FINAL TECHNICAL REPORT
September 29, 2020 to February 28, 2026

Project 5: Long-Term Stewardship of Environmental Remedies: Contaminated Soils and Water and STEM Workforce Development

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Principal Investigator:

Leonel E. Lagos, Ph.D., PMP®
Applied Research Center
Florida International University
10555 West Flagler Street, EC2100
Miami, FL 33174

Florida International University Research Team:

Ravi Gudavalli, Ph.D. (Co-PI, Project Manager, Sr. Research Scientist)
Pieter Hazenberg, Ph.D. (Sr. Research Scientist)
Anthony Abrahao, M.S. (Research Scientist)
Angelique Lawrence, M.S., GISP® (Research Specialist II)
DOE Fellows

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FIU | Applied Research Center
Florida International University

Addendum:

This document represents one (1) of five (5) reports that comprise the Final Technical Reports for the reporting period September 29, 2020 to February 28, 2026, prepared by Florida International University's Applied Research Center (FIU ARC) for the U.S. Department of Energy's Offices of Environmental Management (DOE-EM) and Legacy Management (DOE-LM) under Cooperative Agreement No. DE-EM0005213. It includes a summary of research accomplishments over the FIU Year 1 to FIU Year 4 (September 29, 2020 to September 28, 2024) reporting period and a detailed account of FIU's research activity in FIU Year 5 (September 29, 2024 to February 28, 2026). The period of performance for FIU Year 5 was extended to February 28, 2026 under no cost extensions.

The complete set of Final Technical Reports prepared by FIU ARC for the aforementioned contractual reporting period includes the following documents:

*Project 1: Chemical Process Alternatives for Radioactive Waste
Document number: FIU-ARC-2024-800012997-04b-005

*Project 2: Environmental Remediation Science & Technology
Document number: FIU-ARC-2024-800013918-04b-003

*Project 3: Waste and D&D Engineering & Technology Development
Document number: FIU-ARC-2024-800013919-04b-006

*Project 4: DOE-FIU Science & Technology Workforce Development Initiative
Document number: FIU-ARC-2024-800013920-04b-013

**Project 5: Long-Term Stewardship of Environmental Remedies: Contaminated Soils and Water and STEM Workforce Development
Document number: FIU-ARC-2024-800013922-04b-003

* Project Funded by DOE's Office of Environmental Management
**Project Funded by DOE's Office of Legacy Management

Each document will be submitted to OSTI separately under the respective project title and document number as shown above. In addition, the documents will be available at the DOE Research website for the Cooperative Agreement between the U.S. Department of Energy Office of Environmental Management and the Applied Research Center at Florida International University: https://doeresearch.fiu.edu

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EXECUTIVE SUMMARY

In 1995, the Applied Research Center (ARC) at Florida International University (FIU) and the Department of Energy's Office of Environmental Management (DOE-EM) created a unique partnership to support EM's mission of accelerated risk reduction and cleanup of the environmental contamination legacy of the nation's nuclear weapons program through collaborative research, technology development, testing and evaluation at DOE sites in the areas of radioactive waste processing, facility decontamination and decommissioning, soil & groundwater remediation and modeling, and information technology (IT) development for environmental management. This was coupled with hands-on training of FIU STEM students on relevant technical skillsets to prepare and potentially secure the next generation of skilled scientists and engineers to supplement EM's aging workforce.

In 2019, FIU expanded the DOE-FIU Cooperative Agreement to initiate a pilot program under Project 5, funded by the Department of Energy's Office of Legacy Management (DOE-LM), that would be modeled after the existing DOE Fellows program under Project 4, but tailored to LM's unique requirements of environmental stewardship, such as operation, routine inspection and maintenance of remedial action systems and records related activities. LM was established by DOE in December of 2003 to manage its responsibilities associated with the legacy of the Cold War. DOE has taken major steps in satisfying environmental cleanup and LM ensures post-closure responsibilities are met for the protection of human health and the environment. LM coordinates closely with other Government organizations, including those within DOE, to ensure post-closure obligations are maintained when mission-related sites are closed and transferred to LM for long-term management. LM conducts post-closure site operations at approximately 98 sites in the United States and the territory of Puerto Rico and anticipates increasing to 128 sites by 2030. LM sites are generally described by the regulatory program and the types of environmental residual contamination remaining at the sites after remediation.

As discussed, and agreed upon by DOE EM and LM, FIU's infrastructure and expertise developed under the Cooperative Agreement were leveraged to initiate the pilot program for LM. The program involves research led by FIU relevant to LM's needs that support LM's main goals and mission and simultaneously incorporates a workforce development component which provides interested STEM students at FIU with a unique opportunity to integrate their coursework, Department of Energy (DOE) fieldwork and innovative research at FIU into a well-structured program that would prepare them for potential employment with DOE. To date, eight (8) FIU STEM students have been inducted into the DOE LM Fellows Program and engaged in research topics determined after a needs assessment conducted by FIU and extensive discussion with DOE-LM headquarters personnel and LM site managers. These research efforts span autonomous sensing systems, ground-penetrating radar robotics, hydroxyapatite-based uranium remediation, climate resiliency for long-term stewardship, and advanced remote sensing technologies. Collectively, these studies are in direct alignment with goals of LM's Strategic Plan (2020-2025): Goal 1 – protect human health and the environment and Goal 4 - sustainably manage and optimize the use of land and assets and address severe weather events.

RESEARCH HIGHLIGHTS

The following are key outcomes and deliverables that were successfully produced over the contractual period of performance:

Technologies Developed/Implemented:

- A remotely controlled robotic platform operational over rugged terrain, e.g., on top of DOE-LM disposal cells, equipped with mounted GPR, LiDAR and GPS to enable georeferenced mapping of the surface and subsurface of a given disposal cell.
- A platform extension that can be mounted to a Clearpath Husky robotic platform, equipped with a GPR, LiDAR and GPS for surface and subsurface mapping of unobstructed terrain.
- A Python code to create 3D images of the subsurface from GPR linescan data.

Peer-Reviewed Publications/Conference Proceedings:

- Eleven (11) conference proceedings presented at major national and international technical forums, including RemPlex 2025 Summit and multiple Waste Management symposia (2020 - 2025). A full list of publications and conference proceedings can be found in APPENDIX A: CONFERENCE PARTICIPATION, PUBLICATIONS, AWARDS, ACADEMIC MILESTONES, & COMMUNITY OUTREACH.

Dissertations/Theses Leading to STEM Graduate Degrees:

- Two (2) master's theses based on research conducted under Project 5 were successfully completed and defended by DOE Fellows participating in the DOE-FIU Science & Technology Workforce Development Program, ultimately resulting in the award of STEM graduate degrees in their respective fields. Details are found in APPENDIX A: CONFERENCE PARTICIPATION, PUBLICATIONS, AWARDS, ACADEMIC MILESTONES, & COMMUNITY OUTREACH.

Technology Demonstrations:

- Three (3) successful field demonstrations of the newly developed robotic platform/GPR that enabled subsurface scanning at two DOE-LM disposal cells (Rifle, Mexican Hat]), as well as within Basin 6 of the Nash Draw region west of the Waste Isolation Pilot Plant (WIPP).
- Drone-based mapping of the LM Rifle Disposal Site and subsequent Digital Elevation Model (DEM) creation using photogrammetry methods.

Data and Datasets:

- High-resolution DEM of the Rifle Disposal Site at sub-meter resolution.
- Subsurface GPR line scan data for sections of the Rifle and Mexican Hat disposal cells.
- Data derived from experimental characterization of hydroxyapatite, as well as uranium sorption/desorption studies under various environmental conditions.
- Hyperspectral camera observations of soil samples from multiple DOE-LM disposal cell environments based on lab-scale observations as part of a remote summer internship with RSI.

Networks or Collaborations Fostered:

- Training on the operation of multiple GPR sensors, with technical support provided by David Dryden of Sensors and Software Inc.
- Chris Jarchow and Ray Johnson of DOE-LM contractor, RSI EnTech, LLC, who mentored a remote summer internship of a DOE Fellow in the summer of 2025 and participated in regular

scientific discussions on the development of a robotic platform to enable subsurface scanning of DOE-LM disposal cells.

Other products, such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments, or equipment.

- Education/Curriculum integration, including guest lectures such as *Dr. Pieter Hazenberg* presenting autonomous sensing, photogrammetry, and GPR technologies in the *Development in Construction Technologies* course for FIU Construction Management students.
- Workforce development/hands-on training for STEM careers.
- Lab tours/demonstrations to other FIU students and staff and K-12 outreach.
- Acquired knowledge and skill sets used for other potential funding opportunities, such as DOE and EPA.

PROJECT 5 OVERVIEW

This combined research and workforce development program has been designed to assist LM in achieving its environmental clean-up goals and to provide interested STEM students with a unique opportunity to integrate coursework, Department of Energy (DOE) fieldwork and innovative research at FIU into a well-structured program that could lead to entry into job opportunities within DOE, and/or employment with DOE contractors. The table below outlines the tasks executed over the course of this five-year reporting period (2020-2025).

Task No	Task Name
Task 1 (FIU Years 1 - 5): Use of Apatite for Uranium (U) Sequestration at Old Rifle Site	
Subtask 1.1	Formation Kinetics of Apatite
Subtask 1.2	Incorporation and Co-Precipitation of Uranium
Subtask 1.3	Sorption of Uranium onto Apatite
Subtask 1.4	Desorption Experiments
Task 2 (FIU Year 1): Remote Sensing Technologies for Long-term Surveillance of DOE-LM Sites	
Subtask 2.1	Compile LM Sites' Conditions
Subtask 2.2	Investigate LM Needs for Remote Sensing Data Collection
Subtask 2.3	Evaluate Commercially Available Robotic Systems and State-of-the-Art Sensory
Subtask 2.4	Hands-on Training
Task 2 (FIU Year 2): Climate Resiliency Studies for Long-Term Surveillance of DOE-LM Sites	
Subtask 2.1	Evaluate Commercially Available Geophysical Systems and Sensory State-of-the-Art
Subtask 2.2	Investigate Weather Trends in Disposal Cell Sites
Subtask 2.3	Hands-on Training
Task 2 (FIU Year 3): Climate Resiliency Studies for Long-Term Surveillance of DOE-LM Sites	
Subtask 2.1	GPR Sensor Procurement and Evaluation
Subtask 2.2	Autonomous Ground Platform Development and GPR Sensor Integration
Subtask 2.3	In-house Deployment
Subtask 2.4	Summer Deployments
Subtask 2.5	GPR Image Reconstruction
Task 2 (FIU Years 4 - 5): Climate Resiliency Studies for Long-Term Surveillance of DOE-LM Sites	
Subtask 2.1	Robot Upgrade
Subtask 2.2	Data Analysis

Task No	Task Name
Subtask 2.3	Field Deployment
Task 3 (FIU Years 1 - 5): STEM Workforce Development - LM Fellows Selection	
Subtask 3.1	Recruitment Efforts
Subtask 3.2	DOE-LM Research Identification and Assignments
Subtask 3.3	DOE-LM Fellows Poster Exhibition & Competition
Subtask 3.4	DOE-LM Fellows Induction Ceremony
Subtask 3.5	Summer Internship Program (SIP)
Subtask 3.6	Conference Participation and Presentations
Subtask 3.7	DOE EM and LM Fellows Lecture Series Forum

TASK 1: USE OF APATITE FOR URANIUM (U) SEQUESTRATION AT OLD RIFLE SITE

DOE-LM Strategic Plan 2020 - 2025: *Organizational Core Value - Environmental Stewardship and Goal 1 - Protecting Human Health and the Environment.*
DOE-LM Sites and End-users: *Rifle Site, Old Rifle Site, Mexican Hat, Grand Junction: Jalena Devault (DOE-LM), Christopher Jarchow (RSI), Ray Johnson (RSI).*

Introduction

The Office of Legacy Management (LM) is charged with managing former Department of Energy (DOE) defense sites that have undergone cleanup but still have continuing post-closure management requirements. Although the goal of LM is to transition facilities/lands of these sites to beneficial use, site-specific factors often limit release for unrestricted use. These factors include groundwater that is still being treated, or which could not be effectively treated to regulatory standards, contaminants in the unsaturated zone that are inaccessible, and the presence of on-site disposal cells and landfills.

Many LM sites that were former uranium mill processing facilities that operated throughout the late 1950's, have undergone surface remediation of the uranium mill tailings after which the sites were capped. It was predicted that the uranium remaining in the subsurface under the former processing sites would be flushed by natural groundwater flow; however, uranium contamination still exists in the shallow groundwater and aquifer sediments beneath the sites and have persisted much longer than predicted at elevated concentrations ranging from 200-300 ppb, which exceeds the Uranium Mill Tailings Radiation Control Act (UMTRCA) limit of 44 ppb. According to the 2022 and 2023 Verification Monitoring Report for the Old and New Rifle, Colorado, Processing sites (U.S. Department of Energy, 2022) the U concentration at the site ranges from 0.1-0.2 mg/L at Old Rifle.

Several studies have proven apatite to be effective at attenuating uranium in the subsurface. DOE-LM and the Office of Science have thus implemented an in-situ hydroxyapatite (HA) permeable reactive barrier (PRB) to evaluate the effectiveness of this technology at the Old Rifle site in Colorado, a former uranium mill processing facility currently being reused to house an operations and maintenance facility and conduct biogeochemical research on constituents of concern. While this process has proven to be effective at maintaining uranium groundwater concentrations below UMTRCA limits at the Rifle site, a better understanding of the mechanism of uranium sequestration in the presence of HA is required.

Objectives

The research being conducted under Task 1 aims to investigate the use of apatite injection for sequestering uranium (U) in groundwater. Specifically, FIU's goal is to study the mechanism of U removal/sequestration from groundwater by apatite and determine if the process is reversible. The influence of environmental factors such as pH, temperature, and oxidation-reduction potential (ORP), on the sequestration process will also be investigated. Experimental results will improve DOE-LM's understanding of the mechanism, stability, and longevity of uranium removal from groundwater when using hydroxyapatite injection as a treatment method.

Impact/Benefits

- Establishes an efficient and cost-effective method of uranium sequestration that address the issue of Persistent Secondary Uranium Sources at Old Rifle Site, outlined in the Technical Report "Literature Review of Documented Persistent Secondary Uranium Sources at DOE LM Sites" (ESL-RPT-2019-04).
- Provides DOE-LM with a long-term solution for reducing the health risks associated with elevated levels of uranium present in groundwater at DOE-LM sites due to a legacy of environmental contamination derived from defense-related uranium mining and milling.
- Aligns with LM's core value of environmental stewardship and Goal 1 of DOE-LM's Strategic Plan (2020-2025): to protect human health and the environment by providing experimental data to support long-term surveillance, maintenance and proactive management of uranium contamination and ensure the longevity and effectiveness of environmental remedies implemented at DOE legacy sites.

