SRNL

MATTER

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Robotic and Remote Systems

Matter

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Matter, a Savannah River National Laboratory publication, highlights capabilities and solutions in the Lab's Environmental Management, Nuclear Materials Management and National Security mission areas. This inaugural issue explores SRNL's rich history leveraging robotic and remote systems.

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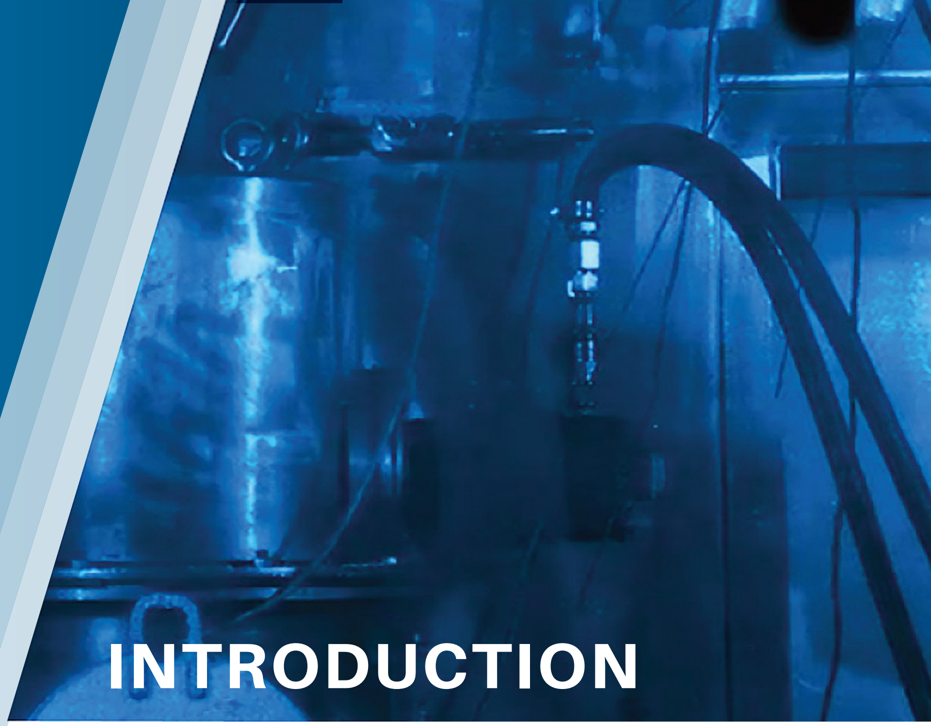
SRNL

Dr. Vahid Majidi
Executive Vice President and Director, SRNL

Christian Harris
SRNL Communications Director
Christian.Harris@srnl.doe.gov



INTRODUCTION

Since 1953, Savannah River National Laboratory (SRNL) has designed, fabricated, and deployed robotic and remote systems to perform diverse jobs in environments that are hazardous or inaccessible to workers, particularly nuclear environments.

Nuclear environments contain not only radiation and radiological contamination but also chemical and physical hazards, including unknown conditions.

Performing work in nuclear environments is challenging both because the environments present risks to workers and also because the structures containing those nuclear environments are designed to prevent hazardous materials from getting out, hindering access to the structures. Access is limited by small entry ports and internal spaces, long internal distances, and circuitous routing.

SRNL robotic and remote systems have been deployed at numerous sites, in a variety of environments, and for many different purposes. Uses include inspection, repair, automation, clean up, nuclear material recovery, contamination mapping, radioactive waste sampling, non-destructive examination, and video recording.

