be for commercial fusion applications requires applying corrosion mitigation strategies. Commonwealth Fusion Systems is leveraging SRNL's expertise in electrochemical and corrosion engineering to monitor corrosion caused by FL:Be in real time, and to enable local control of corrosion rates by adjusting impurity concentrations in FL:Be.

University Partnerships

SRNL is also working with university and workforce development partners on fusion projects, most notably with its BSRA university partners – the University of South Carolina, Georgia Tech, South Carolina State University, The University of Georgia, and Clemson University. Through the Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts (GAMOW) program, SRNL is creating novel solutions that can simplify fuel-cycle processes and reduce equipment cost, as well as provide more efficient solutions that reduce energy and other resource input (e.g., liquid nitrogen) costs.

Two examples of these fusion projects include working with Clemson and the University of South Carolina on the Hydrocarbon Pump Oil Recycling (HyPOR) Loop and the Direct LiT Electrolysis. The HyPOR Loop uses a process to enable the use of commercially available vacuum pumps in the fuel cycle that will reduce costs, improve safety and make the process more energy efficient. The Direct LiT Electrolysis leverages advances in Li-ion battery materials, adapting them to simplify tritium fuel-generation steps to increase efficiency and safety and reduce costs.

SRNL also collaborates with colleges and universities nation-wide such as the Massachusetts Institute of Technology, NC State, and others to help advance tritium processing and fusion fuel cycle technologies through programs with both the DOE and National Nuclear Security Administration (NNSA) that help to advance both fusion and national security programs. In addition, SRNL is leveraging relationships with minority serving institutions that it developed through managing the minority serving institutions partnership program (MSIPP) for DOE EM. SRNL will work also to incorporate energy justice principles for fusion into regulation development, public engagement, workforce development, and other aspects of fusion commercialization.

Other Fusion Research at SRNL

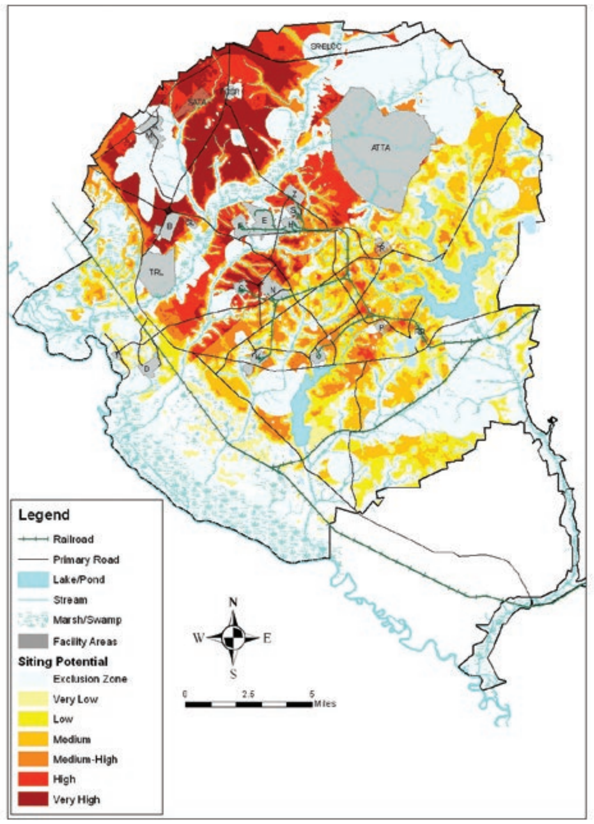
SRNL is active in other areas of fusion research, including Deactivation & Decommissioning, regulation, and non-proliferation. Tritium in fusion waste materials could prevent near surface burial, which is the desired disposal route for fusion waste. Non-proliferation concerns have generated significant discussion and SRNL is engaging with the U.S. and international fusion communities on this issue. Because of the importance of these topics to the future of fusion energy, research at SRNL involves all three research directorates within SRNL – Environmental Management and Legacy Management, Global Security and Weapons Production Technology.

"The projects...will leverage SRNL's expertise in fusion fuel cycle technologies in unique ways to help design and implement improved systems in significantly different fusion concepts."

Brenda Garcia-Diaz, SRNL Fusion Energy Research Program Manager

Fusion Demonstration Facilities at Savannah River Site

In addition to leveraging years of experience working with tritium, the unique resources at the Savannah River Site (SRS) can help advance the commercialization of fusion energy by locating demonstration facilities or siting fusion plants at SRS. Advantages of locating a fusion facility at the site include staying within preapproved tritium inventory amounts, exceptional site characteristics, and having defined environmental analyses.



Savannah River Site Advantages

Well Characterized Site

SRS covers approximately 198,000 acres (310 square miles) adjacent to the Savannah River in Aiken, Barnwell and Allendale counties of South Carolina. Facilities account for approximately only 5% of the SRS area; apart from facilities, land cover is a wide variety of natural vegetation types and the land available is well-suited for siting a plant.

Mature Site Selection

SRS has a mature and systematic site selection process that was developed by SRNL, and which dates to 1990 with the comprehensive evaluation in the siting for a new production reactor. Based on ranking the siting requirements for the proposed facility, this process uses a team approach and GIS technology to identify specific site locations at SRS for new facilities. Based on site requirements and ranking the requirements, the best places for a proposed facility can be seen in the graphic at left – red meaning the best places for a facility at SRS.

Transportation and Utilities

Locations can be identified at SRS that have access to cooling water, grid access, rail and barge transportation, grid interconnection, and access to publicly accessible roads, all of the things needed to build and maintain a proposed fusion plant.

Tritium Research, Development & Demonstration (RD&D) Facility

SRNL is investigating the creation of a tritium research, development and demonstration facility for tritium processing technologies with an unused building on site that was descoped from a previous project. The facility would:

- Create a Category 2 nuclear facility that could enable tritium RD&D with inventories up to 1 kilogram.
- Yield ~8000 sq. ft. or 30% of the available space for a fusion fuel cycle demonstration facility.
- Leverage research and testing capabilities for NNSA missions, advancing both national security and fusion energy.

ITER Tokamak Exhaust Processing (TEP)

by Kelsie Taylor

Savannah River National Laboratory (SRNL) is leading the development of a critical hardware system for ITER—the international collaboration to demonstrate the feasibility of fusion as a carbon-free source of energy based on the same principle that powers the Sun and stars. Using a tokamak approach to magnetic fusion, ITER will achieve a self-heated, or "burning plasma," for hundreds of seconds. This is considered an essential step toward practical fusion energy.

Concept rendering of a tokamak fusion reactor. illustration: AddMeshCube - stock.adobe.com

US ITER, managed by Oak Ridge National Laboratory (ORNL) in partnership with SRNL and Princeton Plasma Physics Laboratory (PPPL), will deliver 12 essential hardware systems for ITER. One of those systems, tokamak exhaust process (TEP) is being developed by SRNL.

TEP is part of the deuterium-tritium fusion fuel cycle necessary for ITER to achieve its mission. TEP is a complex chemical processing system that receives exhaust gases from the tokamak and separates the gases into a pure hydrogen isotope stream and a hydrogen-free gas stream, while providing a technically mature, robust, and cost-effective solution. The system consists of a series of interconnected process components including catalysts, sieves and permeators to separate hydrogen isotopes from impurities.

SRNL was selected to lead the TEP design because of the institutional knowledge and experience used to develop tritium technologies that are deployed at the Savannah River Site (SRS). SRNL is responsible for developing the TEP design, procurement and testing of prototypes of major chemical processing components, and manufacturing, assembly, testing and delivery of the TEP system to the ITER.

The first phase of final design concluded in September 2022. The second design phase activities include a significant prototype manufacturing and testing effort, plus the documentation package required to manufacture six gloveboxes and all the chemical processing equipment necessary to meet the TEP process requirements and design criteria.

The TEP final design is scheduled to conclude in FY25, with early procurements also beginning that year.

Robert Allgood, TEP Program Manager at SRNL, brings years of experience that includes technical and leadership positions in SRNL, the Savannah River Tritium Enterprise, and two years of experience at the ITER Organization in France. The team producing the TEP final design is a multi-disciplinary group of scientists and engineers from SRNL's Tritium Technology and Advanced Engineering organizations in the Weapons Production Technology directorate.

The ITER Facility photo: The ITER Organization

Powering the Future: Unlocking the Potential of Hydrogen Fuel Cells

by Alyssa Yancey

The United States is working toward a power sector free of carbon pollution by 2035. Achieving this ambitious goal requires a commitment to developing renewable energy sources that are commercially competitive.

Savannah River National Laboratory (SRNL) Scientist Patrick Ward is supporting the drive toward a more secure energy future and less carbon pollution by working to make hydrogen fuel cells a more viable option for the transportation sector. In 2022, Ward received a $3 million Department of Energy (DOE) Office of Science Basic Energy Science Program award to further fundamental research aimed at enabling new pathways for hydrogen storage and production technologies.

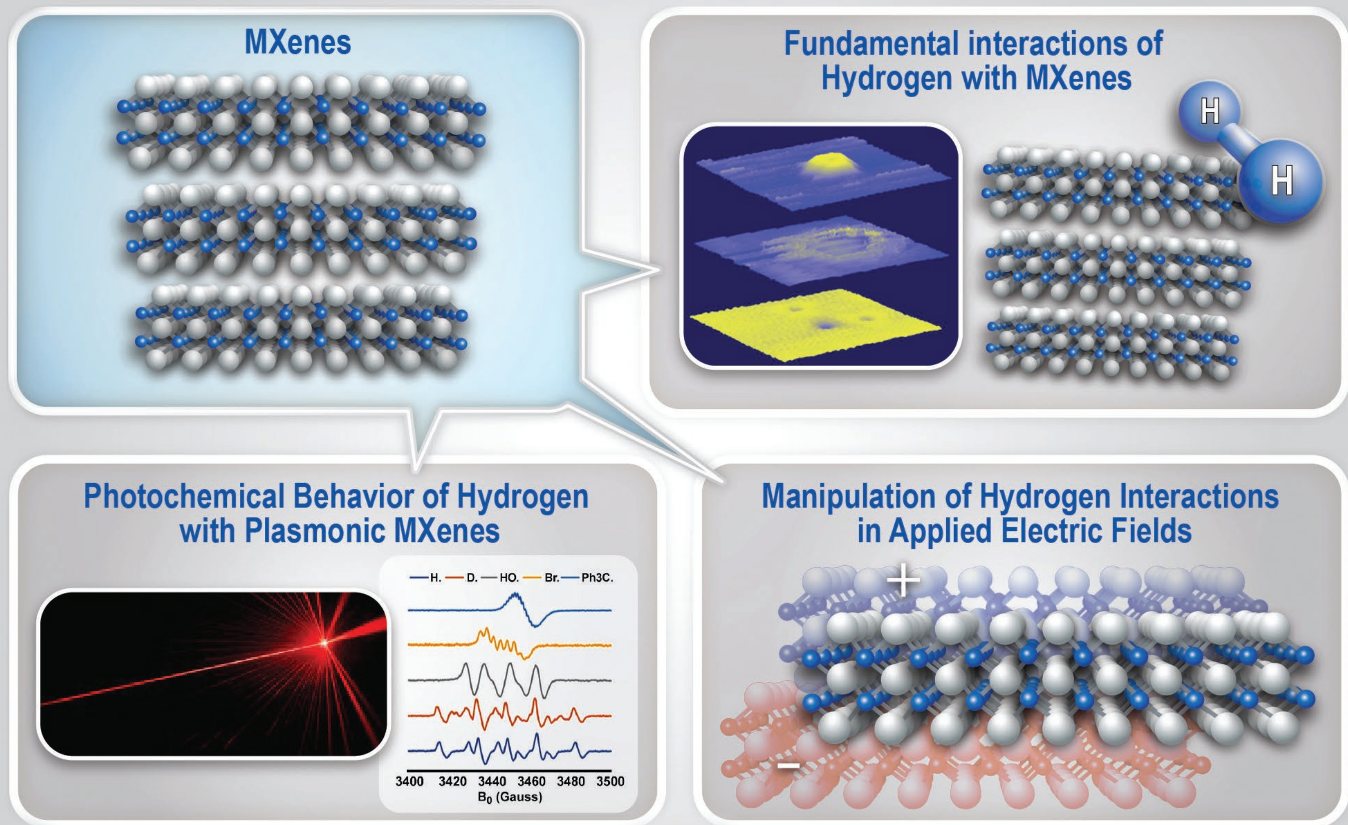
Hydrogen is particularly attractive because it is a cleaner alternative to greenhouse gas-producing fossil fuels and not tied to weather conditions like solar or wind power.