SUBTASK 1.1: FORMATION KINETICS OF APATITE

NOTE: *This subtask was completed in FIU Year 2.*

Understanding the formation kinetics of apatite is essential for determining how hydroxyapatite (HAp) changes under varying environmental conditions. HAp, the most stable form of calcium and phosphate, forms through a sequence of solution reactions that ultimately produce a crystalline mineral phase capable of interacting with contaminants in groundwater systems. Formation kinetics research provides insight into the transitions that occur as calcium-citrate and phosphate react to produce apatite. Parameters such as pH, ionic strength, and precursor concentrations can significantly alter the pace and pathway of mineral formation. By examining how quickly apatite forms, how its structure evolves over time, and which factors influence the rate and consistency of the HAp, the information gained can work to establish a better understanding of how the HAp may behave if injected at sites. Evaluating these effects allows for identification of the conditions that promote stable, reproducible apatite synthesis and ensures that the resulting mineral exhibits the properties needed for subsequent applications.

Major Technical Accomplishments (FIU Years 1 – 2)

- Characterized soil samples obtained from the Old-Rifle site via XRD, SEM-EDS and BET analyzer, accomplishing Milestone 2020-P5-M5. A report on the soil characterization of the Old-Rifle site sediment was submitted.
- Completed characterization of hydroxyapatite samples via energy-dispersive X-ray spectroscopy (EDS).
- Conducted scanning electron microscopy (SEM), X-Ray Diffraction (XRD) analysis of hydroxyapatite precipitates and noticed that the morphology for Scenario C was different from other scenarios.
- Completed batch experiments to study the kinetics of formation of apatite in the presence and absence of Old Rifle sediment.
- Calculated atomic ratios of synthesized hydroxyapatite samples from EDS data and compared that with theoretical atomic ratios for confirmation, concluding Phase 1 of Task 1.

- Conducted scanning electron microscopy (SEM), X-Ray Diffraction (XRD) analysis of hydroxyapatite precipitates and noticed that the morphology for Scenario C is different from other scenarios.
- Performed XRD analysis on the precipitate to ensure that it was pure hydroxyapatite for subsequent use in the experiments.

Subtask 1.1: Overall Conclusion & Lessons Learned (FIU Years 1 – 2)

Hydroxyapatite Synthesis, Kinetics, and Characterization Studies

Based on the research, synthesis with a combination of phosphate salts resulted in formation of hydroxyapatite. At all stoichiometric ratios investigated, the characterization of the resulting precipitate indicated successful hydroxyapatite formation. The synthesis portion of this experiment is being concluded. From the current experiment, scenario 3 appears to precipitate the most solid and has the potential to be the optimal stoichiometric ratio.

Sediment Characterization

This study also investigated the chemical composition, structure, and surface area of the sediment samples obtained from four distinct locations at the Old Rifle Site, CO. Experimental data showed that soil from all four plots were comparable; however, Plot 3 samples consistently displayed anomalies during analysis. The analysis conducted via EDS and XRD revealed that the same elements were being identified in each method, confirming the presence of silicon, oxygen, aluminum, iron, potassium, calcium, magnesium, and sodium. Phosphorus was only found via EDS in trace quantities for Plots 3 and 4, while titanium was found in trace quantities for all locations, but neither was identified via XRD analysis possibly due to the small amount detected. SEM and N2-BET analysis confirmed the surface area and structure were similar for all samples, with Plot 3 contrasting the most. The deviation of Plot 3 from all other locations could be due to varying soil conditions. Overall, the soil samples have comparable characteristics. The data obtained will help fill the knowledge gaps on the mechanisms involved in the removal of U and the stability of the removal and assist DOE-LM in remediating uranium at the site where uranium is present.

SUBTASK 1.2: INCORPORATION AND CO-PRECIPITATION OF URANIUM

NOTE: *This subtask was completed in FIU Year 3.*

Incorporation and co-precipitation of uranium with hydroxyapatite is critical for evaluating how effectively HAp can immobilize U during its formation. As HAp develops from calcium-citrate and phosphate precursors, U present in the solution becomes part of the forming mineral, rendering it immobile. Studying how U becomes integrated into the solid phase can provide essential information into the process that contributes to long-term U remediation at the Old Rifle CO site. Evaluating how incorporation and co-precipitation respond to varying parameters helps identify the conditions that favor strong, stable U uptake and clarifies how reliably apatite can immobilize uranium during mineral formation.

Major Technical Accomplishments (FIU Years 2 – 3)

- Completed the uranium incorporation and co-precipitation studies (Phase 2) and submitted report as Deliverable 2021-P5-D4 on June 24, 2022.

- Completed SEM-EDS analysis of dry precipitate from the "incorporation and co-precipitation of uranium onto hydroxyapatite" experiment and calculated atomic ratios to validate the formation of hydroxyapatite.

Subtask 1.2: Overall Conclusion & Lessons Learned (FIU Years 2 – 3)

Phase two investigated the change in chemical composition and the structure of the various stoichiometric ratios for each scenario. Experimental data showed that hydroxyapatite was successfully synthesized for Scenarios A and D while Scenario C displayed anomalies throughout the analyses conducted, as it did in Phase 1 studies. This may explain why the uranium concentration did not decrease in Scenario C, unlike in Scenarios A and D, which formed hydroxyapatite without anomalies.

From ICP-OES analysis, it was found that hydroxyapatite reaction was initiated within the first week after synthesis. ICP-MS analysis revealed that uranium concentrations also decreased significantly within the first week, indicating that incorporation and co-precipitation could be a key mechanism involved in removing uranium from the groundwater via hydroxyapatite.

The data obtained through these experiments will help fill the knowledge gaps with respect to the mechanisms involved in the removal of U and the stability of the removal and assist DOE-LM in remediating uranium at the site where uranium is present.

SUBTASK 1.3: SORPTION OF URANIUM ONTO APATITE

NOTE: *This subtask was completed in FIU Year 4.*

This phase focused on evaluating the sorption of uranium onto hydroxyapatite under a range of environmental conditions to clarify the mechanisms governing uranium–HAp interactions. Uranium and hydroxyapatite were brought into contact, and changes in uranium concentration in the solution were tracked as the two phases interacted. The influences of pH, temperature, and redox conditions were examined to determine how each factor shapes both the extent and stability of sorption. Because these parameters strongly affect uranium's affinity for the HAp surface, understanding their impact is essential for identifying the conditions under which sorption is most effective.

Major Technical Accomplishments (FIU Years 3 – 4)

- The Submitted paper based on the research conducted under Task 1 to the Waste Management Symposia 2023 titled "Interaction of Hydroxyapatite and Uranium in Groundwater at the Old Rifle Site to Facilitate Site Remediation" was designated a "Superior Paper".
- Conducted experiments to study the sorption of uranium onto hydroxyapatite at varying environmental conditions such as pH, temperature, and oxidation-reduction potential (ORP), to assess their influence on the uranium-hydroxyapatite interaction.
- Completed step one of the Phase 3 experiments, which intends to imitate the application of hydroxyapatite technology once the hydroxyapatite has fully precipitated in the treatment zone and is interacting with the contaminated groundwater.
- Conducted the sorption of uranium onto hydroxyapatite experiment to find the optimum solid-to-liquid ratio for future studies and analyzed samples via ICP-MS. Sorption of uranium reached equilibrium in two (2) weeks.

- Initiated isotherm experiments to study the sorption capacity of uranium at pH 7, room temperature and oxic conditions.
- Conducted an extension of the isotherm experiment, formerly conducted with 1,000 ppb uranium (U) samples, with 2,000 and 5,000 ppb U samples to identify the maximum sorption capacity of hydroxyapatite. It was found that even with an increase in initial uranium concentration to 5 ppm, the sorption isotherm did not reach equilibrium, indicating the hydroxyapatite has an exceedingly high sorption capacity for uranium sequestration.

Subtask 1.3: Overall Conclusion & Lessons Learned (FIU Years 3 – 4)

The most significant impact on uranium removal was at pH 4 throughout all conditions studied, with far less removal seen in most cases. In oxic conditions, pH 7 maintained the highest level of removal. Temperature had a greater effect on uranium sorption in Scenario C, while Scenario A only observed distinct differences at pH 4. It is evident that anoxic conditions had a significantly negative effect on uranium removal in comparison to oxygen-rich environments.

When uranium concentrations were raised up to 1,000 ppb at Old Rifle site conditions (pH 7, T=22°C), hydroxyapatite had the capacity to remove 91-99% of uranium. This indicates that hydroxyapatite technology would effectively remediate uranium at sites with similar conditions. Further studies would be useful to determine the full extent of hydroxyapatite's sorption capacity.

Overall, these studies support the use of hydroxyapatite for uranium remediation in groundwater. Results found here could help guide users on which site conditions would result in more effective uranium removal. The data obtained will help fill the knowledge gaps on the mechanisms involved in the removal of U and the stability of the removal and assist DOE-LM in remediating uranium at the sites where uranium is present.

SUBTASK 1.4: DESORPTION EXPERIMENTS

This portion of the study examines how uranium-bearing hydroxyapatite responds when exposed to a range of environmental parameters that commonly fluctuate in subsurface systems. Factors such as pH, temperature, and redox conditions are varied to assess how they influence the release of uranium from the mineral. Lower pH values may enhance dissolution of the apatite surface and weaken uranium–mineral associations, whereas differences in temperature or oxygen availability can alter uranium speciation and influence its stability. By tracking uranium concentrations during these changes, the study identifies the conditions that promote release and those under which uranium remains effectively immobilized.

Major Technical Accomplishments (FIU Years 3 – 4)

- Completed experiments to study the effect of pH on uranium desorption from hydroxyapatite.
- Initiated two sets of experiments to study the effects of anoxic conditions and low temperature on desorption of uranium from hydroxyapatite
- Completed the deliverable 2023-P5-D3, Draft Progress Report on the Desorption of Uranium from Hydroxyapatite. The findings highlight the sensitivity of uranium sorption and desorption behaviors under varying pH conditions. The results of this study aid in understanding the ability of hydroxyapatite to retain uranium under varying environmental conditions, specifically when pH is altered to 4, 7, and 9.

Methodology

Batch experiments were conducted with 250 µg/L U and 0.02 g of HAp from either Scenario A (SA) or Scenario C (SC). The two scenarios (SA and SC) differed in their phosphate concentration, while calcium and citrate concentrations remained constant at 40 mM for calcium and 100 mM for citrate. SA contained a lower phosphate concentration of 45 mM, while SC had a higher concentration of 90 mM. Anoxic and temperature experiments were prepared by bringing 250 ppb U and 0.02 g of HAp, with slight alterations in their environment. The anoxic studies were divided into two phases.

In phase 1, both sorption and desorption were conducted in anoxic conditions. In phase 2, sorption was performed in an oxic environment and desorption in anoxic conditions. To create a low oxygen (anoxic/anerobic) environment, samples were placed inside a glove box. The glove box was vacuumed to remove moisture and oxygen, then purged with a gas mixture of 95% nitrogen and 5% hydrogen. This vacuum-purge cycle was repeated multiple times until the atmosphere had 2.0-2.5% hydrogen and low levels of oxygen. These anaerobic conditions were maintained throughout the experiment. Temperature study samples were placed in an environmental chamber set to 7°C. A thermometer was used throughout the study to ensure the chamber maintained the desired temperature.

Sorption

The initial step of U interactions with HAp under anoxic, oxic, and low temperatures, involved initiating the sorption process by introducing U to either SA or SC HAp. Sorption spanned a period of 7 days; during this time, the pH of the samples was monitored and adjusted to a neutral (7) pH with either 0.1 M HCl or NaOH. Following pH adjustments, the samples were placed on a platform shaker to allow for sufficient interaction between U and HAp over the course of 7 days. On the final day of sorption, samples were centrifuged at 2700 RPM for 30 minutes. The supernatant was subsequently extracted and collected for analysis.

Desorption

Samples were placed in their designated condition either in a glove box to imitate low oxygen environments, or in an environmental chamber at a constant 7°C. Desorption was performed following sorption and was commenced by introducing fresh deionized water to the U contacted HAp. The pH was adjusted to 4, 7, and 9 with either 0.1 M HCl or NaOH. After monitoring and adjusting pH as needed, the samples were placed onto a platform shaker. Experiments were conducted for a period of 3 weeks and aliquots were collected at regular intervals, at the end of 3-week period, samples were centrifuged, and the supernatant was extracted and analyzed.

Results

Sorption

As seen in Figure 5-1 to Figure 5-3, temperature and anoxic studies (Phase 1 and Phase 2) observed 95-100% U removal from the aqueous phase, demonstrating the capacity of HAp to sorb U at a pH of 7 regardless of temperature and presence of oxygen. The high U removal can be primarily attributed to the neutral pH (7), which promotes decreased solubility and mobility of U(VI) species under these conditions.

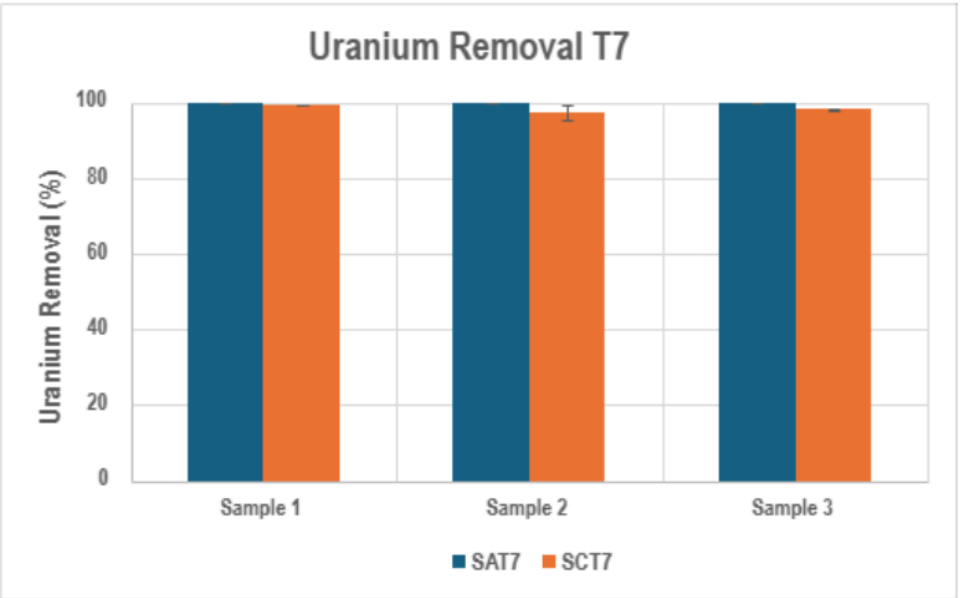

Figure 5-1. Uranium removal from the system by hydroxyapatite after a period of 7 days at pH 7.