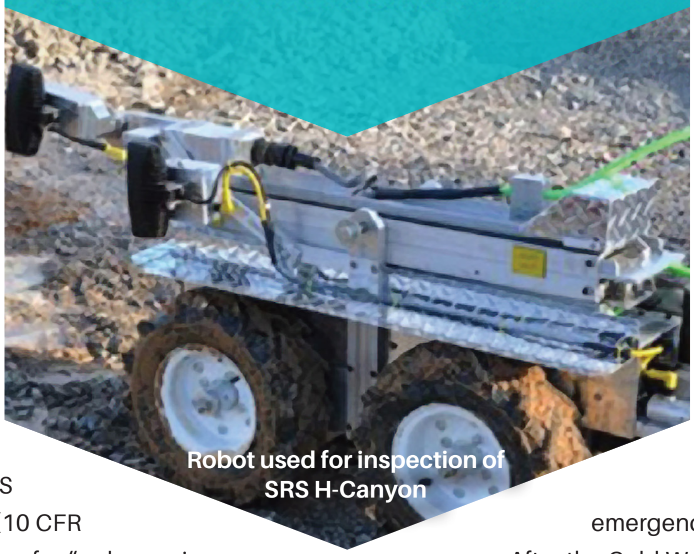
For more than 65 years, SRNL has been dedicated to safe and efficient nuclear operations and has developed expertise in robotic and remote systems.

This issue of *Matter* describes some of SRNL's past and present robotic and remote systems.

The building of the Savannah River Site (originally Savannah River Plant) during the early 1950s represented the growth of a new and important industry, the production of nuclear materials for nuclear weapons as deterrents to nuclear war. Part of the original plant project, the Savannah River National Laboratory (originally Savannah River Laboratory) was the research and development engine that drove the comprehensive nuclear enterprise at SRS, including reactor technology, chemical separations, tritium science, and environmental monitoring.

AS LOW AS IS REASONABLY ACHIEVABLE

The weaponization of nuclear fission had been achieved less than 10 years earlier, and the world had witnessed both its acute destructive power and the chronic consequences of radiation exposure. Dedicated to maintaining a "balance of power" to prevent nuclear war, and recognizing that radioactive sources and materials presented known and also probably unknown hazards, those designing, constructing, and operating the site practiced what came to be codified in the 1970s as ALARA. As defined in the US Code of Federal Regulations (10 CFR 10.1003), ALARA is the acronym for "as low as is reasonably achievable," meaning making every reasonable effort to maintain exposure to radiation as far below defined limits as practical.



Robot used for inspection of SRS H-Canyon

One way the early scientists and engineers of SRNL incorporated the principle of ALARA was through the development and deployment of robotic and remote systems to enable human workers to accomplish work efficiently with minimal risk of exposure. Equipment was designed to automate operational processes in hazardous environments both to reduce opportunities for worker exposures and to ensure the uniformity of the operations.

Additionally, robotics were tailored to address *ad hoc,* off-normal, and emergency conditions.

After the Cold War ended and the production of nuclear materials for weapons at SRS stopped in 1991, SRNL then applied the knowledge and experience gained in nuclear materials production to containing and disposing of nuclear materials and waste, cleaning up the environment, and decontaminating and decommissioning excess nuclear facilities at both SRS and other former nuclear weapons sites, all of which also carry risks of radiation exposure or criticality.

Today, SRNL continues to develop, adapt, and deploy robotic and remote systems to enable the safe and effective performance of its diverse current missions, both at SRS and elsewhere.

Historical SRNL robots demonstrated in the ALARA principle.

SRNL'S HISTORIC ROBIN ROBOT

Arriving in SRS in 1986, SRNL's historic Robin Robot was built to work in DOE nuclear facilities.

1 Robin was built by Odectics, Inc., with specifications from SRNL. **The hexapod was built circa 1983** upon the Odex 1 research platform, which is presently part of the Smithsonian Institution's permanent collection. The robot was borrowed by the National Aeronautics and Space Administration (NASA) in the early 1990s for evaluation.

2 Robin's **high price tag** saved her from use in actual radiation areas and dangerous missions where she could face contamination or damage. However, experimentation with Robin provided the basis for many robotic systems developed by SRNL for use at SRS.