"Hydrogen has a lot of potential because we could convert water into hydrogen and oxygen, use it to propel our vehicles, and then turn it right back

Patrick Ward has a $3 million grant to research new methods of hydrogen storage.
photo: Savannah River Site Photography

"Energy runs the world. You have to have secure and reliable sources of energy to move all of the modern processes, whether it be our laptops or our cars."

Patrick Ward,
SRNL Scientist



graphic: Savannah River National Laboratory

into water," says Ward.

However, it has been challenging to find ways to store and deploy hydrogen safely and efficiently. Ward's research is exploring how to best store hydrogen molecules within the spaces of MXenes, a two-dimensional transition metal carbide, carbonitride, or nitride material. Storing the hydrogen in solid-state materials would be a safer alternative to storing as a compressed gas.

"We're looking at the fundamental interactions between MXenes and hydrogen and trying to understand how we can fine tune these interactions to find the sweet spot in binding hydrogen to the surface. This would allow us to store hydrogen under ambient conditions," says Ward.

"Now it's a too hot or too cold problem. Metal organic frameworks are highly porous materials with high surface areas, but you have to cool your tank down to cryogenic temperatures with liquid nitrogen, or you have these materials that require very high temperatures to pull the hydrogen off. We're basically trying to map out and understand how we tune materials to bind in that middle temperature range."

Ward currently is investigating how hydrogen diffuses into MXenes and the role defects in the material play in the diffusion pathway.

"One of the challenges with hydrogen storage is that you must be able to go to the pump and fill up your car with hydrogen in a reasonable amount of time. If you have to sit there for five or six hours, it's not really feasible anymore. It's not competitive with a gas vehicle," says Ward. "Understanding diffusion in these materials allows us to understand how you can rapidly store hydrogen in them. Having more information about how hydrogen uptakes into materials will give us the insight to tune for the ideal parameters."

The project will also explore how light, and the excitation of surface plasma resonances influence hydrogen dissociation of the surface and how electric fields play a role in the interaction strength between hydrogen and the material.

According to Ward, SRNL is particularly well-suited for this work because of its unique instrumental capabilities.

"We have a large amount of equipment related to being able to measure hydrogen uptake in materials, kinetics and decomposition temperatures, as well as specialized equipment located in argon-filled glove boxes for air sensitive materials," says Ward.

To address these scientific challenges, an excellent research team was assembled between SRNL and University collaborators: Yury Gogotsi from Drexel University, Kah Chun Lau from California State University Northridge and Paul Weiss from University of California, Los Angeles.

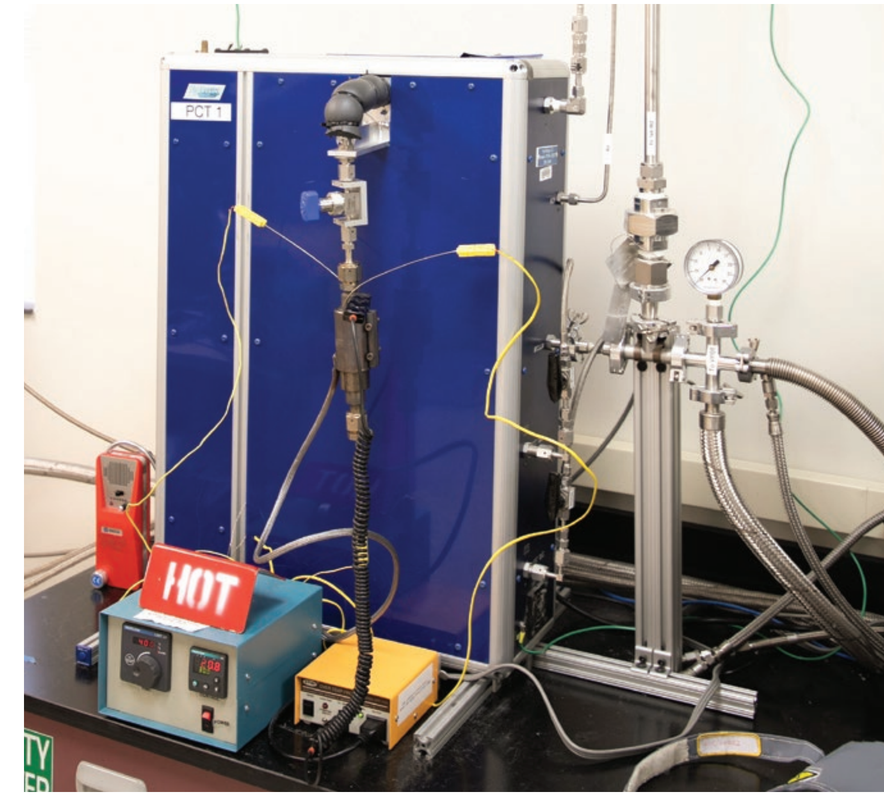
Ward says the biggest challenge facing hydrogen power is commercial infrastructure.

"It's sort of a chicken or the egg problem. No one wants to invest in the fueling stations if there are no cars, and no one wants to invest in the cars if there are no fueling stations," says Ward.

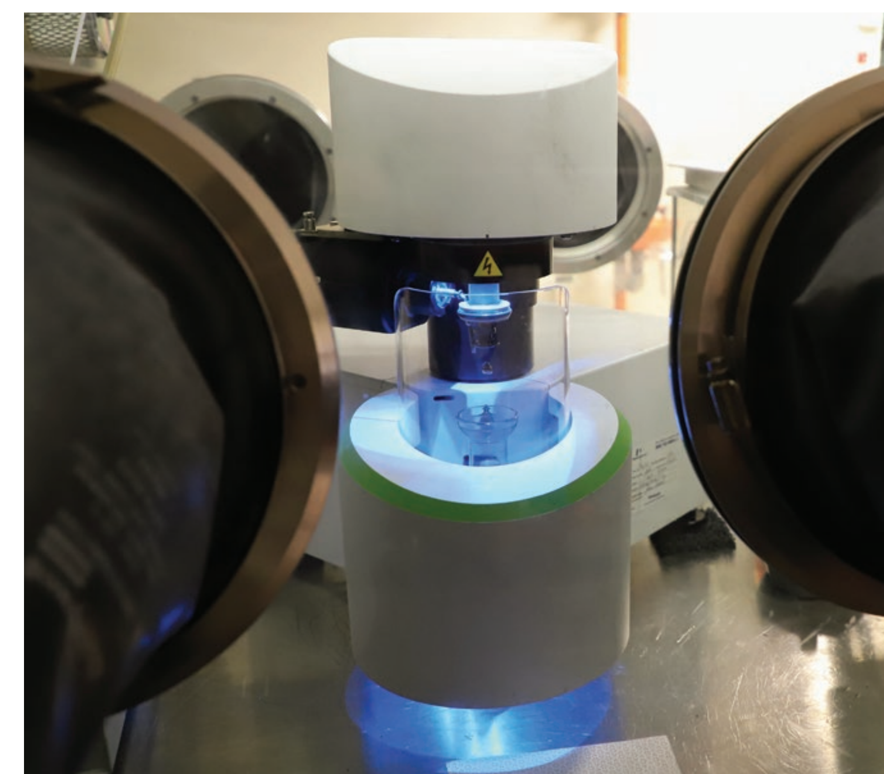
"Hydrogen fuel cell vehicles in the United States are limited by the availability of hydrogen fueling stations and large-scale hydrogen production. It is well-known that a fueling infrastructure and abundant hydrogen availability is required to encourage mass production and initiate the deployment of fuel cell vehicles."

In answer to this challenge, DOE's H2Hubs program aims to establish six regional green hydrogen production hubs in the U.S., providing the critical infrastructure needed to encourage hydrogen fueling station investments and fuel cell vehicle production.

"Energy runs the world. You have to have secure and reliable sources of energy to move all of the modern processes, whether it be our laptops or our cars. By finding alternative sources of energy, we're supporting the endeavor of ensuring energy security for the nation," says Ward.



SRNL's Hydrogen Technology Research Laboratory possesses specialized equipment, such as several custom hydrogen sorption systems (top) and thermogravimetric analysis equipment in inert environments (bottom).
photos: SRNL Communications



Paradigm Shift

by Chris O'Neil, APR

Researchers at Savannah River National Laboratory (SRNL), in concert with Lawrence Berkeley National Laboratory, Massachusetts Institute of Technology, Pacific Northwest National Laboratory, and Florida International University, are leading the Advanced Long-Term Environmental Monitoring Systems (ALTEMIS) Project to move groundwater cleanup from a reactive process to a proactive process, while also reducing the cost of long-term monitoring and accelerating site closure.

Reducing the cost of long-term monitoring is a priority for the Department of Energy (DOE), as the agency's liability for long-term monitoring is projected to expand for decades and cost billions of dollars.

Using Artificial Intelligence and Machine Learning (AI/ML) techniques, the ALTEMIS program is poised to provide a monitoring capability for use throughout the DOE complex that is designed to predict future contaminant flux by tracking real-time master variables that predict contaminant migration and provide early warning of unwanted plume behavior.

"The typical long-term monitoring paradigm is to have a network of sampling wells, send humans to the field to take samples—typically quarterly—analyze the samples in the lab for a variety of contaminants, and identify if contaminant concentrations exceed regulatory limits," said Thomas Danielson, Ph.D., Principal Scientist in SRNL's Environmental Sciences and Dosimetry group. "The Government Accountability Office estimates the long-term monitoring liability for EM to exceed $500 billion, and a large portion of this cost is related to these sampling efforts."

Long-term monitoring is necessitated by the widespread implementation of passive processes for remediation of complex groundwater plumes. Active remediation is very expensive and requires pumping contaminated groundwater out of the ground, treating it and injecting the clean water back into the ground. Passive remediation strategies are based on addition of an

Opposite: Close-up of ALTEMIS monitoring device.
Below: Researchers install a monitoring device in a well.
photo: Brad Bohr

amendment to the groundwater to precipitate the contamination, removing it from the ground water but leaving the contaminant in the ground as a solid precipitate that won't dissolve back into the groundwater. This passive approach brings with it considerable cost savings when compared to active remediation techniques; however, it requires continued monitoring of the attenuated contaminants. This new approach led to discussion of how monitoring could be done more effectively.

"On the Savannah River Site, in F-Area, we have worked with the site customer to successfully implement an innovative passive remediation system, so now our team has been focused on a better approach for effective monitoring of this new system," said Carol Eddy-Dilek, program manager for ALTEMIS at SRNL. "Most people are talking about placing sensors in the [monitoring] wells to measure the contaminant concentrations. These sensors tend to be very expensive and require frequent calibration.

We came up with an alternative concept based on the paradigm that a contaminant plume is essentially a subsurface geochemical perturbation that is not in equilibrium with the environment. In F-Area, we have all these radionuclides in the groundwater plume and the pH is around 2, with the background pH around 5 to 6, a very significant geochemical shift. We need to monitor to ensure that the attenuated contaminants remain stable as the groundwater system, specifically pH, returns to baseline conditions over the next two or three decades. So, we've implemented a monitoring system focused on measuring key geochemical changes," said Eddy-Dilek.

"We can't have a big release of attenuated strontium or something like that," she said. "So, we came up with the concept of measuring the controlling chemical variables that cause contaminants to be released into the groundwater, and by measuring those, we can actually predict movement before it even happens," said Eddy-Dilek. "It's a real paradigm shift."