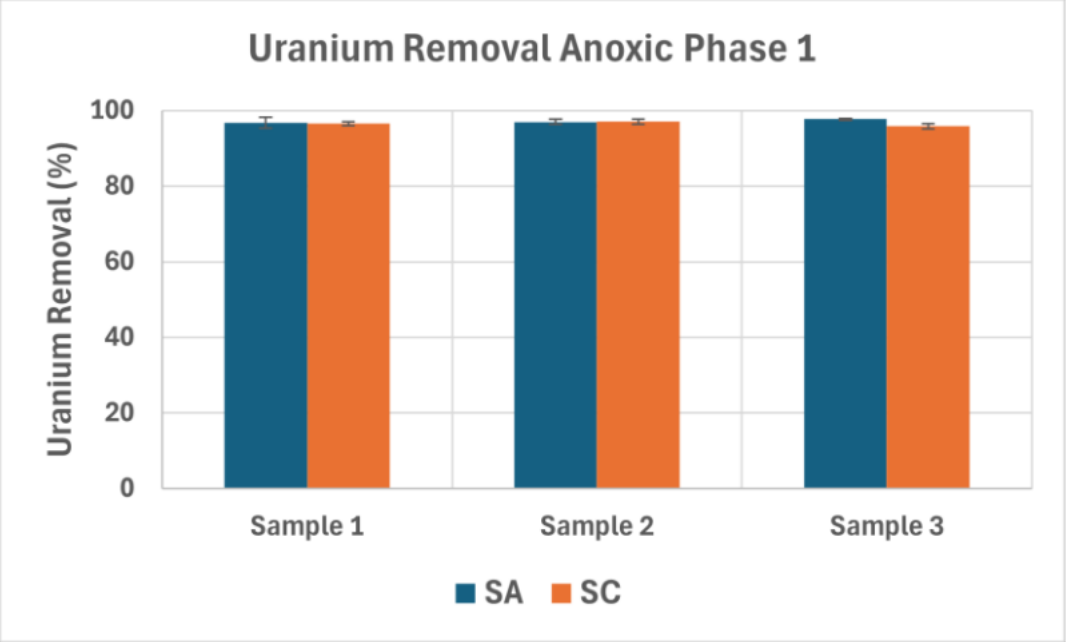

Figure 5-2. Uranium removal from the system by hydroxyapatite under anoxic conditions after a week at pH 7.

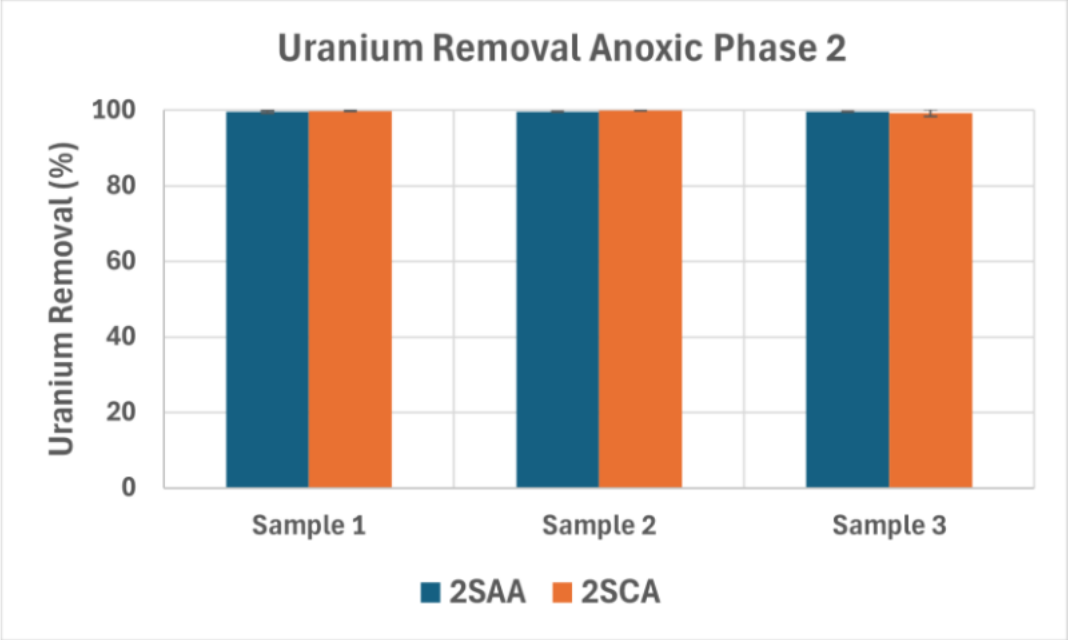

Figure 5-3. Uranium removal from the system by hydroxyapatite in oxic conditions at a pH of 7.

Desorption

A common trend observed throughout the desorption study regardless of parameter (temperature and redox conditions) is the elevated desorption of U at pH of 4. At low pH, hydroxyapatite begins to dissolve, releasing the U previously bound to it (Huang et al., 2025). On the other hand, samples at a neutral and basic pH had an opposite effect with little U being desorbed from HAp, due to the HAp being able to retain its structure.

Temperature

The effect of temperature and pH on aqueous uranium concentration was monitored over time. For SA samples at pH 4, the U concentration decreased between days 1-4, then stabilized beyond day 9. At pH 7, a decrease consistent with previous trends occurred during the first 4 days; however, by days 3-4, little to no U remained in the solution (Figure 5-4). This near-complete removal was also observed under slightly basic conditions (pH 9). Unlike at pH 4 and 7, there was very little to no U present in the system throughout the experiment for pH 9.

Overall, SA pH 4 began with about 40-50% U concentration in the solution and ended with about 60%. The elevated U release at pH 4 can be attributed to HAp dissolution under strongly acidic conditions. Notably, significant U desorption was still observed at 7°C, despite the reduced reaction kinetics expected at low temperatures. At cold conditions, the instability of HAp at pH 4 likely caused mineral breakdown, disrupting U-HAp bonds and mobilizing the U into the solution. At pH 7 and 9, little to no U desorption was observed. A factor that encouraged the low amounts of U desorption was the pH at which the samples were kept in. At these pH levels, the HAp can retain its crystalline structure and negative charge, in turn allowing the U to stay retained onto the HAp (Zhang, 1999).

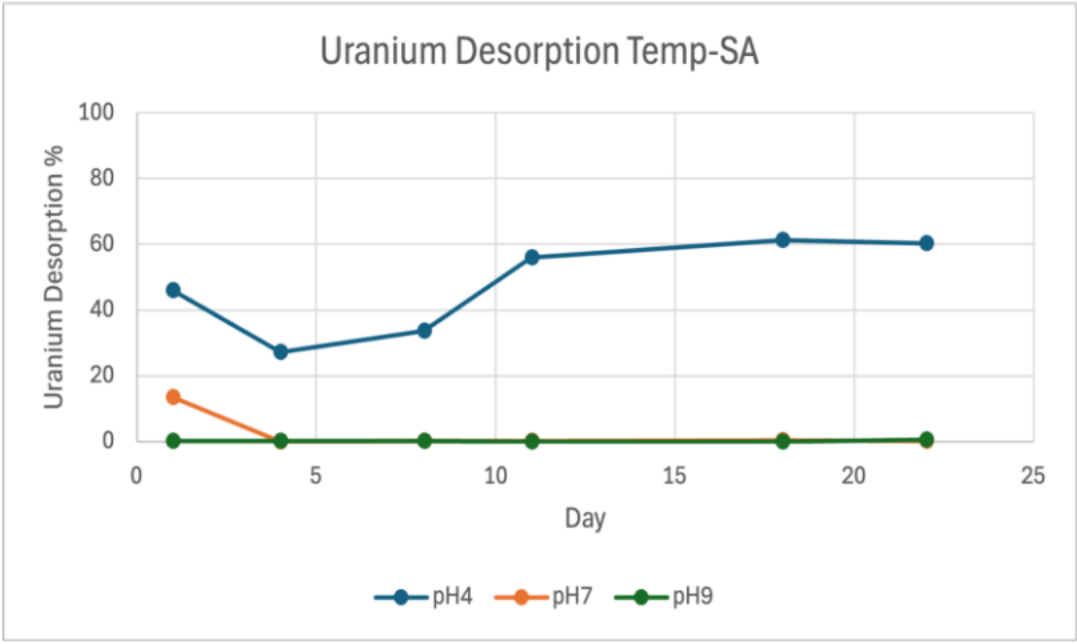

Figure 5-4.Uranium desorption of U off HAp at varying pH under 7C.

SC showed an overall trend akin to SA, with pH 4 exhibiting the highest U desorption compared to both pH 7 and 9. At pH 4 in SC, U desorption steadily increased over the first 7-9 days, reaching approximately 50-57%, before stabilizing on day 11 at around 45-50% for the remainder of the experiment (Figure 5-5). Both pH 7 and 9 began with little to no U desorption and remained unchained throughout the experiment.

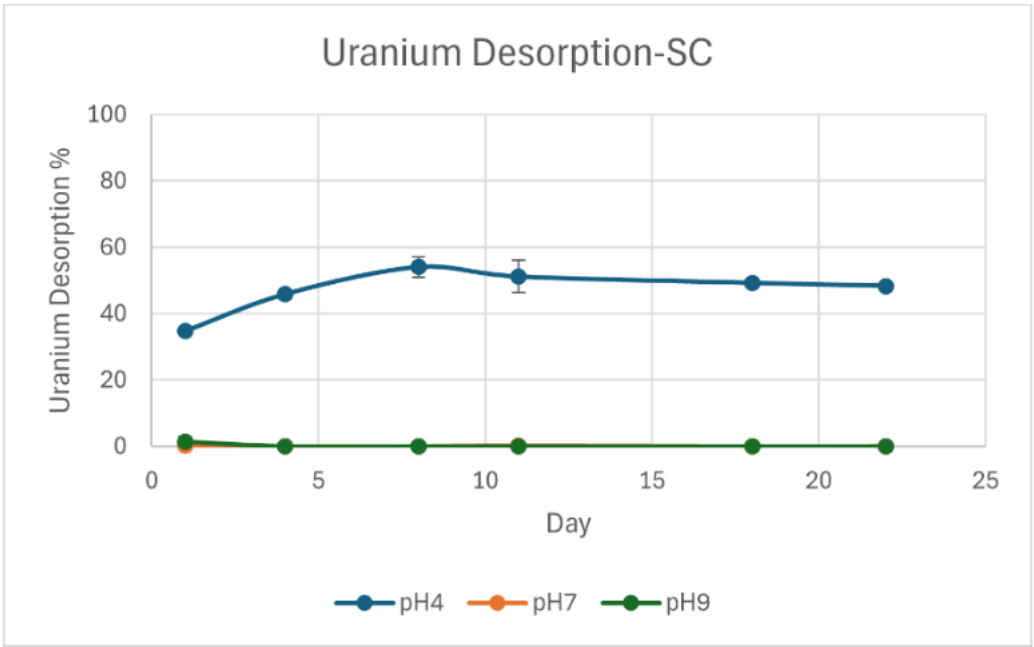

Figure 5-5. Uranium desorption of uranium off hydroxyapatite under low temperatures (7C).

Anoxic Phase 1

Phase 1 of anoxic studies focused on performing both sorption and desorption under anoxic conditions in a glove box. At pH 4, SA initially showed about 60% U desorption, but this steadily declined over the following days, reaching roughly 25–30% by day 10. During days 10-18, the U desorption increased. On day 19, the U concentration stabilized and ended with 60-65% U desorption (Figure 5-6). At pH 4, the dissolution of HAp likely promoted large amounts of U desorption.

At pH 7 and 9, both showed lower amounts of U desorption (Figure 5-6). The neutral samples started with little to no U desorption in the system but increased to 15-17% in the first 3-4 days. Following day 4, the U desorption decreased and remained relatively low for the remainder of the study and ended with around 5-10% U desorption in the system. Likewise, pH 9 followed a pattern consistent to that of the neutral samples with U desorption being approximately 0% and slightly increased to 25-30% by day 23. However, this point has been recognized as an outlier; overall, pH 9 ended with 0-5% U desorption. In anoxic conditions, U is reduced into its tetravalent form U(IV), which is less soluble and mobile, thereby decreasing the U desorption as seen throughout this study.

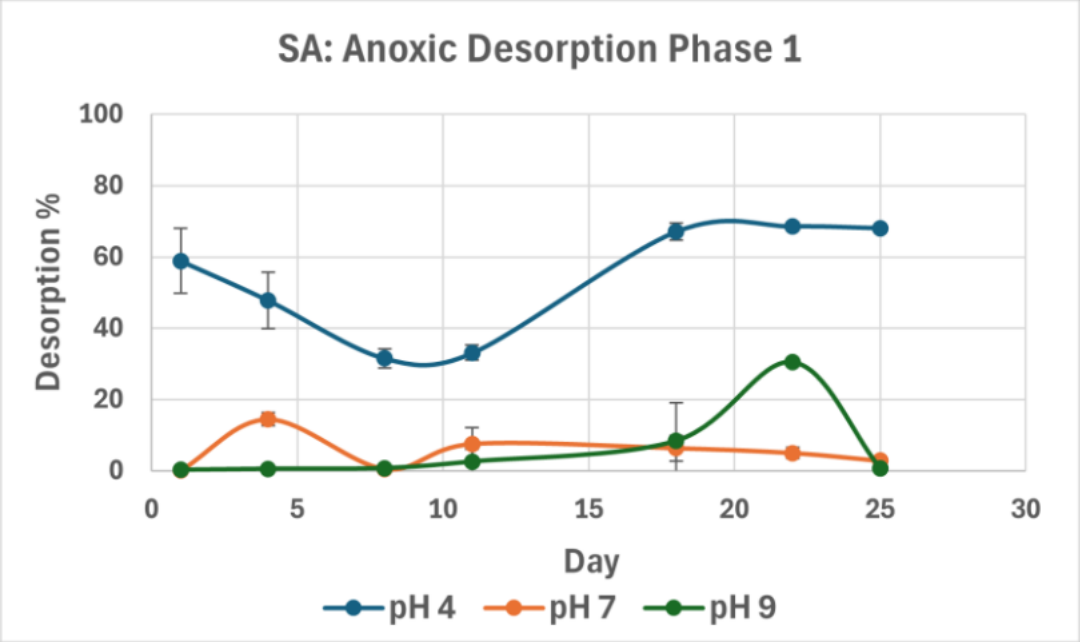

Figure 5-6. Scenario A Anoxic studies for phase 1 which focuses on U sorption and desorption under anoxic conditions.

SC samples exhibited similar behavior SA samples with pH 4 having the greatest amount of U desorption of ~60%, and with pH 7 and 9 leaching low amounts of U throughout the experiment (Figure 5-7). Both pH 7 and 9 began with little to no U present in the initial dates and slowly increased around day 21. Samples at neutral conditions ended with 0-15% U desorption, and basic samples ended with 0-10% U desorption.