Archival photo of SRNL's Robin the Robot

3 Members of the SRNL robotics team – known then as the Savannah River Lab Robotics group – worked with Robin over the years to develop techniques and procedures for use in **emergency response and maintenance** situations.

6 Today Robin Robot, whose name was derived from its resemblance to a "ROBotic INsect," is part of the **SRS Cold War Historic Preservation collection.**

5 Robin was **capable of lifting up to 1500 pounds, twice its own weight.**

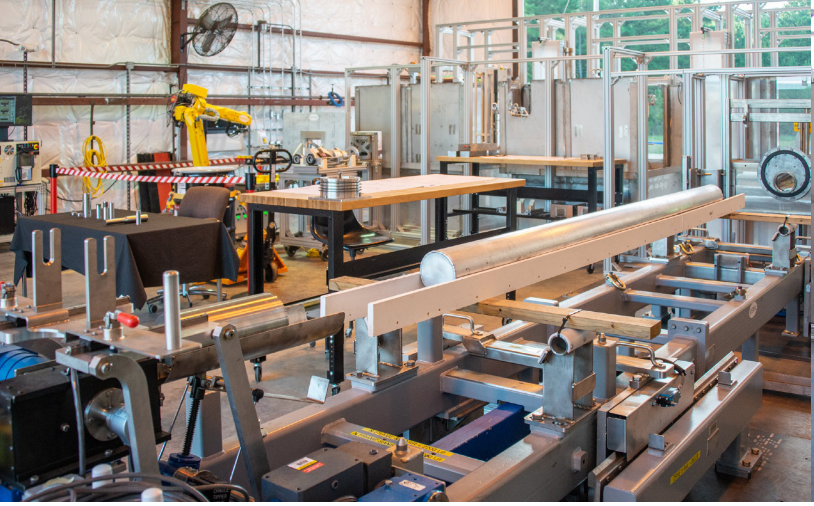
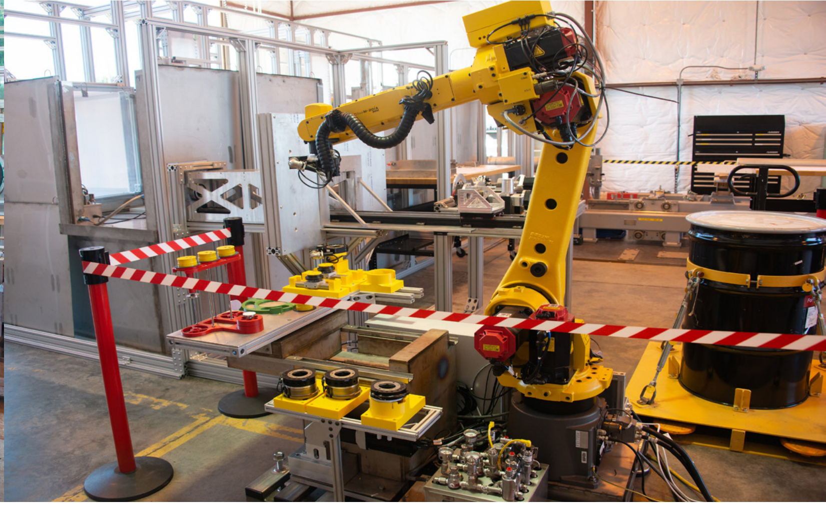
>> Its shape could be reconfigured to be tall and slender or short and squat, and it was able to walk in either configuration.

>> Its onboard computer was operated remotely, and the robot moved under its own power.

4 Robin featured a camera system that allowed remote users to view the robot's surroundings.

>> Each of its **six legs** had its own minicomputer providing a high degree of dexterity and the ability to step over and up unlevel surfaces and stairs, unlike wheeled robots.

>> The most significant feature added for the DOE mission was the **telescoping, jointed arm mounted on a rotating turret** enabling the robot to manipulate objects in the environment.