Because this is the first implementation of this approach for groundwater monitoring, it requires substantive validation of the robustness of the system. Past research activities at F-area included detailed subsurface characterization, where geologic layers in the ground that control contaminant movement were mapped and characterized. The resultant information was then integrated into the development of a sophisticated reactive transport model that can be used to evaluate the innovative monitoring approach.

"That allows us to look at how and where the uranium is going to move in the future and how the geochemistry is going to change over time," said Eddy-Dilek. The model allows the team to use decades of past sampling data to predict what will happen in the future.

This area of wetlands and sediment-capped basins is being monitored by ALTEMIS.
photo: Savannah River Site Photography

"By incorporating passive in-situ sensing technologies and artificial intelligence/machine learning with the reactive transport model, we can shift the paradigm from reactive sampling to proactive long-term monitoring by measuring data that can indicate changes in the environmental conditions such as hydrological, geochemical and geophysical, and then using those data to make predictions or forecasts of what the resulting impacts will be to contaminant concentrations in the future," said Danielson.

According to Danielson, not only does ALTEMIS represent a seismic shift in monitoring effectiveness, ALTEMIS has the potential to reduce the long-term monitoring costs by up to 90 percent.

"AI/ML plays several key roles in ALTEMIS and long-term monitoring, said Danielson. "First, it allows us to characterize the system by identifying geo-physical and chemical master variables that are strongly correlated with contaminants of concern. In other words, it tells us what data we need to be measuring for a given system. It also enables spatiotemporal optimization for location of the sensor networks, telling us how frequently and where we need to be measuring the data," he said.

Danielson said that balancing both cost and data quality is part of the process, noting that installing too many sensors would increase costs and potentially lead to less accurate datasets. He also said use of AI/ML allows prediction of contaminant concentrations out into the future with high enough accuracy to guide decision making.

The ALTEMIS Project sensors transmit data via a cellular network to the cloud where researchers from several institutions can access the data to apply ML techniques or to incorporate spatiotemporal data into deterministic hydro-geophysical and chemical models. There is an array of sensor types in addition to the sensors located in wells.

Another key need for F-Area is to prevent migration of any contamination from the residual waste disposed on the onsite disposal facility. The ALTEMIS team deployed resistivity tomography system in the basin cap by installing a cable with electrodes measures the conductivity of soil, according to Hansel Gonzalez-Raymat, a senior scientist in SRNL's Environmental Sciences and Dosimetry Group. "And the cool thing is you can detect the conductivity of the soil at different depths," said Gonzalez-Raymat. "You'll be able to see if conductivity has changed at different depths after a rain event indicating a leak in the cap. We're using this approach to ensure the protectiveness of the cap" he said. "With the sensors, you can see what is happening within the cap, so when you see changes in conductivity, you'll be able to tell if the cap was degraded or leaking," Gonzalez-Raymat said.

The paradigm shift is underway in other locations beside the Savannah River Site's F-Area.

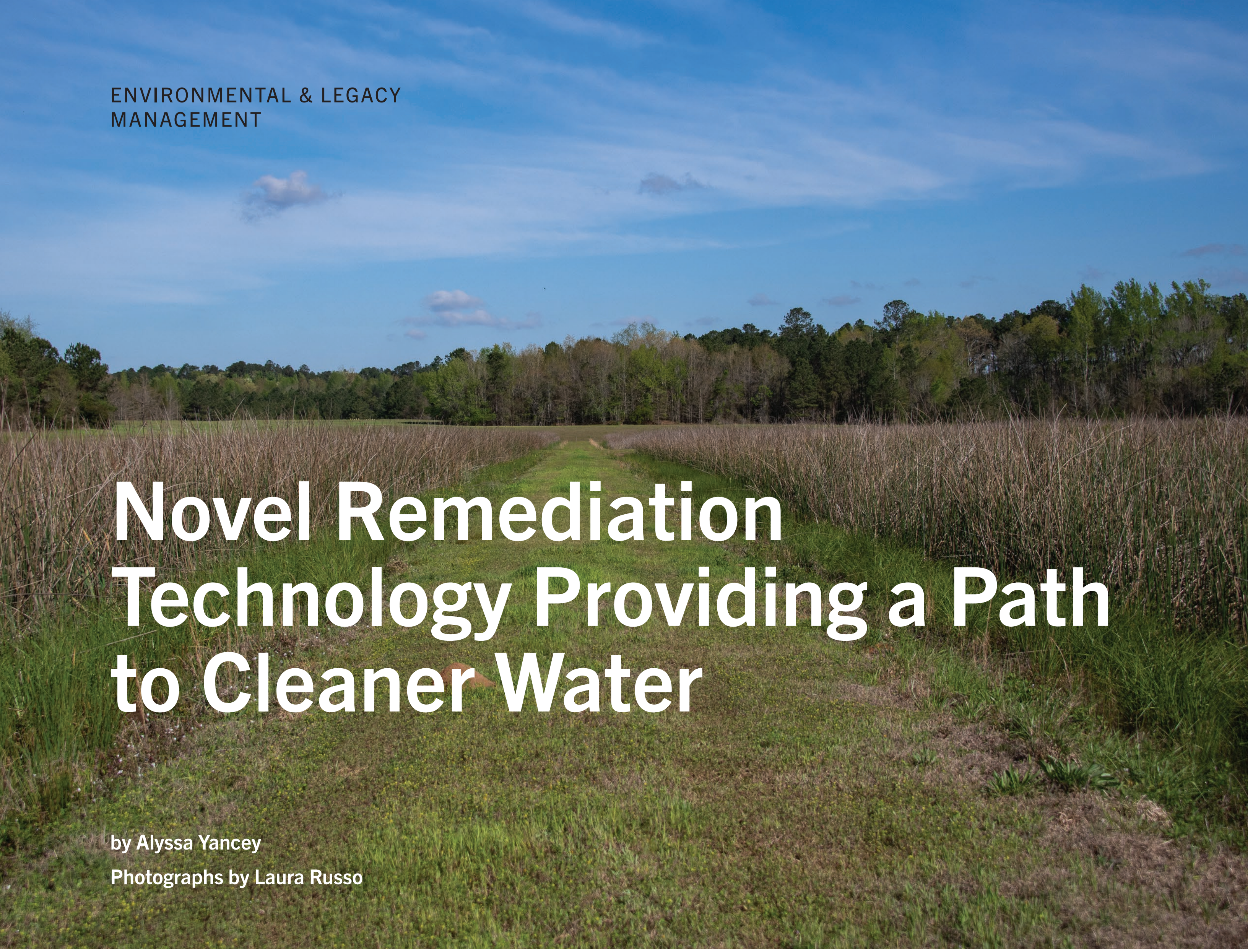
"We are working to apply ALTEMIS techniques to groundwater plumes containing heavy metal contaminants emanating from facilities containing coal combustion residuals," said Danielson. "We are also applying AI/ML for mercury vapor monitoring at Oak Ridge's Y-12 legacy mercury use facilities to understand controlling variables, meteorological driving forces, and make predictions of mercury vapor releases inside buildings undergoing deactivation and decommissioning. That work is guiding worker safety," he said.

"Now we need to start talking to the [state] regulators and stakeholders, to educate them about the benefits of the system," said Eddy-Dilek, "If we're going to institutionalize this, maybe we can use these techniques to improve long term monitoring and minimizing costs by reducing the locations and frequencies of well sampling and analysis."

While ALTEMIS can be applied to at least nine DOE sites, the system is not a one-size-fits-all. The variables ALTEMIS will monitor for are determined in part by the ML that shapes the model and determines the correlations between the controlling geochemical factors and the contaminants. That information determines what needs to be monitored and how frequently.

"So, for Moab, Utah, we're also thinking about using electrical resistivity tomography, but the application is different," said Eddy-Dilek. " We're looking at putting electrodes on the surface to monitor the stability and location of ammonium plume, because the conductivity of the ammonium plume is fundamentally different from the overlying groundwater. At F-area we're talking about a depth of 10-feet, at Moab we're looking at about 100-200 feet below the surface," said Eddy-Dilek.

The DOE-EM mission is, "to address the nation's Cold War environmental legacy resulting from decades of nuclear weapons production and government-sponsored nuclear energy research." That legacy contains some of the most challenging radioactive sites. With the responsibility for completing cleanup of these nuclear materials, being able to leverage new technologies like ALTEMIS has the great potential to reduce costs and speed site closure.



Novel Remediation Technology Providing a Path to Cleaner Water

by Alyssa Yancey
Photographs by Laura Russo

Wetlands constructed on the Savannah River Site for environmental research.

> "Everywhere there is contamination in the aquatic environment. We can't just walk away; we need to really concentrate on trying to bring our water back to a clean state."
>
> Anna Sophia Knox, Ph.D.

On the afternoon of March 11, 2011, Japan was devasted by a 9.0 magnitude earthquake. The quake caused a 47-foot tsunami wave to crash into the Fukushima Daiichi Nuclear Power Plant, resulting in wide scale contamination of the area's waterways.

Meanwhile, halfway across the world, Savannah River National Laboratory (SRNL) researcher Anna Sophia Knox, Ph.D., was developing novel remediation technologies for contaminated aquatic environments. Knox says her technique, known as Multiple-Amendment Active Caps or MAAC Technology, could help remediate the contaminated waterways near Fukushima, as well as the many other contaminated bodies of water closer to home.

A multiple-amendment active cap MAAC consists of a mixture of amendments combined with sand or other neutral materials such as clay or clean soil/sediment. MAACs represent a one-step, simple, and versatile technology that permits the rapid construction of active caps to meet diverse remediation challenges. MAACs incorporate chemically active amendments to remediate a variety of contaminants and can include bentonite (to resist erosion). Advantages include low cost, simplicity, potential to remediate a mix of contaminants, easy adaptation to site requirements, and lack of harmful environmental impacts.

Recent studies indicate more than half of the lakes and rivers in the United States have unsafe levels of contaminants like mercury, arsenic and lead. The presence of unsafe levels of heavy metals and radioactive elements in water can have serious impacts on the biota in the effected waterways, and the people who drink the water or consume the impacted organisms.

"Everywhere there is contamination in the aquatic environment. We can't just walk away, we need to really concentrate on trying to bring our water back to a clean state," says Knox.

Knox has a master's degree in geochemistry and mineralogy, and a doctoral degree in agronomy and soil science, the perfect combination to study how natural minerals can be applied in remedial technologies. Upon her arrival at SRNL nearly 20 years ago, Knox worked on the remediation of legacy cesium, one of the same radioactive elements released during the Fukushima disaster, from the cooling systems at Savannah River Site. Knox and her collaborators (Dr. Hinton and Dr. Kaplan) discovered that adding a thin layer of amendments (e.g., clay mineral illite) on top of contaminated sediments in Pond A, a legacy cooling pond, could sequester the radioactive cesium and lower the cesium concentration by 25- to 30-fold in water, 2- to 3-fold in fish and 4 to 5-fold in aquatic plants.

Researcher Anna Sophia Knox has developed novel remediation technologies for contaminated aquatic environments.

"That was a very exciting project for me and that led to 15 years of research into a multiple-amendment active cap or MAAC technology," says Knox. "The basic concept is that we create a barrier with contaminant absorbing amendments between the water and the sediments."

Historically, there were two options for environmental clean-up of aquatic environments: environmental dredging, which is very expensive and can lead to the additional releases of contaminants, and monitored natural recovery, which is only suitable for areas with low levels of contamination. In the 1980s, researchers began developing passive caps, where a layer of material is placed on the top of sediments. This layer acts as a physical barrier that prevents the release of contaminants and slowing the transport into the water column. Knox's research sought to improve upon the passive cap concept.

"We were investigating how we could enhance the performance of these barriers. There was really only one parameter we could change – absorption of the contaminants by the material that we place in the cap," says Knox. "So, for passive caps we use clean sediment or sand and for active caps we use chemically active materials – minerals or modified minerals by surfactants, etc. -- to absorb specific contaminants."

During her early research on multiple amendment active capping, Knox determined how to best deploy the technique, as well as which amendments worked best for different contaminants.