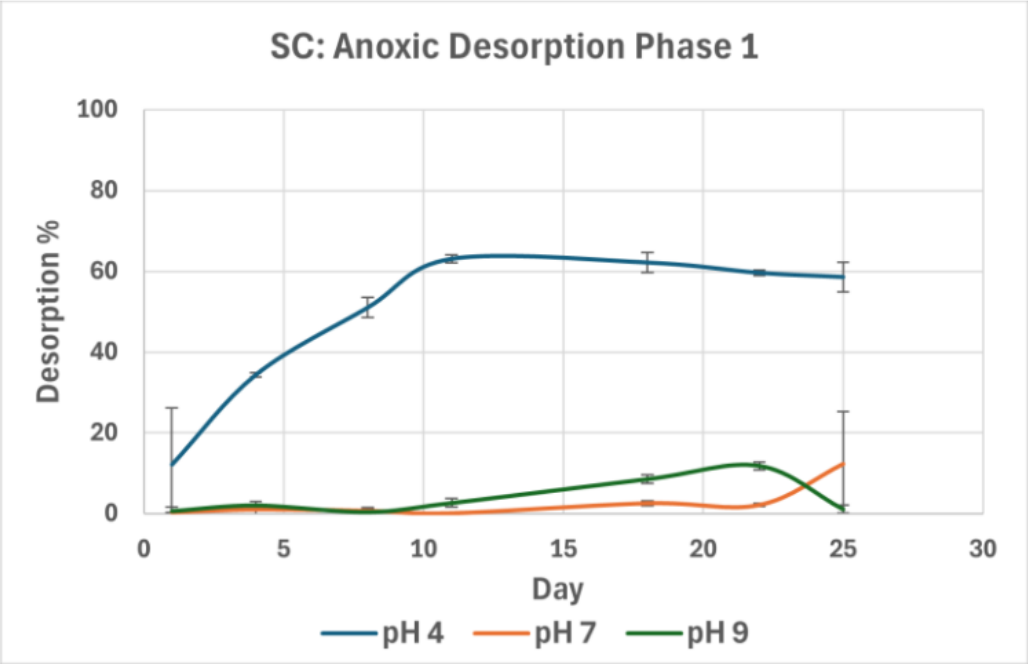

Figure 5-7.Scenario C anoxic studies for section, that works with batch experiments under both anoxic sorption and desorption.

Anoxic Phase 2

In Phase 2 of anoxic studies, U sorption was first carried out under oxic conditions. The samples were then transitioned to anoxic conditions for desorption. SA acidic samples commenced with approximately 60% U desorption in the system, but gradually declined until day 10, reaching 20-25%. Following day 10, U desorption gradually increased, stabilizing by day 15 and ending with approximately 90% by the final day (Figure 5-8). Neutral samples displayed a pattern resembling that of pH 4 during the first days, with initial fluctuations. By day 10 the U desorption remained relatively stable at approximately 20%. Unlike acidic samples, basic samples did not exhibit an initial decline in U desorption during the first 10 days. Instead, U desorption saw a gradual increase until day 14, followed by a plateau, ending with approximately 20% U desorption (Figure 5-8).

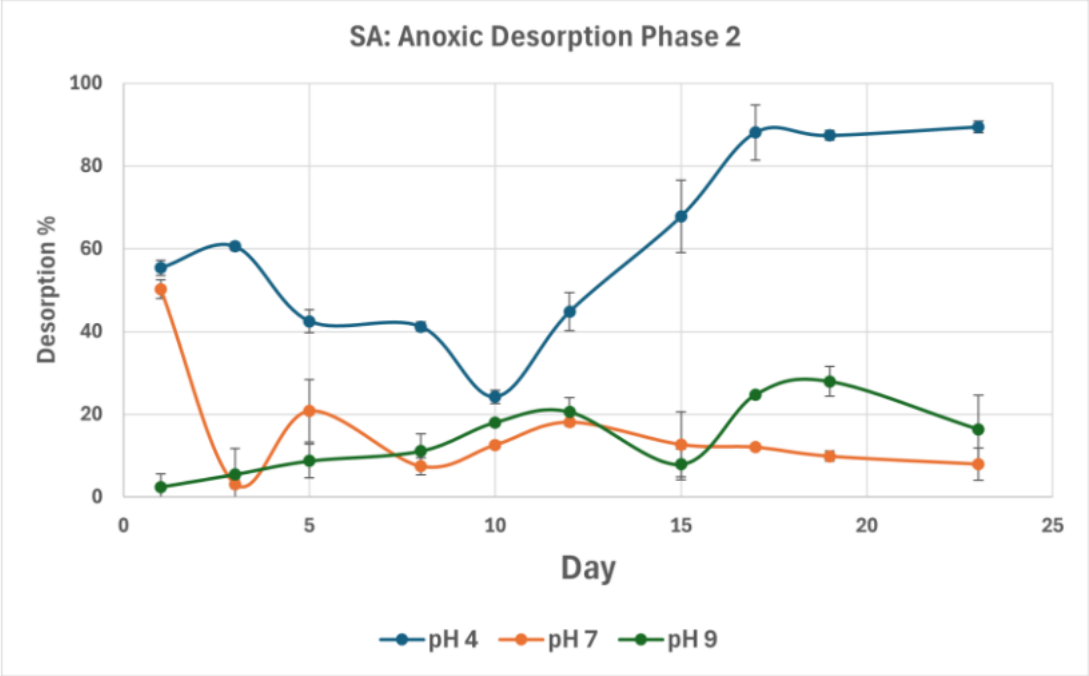

Figure 5-8. Scenario A Anoxic Studies for phase 2. With sorption performed in oxic conditions, and desorption performed in anoxic.

In Phase 2, SC at pH 4 and 7 showed no decrease in U desorption during the first 10 days, unlike SA samples, in which U desorption at both pH 4 and 7 declined. pH 9 in both SA and SC followed the same trend, ending with approximately 20% U desorption. Samples maintained at acidic pH consistently showed increase in U desorption, ultimately reaching approximately 80% U desorption (Figure 5-9). Samples at pH 7 and 9 gradually increased throughout the study, ending with similar amounts of U desorption of approximately 15-20%.

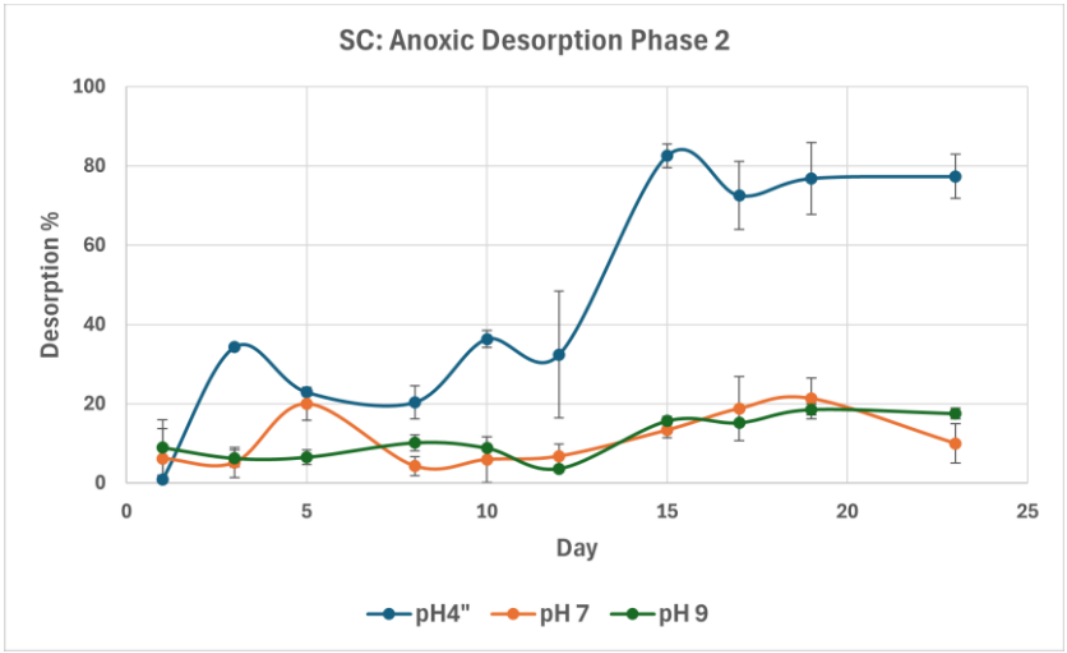

Figure 5-9. Scenario C Phase 2 with sorption performed in oxic conditions and desorption in anoxic conditions.

Phase 2 SA and SC generally had slightly higher amounts of U desorption compared to Phase 1 of anoxic studies. This is especially true at pH 4 with Phase 2 having approximately 20% higher amounts of U desorption (Figure 5-6 to Figure 5-9). A prominent reason for this increase in U desorption between Phase 1 and Phase 2 is likely due to bonds formed in Phase 2 in the presence of oxygen. In the presence of oxygen, U often forms multiple complexes with carboxyl groups, but when placed under anoxic conditions those bonds often break. This occurs as the U is reduced to U(IV) which is less soluble and mobile; this change can release the U from the carboxyl groups as the original uranyl- carboxylate is no longer stable. This action can cause for there to be more leaching of U in the samples in turn causing slightly higher amounts of U concentration into the system which can be seen in Phase 2 SA and SC. Desorption results indicate a high favorability for U release at acidic pH (4). Unlike samples at pH 7 and 9 exhibited minimal U desorption throughout the study.

Conclusions (FIU Year 5 Scope)

Sorption for both SA and SC had close to 100% removal when placed at neutral pH regardless of the environmental conditions. U desorption under acidic pH was elevated under both low temperature and anoxic conditions having approximately 60-80% desorption. On the other hand, when at neutral and slightly basic pH, there was low leaching of U. This was especially observed at low temperature with both pH achieving close to 0% U desorption. At Phase 1 and Phase 2 the desorption behavior was similar with slightly higher U desorption of approximately 5-10%. The results achieved throughout this experiment demonstrate the ability for HAp to not only sorb but also retain U under neutral and basic pH and at anoxic and low temperature.

Task 1: Overall Conclusion & Lessons Learned (FIU Years 1 – 5)

Hydroxyapatite Synthesis, Kinetics, and Characterization Studies

Based on results, synthesis with a combination of phosphate salts resulted in formation of hydroxyapatite. At all stoichiometric ratios investigated, the characterization of the resulting precipitate indicated successful hydroxyapatite formation. The synthesis portion of this experiment is being concluded. From the current experiment, scenario 3 appears to precipitate the most solid and has the potential to be the optimal stoichiometric ratio.

Sediment Characterization

This study examined sediment composition from four locations at the Old Rifle Site, CO, and found generally comparable mineralogy and surface characteristics across samples, except for Plot 3, which consistently displayed minor anomalies. EDS and XRD confirmed the presence of common soil minerals, including Si, O, Al, Fe, K, Ca, Mg, and Na, while trace P and Ti were detected only by EDS, likely due to their low abundance. SEM and BET analyses indicated similar surface areas across samples, with Plot 3 showing the greatest deviation, potentially reflecting localized soil differences.

Hydroxyapatite (HAp) synthesized in Phase 1 formed successfully under most stoichiometric ratios, except Scenario C, which repeatedly showed incomplete precipitation and mixed mineral phases. Phase 2 results confirmed these findings: Scenarios A and D produced HAp, while Scenario C continued to exhibit chemical and structural inconsistencies. ICP-OES and ICP-MS data showed that HAp formation and uranium removal occurred rapidly (within the first week) in scenarios where

pure HAp formed, suggesting incorporation and co-precipitation as key mechanisms of U(VI) attenuation. Further SEM-EDS analysis and Phase 3 comparisons will strengthen these observations.

Environmental testing demonstrated that uranium sorption by HAp was highest at pH 4, though oxic conditions at pH 7 also supported strong removal. Anoxic conditions reduced sorption efficiency. Across scenarios, uranium removal typically reached 97–100% under standard site conditions (pH 7, 22°C), indicating that HAp is a strong candidate for remediation at sites similar to Old Rifle. Desorption studies showed that uranium release increased at pH 4, likely due to HAp dissolution, while pH 7 and 9 maintained greater stability.

Overall, these results support hydroxyapatite as an effective amendment for uranium sequestration. The findings clarify mechanisms controlling U sorption and stability, highlight environmental factors that influence performance, and provide useful guidance for DOE-LM in developing long-term remediation strategies.

Sorption and desorption

Sorption in both Scenarios A and C was nearly 100% at neutral pH under all environmental conditions tested. During desorption, uranium release was highest under acidic conditions, with low temperatures and anoxic environments producing approximately 60–80% desorption. In contrast, neutral and slightly basic pH showed minimal leaching, particularly at low temperature, where uranium desorption approached 0% for both pH levels. Phase 1 and Phase 2 showed similar trends, though desorption was slightly higher overall (approximately 5–10%). These findings indicate that HAp is effective not only at removing uranium but also at retaining it under neutral to basic pH, even in low-temperature or oxygen-limited conditions.

TASK 2: CLIMATE RESILIENCY STUDIES FOR LONG-TERM SURVEILLANCE OF DOE-LM SITES

NOTE: *This task was previously titled "Remote Sensing Technologies for Long-term Surveillance of DOE-LM Sites" in Year 1.*
DOE-LM Strategic Plan 2020–2025: *Organizational Core Value – Environmental Stewardship and Goal 4 – Sustainably manage and optimize the use of land and assets and address severe weather events.*
DOE-LM Sites and End-users: *Rifle Site, Old Rifle Site, Mexican Hat, Grand Junction: Jalena Devault (DOE-LM), Christopher Jarchow (RSI), Ray Johnson (RSI).*

Introduction

Florida International University (FIU) has been investigating the potential impacts of long-term changes in weather patterns and the occurrence of extreme hydrological events on disposal cells to address concerns of premature erosion expressed by the U.S. Department of Energy's Office of Legacy Management (LM).

Even though LM's disposal cells were designed to be effective for at least 200 years, concerns started when spots of subsurface erosion were discovered in 2017 at the Mexican Hat cell in Utah. The erosion only manifested in the surface as slight depressions where the rock cover had subsided into the voids. Construction issues, including dispersive clays in the interbed layers between the radon barrier and the overlying rock cover, are potential causes; however, LM also suspects changing weather patterns and extreme storm events to be a contributing factor. Furthermore, within the Rifle disposal cell in Colorado, saturated subsurface conditions were unexpectedly observed.

Despite the southwest USA being dry, projections of future long-term weather patterns indicate that precipitation events will be more intense and are showing up in the meteorological record for the site. During short, severe rainfall events, the rock cover essentially plays little role in slowing runoff. Rounded cobbles may also play a role, as water runs off their surfaces and into the interstices more quickly than it would with angular rock. There is a need, therefore, to effectively characterize and perform long-term monitoring of LM's disposal cells to determine the potential for premature erosion on the surface and undesirable subsurface hydrological conditions over time, which could compromise their integrity and performance.