Top Left: Equipment for the plutonium-244 recovery campaign in the SRNL mock-up facility; **Top Right:** Commercial robotic arm typically used in a non-radiological environment adapted by SRNL to remotely remove the radioactive material from the shielded workspace and place it in a shielded container for transport.

RECOVERY OF NUCLEAR NATIONAL TREASURE

SRNL is conducting a campaign to recover the rare and valuable plutonium-244 that is contained only in cylinders stored at the Savannah River Site (SRS). SRNL has invented or adapted equipment and processes to safely transport and remotely unpackage, size-reduce, and dissolve the cylinders, and then to separate, package, and store the nuclear material.

Plutonium-244 is a highly valuable Certified Reference Material, or measurement standard, used in applications such as nuclear forensics and medical research.

The material is thought to exist in nature in almost undetectable quantities as a relic of the violent galactic activity that contributed to the formation of our solar system more than 4.6 billion years ago. It has a half-life of 81 million years.

The only plutonium-244 known to have originated through human activity, other than that dispersed from nuclear weapon explosions, was produced in the unique high flux reactors, now decommissioned, that operated at the Savannah River Site (SRS) during the Cold War.

Only 20 grams of this material exists in only one place: the 65 Mark-18A "targets," or nuclear material assemblies, stored at SRS. In 2011, the Department of Energy (DOE) asked SRNL to preserve the valuable, rare, and irreplaceable plutonium-244.

Recovering the materials from the Mark-18A targets is no easy task. They are mixed together in each assembly and must be chemically separated before they can be used.

H Canyon at SRS is the only operating, production-scale, radiologically-shielded chemical separations facility in the United States. However, the facility is designed to handle large quantities of nuclear materials, so recovering the relatively small quantity of Mark-18A target material there is impractical.

SRNL decided to process the targets in a special facility at SRNL that contains cells providing shielding and confinement necessary to work with radioactive materials. A specially trained operator stands safely outside each cell to perform tasks remotely inside the shielded workspace.

The laboratory has invented equipment to enable processing of the 14-foot-long Mark-18A target bundles inside the 6-by-6-foot workspaces of the SRNL shielded cells.

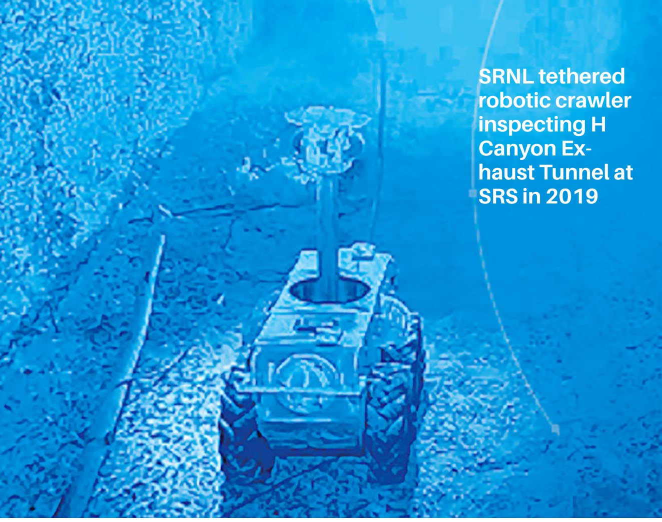
One is a shielded transfer cask that will safely package, transport, and deliver a target from wet storage in L-Basin at SRS into a shielded cell.

Another is a cell insert that will seal the open cell; align the target as it is inserted into the cell from the transport cask so a saw can slice pieces to be processed in the limited workspace of the cell; and provide shielding during operations in the cell.

SRNL also has adapted a commercial robot typically used in the automotive industry to remotely remove the radioactive material from the shielded workspace and place it in a shielded container for transport to Oak Ridge National Laboratory. SRNL has outfitted the robot with machine vision to enable remote operation and with several grippers for the various tasks it must perform.

In August 2019, SRNL hosted a ribbon-cutting for the Mark-18A mock-up facility in which equipment testing and operator training will be conducted to prepare for an expeditious start of plutonium-244 recovery operations.