"We didn't know if, when we combined amendments, they would need to be in individual layers, like a sandwich, or mixed together. We also didn't know how much we would need. We tested it for five years and found a mixture with clean sediment or sand works very well. We also found that a very small amount is all that is needed to remediate contaminated sediment, which makes it a very cost effective and efficient method," says Knox.

Knox has presented at sessions across the globe and published in an array of journals; however, she says more awareness of MAAC Technology and its benefits is needed.

"Even in the US, the traditional approach to contaminated sediments, environmental dredging and passive caps, is still being used," says Knox. "We need to communicate and convince regulators that this method is cheaper and more effective."

Knox is optimistic that there will soon be more deployments of MAAC Technology, and she's even had discussions with colleagues working on the clean-up in Fukushima. Long-term, she hopes her work will have the legacy of creating a cleaner environment for future generations.

"SRNL was founded with the mission to not only support legacy clean-up at Department of Energy sites, but also to work toward a cleaner environment for everyone. Remediation technology, like multiple-amendment active capping, is providing a solution to help bring contaminated environments back to their natural states so biota and humans can live in harmony."

Anna Sophia Knox in the field.

The Power of Plants

In addition to her work on multiple-amendment active capping, Knox has also helped develop and maintain constructed wetlands on the Savannah River Site. The A-01 constructed wetland treatment facility (CWTF) is an 8-acre, artificial wetland designed to remove metals from industrial runoff using the natural filtering power of aquatic plants. Built in 2000, it was the first constructed wetland permitted in South Carolina to serve as a National Pollutant Discharge Elimination System (NPDES) treatment facility and, at the time, was the largest constructed wetland in the world explicitly built to remove metals from industrial effluent.

"The planted bulrush stands in the A-01 wetland utilize the natural biogeochemical cycles within this aquatic system to bind the metals to sediments and soils, with some uptake by the plants themselves," says Knox. "The system has been in place for more than 20 years and is still working very well."

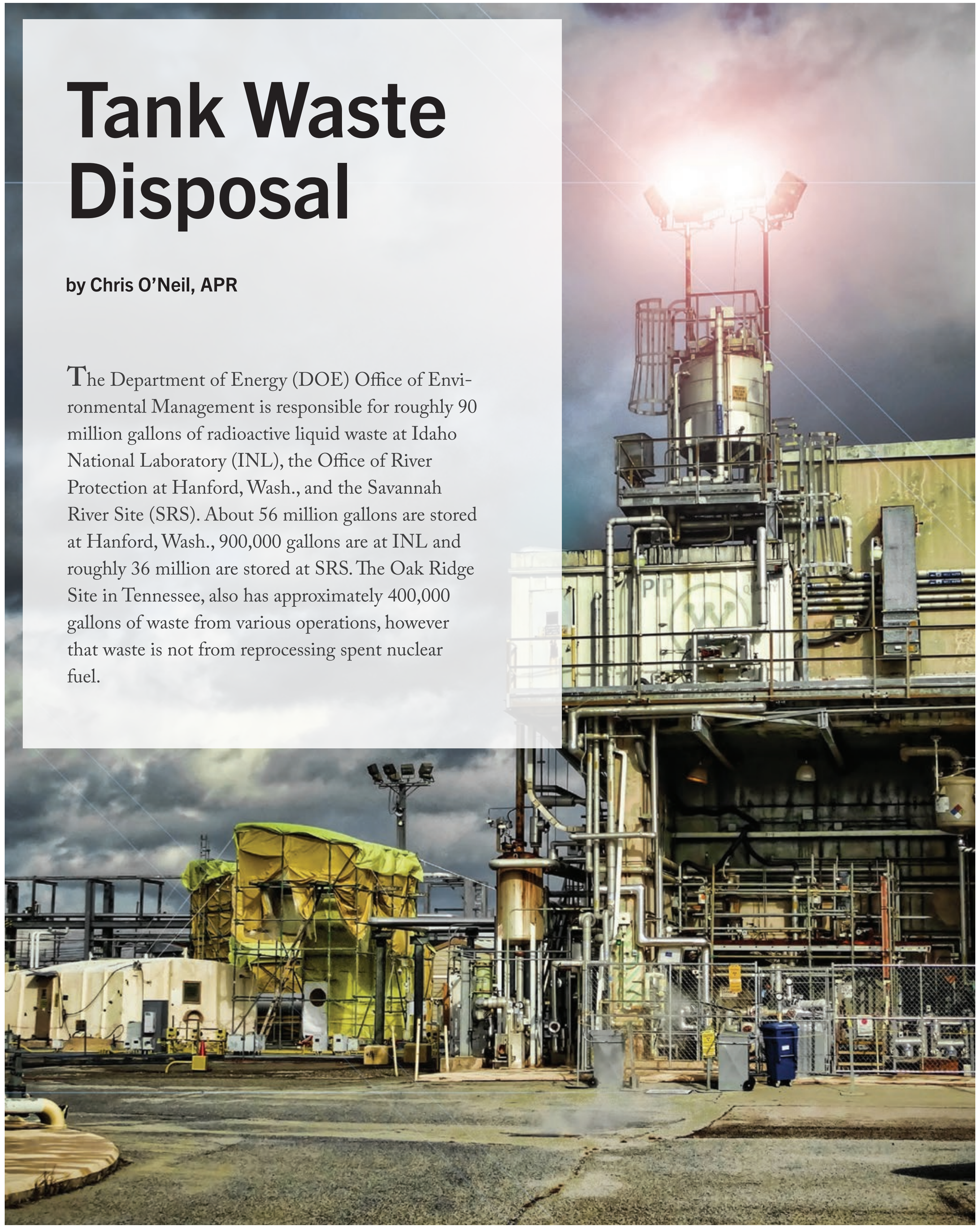
Fellow SRNL researcher and project lead Jack Mayer says, "The A-01 constructed wetland is a groundbreaking and award-winning compliance facility that has served the Savannah River Site superbly over the past two decades, continuing to provide significant cost savings over the operations and maintenance costs of the other compliance technologies that were being considered back in the late 1990s for treatment at this NPDES outfall."

SRS's A-01 constructed wetland
photo: Savannah River Site photography

Tank Waste Disposal

by Chris O'Neil, APR

The Department of Energy (DOE) Office of Environmental Management is responsible for roughly 90 million gallons of radioactive liquid waste at Idaho National Laboratory (INL), the Office of River Protection at Hanford, Wash., and the Savannah River Site (SRS). About 56 million gallons are stored at Hanford, Wash., 900,000 gallons are at INL and roughly 36 million are stored at SRS. The Oak Ridge Site in Tennessee, also has approximately 400,000 gallons of waste from various operations, however that waste is not from reprocessing spent nuclear fuel.



The 2F Evaporator at the Savannah River Site. photo: Savannah River Site Photography

Millions of gallons of liquid waste are part of the legacy of America's race to win the Cold War. The production of plutonium for nuclear weapons to defend our nation that began nearly 70 years ago resulted in high level radioactive waste, which is a mix of liquid, sediment, salts and sludge. A treatment path for these wastes was not available, so the waste was simply stored in large underground storage tanks. The tanks were arranged in groups which soon became known as tank "farms." These tanks have outlived their design lives, posing a threat to the environment. Some of the tanks have known leaks.

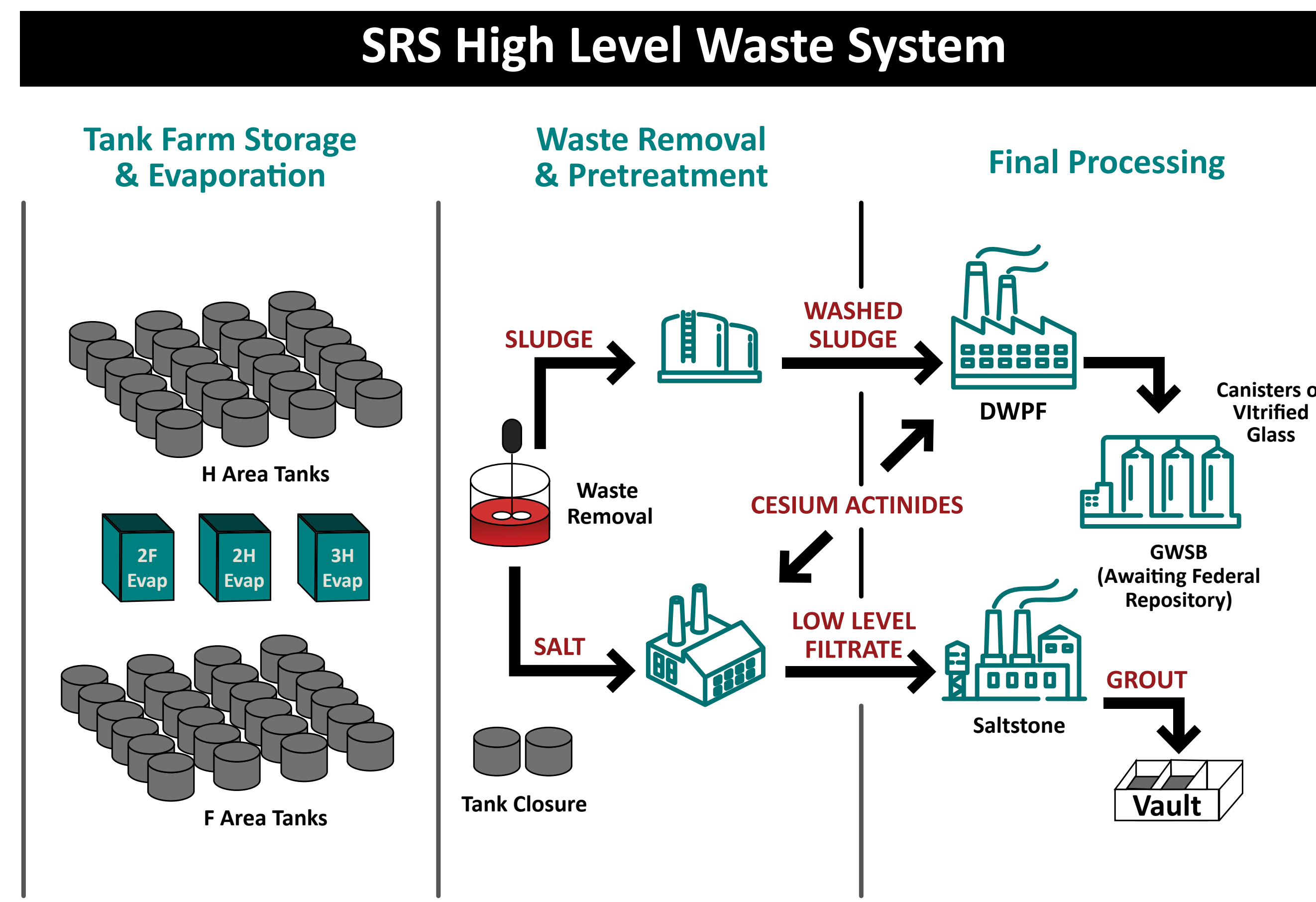
"The radionuclides in the tank waste are essentially all the daughter products from the fission process that weren't considered useful for other reasons," said Michael Stone, an engineer and program lead for the Savannah River National Laboratory (SRNL) DOE HQ Technology Development, Lab Policy Office, Hanford WRPS Integrated Flowsheet and Hanford ORP Real-Time In-Line Monitoring. "For example, the plutonium, uranium, neptunium, americium and curium were extracted, but the processes were not 100% efficient and some of these materials were later determined to be excess and got put back into the tank farm. But the most radioactivity in the waste comes from the cesium and strontium," Stone said.

But radionuclides aren't the only ingredients in the waste that have to be handled.

"When you go through reprocessing, you end up adding a lot of chemicals to first dissolve the fuel rod material. That's where the nitric acid is used and that's where a lot of the nitrate comes from that's present in the waste," said Stone.

Stone also noted that mercury was added to some fuel rods for the dissolution process. "Then there's some scavenging that's done, to get rid of what they called the 'do-bads' – that's the official term – that impacted the separations process and that is where some of the magnesium came from and some of the silica. A lot of the aluminum in our waste is a result of dissolving the fuel pellets, or the target pellets that were aluminum clad but the actual reactor rods were an aluminum-uranium matrix, so aluminum became a byproduct," he said.