Objectives

The main goal of this task is to evaluate the viability of using a Ground-Penetrating Radar (GPR) sensor for cost-effective site characterization and monitoring of existing subsurface conditions of LM's disposal cells. During Years 3 and 4, a compact ground platform carrying a GPR sensor was developed at FIU. This platform was successfully demonstrated at the Mexican Hat and Rifle Disposal Cells during the summer of 2023; however, there were some issues with maneuverability of the platform on the top of the disposal cell which has an uneven, rocky topography. In addition, the GPR measurements were of poor quality as the data was not georeferenced and the actual spatial location of the data was not available. In Year 4, the platform was therefore updated and improved to traverse over the disposal cells more easily. Furthermore, a LiDAR was added to measure small-scale surface elevation variations, as well as a GPS which interacts with the GPR, allowing location coordinates to be recorded. These systems were integrated with the rover platform to enable the

collection of sensor data from an autonomously controlled moving vehicle. For FIU Year 5, the goal was to evaluate the performance of the updated platform and pursue the following objectives:

- Upgrade the system's autonomous driving and data acquisition capabilities.
- Develop the software for acquisition of GPR and LiDAR observations and generate spatial images of the surface and subsurface.
- Test the improvement of the robot's hardware and software.
- Test the GPR system again at the Mexican Hat site in Utah, Rifle Disposal Cell in Colorado, and potentially other disposal sites during the summer of 2025, covering larger areas.
- Install a lower frequency GPR antenna to image deeper cell layers and enable the measurement of saturated soil layers (e.g., perched water and groundwater). Two DOE Fellows will support this task.

Impacts/Benefits

- Autonomous surveys using LiDAR and GPR sensors produce detailed surface and underground imagery enabling cost-effective site characterization and monitoring of existing subsurface conditions. It is anticipated that the use of GPR technology will provide a 3-dimensional view to effectively characterize the subsurface underlying LM's disposal cells and detect undesirable subsurface conditions and hydrological trends.
- This research will directly support the surveillance and maintenance of the disposal cells by providing early detection of any deterioration of the facilities, thus enabling preventive maintenance and better protection of human health and the environment.
- This non-invasive method images sites without surface disturbance or potential radiological exposure if the radon barrier erodes.
- Using GPR surveys to inspect disposal cells over time will benefit LM in detecting many landfill changes, such as water flow, sinkholes, underground erosion, ground creep, and sediment flow. The proposed imager can monitor long-term effects, correlating underground erosion with climate resilience and extreme weather events.

MAJOR TECHNICAL ACCOMPLISHMENTS (FIU YEARS 1-4)

NOTE: *To simplify presentation and account for changes in subtask numbering over the course of the CA, subtask identifiers have been removed. Accomplishment titles are now listed in chronological order to reflect the progression of work from Years 1 through 4 for the overall Task 2.*

The 5-year period of performance was initiated by FIU's evaluation of the site conditions of the various LM sites across the US and assessment of their research needs to ensure that the sites continue to be sustainably managed, considering potential effects of hydrological extremes due to anticipated long-term changes in weather patterns. An investigation of various remote sensing and geophysical surveying methods and equipment was then conducted to determine the one most suitable for subsurface characterization of LM's disposal cells. FIU's research then became focused on developing an integrated system consisting of the selected sensory equipment mounted onto a platform that could be autonomously maneuvered over uneven, rocky terrain characteristic of LM's disposal cells. Several in-house and field tests were carried out in an attempt to optimize the integrated system and acquire results for the research team to conduct data analyses and learn how to best visualize and interpret the results.

FIU laid the foundation necessary to carry out a study which involved the compilation of remote sensing platforms and technologies to determine the most suitable for characterization of environmental and topological features at LM sites to assist DOE-LM in meeting its post-closure responsibilities for the management, long-term monitoring and protection of human health and the environment. The sequence of activities over FIU Years 1-4 are summarized below.

Compile LM Sites' Conditions

NOTE: *This subtask was completed in FIU Year 1.*

- Acquired site characterization data for a total of 84 DOE-LM sites across the U.S. Characterization data included land cover, topographical features, elevation, weather conditions, hydrology, winds, current land use, and a climate summary from federal agencies such as NOAA, USGS. In addition, evaluated sites encompassed all CERCLA/RCRA, NWPA, D&D, and FUSRAP sites, making environmental information also available, such as the type of contamination at the sites (radiological, chemical, or other hazardous materials).
- Created a simple searchable database within an Excel framework containing the LM site characterization data collected, which can be used as a reference by site personnel to find specific site characteristics of LM sites of interest.

Investigate LM Needs for Remote Sensing Data Collection

NOTE: *This subtask was completed in FIU Year 1.*

- Developed and proposed a cohesive study plan relevant to DOE-LM needs.
- Submitted a Draft Summary Document for the LM Needs for Remote Sensing Data Collection, accomplishing Deliverable 2020-P5-D3.
- Successfully completed UAV flight and remote sensing training for image data retrieval.

Evaluate Commercially Available Robotic Systems and State-of-the-art Sensory

NOTE: *This subtask was completed in FIU Year 1.*

- Demonstrated UAV technology in-house at FIU and then at LM's Rifle Disposal Site using photogrammetry and LiDAR remote sensing methods, captured in Figure 5-10.
- Executed Rifle Disposal Site flight plan and risk assessment in accordance with DOE and FAA compliance requirements.
- Acquired 71+acres of photogrammetry data over a span of 4+ days with support from Visual Observers (VO) while under review by sUAS DOE Surveying evaluator (Figure 5-11).
- Post-processed the data collected to develop a 3D digital elevation model (DEM) with the possibility of employing depression detection techniques in future.

Figure 5-10. Demonstation of UAV technology at LM's Rifle Disposal Site.2022, Photogrametry and LiDAR demostration at Rifle Disposal Cell in Colorado.

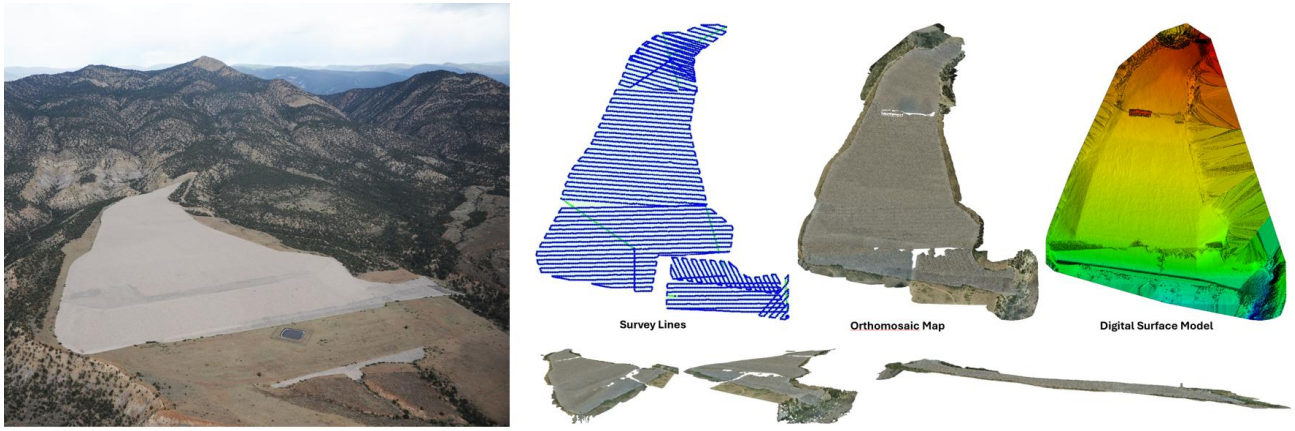

Figure 5-11. Overview of the 71-acre Rifle Disposal Cell area and resulting digital surface model (DSM).

Investigate Weather Trends in Disposal Cell Sites

NOTE: *This subtask was completed in Year 2.*

- Processed historic weather data, temperature and precipitation for Rifle, CO and extended future data using representative concentration pathways (rcp) 4.5 and 8.5.
- Utilized historical climate database from the Analysis of Record Calibration (AORC) to graph temperature and precipitation in a time-series format.
- Gained an improved understanding of the occurrence of extreme precipitation events and temperature variations for adverse climate conditions, and how this potentially impacts the occurrence of erosion.

Evaluate Commercially Available Geophysical Systems and Sensory State-of-the-Art

NOTE: *This subtask was completed in Year 2.*

- Conducted a literature review of various geophysical survey methods with the potential to map the subsurface in LM's disposal cells and drafted a summary report on the state-of the-art geophysical sensors and their potential applications to LM disposal cells.
- Conducted a literature review of ground penetrating radar (GPR) technology and its capabilities and selected Noggin 250 GPR from Sensors and Software Incorporated for imaging and detecting subsurface erosions at the LM's Rifle disposal cell.
- Studied the application of void detection of concrete slabs and plans to incorporate this methodology for LM's disposal cell sites.

GPR Sensor Procurement and Evaluation

NOTE: *This subtask was completed in Year 3.*

- Assessed the mobile robotic platform's autonomous behavior by improving the turn radius and overshooting between each desired point. FIU also tested the all-terrain wheeled robot system that is designed to traverse Legacy Management's Rifle Site disposal cell. In addition, the ground penetrating radar, and the software development kit for mapping the subsurface of LM's Rifle, CO disposal cell was received, and each component modeled in CAD software.

Autonomous Ground Platform Development and GPR Sensor Integration

NOTE: *This subtask was completed in Year 3.*

- The FIU team designed and built three testbeds to evaluate the GPR's capabilities in mapping subsurface erosion at LM's disposal cells. DOE Fellow, Shawn Cameron, also continued the GPR's deployment platform development. Shawn focused on building a functional prototype of FIU's autonomous ground-penetrating radar (GPR) ground platform and prepared the system for demonstration at LM's disposal cell during the summer. In addition, he drafted a summer learning experience plan and discussed it with LM and FIU. Shawn participated in an 8-week summer internship at Grand Junction, CO from July 10 – Aug 25, 2023 where he conducted site integration and participated in sampling activities with LM site managers.
- Developed a robotic platform that contains a GPR to scan surface and subsurface conditions for a given spatial location. This allows for automated observations of the disposal cell, leading to faster completion of observations and improving safety conditions as it reduces the need to climb a given cell.
- DOE Fellow, Shawn Cameron, manufactured the components needed to assemble the mobile robotic platform to demonstrate ground-penetrating radar (GPR) at the Legacy Management's disposal cells during his summer internship.
- The DOE Fellow built a functional prototype of FIU's autonomous GPR ground platform and prepared the system for a demonstration at an LM disposal cell at the Grand Junction site in Colorado during the summer.

In-House Testing

NOTE: *This subtask was completed in Year 3.*

- Designed and built an outdoor testbed at FIU's Engineering Center to evaluate the GPR's capabilities in mapping subsurface erosion at LM's disposal cells.
- Tested the all-terrain wheeled robot system that is designed to traverse Legacy Management's Rifle Site disposal cell. Conducted an assessment of the mobile robotic platform's autonomous behavior by improving the turn radius and the overshooting between each desired point.

Summer Technology Demonstrations

NOTE: *This subtask was completed in Year 3.*

- Prepared a summer technology demonstration test plan and worked on developing the mobile GPR system design at FIU for demonstration at the Rifle's cell in Colorado during the summer, demonstrating the potential of the inspection tool (Figure 5-12). Field interactions and site personnel feedback are paramount in developing a valuable inspection tool tailored to LM needs.
- DOE Fellow, Shawn Cameron, and the FIU team successfully demonstrated FIU's ground penetrating radar (GPR) autonomous rover at LM's Mexican Hat, and Rifle disposal cells during his summer internship.
- Completed Deliverable 2022-P5-D3 which involved the development of a draft summary document for GPR summer application at LM sites.
- Tested the GPR robot at Basin 6 of the Nash Draw region near the WIPP to inspect the subsurface conditions at areas with known sinkhole locations and surface depressions, to support Project 2's hydrology modeling and research activities in Carlsbad, New Mexico.

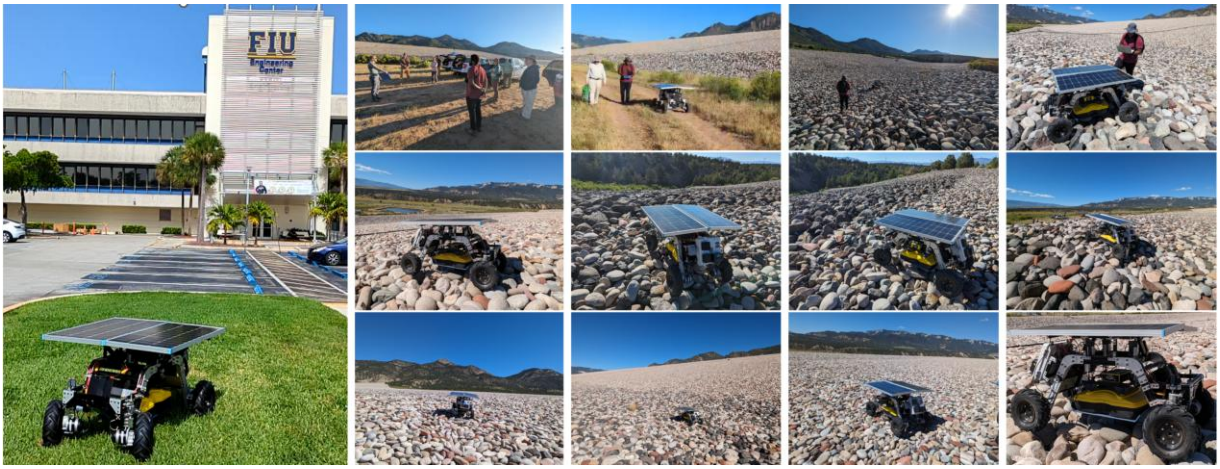

Figure 5-12. 2022 GPR Robot Demostration at the Rifle Disposal Cell in Colorado.

GPR Image Reconstruction

NOTE: *This subtask was completed in Year 3.*

- Developed the technology to create 2D information and images of the subsurface for a given location from GPR observations as well as the detection of features of interest. This technology was tested for a mockup site created by FIU that mimics the actual disposal cell conditions.

- The disposal cell cross-section was created from GPR subsurface images. Noticeable depressions in the model show potential as a cost-effective tool for monitoring LM disposal cells' current subsurface conditions and premature erosion.
- Created the foundation for AI data analytics for subsurface imaging analysis.

Data Analysis

NOTE: *In FIU Year 4, this subtask was reported under Subtask 2.2.*

- Evaluation of the GPR observations obtained at the Rifle and Mexican Hat disposal cells during the summer of 2023. Although certain features of interest were shown, the data was not completely georeferenced making it difficult to link the observed results to explicit spatial features of each cell.

Robot Upgrade

NOTE: *In FIU Year 4, this subtask was reported under Subtask 2.1.*

- Upgrade of the mobile platform rover design using high-torque motors to improve maneuverability; upgrade of the electrical panel; utilization of a new controller; and installation of a GPS feature to enable complete autonomous scanning.
- Connection of a GPS unit to the NOGGIN® GPR to facilitate co-location of the GPR and the scanning data, and installation of a LiDAR sensor at the front of the rover to measure elevation variations that can be linked to changes in the subsurface measured by the GPR (Figure 5-13).