The actual recovery operations are scheduled to begin in 2021. Recovery from all 65 targets will take approximately seven years.



SRNL tethered robotic crawler inspecting H Canyon Exhaust Tunnel at SRS in 2019

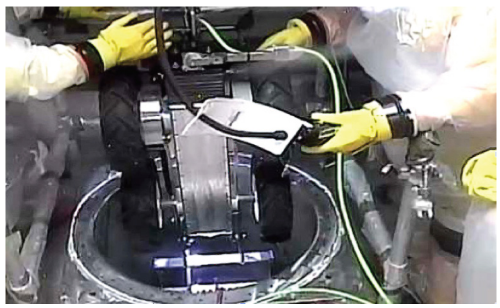
STRUCTURAL INTEGRITY INSPECTION OF SUBTERRANEAN EXHAUST TUNNEL

Incorporating lessons learned from previous years' inspections, the SRNL-designed tethered vehicles deployed in 2019 were able to more thoroughly examine the structural integrity of the over 1,000-foot-long H Canyon Exhaust Tunnel at SRS, parts of which are over 60 years old.

The H Canyon Exhaust Tunnel contains and directs the exhaust air flow from the canyon process areas to the sand filter system, which removes radionuclide particles prior to release of the air to the environment.

Initially, technology for inspecting the tunnel consisted of a camera attached to a pole manually inserted through ports into the tunnel interior. That method was not ideal in the harsh conditions of the tunnel, which include radiological and chemical hazards and physical impediments. Over the years, SRNL methods for inspecting the H Canyon Exhaust Tunnel have evolved from the very basic to the more sophisticated: the "crawler."

The first tunnel crawler was deployed in 2003. Since then, SRNL has developed and adapted crawlers for the particular conditions of the air tunnel, making improvements in the design of each new crawler based on experiences with previous tunnel crawlers.



Insertion of 2019 crawler into H Canyon exhaust tunnel through 30" diameter pipe

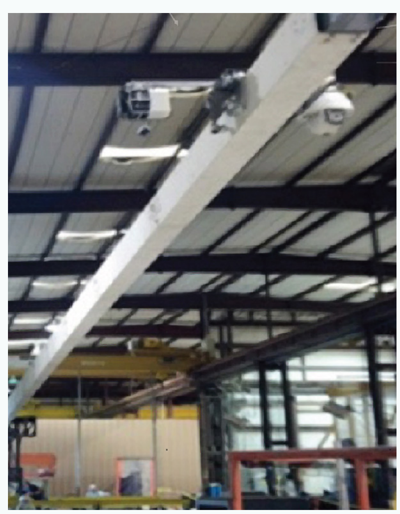
Earlier crawlers had limitations in performing full inspections, such as the inability to traverse or view some tunnel areas and poor camera image resolution.

SRNL developed the latest crawler in collaboration with multiple organizations in H Canyon. Conceptual design of the crawler began in March 2018, and the crawler was deployed in March 2019. The SRNL's H Canyon tunnel crawler design deployed in 2019 demonstrated increased terrain handling capability, greater range of camera motion to enable inspection of previously inaccessible areas, and increased resolution of the captured imagery.

Last year's inspection of the H Area Canyon Exhaust Tunnel was also the first time two crawlers were deployed simultaneously in the tunnel, allowing for a more through, end-to-end tunnel inspection.

Confirmation of Release-Event Scenario In **Underground Waste Repository**

In February 2014, an incident in the Waste Isolation Pilot Plant (WIPP) underground repository near Carlsbad, New Mexico, resulted in the release of radioactive material into the environment. SRNL was asked to design, build, and deploy a remote system to investigate the cause and source for the radiological release. In January 2015, SRNL deployed an elongated boom carrying sophisticated dome and drop-down video cameras that used a laser locator to pinpoint the exact location and long-range wireless technologies to transmit signals and images. "Project REACH" safely captured video supporting the characterization of the event scene.