Adding to the toxic mix is iron sulfamate, which was added for



graphic: Alphonzo James, SRNL

The Defense Waste Processing Facility (DWPF) at the Savannah River Site. photo: Savannah River Site Photography

reduction reactions, along with chromium, manganese and nickel. Then there's the salt:

"When you go to carbon steel tanks [with the waste] you can't add nitric acid to them, so they neutralized the nitric acid with sodium hydroxide. That neutralization step is the source of most of the sodium in the tank waste," said Stone. "When you add the hydroxide, a lot of the metals will drop out into a metal hydroxide/oxide sludge layer."

When the metals drop out, it leaves a supernate on top and when evaporated, the supernate forms a salt cake, and this is where the salt waste comes from. The supernate is evaporated because it is easier to deal with the salts in its solid form – if left in a liquid state, sites would have to build twice as many storage tanks.

The sludge, salt and supernate would all be classified as high-level waste as stored. According to Stone cesium will be present in the salt waste whereas a lot of the long-lived radionuclides are in the sludge waste.

Today the race is on to process that waste and make its long-term storage less of a threat to the environment, and SRNL is leading that race as the Environmental Management Corporate Laboratory.

Through the years an array of processes including vitrification (incorporating radionuclides in the molecular structure of glass), calcination and sending low level waste into cementitious grout and saltstone were created. The goal is not elimination of the radioactive materials (because it isn't possible), rather, safely remove liquid waste from tanks and convert the liquid waste into a safer form for long-term storage. This conversion removes the threat to the environment from leaks, spills or leaching and allows for closure of aging waste tanks.

While sites have similar issues with handling liquid waste, they adopted differing processes to deal with it, and those processes have had varying levels of success, cost and efficiency.

"When SRNL started working on the tank waste problem, we were trying to figure out what was the right waste form for the high-level waste," said Connie Herman, Associate Lab Director for Environmental and Legacy Management at SRNL. "We were looking to solve the DOE problem of what is the right choice, but then we went specific after that and looked at how do we design the equipment, what kind of plant do we need here for our specific tank waste at the Savannah River Site," she said. "We knew we had to get to glass [vitrification], the question became how to do that here in a remotely operated environment."

Herman said the technology for putting high-level waste in glass for long term storage was developed in the 1970's. Construction for the Defense Waste Processing Facility (DWPF) started in 1982, with the facility doing cold operations in 1994 and moving to rad operations in 1996.

"In those 10 years there was some work done in the tank farms to get them ready to send waste for processing," said Stone. "There were also some aborted techniques in that time span. A sludge washing facility was designed, but not built, because we figured out sludge treatment could be done in the existing tanks," he said.

"The salt waste or low-level fraction of our waste was going down a process that essentially failed," said Stone. "The process required salt processing in small batches and initially they tried to do it in one of the tank farm tanks. That led to a lot more benzene than we had anticipated, so for salt processing, we had to rethink our original ideas on how to do that," said Stone.

Stone said they switched to a solvent extraction process used at the Savannah River Site's Salt Waste Processing Facility (SWPF). After abandonment of the failed process and before the start-up of the SWPF solvent extraction process, implementation of TCCR (Tank Closure Cesium Removal) made substantial changes happen.

"First we had to very quickly develop a way to process at DWPF without the salt waste," said Stone. "And then we had to incorporate the revised salt processing methods and streams into DWPF."

Stone said the treatment process to make the low level waste fraction includes a filtration or settling step to ensure none of the sludge solids get into the treated salt waste.

He noted that at SRS they can also treat the soluble actinides by adding monosodium titanate. The monosodium titanate absorbs the actinides and can absorb or dissolve strontium as well. The monosodium titanate is filtered out when the solid step filtration is complete, leaving a relatively clean supernate stream.

The supernate has a lot of cesium in it at this point, and so a solvent-extraction process (like at SWPF) or CST (crystalline silicotitanate ion exchange) is used to extract the cesium (as was done in TCCR). With the cesium removed from the supernate, the decontaminated salt solution then moves to salt stone as a low-level waste.

Stone said the low-level waste goes into surface disposal or near surface disposal. At SRS that means vaults.

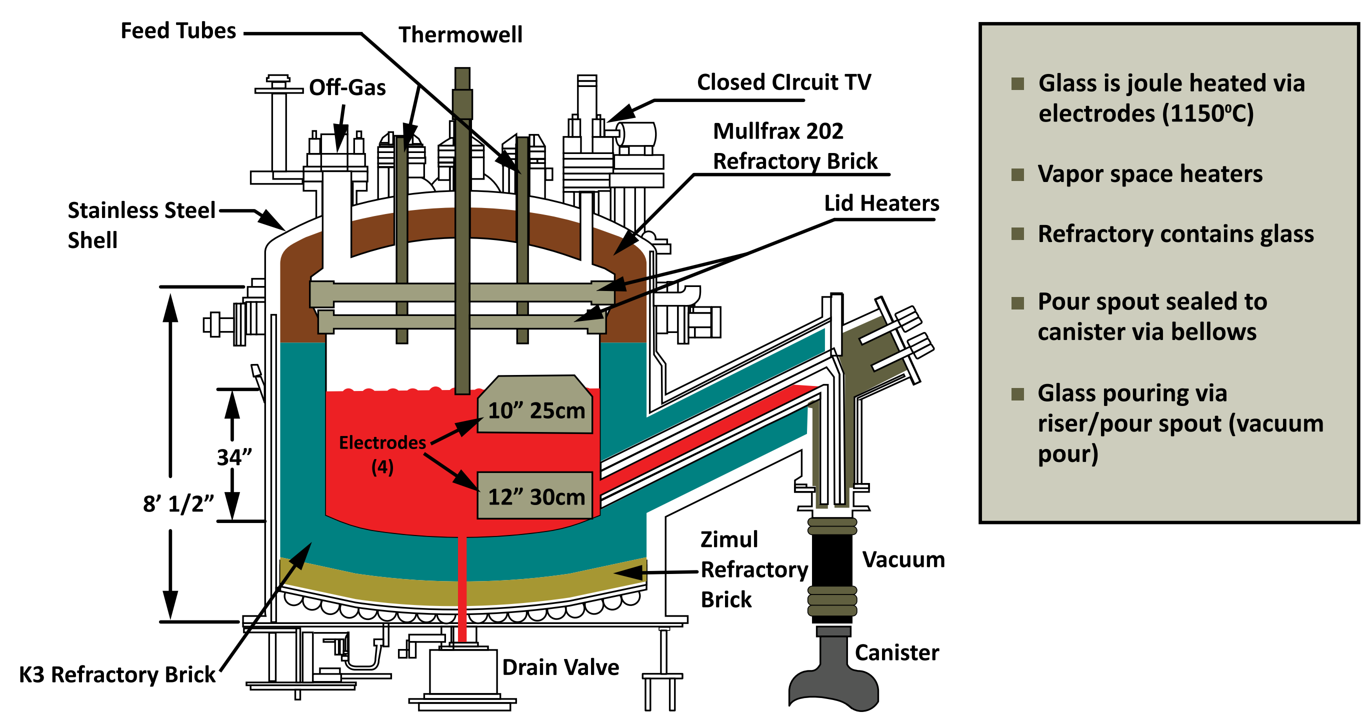
Oddly enough, the vaults look a lot like – tanks.

"The original structures were rectangles and looked like vaults, hence the name," said Stone. "Then they went to 'coliseums' – a supersized vault – and it became round but kept the name."

The vaults are rated for a 500-year life. And while the minute amount of cesium in the salt stone has a very short half-life, species like technetium 99 and iodine 129 are both relatively long-lived. The storage system requires the ability to remain below a specific dose release factor for 1,000 years.

While the low-level supernate part of the waste is in saltstone in vaults, the sludge from the tanks, a high-level

DWPF Melter



graphic: Alphonzo James, SRNL

DWPF canisters. photo: Savannah River Site photography

waste, with all its metals, has a lot of the long-lived radionuclides like plutonium, uranium, and neptunium, requiring a different process.

Stone says the sludge goes through 'sludge washing' to remove as much of the soluble materials as practical – the dissolved species are eventually sent to saltstone. Sludge washing reduces the amount of waste going through high-level waste disposal and allows for higher waste loading during vitrification. Washing also helps remove a lot of sulfur, which is problematic in vitrification as it causes a highly corrosive layer due to its limited incorporation in glass.

"So, we go through basically a process to get rid of the highly-concentrated residual supernate and the sludge in the interstitial pockets, as well as to dissolve some of the sulfate and sodium," said Stone. He also said those batches with high amounts of aluminum can go through a process to dissolve the aluminum and force it into the supernate, which then goes to saltstone as a low-level waste, rather than going to vitrification with the high-level waste.

Stone notes not all sludge batches go through that process. The waste qualification process helps determine how much the sludge should be washed and whether or not aluminum removal is performed. SRNL receives samples from the tank waste, puts it through the washing process and then puts the sample through processing evaluations to evaluate how the sludge will be processed. Qualification of the sludge batches is a requirement for the DWPF to accept a sludge batch.

When a sludge batch is accepted at DWPF for vitrification, they will add back any solids that were filtered out at SWPF, as well as the removed cesium and other radionuclides contained in the solvent stream. The sludge is later acidified using a blend of nitric and glycolic acids. It is then boiled to reduce the volume. While at boiling temperature, the nitrite is destroyed, and mercury is reduced to elemental mercury and removed from the waste via steam stripping. Stone said this is where a lot of other redox chemical reactions happen. The process is designed to have a balanced redox, so that about 20 percent of the iron will be in a reduced state in the final glass product. This balanced redox allows for faster glass melting while not being so reducing that metallic species form in the melter.

When boiling is completed, the stream is sent to a tank where it is mixed with frit or pre-determined glass formers that are specific to the batch. The frit is added as a water slurry and then all the water is evaporated off. The boiling leaves the melter feed as concentrated as possible. When it reaches the target solids endpoint a chemical composition evaluation is done. The evaluation shows the chemical composition in this slurry melter feed will make glass with the desired properties.

The glass, which more closely resembles obsidian rather than window glass, goes into stainless steel canisters, which are then safely stored for eventual geologic disposal.

While the treatment of tank waste in this article focuses primarily on SRS, it's important to note that SRNL is working with other DOE sites to implement the lessons learned in tank waste processing to operations at Hanford, Oak Ridge and Idaho.

These processes were developed to clean up the millions of gallons of liquid waste resulting from Cold War production of plutonium and uranium. And while these processes move forward, and waste tanks get closed, SRS and Los Alamos are poised to begin production of plutonium pits to ensure the readiness of the nation's nuclear arsenal. Fortunately, much has been learned during the past several decades and researchers are already at work to find ways to reduce waste products from weapons production.

"Can we stabilize some of the waste from pit production, in let's say grout, so we don't have tanks of liquid waste," said Herman. Any of the potential secondary waste that might be generated, like plutonium and the transuranic (job control) waste will be evaluated. SRNL is working with the Carlsbad Field Office with the Waste Isolation Pilot Plant to determine if we can dispose of that secondary waste directly to those locations.

"The problem is the original inventory targeted for disposition at the Waste Isolation Pilot Plant was much lower in plutonium, so we are working with the Carlsbad office to evaluate the impact of that additional plutonium," said Herman. "So yes, we have learned the key part of this is if you design the process with the end in mind and thinking about that you've got to generate waste and you've got to get rid of the waste and you incorporate the researchers who know how to do that. Then you don't create as much waste, number one, or in the end you create a waste that's hopefully got a smaller volume," she said.

"But that waste stream will be significantly different than the tank waste because you're not going through spent nuclear fuel reprocessing to get the material that's going in the pits this time," said Stone.

Even as SRS and Los Alamos gear up for pit production, and as the National Nuclear Security Administration prepares to take ownership of SRS, SRNL's environmental management researchers are not only executing DOE-EM's mission today, but they are also preparing to minimize the risk to our environment with the production of the next generation of plutonium pits.