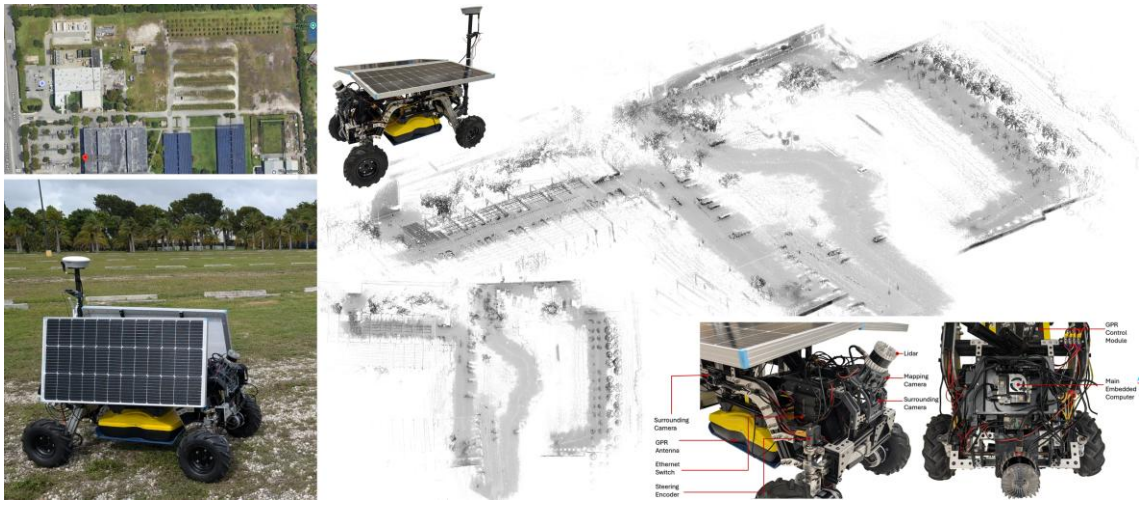

Figure 5-13. GPR Robot LiDAR integration FIU.

Field Demonstrations

NOTE: *In FIU Year 4, this subtask was reported under Subtask 2.3.*

- Construction of an in-ground mock-up outside of the FIU Engineering and Computing facility, which enabled testing of the GPR settings and the impact of using different GPR frequencies.

Technical Progress Summary (FIU Year 5)

SUBTASK 2.1: ROBOT UPGRADE

Methodology

During Year 5, FIU focused its efforts on the integration between the available robot hardware and software. A high-precision NOGGIN 250 GPR was integrated into the system's sensory network to enable autonomous driving and data acquisition. Furthermore, a GPS has been connected to the GPR to allow for geolocation of the observed data. A GPS-based mapping algorithm will also be implemented to scan the cells autonomously. The vision is an operator selecting an area over satellite images and the robot driving to the location and scanning the cells fully autonomously, alleviating the operator's burden of operating the system. A ground station computer or tablet will display execution details to operators supervising the mission. The system was tested at the mockup facility developed at FIU.

Results

The wiring of the rover robotic platform was upgraded to ensure communication among the LiDAR units, a GPS module, solar panels, and the NOGGIN 250 Ground Penetrating Radar (GPR). Additionally, a docker container is being developed to enable seamless transfer of software and navigation packages across platforms that will also contain the GPR, LiDAR and GPS sensors.

To develop the autonomous driving procedure for the robotic platform developed in Years 2-4 of the project, it was decided to first apply this capability for two commercial robotic platforms; the Clearpath Robotics Jackal and the Clearpath Robotics Husky A300. These commercial platforms enable quicker testing and software integration. More specifically, the Jackal was used to update and test the autonomous driving capabilities, while the Husky was used to integrate the GPR, LiDAR and GPS sensors. Once completed, the developed products will be migrated into the previously developed platform.

One DOE Fellow assigned to this subtask initially programed the Jackal platform to support remote control autonomous driving functionality, using the Robot Operating Software (ROS), which governs the platform's operation.

Concurrently, with software development, the other DOE Fellow assigned to this subtask designed an extension for the Clearpath Robotics Husky robotic platform, underwent redesign and modification, and integrated the required components. This modified platform was specifically engineered to support remote GPR deployment and contains a LiDAR and GPS sensor for surface elevation mapping and georeferencing (Figure 5-14).

Figure 5-14. Huskey A300 robotic platform with mounted GPS and LiDAR *(left)*; robotic platform modified platform with extension to allow mounting of GPR *(center)*; robotic platform with mounted GPR (right).

Upon completion of the modifications, the Clearpath Robotics Husky A300 platform was taken to an outdoor mockup at FIU's Engineering Center for real-world testing. These tests successfully validated stable communication between the robot and the GPR unit and confirmed the integrity of the collected data. A controlled field simulation further assessed the platform's mobility and scanning reliability, demonstrating the system's ability to maintain signal stability during motion and capture consistent, high-quality line scans across diverse terrain.

Following the software upgrades, attention shifted to testing the modified Clearpath Husky robotic platform at Hanford Tank Waste Operations & Closure (H2C). Due to the cancellation of the field demonstration at an LM disposal cell during the summer of a DOE-LM Fellow's summer internship, the system was instead transported to H2C where a DOE-EM Fellow tested its effectiveness for underground characterization at a tank farm. Testing of the Huskey and the GPR system then continued to resolve most of the software bugs, including the timing delay between the LiDAR camera and the Husky camera.

Upon the return of the robotic platform to FIU, the DOE-LM Fellow also resumed in-house testing of obtained GPR observations. This phase involved operating Husky robotic platform over a previously constructed mockup located outside of FIU's Engineering Center to collect both GPR and LiDAR data. Numerous GPR scans were conducted. Observations made by the OUSTER LiDAR have also been incorporated to transition the navigation stack to full outdoor autonomous operation, and integration of GPS will enable large-scale waypoint tracking and autonomous traversal across disposal cells. The platform was further modified to consolidate and configure both the LiDAR and GPR systems onto a single platform for streamlined data analysis.

Conclusions (FIU Year 5 Scope)

In Year 5, substantial progress was achieved by FIU with the aid of DOE-LM Fellows, to integrate required software and hardware onto a ruggedized rover platform that will allow autonomous traversal and subsurface characterization of LM's disposal cells. FIU developed robotic platform underwent comprehensive electrical and structural upgrades to accommodate and enable integrated communication among the LiDAR, GPS, and GPR instrumentation. An extension to this robotic

platform was developed to support remote GPR surveys, including a custom-engineered extension to mount the NOGGIN 250 GPR. Field validation at FIU's Engineering Center mockup site confirmed stable robot–GPR communication, data integrity, and reliable signal acquisition under dynamic operating conditions.

Subsequent efforts focused on implementing autonomous navigation and remote-control functionality. Autonomous testing was initially developed for a Clearpath Robotics Jackal Platform, making use of the Robot Operating System (ROS) environment. The next step is to transfer this capability for the Clearpath Robotics Husky robotic platform, before finalizing the design for the FIU developed robotic platform.

In lieu of technology demonstration, testing and evaluation of the modified platform by the DOE-LM Fellows at an LM site, further evaluation of the system was successfully carried out through its incorporation in an on-site demonstration of FIU's robotics technologies conducted by DOE-EM Fellows at Hanford's Tank Waste Operations & Closure (H2C) facility over the summer of 2026.

Upon the return of the system to FIU, in-house testing resumed, integrating synchronized LiDAR and camera systems for autonomous navigation and concurrent GPR data acquisition. Continued system refinement addressed software latency issues and platform interoperability. A Docker container was developed to streamline deployment of navigation and data acquisition packages across operational platforms. Future work will involve modification and testing of the Clearpath Husky platform in the same manner.

SUBTASK 2.2: DATA ANALYSIS

Methodology

During FIU Year 5, FIU's aim was to continue evaluating the potential of GPR surveys in producing detailed underground images without surface disturbance or potential radiological exposure in case the radon barrier has eroded. The data will be combined with the available GPS geolocation information to enable the development of spatial images.

GPR and LiDAR observations were obtained from the mock-up facility at FIU and additional scans were taken when necessary to better understand the performance and sensitivity of the GPR to detect changes in soil layers and the various artificial materials. As part of these data analyses, the team generated Python code and wrote the necessary Python libraries to perform the data evaluation. Once the Python code was written, the additional field observations taken at FIU were evaluated.

Results

Initial training in Ground-Penetrating Radar (GPR) operations and data interpretation was launched to establish a strong foundation for data analysis. As part of this effort, new DOE Fellows conducted an in-depth review of the technical specifications of the SPIDAR and NOGGIN systems through a combination of literature review and guided instruction. A significant milestone was achieved with the successful independent activation of the SPIDAR unit, marking significant progress in operational familiarity.

To support data analysis, the DOE Fellow assigned to this subtask reviewed historical datasets provided by the former student assigned to the project, using EKKO Project software. This exercise reinforced key concepts in GPR signal processing and data collection techniques. Simultaneously,

system infrastructure was enhanced by verifying GPS connectivity to ensure accurate geospatial tagging of future scans. In preparation for automation tasks, essential software tools such as Anaconda and PyCharm were installed and configured to support Python-based scripting and development.

An initial test scan was performed to evaluate overall system functionality and build familiarity with baseline data acquisition procedures. This early scan served as a benchmark for refining future methodologies. Additional test scans and iterative adjustments, such as attenuation refinement, further improved understanding, and operational confidence with the GPR equipment.

Python training progressed with dual objectives: developing a streamlined data acquisition interface and initiating 3D data visualization capabilities. These advancements are expected to enhance efficiency and responsiveness of field operations.

Using the extended Husky platform developed in Subtask 2.1, the DOE Fellow conducted multiple GPR measurements to generate a 3D model of the subsurface. For data processing, the Python-based tool GPRPy was installed and utilized. Shown in Figure 5-15, a preliminary 3’ × 5’ grid was established at the FIU mockup site to enable 3D interpolation of the collected data. Following the installation of a new GPS unit, geospatial data was successfully configured to display relative positioning within the EKKO Project software. While individual line scans were effectively processed using GPRPy, the software lacked the capability to perform 3D interpolation. External software such as ArcGIS was therefore initially identified as a requirement for this task; however, GPS configuration successfully enabled visualization of its geospatial location within EKKO Project, thus eliminating the need for any external software.

Figure 5-15. Testing of the GPR platform and creation of 3D subsurface data from individual lines at FIU’s mockup site.

The DOE-LM Fellow working on this subtask then began analyzing the GPR and GPS data collected at the FIU Engineering Center mockup site using the Ekko Project software. Preliminary analysis revealed that the resolution of the individual line scans was not sufficient to generate a 3D image. As a result, subsequent efforts focused on repeating the GPR scans using a higher resolution of line

spacing. The newly acquired data was successfully converted into a 3D image, which was then converted into point cloud data to enable comparison with the LiDAR data outputs.

Figure 5-16 shows a 3D image of observed GPR data for a 15 x 15-foot testing grid at the mockup site. These data lines were used to generate a 3D point cloud and subsequent 3D array.

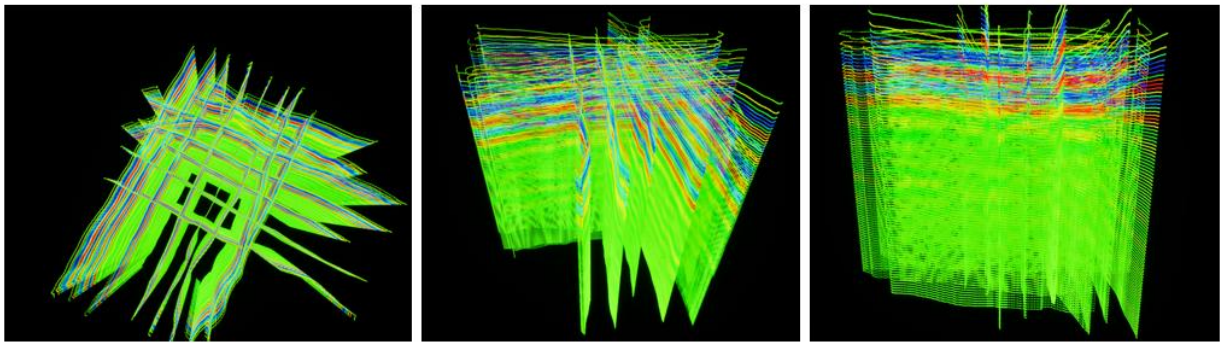

Figure 5-16. Top and side view of multiple line scans in both vertical and horizontal directions.

Conclusions (FIU Year 5 Scope)

Initial training in Ground-Penetrating Radar (GPR) operations and data interpretation established a technical foundation for advanced subsurface characterization. DOE-LM Fellows conducted a comprehensive review of the SPIDAR and NOGGIN system specifications and achieved independent activation of the SPIDAR unit, demonstrating operational proficiency. Historical datasets were analyzed using EKKO Project software to reinforce signal processing and data acquisition concepts, while GPS integration was verified to enable accurate geospatial tagging. System capabilities were further enhanced through the installation of Python development tools and GPRPy to support automation and 3D visualization. Field validation included multiple test scans and iterative parameter refinement, followed by structured data acquisition using a 3 × 5 grid at FIU's outdoor mockup site to support 3D interpolation. Although initial line-scan resolution was insufficient for volumetric reconstruction, higher-density rescanning enabled successful generation of a 3D subsurface model, which was subsequently converted to point cloud format for comparison with LiDAR datasets.

SUBTASK 2.3: FIELD DEMONSTRATION

Methodology

The GPR robot was to be demonstrated at Mexican Hat, Rifle, and potentially other LM disposal cells during the spring/summer of 2025. The efforts were to include packing, transport of the robot, and coordination of demonstrations with site managers and other LM officials.

Results

As requested by the funding organization, this subtask was cancelled. As such, field testing of the GPR and the rover platform being developed under Subtasks 2.1 & 2.2 at an LM disposal site during the summer was cancelled. The system was therefore used by a DOE-EM Fellow during a technology demonstration over the summer at Hanford Tank Waste Operations & Closure (H2C) to assess its effectiveness at tank farm underground characterization. This was an excellent opportunity

to test the performance of the robotic platform as well as its ability to obtain surface and subsurface observations using LiDAR and GPR. Testing of the system during the summer has been reported under Project 1 Subtask 18.4.2, Hanford Summer Deployment. Once the robotic platform containing the GPR and GPS was returned to FIU, it was used for further in-house testing using the outdoor mockup created outside of the FIU Engineering Center to evaluate the possibility of generating a 3D data visualization (see Subtask 2.2).

Conclusions (FIU Year 5 Scope)

As this subtask was cancelled, field testing at an LM disposal site was not conducted. The modified rover system, however, was evaluated by a team of DOE-EM Fellows as part of an FIU-ARC robotics tech demo at Hanford's Tank Waste Operations & Closure (H2C) facility to assess its effectiveness at tank farm underground characterization, which is described in more detail under Project 1 Subtask 18.4.2, Hanford Summer Deployment.

TASK 2: OVERALL CONCLUSION & LESSONS LEARNED (FIU YEARS 1 - 5)

The objective of this effort was to evaluate the effectiveness of a Ground Penetrating Radar (GPR) system for rapid scanning of disposal cells, characterization of subsurface conditions, and support of long-term monitoring through calibrated field data collection, while concurrently demonstrating autonomous robotic platforms capable of navigation and inspection without continuous human intervention.