Camera boom designed by SRNL (pictured in laboratory, left, and in underground room containing breached drum at WIPP, above) investigated the cause of WIPP radioactive release.

Remote Aerial Surveillance and Remediation of Entombed Reactor Buildings

Top Left: Unmanned aerial vehicle view of SRNL operators from above an entombed reactor building at SRS; **Top Right:** Potentially intrusive vegetative growth on entombed nuclear reactor building recorded by unmanned aerial vehicle

In 2018, SRNL began deploying a more efficient and less expensive method to locate and eliminate potentially damaging vegetative growth on the entombed nuclear production reactor buildings at SRS: unmanned aerial vehicles (UAVs).

The successful entombments completed in 2011 of the P and R nuclear production reactor facilities at SRS were the first in the DOE Complex and the largest nuclear facility in situ decommissioning (ISD) achievements in the world. ISD uses the existing hardened structure as the disposal site, permanently entombing and stabilizing residual contamination and debris in the subsurface areas with specialized grout while leaving sound above-ground structures intact. The SRS ISD undertakings were complex, including performing environmental assessments, modeling structural stability, developing multiple specialized grouts, installing remote sensors, and providing clear technical bases to assure stakeholders of the long-term safety of the ISDed structures. In addition, a long-term maintenance plan ensures the integrity of the entombed structures over time. Initially, a helicopter crew and site photographer were used to determine the amount of growth and then spray the plants.

In February 2018, at the request of the SRS Management & Operating Contractor, Savannah River Nuclear Solutions, SRNL remotely captured high-resolution, close-up video of the roof tops of the entombed P Reactor building using a commercial UAV, providing a more thorough inspection than was possible by the helicopter crew, at half the cost. SRNL was asked also to perform UAV surveillance of the entombed R Reactor. SRNL then partnered with Virginia Polytechnic Institute and State University (Virginia Tech) to build a special hexacopter equipped with a targeted herbicide spray apparatus to treat unwanted vegetation on the rooftops of the reactors.

The SRS UAS team, which included SRNL, SRNS Area Completion Projects, and DOE-Savannah River Operations Office personnel, received the 2019 DOE Sustainability Award for the innovative use of drones for post-closure waste site maintenance and surveillance.

Commercial drone modified by SRNL for aerial surveillance and remediation of entombed reactor buildings

Enabling Safe and Efficient D&D **Of Nuclear Facilities**

Deactivation and decommissioning (D&D) of DOE's legacy facilities and equipment across the country is a challenging undertaking.

For example, how to determine the exact location and intensity of radioactive contamination safely, efficiently, and effectively is a tremendous challenge. In a real sense, workers are blind to the hazards they face. Such determinations have historically been performed with portable count-rate instruments operated by personnel wearing protective gear, which can consume many man-hours and expose personnel to radiation or contamination.

In addition, many legacy facilities predate Computer Assisted Design (CAD) software, so there can be thousands of drawings defining a facility, and the personnel who designed, built, and operated the facility decades previously often are unavailable to share their knowledge with the current workforce.

SRNL remote radiation mapping and virtual reality modeling technologies are addressing those challenges. >

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Remote Radiation Mapping

The patented GrayQb™ (pronounced "Gray Cube") Single Faced Version 2 (SF2) is a non-destructive examination device developed by SRNL to remotely generate radiation contour maps showing source locations and relative radiation levels present in the area under examination.

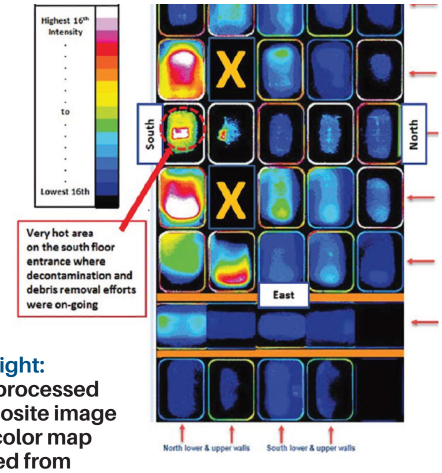
One deployment of SRNL's GrayQb™ was in the Plutonium Reclamation Facility (PRF) at the Hanford site in September 2015. In partnership with CH2M Plateau Remediation Company, SRNL deployed the GrayQb™ SF2 to locate radiological "hot spots" in the PRF canyon to support the facility D&D effort.