Corralling Cesium with CST

by Chris O'Neil, APR

For as long as scientists have worked to develop nuclear energy and nuclear weapons, scientists have also labored to develop effective means of disposing of nuclear waste products. This need is the mission of the Department of Energy, Environmental Management (DOE-EM), "to complete the safe cleanup of the environmental legacy brought about from decades of nuclear weapons development and government-sponsored nuclear energy research."

One solution to the problem, a problem that was decades in the making, also required decades of work to resolve. Recent news articles heralded the start of the "first large-scale pretreatment" of millions of gallons of radioactive waste stored at the Hanford and Savannah River (SRS) sites. Largely missing from that mainstream media coverage is discussion about the years of technology development and refinement that make such milestones possible.

Cesium is present in the by-products of nuclear material production that have been pumped to waste tanks since the 1940s and 1950s. Modern-day processing of nuclear materials continues to produce liquid wastes requiring storage and treatment. While storage tanks were built to safely hold these waste materials for 50 years, the reality is many tanks have reached or are reaching their planned lifetime, lending a sense of urgency to safely remove and treat the waste within them.

According to Daniel McCabe, Ph.D., senior fellow scientist at Savannah River National Laboratory (SRNL), Sandia National Laboratory and Texas A&M University first developed a synthetic inorganic ion exchange technology to absorb cesium – the primary soluble radionuclide found in the waste – that was subsequently deployed in practice for DOE. "The intent was always to treat the waste and dispose of the waste in an environmentally stable form," said McCabe. "CST [Crystalline Silicotitanate ion exchange] is just one of the technologies developed to do that.

SRNL didn't invent the technology, but SRNL did play a key role in maturing the technology, demonstrating its use, and providing engineering parameters that support design and safe operation of the technology. McCabe says SRNL has more than 80 published reports on CST and his first report on the technology was in 1995.

What is unique about CST, according to Frank Pennebaker Director, Chemical Processing and Characterization at SRNL, is that CST can be deployed near a tank and used there to remove cesium from the waste, thereby negating the need for removal and transport of the waste to another location for treatment. Deploying the semi-modular technology "at tank" provides savings in time and money, while reducing risk. Using CST gets the waste from a liquid to a more stable (and safer) solid state and ultimately allows for the closure of the tanks.

"At the Savannah River Site, the bulk of the waste is removed from the tanks," said Bill King, a scientist in SRNL's Chemical Flowsheet Development Group, "And the tanks are cleaned sufficiently for the state to approve the closure of the tanks." According to Pennebaker, maximum removal is the state we want to get to – where most of the risk has been remediated.

While the CST technology was matured with the Savannah River Site in mind, the proven and scalable technology is also being used at the Hanford site and at Fukushima, Japan, as part of the cleanup from the 2011

H-Area Tank Closure Cesium Removal.
photo: Savannah River Site Photography

tsunami-induced disaster.

There are 51 tanks at SRS, eight of which have been closed, with the goal of having them all closed by 2033. At Hanford, where CST was most recently deployed, there are 177 tanks needing to be closed.

McCabe said the first testing of CST for use at SRS was done in collaboration with the Oak Ridge National Laboratory April 25, 1997. "A lot of people have been involved for a lot of years. SRNL led the work, but there were contributions from Oak Ridge, Sandia, and PNNL, we've all done testing with it," he said.

McCabe points to the early absorption testing in the late 1990s and the computer modeling SRNL did for the Hanford and SRS at the turn of the century as significant milestones in the 23-year project, as well as determining the proper CST column size to mitigate heat and dose effects. McCabe said there were multiple designs as the technology evolved, but the startup of TCCR at SRS marks the first time CST was built and operated in the DOE complex. The 2001 engineering-scaled demonstration, with a column of actual waste, marked another milestone in the project.

"The computer modeling allowed us to take small-scale experiments and scale them up to how an engineering scale process would perform," said McCabe. Computer modeling was also used to validate recent assumptions to operate CST as efficiently as possible and optimize its use, which saves taxpayer dollars, according to Pennebaker.

The CST media is an inorganic, highly stable material that is highly selective for removing Cesium in tank waste solutions. The media absorbs Cesium, and development of an engineered form and large-scale production by UOP of Des Plaines, IL, U.S.A., was key to making the operations feasible.

"Cesium is typically the highest dose radionuclide in high-level tank waste – removing that Cesium from the tank waste is a big, big step toward the remediation of waste on site," said King.

It has taken 25 years to perfect and implement the CST technology, and it is easy to lose sight of how, in the nuclear waste industry, it is not uncommon for solutions to take a long time to come to fruition. "In a career in this business, you might get to see one or two or maybe a handful of things actually implemented," said King. "Because there are so many potential problems and potential issues in implementing any kind of technology in this environment, this is just the time scale you're looking at. It's just the reality," said King.

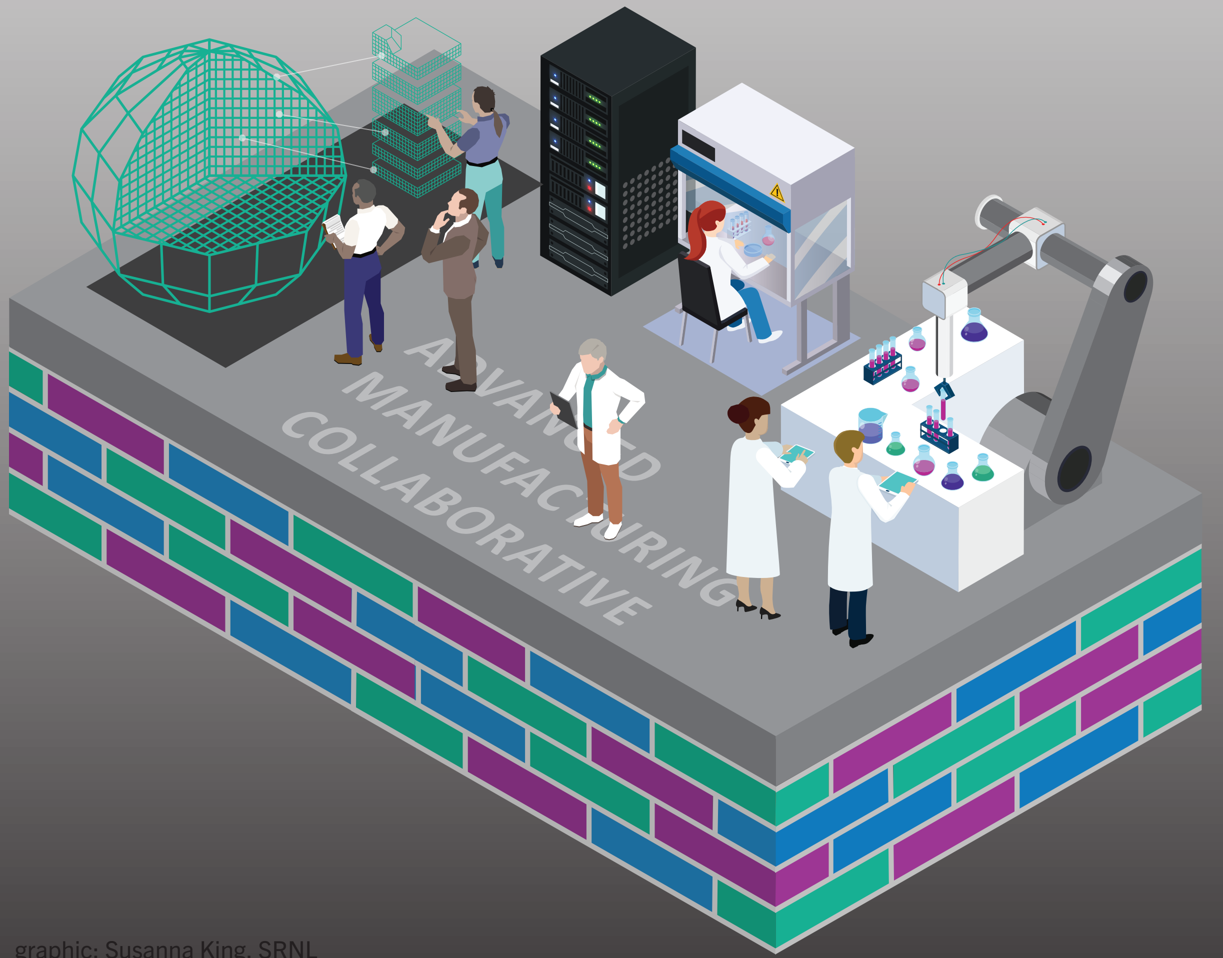
F Area tank farm at SRS. photo: Savannah River Site Photography

Advanced Manufacturing Collaborative

by Chris O'Neil, APR

"Advanced manufacturing is about discovering new processes, pathways and approaches for carbon-neutral manufacturing outcomes."

Sue Clark, Ph.D., Deputy Director of Science and Technology at Savannah River National Laboratory



graphic: Susanna King, SRNL

Future manufacturing technologies for the Department of Energy's Office of Environmental Management took a giant step forward recently as site work began for the construction of the Savannah River National Laboratory's Advanced Manufacturing Collaborative on the University of South Carolina Aiken campus.

"Advanced manufacturing means many things to many people, and there are a number of notionally similar capabilities across the country and with other national laboratories," said Vahid Majidi, Director of Savannah River National Laboratory. "But what really sets our AMC apart is its focus on reducing the carbon footprint and moving toward a manufacturing environment where energy associated with production and the feed materials, all have a very low or zero carbon footprint," said Majidi. "Reductions in a carbon footprint in itself is a significant goal to meet many of the DOE's future needs in environmental cleanup."

There are many ways to reach a zero carbon goals, and the AMC will help generate unique pathways to that end. Majidi said the AMC will help industry achieve this end through several mechanisms such as:

- Low-Carbon Waste Forms
- Bio Manufacturing
- Alternative energy sources, including Fusion
- Energy Storage
- Process Intensification

"Advanced manufacturing is about discovering new processes, pathways and approaches that can lead to manufacturing outcomes that enable carbon neutrality," said Sue Clark, Ph.D., Deputy Director of Science and Technology at Savannah River National Laboratory.

When describing advanced manufacturing, Sharon Marra, Deputy

Architect's renderings of what the completed AMC will look like

Laboratory Director for Operations at Savannah River National Laboratory, pointed to process intensification.

"It's about taking traditional manufacturing methods and modernizing them in terms of making them smaller, modular, more efficient, more cost effective, and perhaps more integrated," she said.

"SRNL is uniquely good at process intensification," said Majidi. "This is where we reduce the carbon footprint by increasing the efficiency of manufacturing's chemical and physical processes." Increasing efficiency in these processes has the potential to reduce or prevent waste, thereby reducing or eliminating the need for environmental cleanup or remediation.

But increasing efficiency of processes isn't the only way SRNL will help get to a zero-carbon footprint. SRNL is also ensuring the AMC building itself has the lowest carbon footprint possible.

"The building itself will be LEED [Leadership in Energy and Environmental Design] certified so that the building will use less energy and be more efficient," he said. "We will monitor all the processes happening in the building, and we'll also monitor the building itself through various sensors feeding into a well-curated cloud database. This allows us to use artificial intelligence to optimize manufacturing conditions and identify energy efficiencies in near real time," said Majidi.

Materials substitution is another mechanism through which a manufacturer can achieve a lower carbon footprint.

"We are researching biomanufacturing techniques to produce a library of fine chemicals used in standard manufacturing processes. We will discover ways to apply non-fossil fuel-based hydrocarbons that will feed modern processes familiar to industry to produce the materials we all use every day," said Majidi.

With increasing use and reliance on automation, cyber security is a concern for integrated control systems employed on most modern manufacturing floors. A key element of SRNL's AMC will be a strong layer of dynamic cyber security that will protect all of the automated chemical and physical processes.

"With that threat in mind we will develop a robust cyber defense approach to protect our systems and recognize intrusion attempts; the goal is to prevent unauthorized access to our manufacturing processes," said Majidi. "By building and demonstrating cyber security around programmable logic controllers, digital relays and industrial control systems, we will support industry's need to ensure uninterrupted operation while maximizing the quality of manufactured items."