A compact ground-based platform equipped with a GPR sensor was developed at FIU. The system was successfully demonstrated at the Mexican Hat and Rifle Disposal Cells in summer 2023; however, maneuverability challenges were encountered on the uneven, rocky surface of the disposal cell covers. In addition, the quality of the GPR data was limited due to the absence of spatial coordinates needed for proper georeferencing. The platform was therefore redesigned and enhanced to improve its mobility across the disposal cells.

A LiDAR sensor was incorporated to capture small-scale surface elevation variations, and a GPS unit was integrated with the GPR system to record precise location coordinates. These upgrades were fully integrated into the rover platform, enabling the collection of synchronized sensor data from an autonomously operated mobile vehicle. The robotic platform was also connected with a GPS module, to enable autonomous scanning of the disposal cells. To develop this autonomous driving capability, it was decided to first make use of a Clearpath Jackal and Clearpath Husky A300 robotic platform, before integrating this capability into the FIU developed robotic platform.

Significant extensions were made to the Clearpath Husky robotic platform to enhance and integrate a Noggin 250 GPR module for non-destructive, high-frequency subsurface imaging. This configuration enables real-time detection and mapping of buried objects and stratigraphic features, supporting infrastructure inspection, environmental monitoring, and informed decision-making. The platform was further equipped with a LiDAR sensor to facilitate autonomous navigation.

By the end of FIU Year 5, collected GPR data was post-processed to enhance interpretability and subsurface characterization. Two-dimensional GPS-referenced scans identified soil composition variations and buried features, with signature morphology suggesting metallic versus nonmetallic properties. Volumetric rendering techniques improved discrimination between the pipe and

surrounding soil strata, enabling clearer interpretation. Three-dimensional GPR surveys further demonstrated the capability to visualize a buried pipe at FIU. Ongoing efforts include integration of a Clearpath Husky robotic platform UGV to autonomously generate dense 3D information of the subsurface and precise GPR georeferencing. An OUSTER LiDAR sensor is being incorporated to transition the navigation stack to full outdoor autonomous operation, and integration of GPS will enable large-scale waypoint tracking and autonomous traversal across disposal cells. These key components, Husky rover, LiDAR, and GPS, are depicted in Figure 5-17, which illustrates the hardware configuration supporting this integrated sensing framework. Collectively, these advancements demonstrate a scalable, integrated robotic sensing framework for efficient, high-resolution subsurface assessment and long-term monitoring of disposal sites.

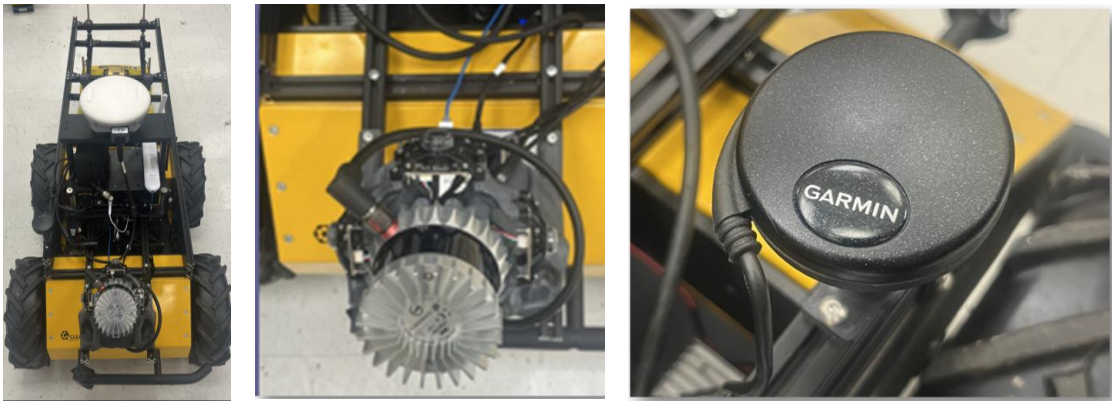

Figure 5-17. Clearpath Robotics Husky Rover *(left),* OUSTER LiDAR *(center),* and Garmin GPS *(right)*.

TASK 3: STEM WORKFORCE DEVELOPMENT- LM FELLOWS SELECTION

LM Function: *Supports an effective and efficient workforce structured to accomplish departmental missions.*
DOE Site(s) and End-users: *DOE LM HQ: Jalena Dayvault (Grand Junction Office (GJO))*

Introduction

The Applied Research Center (ARC) at Florida International University (FIU) has provided critical support to the Department of Energy's Office of Environmental Management (DOE-EM) mission of accelerated risk reduction and cleanup of the environmental legacy of the nation's nuclear weapons program. Under the DOE-FIU Cooperative Agreement, ARC's research, technology development, test and evaluation, and STEM workforce development covers four major areas of environmental cleanup operations: radioactive waste processing, facility decontamination and decommissioning (D&D), soil and groundwater remediation and modeling, and information technology (IT) development for environmental management. DOE-LM is leveraging the DOE-EM FIU Cooperative Agreement to support DOE-LM Fellows as described in the Cooperative Agreement. To this end, the research and student training will be structured as appropriate and within the parameters of the DOE-FIU Cooperative Agreement (CA). Coordination at the proper level will occur with the sites and national laboratories involved in the project research efforts as well as with the points-of-contact at DOE Grand Junction Office (e.g., HQ Project Leads, Legacy Management Office, CA Technical Monitor, COR, etc.).FIU ARC has expanded the DOE-EM Cooperative Agreement (CA) to include this project (Project #5) within the already established DOE-FIU Cooperative Agreement to support LM's main goals and mission. Two (2) [three (3) in Year 5] FIU STEM students are competitively selected to support the research conducted under this project. FIU worked closely with LM management and defined high target, high priority technical topics to ensure that the students are trained in pertinent technical areas that directly support LM's goals. Based on FIU's past performance, skill sets, and infrastructure at FIU, some of the technical areas of concentration include long-term monitoring; technology identification, selection, testing/evaluation; fate and transport modeling of contaminants of concern. Students selected for the program have presented their research at relevant conferences such as the Waste Management Symposia and have completed summer internships at designated LM sites. Students have also incorporated these research topics into their dissertation/thesis and have gone on to publish their research findings in appropriate peer-reviewed journals.

Objectives

The goal of this project is to develop a well-trained, job ready workforce by providing FIU STEM students with immersive training and mentorship in DOE-LM's mission areas including long term site monitoring, data management, and stakeholder engagement, ensuring the continued protection of human health and the environment at legacy sites.

Impacts/Benefits

- Involves students in active DOE-LM research projects to develop a future pool of scientists and engineers specially trained and mentored in DOE-LM technical issues.

- Maintains and transfers knowledge to the future generation of LM's workforce, ensuring greater likelihood of continuity in the efforts to sustainably manage and maintain DOE's legacy sites.
- Leverages cost savings to DOE-LM by utilizing student participation in projects.

SUBTASK 3.1: RECRUITMENT EFFORTS

Methodology

FIU conducted recruitment efforts as needed during the Fall, Summer, and Spring semesters each year. The DOE Fellows already in the program were required to actively participate in the various activities involved in the identification and recruitment of new DOE Fellows, which included the following:

1. Posting flyers across the FIU campuses to promote awareness of the program and encourage eligible STEM students to apply.
2. Attendance of members of the DOE Fellowship Committee at faculty meetings, meetings of relevant student societies, as well as classrooms to educate FIU students about the program and collect applications from interested students.
3. Hosting of open houses at ARC at the beginning of each Fall semester, allowing FIU students to tour ARC's facilities and become educated on the DOE Fellows program, the various research projects being conducted and their relevance to DOE's clean-up challenges across the nation, the type of hands-on work experience, specialized training and skillsets that could be acquired to complement their academic goals, as well as the mentoring, internship and networking opportunities that are additional benefits of the program.
4. Participation at the FIU Career Fair and engineering senior design expo during the Fall and Spring semesters.
5. Announcements on webpages designed and dedicated to the DOE-FIU Science and Technology Workforce Development Program. The webpage was developed in 2007 (https://fellows.fiu.edu) and contains information related to the program. This webpage is constantly being updated with new information and DOE Fellows research updates.

It is projected that STEM students from the College of Engineering and/or the College of Arts and Sciences will be selected for this program. The Fellows will be asked to demonstrate their commitment to the program by completing the DOE-FIU Science and Technology Workforce Development Program application package found on the DOE Fellows webpage (https://fellows.fiu.edu). Each application package will consist of an application form, research abstract, updated resume, unofficial transcripts, two letters of recommendation from FIU faculty, and instructions for completing the application packet.

Upon completion of the application and forms, the student applicant will be interviewed by the DOE Fellowship Committee, who will rate the student on academics, aptitude, interpersonal skills, and any additional selection criteria developed by the Committee. The final selection of students will occur after all applicants have been interviewed and assessed.

Major Accomplishments (FIU Years 1 – 4)

Since the inception of the program with DOE-LM, eight (8) FIU students have been competitively selected to become part of this program and officially inducted during the annual DOE Fellows Induction Ceremonies for FIU Years 1-4.

Progress Summary (FIU Year 5)

Florida International University (FIU) successfully completed its Fall 2024 recruitment for the U.S. Department of Energy Office of Legacy Management (DOE LM) Fellows Program. Following a competitive selection process, two students were selected to join the DOE-LM Fellows, Class of 2024:

- Tyler Coy, B.S. in Computer Engineering
- Sahaira Paz, B.S. in Mechanical Engineering

They joined Valeria Ocampo, B.S. in Environmental Engineering, who was already participating in the program. Together, these Fellows are contributing to a range of research tasks that support DOE-LM's mission. Future recruitment efforts will continue as current Fellow's graduate or as program needs evolve.

SUBTASK 3.2: DOE-LM RESEARCH IDENTIFICATION AND ASSIGNMENTS

Methodology

FIU's Applied Research Center will provide leadership in the development and management of this program. The DOE Fellows directly support FIU-ARC scientists and engineers in the development and execution of technical work under this agreement. The Fellows are assigned to supervisors/mentors and support the ongoing research by working on a part-time basis (approximately 20 hours/week). The DOE Fellows support all tasks under the Cooperative Agreement while pursuing their STEM degrees at FIU.

It is expected that the research being conducted will provide the basis for the development of master's thesis and/or PhD dissertation topics for Fellows pursuing graduate degrees. The research will also provide senior design research projects and/or capstone project opportunities for DOE-LM Fellows pursuing undergraduate technical degrees.

Major Accomplishments (FIU Years 1 – 4)

- DO-LM Fellows Olivia Bustillo and Eduardo practiced drone operation and collection of photogrammetry and LiDAR data, as well as collection of soil/water samples.
- DOE Fellows, Olivia Bustillo and Eduardo Rojas, travelled to Colorado to visit DOE-LM sites and experience site surveys.
- DOE-LM Fellows participated in the Annual FIU Research Review held on September 27–28, 2022, presenting their research accomplishments to DOE-HQ and site points of contact (POCs).

- Shawn Cameron presented his research during the Annual FIU Research Review on September 28, 2022, highlighting accomplishments including ground-penetrating radar (GPR) surveys conducted during his summer internship.
- Valeria Ocampo shared her research accomplishments during FIU Year 4 of the DOE-FIU Cooperative Agreement, as part of the Annual FIU Research Review.

Progress Summary (FIU Year 5)

DOE Fellows have supported two research tasks under the DOE-FIU Cooperative Agreement. Valeria Ocampo is currently supporting Task 1, while Tyler Coy is working on Task 2, specifically on Subtask 2.1 involving robot upgrades. Sahaira Paz previously contributed to Subtask 2.2, focusing on data analysis.

SUBTASK 3.3: DOE-LM FELLOWS POSTER EXHIBITION & COMPETITION

Methodology

FIU ARC will coordinate and host the DOE Fellows Poster Exhibition & Competition in November 2024. DOE-LM Fellows will prepare posters to be presented at this annual event to highlight their research accomplishments in the identified/selected areas of research. The DOE-LM Fellows will present their research conducted at ARC or during summer internship assignments.

Major Accomplishments (FIU Years 1 – 4)

- Eduardo Rojas and Olivia Bustillo participated in the undergraduate and graduate sessions, respectively, of the Annual DOE Fellows Poster Exhibition and Competition during FIU Year 1 (2021), earning second and third place, respectively.
- Two DOE Fellows presented their research at the 16th Annual DOE Fellows Poster Exhibition and Competition held on November 7, 2022, during FIU Year 2. Olivia Bustillo received third place and was recognized during the DOE Fellows Induction Ceremony on November 8, 2022.
- Shawn Cameron was awarded third place in the 17th Annual DOE Fellows Poster Competition for his research presentation, with the award presented during the induction ceremony in FIU Year 3 (2023).

Progress Summary (FIU Year 5)

DOE Fellow, Valeria Ocampo, prepared and presented a poster, titled *"Hydroxyapatite as a Remedial Agent: Examining Uranium Sorption and Desorption,"* at the 18th Annual DOE Fellows Poster Exhibition and Competition held on November 12, 2024. Valeria won 1st place among the undergraduate posters presented and received a certificate during the induction ceremony held the following day (Figure 5-18).

Figure 5-18. DOE Fellows, Valeria Ocampo and Kevin Yukowlski, receiving "Best Poster" awards in the undergraduate poster session at the FOE Fellows Poster Exhibition & Competition.

Planning and coordination of the 19th Annual DOE Fellows Poster Exhibition and Competition were initiated in anticipation of the event's originally scheduled date of November 6, 2025. Meetings were being held on a bi-weekly basis; however, the event was postponed due to a temporary pause in federal operations and has been rescheduled for the spring semester of 2026.

SUBTASK 3.4: DOE-LM FELLOWS INDUCTION CEREMONY

Methodology

FIU ARC coordinated and conducted the DOE Fellows Induction Ceremony in November 2024 during which DOE Fellows selected during FIU Year 5 were inducted as DOE-LM Fellows. DOE-HQ officials, DOE site mentors, FIU faculty and administrators, FIU ARC scientists, and existing DOE Fellows will be invited to participate in this event.

Major Accomplishments (FIU Years 1 – 4)

- Eduardo Rojas (Class of 2020) was formally introduced as a DOE-LM Fellow during a virtual ceremony on November 19, 2020, and later inducted into the DOE Fellows Program alongside Shawn Cameron (Class of 2021).
- Daniel Coelho (Ph.D. student) and Valeria Ocampo (undergraduate student) were inducted into the DOE Fellows Program as part of the Class of 2023.

Progress Summary (FIU Year 5)

FIU conducted the DOE Fellows induction ceremony on November 13, 2024. LM was represented by David VonBehren (LM Director of Education, Communication, History, and Outreach), Chris Jarchow (RSI), Ray Johnson (RSI), and Brian Peake (RSI). Two DOE-LM Fellows, Tyler Coy (B.S., Computer Engineering) and Sahaira Paz (B.S., Mechanical Engineering), were officially inducted into DOE Fellows Class of 2024 (Figure 5-19).