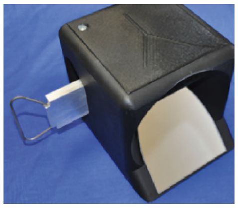
The PRF operated for 40 years starting in 1949 to turn plutonium that arrived in a liquid solution at the plant into hockey-puck-sized buttons or into a powder for shipment to the nation's nuclear weapons production plants.

The work left much of the facility highly contaminated with plutonium, other radioactive material, and hazardous chemicals.

By 2015, the 52 long, skinny "pencil" process tanks that had hung along the central canyon had been removed, and decontamination/debris removal operations were ongoing. SRNL completed ten GrayQb™ deployments, with each deployment consisting of a cluster of four GrayQb™ devices mounted on a crane platform fixture. The GrayQb™ deployments mapped radiation on over 80% of the canyon surfaces, enabling planning for efficient contamination removal.

The D&D project was completed in December 2017 with the demolition of the PRF structures.





Top Right: Post-processed composite image with color map applied from GrayQb™ examination of Hanford Plutonium Reclamation Facility canyon; Bottom Right: SRNL's GrayQb™ Single Faced Version 2 device

Above: Laboratory demonstration of SRNL Virtual Reality training program designed to improve workers' abilities to safely and efficiently disassemble the massive converters and associated process components in the Portsmouth Gaseous Diffusion Plant; Below 3D visualization to determine optimal locations for deployment of GrayQbTM device clusters in Hanford Plutonium Reclamation Facility canyon

Virtual Reality Modeling

SRNL has perfected several ways to create virtual reality (VR) representations of DOE hazardous facilities and equipment to aid in their safe and efficient D&D. VR is a technique that allows people to view a computer, or virtual, representation of the real world. Factors such as the age of the facility, availability of data sources, access around equipment, and intended end use of the VR model all factor into the decision as to how best to create the VR environment.

For the remote radiation mapping of the Hanford PRF canyon, the SRNL 3D Visualization System was employed to assist in determining the minimum number of deployments required to examine all surfaces given the field of view (FOV) of the GrayQb™ device. The PRF canyon drawings and the GrayQb™ device design files were imported into the 3D system, and the GrayQb™ device FOV was projected and moved about on the virtual canyon surfaces to determine optimum placements for complete coverage.

In 2017, the SRNL 3D Visualization System was employed to verify decommissioning plans and to train Portsmouth personnel to safely perform pending decommissioning activities in the X-333 Process Building at the Gaseous Diffusion Plant in Piketon, Ohio.

X-333 served as the entry point for feed material into the Portsmouth uranium enrichment process; to handle the largest capacities, X-333 therefore housed the largest equipment. 640 pieces of gas processing equipment weighing about 33 tons apiece must be cut into segments to allow their steel shells to be safely disposed of. In addition to hazards associated with their large size and weight, they are also internally contaminated with radioactive material.

The complexity of the piping and other equipment in conjunction with the hazards of accessing some areas in X-333 made laser scanning difficult. Construction completed in 1955, so building information was contained in hand-drawn blueprints. SRNL determined that the most viable option for reliable VR representation of X-333 was to recreate the 2D drawings of the facility in 3D.

Currently, workers at the Portsmouth site are using the modeling and virtual reality training to simulate the work they will be performing in the Material Sizing Area (MSA) recently established in X-333. A dedicated Training and Demonstration Area has been established to accomplish worker qualification and procedure development in anticipation of the MSA mission.