Located on the University of South Carolina Aiken (USCA) campus, the 60,000-square foot building will be the result of a close partnership between the Department of Energy Office of Environmental Management (DOE-EM), USCA and North Wind Construction Services, LLC. The location was selected to maximize the AMC's impact for industry, academic community, and SRNL.

"Perhaps the biggest advantage of the AMC is that it will be on the University of South Carolina Aiken's campus, which opens a brand-new opportunity to directly interface and collaborate with students," said Majidi. "We are looking at this as an educational gateway and future pipeline for SRNL and the Savannah River Site, that will bring new ideas to the Department of Energy."

Marra said having access to the university's students and developing the next generation of researchers, engineers and scientists was at the forefront of the decision to have the AMC at the university, giving SRNL access to potential interns, graduate students, postdoctoral candidates and the students in general, while giving them access to potential mentors, hands-on, real-world experience, and career opportunities.

"The AMC will be a place to bring together a diverse group of people to solve problems including industry, academia and SRNL to learn how to make processes work better, or create new ones, in order to manufacture in a more cost effective and efficient manner," said Marra.

"This is the kind of environment where a national lab can come together with both industrial and academic partners to accelerate discovery and demonstrate solutions for industry more rapidly than if we were trying to do so on our own," said Clark.

"The AMC allows our researchers to collaborate with industry and academia in a more accessible and open space than behind the fence at the Savannah River Site. said Marra.

To the casual observer, the nexus between the DOE-EM mission and advanced manufacturing may not be readily apparent, but to Majidi it's crystal clear.

"DOE-EM's mission is to deal with legacy [nuclear] waste generated during the Cold War," said Majidi. "What we're focusing on are future processes that minimize, reduce or eliminate waste altogether. So, if we can develop separation processes that minimize the waste, if we can develop manufacturing processes that minimize the waste and its associated carbon footprint, then we have integrated total waste reduction of into those processes. EM is the driver for reducing or eliminating future waste resulting from activities we are doing today. EM is working today to deal with the legacy of waste left behind. Our goal [AMC goal] is to not leave legacy waste behind for the future generations," he said.

Reductions in manufacturing's carbon footprint and reducing the need for remediation of waste from manufacturing are significant milestones for our nation, and the AMC advances our economic competitiveness as well.

"Two of the major expenses in manufacturing processes are energy input and waste disposition. Regardless of if you're an environmentalist or not the processes that involve energy reduction and waste reduction ends up always saving production costs at the end of the day. Processes developed at the AMC are going to reduce costs," said Majidi.

Because of its location on the university campus and collaborations with industry and academia, the activities in the facility will involve non-radioactive systems, and information that can be publicly shared. These activities provide a foundation for discovery and advancement that can be used to accelerate innovation for manufacturing of classified and/or nuclear components and radioactive materials.

The Advanced Manufacturing Collaborative is slated for completion and occupancy in fiscal year 2025.

Gaining Momentum

by Chris O'Neil, APR

A little more than a year ago a charter was signed formally establishing the Regulatory Center of Excellence (RCE) at Savannah River National Laboratory (SRNL), ushering in a new resource to sites across the DOE complex facing the toughest regulatory compliance challenges

Designed as an "as-needed" resource for sites, the RCE provides innovative strategies that address mission-critical, regulatory compliance challenges. The RCE is able to provide this support because of its ability to draw upon the collective expertise of SRNL, Longenecker and Associates, the Network of National Laboratories for Environmental Management and Stewardship (NNLEMS) and the Battelle Savannah River Alliance's (BSRA) University partners to serve as a critical resource for connecting research developments and regulatory compliance strategies. Within the RCE team itself is more than 90 years of collective experience available to its customers.

As a resource, the RCE is designed to be scalable, relevant to the scope or complexity of a problem the RCE is invited to work on. "We bring in only the specialists who are needed for the challenge presented to us, and bring them in as they are needed," said Stephanie Jacobs, Director of the RCE.

Stephanie Jacobs, Connie Herman, and Vahid Majidi signed the agreement creating the RCE in 2022.
photo: Savannah River Site Photography

"What we can do spans the breadth of what our customer may need. It's fully scalable, if you need someone who is more on the education side for educational outreach, we can provide that strategy. If you need highly technical assistance to find a solution, we can provide that expertise. Need someone to help you develop a strategy to engage stakeholders about your highly technical solution? We have specialists to provide you with that expertise," said Jacobs.

"What SRNL and our partners bring to the table is the demonstrated ability to facilitate communications between DOE sites, communities and regulators and bringing in those groups' perspectives," said Connie Herman, Associate Laboratory Director for Environmental and Legacy Management at SRNL.

What the RCE is not, is a strike team or other kind of deployable asset. "The RCE is not a deployable force, meant to take over operations or even augment a staff," said Jacobs. "The RCE is a resource, a conduit to innovative solutions to our customers' toughest challenges."

As an example, one of the RCE partners is the University of Georgia's School of Public and International Affairs. "We have a very deep bench of experts – if we can't help you directly in the School of Public and International Affairs, we can connect you with experts on campus to talk to," said Justin Conrad, RCE member and Associate Professor at the University of Georgia. "The RCE can advise in a number of areas from technical issues to communications issues but what the RCE is especially good at is overcoming barriers to statutory compliance and risk mitigation that stem from regulatory and public engagement challenges. The RCE does not have a magic blueprint, and that in fact a standard blueprint would be unhelpful as these challenges are highly contextualized," said Conrad.

One of SRNL's partners, Longenecker & Associates, Inc., has several staff who were state or federal regulators who bring a unique perspective to regulatory issues. "They get both sides, they understand what the state, DOE and the contractor are looking for and that allows Longenecker & Associates and the RCE to identify areas for innovation, collaboration and compromise," said Katie Roberts, Vice President for Regulatory Assurance at Longenecker and Associates. "Our stakeholder and engagement outreach expertise are well-known throughout the DOE complex."

The RCE is already adding value in the DOE complex, working on issues such as:

- Per- and polyfluoroalkyl substances (PFAS)
- State regulatory Oversight Models for Consolidated Interim Storage Facilities
- Groundwater and Soil Remediation Regulatory Challenges
- Comprehensive Regulatory Analysis on Requirements from DOE Orders 435.1 and 458.1 for Closing Sites with Soil Contaminated with High Level Waste
- Analysis of the Dispute Resolution Process for State of California Environmental Agency Department of Toxic Substances Control Administrative Order of Consent

Within the RCE's charter is the task of developing a "warehouse" of best practices for regulatory compliance outreach, education and communications. The concept of operations is to build a virtual library with case study summaries and the planning, strategy and collateral documents associated with successful regulatory compliance projects.

The technical, regulatory and communication challenges inherent in DOE-EM work require constant attention, expert management and superior execution. The RCE is poised to provide counsel, expertise and strategies that will help sites and DOE-EM and other sites meet those challenges and excel in mission completion.

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SRNL's ASET an Asset to the Nonproliferation Stewardship Program

by Scott Shaw

The Actinide Science and Engineering Testbed (ASET) at Savannah River National Laboratory (SRNL) plays a key role in the Department of Energy (DOE), National Nuclear Security Administration (NNSA) Nonproliferation Stewardship Program (NSP), as part of the Athena plutonium program. The NSP seeks to ensure foundational technical competencies at DOE/NNSA are sustained and available to support the nation's nonproliferation missions. To do this NSP is investing in:

1. Enabling Infrastructure
2. Enabling Science and Technology
3. Expert Workforce

Enabling Infrastructure and Science and Technology

ASET, the nation's engineering-scale nuclear materials processing capability, includes knowledgeable staff with the tools necessary to support the nation's plutonium separations Science and Technology (S&T) needs. The capability is housed within an adaptable nuclear facility with shielded cells, laboratory spaces and analytical capabilities. This

The ASET Mission

- Equipping the DOE complex to allow for engineering-scale, nuclear material processing relevant to nonproliferation and civilian uses of nuclear materials;
- Developing subject-matter experts able to effectively learn, be informed by, and innovatively experiment with U.S. and international processing activities, and;
- Integrating a multi-disciplinary science and technology agenda engaging a diverse workforce across the DOE complex to develop baseline skills that evolve and grow into a variety of nonproliferation missions

ASET Infrastructure and Capabilities

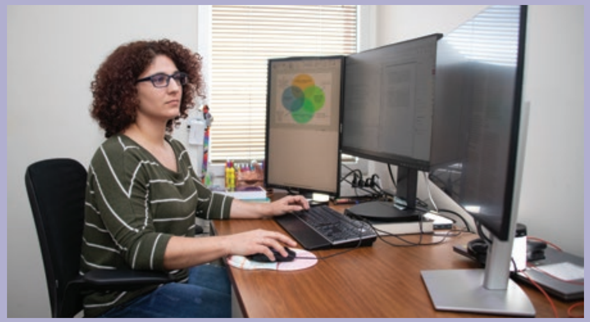
Full size irradiated fuel receipt.

Shielded Cells used for fuel dissolution and first cycle solvent extraction.

Gloveboxes used for second cycle solvent extraction.

Lab-scale activities used to understand and evaluate processes.

Analytical equipment utilized to provide analysis.



Modeling utilized to further knowledge and to feed back into process knowledge.

infrastructure will enable long-term innovative nuclear energy and materials use through S&T advancements in support of industry use as well as developments to improve the ability to safeguard material and reduce proliferation concerns.

"SRNL offers unique capabilities to assist the DOE and NNSA in meeting its Nonproliferation Stewardship Program objectives of ensuring foundational competencies and capabilities to meet future mission needs," says Matt Griffin, Nonproliferation Stewardship Program Manager at SRNL. "Having a knowledgeable workforce with the appropriate tools is critical to successfully enable the benefits of nuclear technologies."

SRNL's ASET provides engineering-scale processing that offers opportunities to gain information that is currently unavailable from past large-scale production facilities or from current lab-scale operations. Information from ASET will enable better utilization of nuclear material for medical, energy and industrial applications. Because of SRNL's location on the Savannah River Site, SRNL's unique capabilities include:

- Staffing expertise that supported Savannah River Site H- and F-Canyon operations for past several decades
- Access to spent nuclear fuel (SNF) at Savannah River Site L-Reactor basin including shipping casks, fuel handling, and other SNF special-handling infrastructure
- Existing SRNL infrastructure (hot cells, intermediate level cells, glove boxes, specialized equipment) with the unique capability to manipulate substantial amounts of material
- Specialized instrumentation to analyze chemical forms and radioisotopes
- Expertise gained from the NA-ESH-10 sponsored MK-18A Target Recovery Program; processing Pu targets to recover Pu-244

ASET is renewing, reviving, and restoring facilities and experts in nuclear materials separations, plutonium production sciences, and the nuclear nonproliferation topics associated with these areas. Along with modernizing infrastructure, "development of the next generation workforce and transferring knowledge from the current experts are at the center of all activities within the Athena program," said Harris Eldridge, Senior Engineer and an Athena Lead.

Maintaining these experts and the tools that are required to understand nuclear materials will ensure confidence in the deployment of future nuclear technologies, as well as the knowledge to secure and safeguard such technologies.

Expert Workforce

Maintaining an expert workforce will enable U.S. technical leadership in disposing used nuclear fuel and in the recovery of valuable nuclear material. The program has hired many new people to support these endeavors. Samuel Uba, a recently hired scientist at SRNL, has engaged with NSP Athena initiatives to increase plutonium monitoring and material characterization capabilities.

"My experience since joining SRNL has been positive, motivating and exciting," says Uba. As part of the Online Monitoring team for Athena, Uba is involved in the static and real-time characterization of the chemical process flow, utilizing an optical spectroscopy technique for real-time quantification. He's also involved in other nuclear nonproliferation-related projects providing technical support as a spectroscopist and materials scientist. "These work experiences have improved my knowledge in nuclear nonproliferation technologies," says Uba. "The support across the Athena team and laboratory partners has been collaborative, from team members, project managers and laboratory leadership."

Uba is experiencing first-hand the impact NSP is having on building and sustaining nonproliferation competences and capabilities. Updating infrastructure and executing relevant science and technology will help attract and retain new talent.

The goal of the Athena initiative is to onboard 75 early and mid-career scientists and engineers to become experts in stewarding key plutonium processing competencies, 25 people alone with SRNL's ASET. Early career scientists and engineers are joining the project and providing meaningful contributions. Significant knowledge transfer is happening amongst staff working in tandem with laboratory fellows and experts. These activities collectively augment processes and bolster resources amongst the program teams and its partner labs.

NSP: NNSA Nonproliferation Stewardship Program

Athena: Collaborative NSP plutonium stewardship program led by Pacific Northwest National Laboratory (PNNL), Idaho National Laboratory (INL), Argonne National Laboratory (ANL), and Savannah River National Laboratory (SRNL)

ASET: SRNL's Actinide Science and Engineering Testbed positioned to provide engineering-scale processing capabilities to enable nuclear technologies

Matt Mills, Rebecca Carter, Drew Fairchild work with centrifuges as part of the Athena program.
photo: Savannah River Site Photography

Savannah River National Laboratory MK-18 program prevents critical isotopes from being lost

Rare plutonium isotope (Pu-244) might not be seen again on Earth if not for important SRNL mission

by Mike Ettlemyer

For decades the Savannah River Site (SRS) has stored irradiated MK-18 target assemblies, produced in SRS nuclear reactors during the Cold War. A 2014 National Nuclear Security Administration (NNSA) sponsored collaboration between SRNL and Oak Ridge National Laboratory (ORNL) brought the stored material back into focus as a rare and valuable resource to benefit research and analysis in nuclear non-proliferation national defense missions.

The primary isotope of interest from the MK-18 program, Plutonium-244 (Pu-244), is both very rare and stable. It is extremely important as a certified reference material in nuclear forensics and non-proliferation related applications.

Pu-244 is mostly found in outer space, so it is hard to come by and is highly sought after as a plutonium source. The U.S. supply is very low. What remains came from other MK-18 targets that were processed to recover the rare isotope in the 1970s.

Using material that would otherwise go to waste

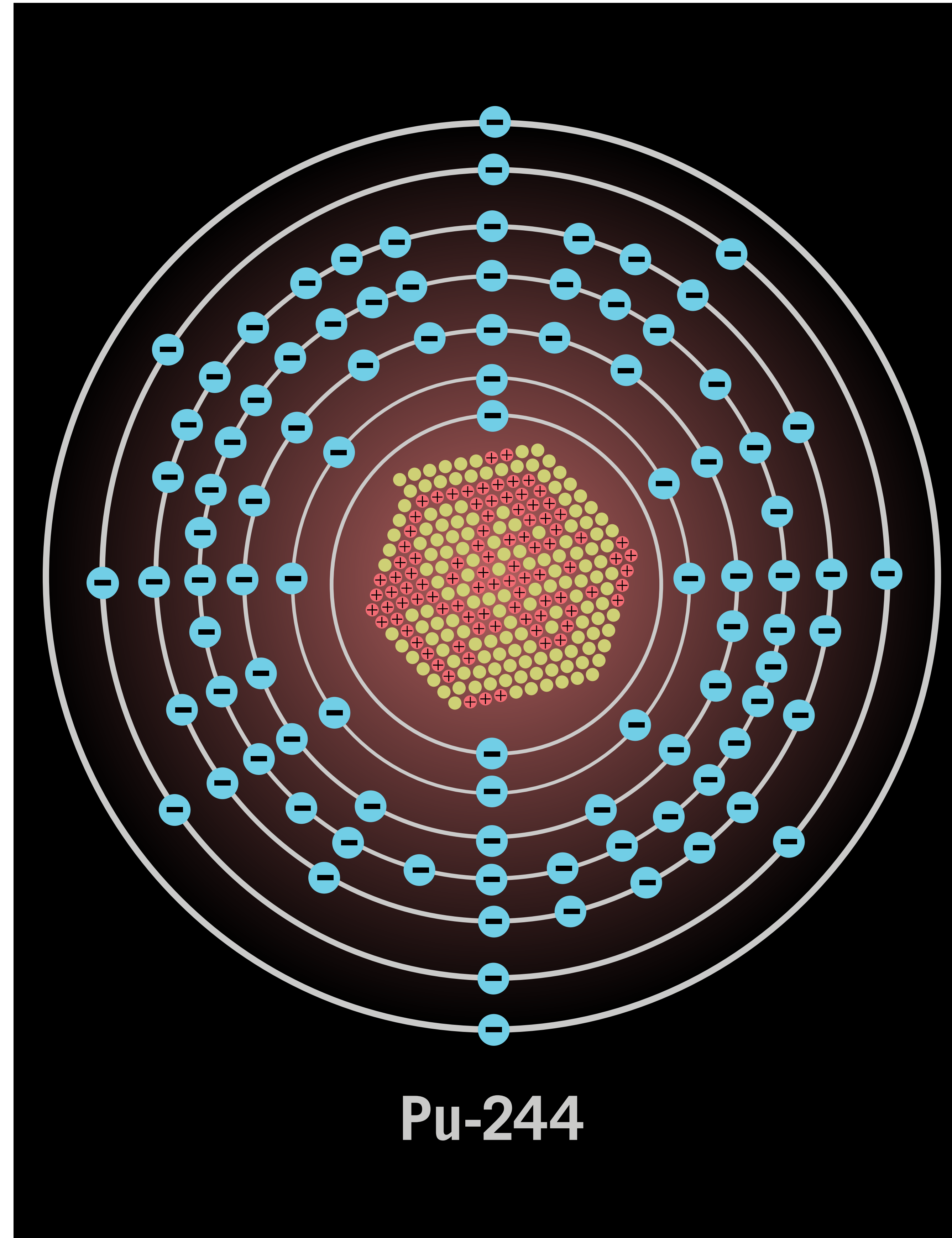
The MK-18 program is a prime example of the essential environmental and legacy management work performed at SRNL.

MK-18 refers to physical components once used in production reactors. "Back in the '70s, a small number of the MK-18 targets were sent to Oak Ridge National Lab for recovery of the Pu-244 and the rest stayed at SRS in storage," says Bill Bates, deputy associate laboratory director for the Environmental and Legacy Management Directorate at SRNL. "The focus now is the preservation of the remaining Pu-244 in the remaining targets for eventual recovery and purification."

The U.S. inventory is down to the last one or two grams of separated Pu-244. The country needs more of it.

"We're performing a beneficial reuse mission -- to recover material from something that otherwise would've simply gone into the waste stream," says Bates.

The team plans to recover about 20 grams of Pu-244 from the remaining MK-18 target assemblies. If not recovered, the material would be dissolved and would go into waste, effectively lost



graphic: Susanna King, SRNL

A cask for carrying MK-18 targets. photo: Savannah River Site Photography

forever as a usable certified reference material.

Entering a new phase

In the next few months, the MK-18 program team will start moving process equipment into SRNL's shielded cells. It is a readiness phase to ensure the material can be properly removed from storage, shipped to the lab, and moved into the shielded cells in accordance with SRNL's high safety standards. "We won't have our actual 'hot start' with a real MK-18 assembly until May 2024," says Bates.

The team has completed cold testing in a separate SRNL facility, involving a full pilot mockup before the readiness phase. Mock assemblies were cut and dissolved, with the full process simulated using non-nuclear materials. The use of a full-scale pilot mockup is a best practice that has proven beneficial in preparing the hardware and allowing staff to gain familiarity with it prior to going into the shielded cells.

Three of 16 shielded cells at SRNL will be used do the actual "hot" operations. The first will be where the target assemblies are transitioned in and cut, the second will be where all the dissolution and separations will be performed, and the third cell will be where waste and final product materials are packaged for removal from the cells.

A secondary benefit of the MK-18 program is the recovery of curium to reduce waste disposal impacts. Additionally, the curium can be used at ORNL's High Flux Isotope Reactor to produce Californium-252, which is used as a source in numerous instruments that perform nuclear material measurements.

SRNL will do the front-end work of processing the MK-18 and recovering the plutonium (including the Pu-244) and the curium. ORNL, a close collaborator since the 2014 mission start, is envisioned to perform the isotopic separation and purification of the curium and will store the plutonium for future purification.

"This program is a great example of using SRNL competencies and capabilities -- our knowledge and experience with radiochemistry, chemical separations and packaging technologies -- to recover assets from legacy nuclear materials that can support a range of national needs, particularly in the national security arena" says Bates.

Nonproliferation Applied Science Center Energizes Cross-cutting Competencies to Enable Solutions

by Scott Shaw

NASC director Anthony Belian, Ph.D.
photo: Savannah River Site Photography

Since coming on board in January 2023, Anthony Belian, Ph.D., the director of the Savannah River National Laboratory's (SRNL) Nonproliferation Applied Science Center (NASC) has been working on refining and shaping its vision and mission. He is leading the NASC's efforts in advancing nonproliferation research and development to reduce security concerns, modernizing nonproliferation concepts to accelerate nuclear as a clean energy source and aligning emerging nonproliferation concepts with the growing reactor and fuel-cycle markets. In addition to these areas, his focus is to enable the NASC to be an "incubator of small projects" that crosscut national laboratory competencies and sponsor spaces.

"The goal is to grow small projects into large programs at SRNL," says Belian. "The NASC will take on projects touching on problems that are common or related to multiple customers, but maybe aren't high enough in priority for any single customer. In this way we hope to chip away at grand challenges within nuclear nonproliferation that have broader impacts than just nuclear nonproliferation." The research and development work would be done

> "The NASC will look for competencies across SRNL and across other labs, plants, sites and universities to tackle problems we see across sponsor spaces."
>
> Anthony Belian, NASC Director

within the existing technical arms of SRNL with the NASC interfacing with sponsors, securing funding, and overseeing projects. He goes on to say that an example of this would be what to do with aging spent nuclear fuel from power reactors.

Belian explains that the typical organization of national labs has expertise collected and concentrated into groups. These groups typically seek funding for projects from one or two sponsors within the Department of Energy. Over the years of operating in this model, labs tend to build up what he calls "silos of excellence." He goes on to say that this model is good for a sponsor with unique needs and a working group with unique skills that match, but this is rare. "The NASC will look for competencies across SRNL and across other labs, plants, sites and universities to tackle problems we see across sponsor spaces," says Belian. "It will take drawing on relationships built over the years through past engagements, projects, and assignments to make this kind of model work."

Belian and NASC Senior Fellow and Georgia Tech Joint Faculty Appointee Margaret E. Kosal, PhD, are working on some collaborative projects related to NASC mission objectives. "We want to leverage data analytics to help develop new tools that can assist policy makers in developing and implementing a wide range of nuclear policy areas," says Kosal. "Huge amounts of data are everywhere; we need better tools to make sense of it all, to meaningfully integrate different types of data, and provide timely, actionable input to help policymakers as they make decisions."

Additionally, the NASC is formulating ways to utilize a nuclear fuel processing line to develop and improve tools used in nuclear compliance activities. "The fuel processing project for one sponsor could be utilized to produce tools for a different sponsor," says Belian. "These tools range from sampling waste tank head space gasses for specific fission products, to providing a test bed for another national lab's radiation detection instruments, to researching ways to solidify liquid samples for easier transport while retaining the integrity of the liquid sample."

The scope of the NASC is broad. There is work being done to explore the nexus of climate change, nonproliferation, and clean energy. Clean energy is one important component of SRNL's overall mission and the NASC is exploring where it can make an impact. For example, the NASC could contribute to tritium science to the benefit of fusion energy, or the use of "traditional" nuclear power to produce green hydrogen.

Belian and Kosal will work closely together to further establish the NASC and build upon its mission objectives. Additionally, they will seek to further engage Battelle Savannah River Alliance university partners, other local and regional universities, and, in time, foreign nationals from international organizations and universities, which is increasingly critical in a globally connected world of strategic competition. Near term, the NASC is looking for a second senior fellow to join the team and is looking to build a talent pipeline through university partnerships for summer internships.

illustration: Blue Planet Studio - stock.adobe.com

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