Figure 5-19. DOE-LM Fellows Class of 2024, Tyler Coy and Sahaira Paz, during the 18th Annual DOE Fellows Induction Ceremony.

Planning and coordination of the 19th Annual DOE Fellows Induction Ceremony were initiated in anticipation of the event's originally scheduled date of November 6, 2025. Meetings were being held on a bi-weekly basis; however, the event was postponed due to a temporary pause in federal operations and has been rescheduled for the spring semester of 2026.

SUBTASK 3.5: SUMMER INTERNSHIP PROGRAM (SIP)

Methodology

FIU-ARC personnel assisted in the planning, coordination, and execution of the Summer Internship Program (SIP). Through this program, the Fellows participate in a 6 to 8-week summer internship at a DOE facility. DOE Fellows will be paired with scientists/engineers at DOE facilities and/or national laboratories and DOE contractors. During the six to eight weeks, the Fellows will work on environmental research projects under the guidance of their site mentors/scientists and in accordance with the LM approved summer plan. FIU personnel will provide assistance in monitoring the progress of summer interns and their research work. FIU personnel, with the help of DOE site internship program coordinators, will identify mentors at selected DOE sites to work with the FIU summer interns. FIU will collaborate with DOE-LM GJO in the coordination and identification of summer internship opportunities and assignments at DOE-LM GJO, DOE-LM Sites and contractors' facilities.

Upon completion of the summer internships, the DOE Fellows prepare Summer Internship Technical Reports on the research work they performed over the summer. Each DOE Fellow will seek input and review of the report from their site mentors/scientists and final reports will be submitted to DOE-LM GJO and made available on the DOE Fellows website.

Major Accomplishments (FIU Years 1 – 4)

DOE Fellows have participated in several summer internships at DOE-LM sites including Old Rifle, Grand Junction, and the Oak Ridge Reservation (the latter directly sponsored by United Cleanup Oak Ridge, UCOR).

- In 2021, DOE Fellows Olivia Bustillo and Eduardo Rojas completed 8-week internships at LM sites in Colorado. As part of their assignments, they developed and revised Summer Internship Plans, coordinated travel logistics with DOE-LM, and conducted field activities such as drone operations, photogrammetry and LiDAR data collection, and soil/water sampling.
- Olivia Bustillo completed an 8-week summer internship in 2022 at Grand Junction, CO, under the mentorship of Dr. Kenneth Williams and Ms. Jalena Dayvault. She later presented her research accomplishments to LM senior management and staff alongside fellow DOE Fellow Shawn Cameron.
- Shawn Cameron completed a 10-week internship in 2023 at Grand Junction, CO, under the mentorship of Ms. Jalena Dayvault.
- In summer 2023, Olivia Bustillo participated in an internship at DOE's Oak Ridge Reservation, directly sponsored by UCOR.
- Valeria Ocampo completed a summer internship at Grand Junction under the mentorship of Chris Jarchow and Ray Johnson, then prepared a draft report summarizing her work.

Progress Summary (FIU Year 5)

DOE Fellow Valeria Ocampo prepared a summer internship report based on the work she performed during summer 2024. After approval from her mentor, Ray Johnson, the report was published on the DOE Fellows website (DOE Fellows Internships Reports - 2024).

Due to the cancellation of the planned field demonstration at an LM disposal cell, DOE Fellow Tyler Coy instead completed a remote summer internship with RSI. In alignment with Task 2's objective to evaluate hyperspectral imaging for site characterization, he developed a lab-scale mockup and methodology to analyze soil samples and evaporites from several DOE-LM sites using a hyperspectral camera and assess its effectiveness at determining their spectral signature. This provided an opportunity for the Fellow to gain hands-on familiarity with the camera's operation and to practice techniques for visualizing and interpreting the spectral data. Although not a filed demonstration, the internship provided foundational experience relevant to future applications. Tyler presented his research accomplishments to DOE-LM leadership during a virtual meeting.

DOE Fellow Sahaira Paz completed an in-person 10-week summer internship at DOE-EM headquarters in June 2025. The primary focus of her internship involved drafting justifications for task change requests related to robotic technologies and conducting comparative analyses against commercial, off-the-shelf systems to ensure efficiency and alignment with program objectives. The details of her internship will be reported under Project 4.

SUBTASK 3.6: CONFERENCE PARTICIPATION AND PRESENTATIONS

Methodology

DOE-LM Fellows will attend and participate in industry conferences, including the Waste Management Symposia, American Geophysical Union (AGU), and other relevant conferences, as

budget allows. The students will submit abstracts and develop student and professional posters as well as oral presentations based on their research performed at FIU ARC and during their summer internships.

Major Accomplishments (FIU Years 1 – 4)

DOE Fellows participated and presented in various activities and conferences including Waste Management Symposia Conferences and received various awards including *Best Poster* awards and Roy G. Post foundation scholarships.

- FIU Year 1 (2020–2021): Key Activities and Accomplishments
    - The two DOE-LM Fellows gained experience in public speaking and delivering presentations when they attended the WM2021 Symposia held virtually and presented posters based on their research along with 5-minute pre-recorded videos describing their posters during the WM2021 student poster competition.
    - Fellows participated in the DOE-LM All Hands meeting held in St. Louis, Missouri, and took part in a tracer test conducted at the Moab, Utah site.
    - Fellows also attended the International Atomic Energy Agency (IAEA) meeting in Grand Junction, which included representatives from Uzbekistan, Kyrgyzstan, Tajikistan, and DOE staff from across the United States.
- FIU Year 2 (2021–2022): Key Activities and Accomplishments
    - DOE Fellow Olivia Bustillo attended the 2022 Waste Management Symposia held in Phoenix, Arizona from March 6–10. She presented her research through both an oral and poster presentation and participated in the panel discussion, "Graduating Students and New Engineers – Wants and Needs – Are Companies Even Listening?," where she spoke about the evolving workplace culture shaped by Gen Z.
    - During the symposia, Ms. Bustillo, Drs. Lagos, and Gudavalli met with LM Director, Mr. Carmelo Melendez, and Technical Director for Long Term Stewardship Dr. David Shafer.
    - Ms. Bustillo also attended the DOE-LM All Hands meeting in St. Louis, Missouri, and participated in a tracer test at the Moab, Utah site, which served as a precursor to the planned hydroxyapatite injection.
    - Additionally, she took part in the International Atomic Energy Agency (IAEA) meeting held in Grand Junction, which included participation from government representatives of Uzbekistan, Kyrgyzstan, and Tajikistan, along with DOE staff from across the United States.
- FIU Year 3 (2022–2023): Key Activities and Accomplishments
    - DOE Fellows Olivia Bustillo and Shawn Cameron attended and participated in the Waste Management Symposia 2023, held in Phoenix, Arizona from February 26 to March 2, 2023.
    - Olivia Bustillo was actively involved in multiple sessions at the Waste Management Symposia 2023 conference:

- Presented a poster as a Roy G. Post Foundation scholarship recipient during Session 039: *Posters – Roy G. Post Scholarship 2023 Winners* on Sunday, February 26.
- Presented a second poster during Session 095: *Posters – Environmental Remediation (7.1)* on Tuesday, February 28. Her poster received the award for Best in Track 7 – Environmental Remediation.
- Served as a panelist in Panel 130B: *U.S. DOE National Labs and Academia – Successful Partnerships in the Development and Training of the STEM Workforce*, where she shared a student's perspective on the value of university–national lab collaborations and current workforce development programs.

- FIU Year 4 (2023–2024): Key Activities and Accomplishments
  - Former DOE Fellow, Olivia Bustillo, and Senior Research Scientist, Dr. Ravi Gudavalli, received the ASME Award for Best Poster/Paper Presentation at WM2023 for their poster titled *"Interaction of Hydroxyapatite and Uranium in Groundwater at the Old Rifle Site to Facilitate Site Remediation."* The award was presented during the WM2024 award luncheon on Tuesday, March 12, 2024.
  - DOE Fellow Valeria Ocampo attended and participated in WM2024, engaging in various sessions including one coordinated as part of Long-Term Stewardship (LTS) Day, organized by the DOE Office of Legacy Management.

Progress Summary (FIU Year 5)

Two abstracts were submitted to the student poster competition session at the 2025 Waste Management Symposia, held in Phoenix, AZ from March 9–13, where DOE Fellows, Valeria Ocampo, and Tyler Coy, participated and presented their research posters.

Photographed in Figure 5-20, DOE Fellow Valeria Ocampo, was awarded first place in the Undergraduate Student Poster Competition at the Waste Management Symposia, AZ. The poster titled, *"Hydroxyapatite as a Remedial Agent: Examining Uranium Sorption and Desorption,"* included data from experiments conducted at the Applied Research Center (ARC) as well as findings obtained during a summer internship with the Department of Energy's Office of Legacy Management in Grand Junction, CO. The poster focused on uranium and hydroxyapatite interaction under two different environmental conditions. The first batch experiment was conducted under anoxic conditions in a glove box, while the second set was carried out at 7°C in an environmental chamber. Additionally, the poster included results from the internship project, which examined the effectiveness of HAp in sorbing uranium from contaminated sediments.

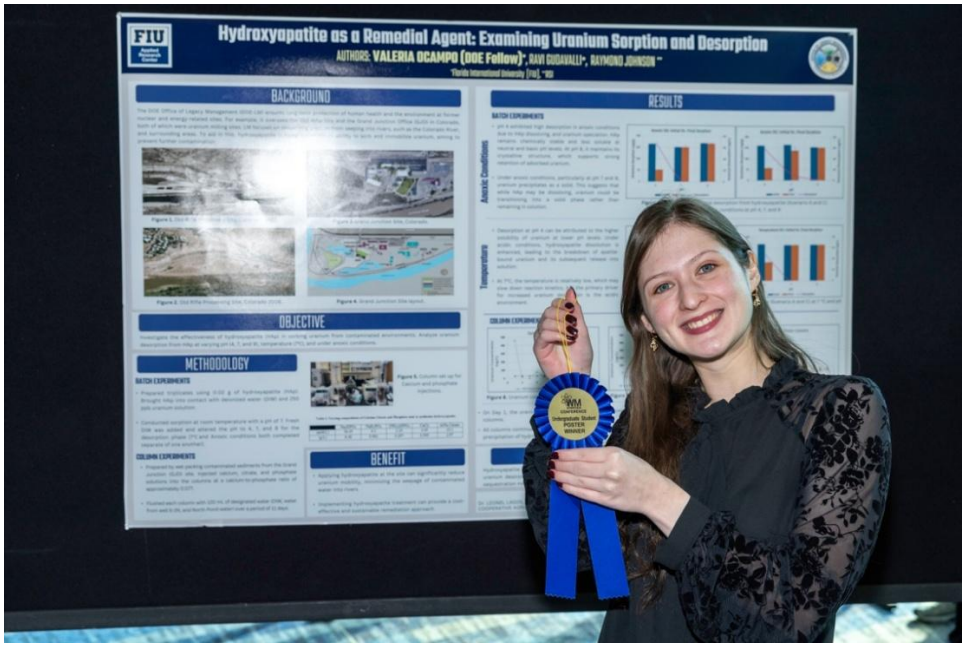

Figure 5-20. DOE-LM Fellow Valeria Ocampo at the 2025 Waste Management Symposia.

SUBTASK 3.7: DOE EM AND LM FELLOWS LECTURE SERIES FORUM

Methodology

FIU will host a DOE Fellows Lecture Series Forum where DOE-EM and LM staff (sites and HQ) and national lab personnel can discuss important DOE-EM and LM topics with DOE Fellows and FIU students. It is hoped that via this forum, DOE-LM Fellows will learn about DOE-EM and LM environmental issues directly from DOE scientists and engineers. FIU will collaborate with DOE-HQ and national labs to identify potential speakers.

Major Accomplishments (FIU Years 1 – 4)

FIU hosted **19 Tech talks** on KM-IT which involved collaborations with Savannah River National Laboratory (SRNL), Washington River Protection Solutions (WRPS), Lawrence Berkeley National Laboratory (LBNL), Idaho National Laboratory (INL), Argonne National Laboratory (ANL), Institute for Energy Technology in Norway, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Los Alamos National Laboratory (LANL) and Florida International University's Applied Research Center (FIU-ARC) research team to present topics relevant to the DOE EM Complex. Topics included:

1. AI-Accelerated Strategies and Solutions in Environmental Technology (AI-ASSET)
2. Next-Generation Knowledge Management: Developing Agent-Driven Systems for Enhanced User Interaction
3. Graph Analytics on Exascale Systems
4. Significance of Resilient Analytics in Achieving the Energy Resilience of Microgrids

5. A Case Study: The Strategic Integration of Consensus Standards to Facilitate Fixative Technology Development, Deployment, and Acceptance
6. Development and Deployment of a ground robotic platform for radiation Radiological Contamination Detection
7. Uranium Characterization and Remediation at the Hanford Site
8. Natural Language Processing for Event Discovery, Extraction, and Inferential Forecasting
9. AI/ML Research support for Advance Long-Term Environmental Monitoring Systems (ALTEMIS)
10. DOE's ALTEMIS Project: Advanced Long-Term Monitoring of Complex Groundwater Plumes
11. International Perspective on Decommissioning with focus on 3D hazard aware digital and robotics technology-based transformation
12. University R&D and Deployment of Robotics Systems at DOE Facilities
13. Understanding Decontamination
14. Decommissioning Knowledge Sharing in the 21st Century
15. Crack Detection and Localization Using Deep Learning Techniques
16. The Potential of Artificial Intelligence in the Nuclear Power Industry
17. Advanced Environmental Monitoring Systems (ALTEMIS): New Paradigm of Long-term Monitoring
18. Use of Robotics in Nuclear Applications
19. Successful Deployment of Fire-Retardant Fixative at SRS 235

Progress Summary (FIU Year 5)

The DOE Fellows attended a series of Tech Talks over the past year, including:

- On October 17, 2024, FIU collaborated with Oak Ridge National Laboratory (ORNL) to feature a Tech Talk from Aditya Sundararajan titled "Significance of Resilient Analytics in Achieving the Energy Resilience of Microgrids".
- "Graph Analytics on Exascale Systems" – presented by Dr. Mahantesh Halappanavar from Pacific Northwest National Laboratory (PNNL) on January 21, 2024.
- On April 22, 2025, FIU hosted a Tech Talk titled "AI/ML Research support for Advance Long-Term Environmental Monitoring Systems (ALTEMIS)", presented by Dr. Jayesh Soni, a Postdoctoral Associate at FIU.
- "AI-Accelerated Strategies and Solutions in Environmental Technology (AI-ASSET)" (July 23, 2025). – presented by former DOE Fellow Alejandro De La Noval, a MSIPP Fellow at Savannah River National Laboratory (SRNL).
- DOE Fellows attended a Tech Talk on October 29, 2025, hosted by FIU titled "Quantum AI Innovations at Savannah River National Laboratory (SRNL)" by speaker Dr. Larry M. Deschaine from SRNL.

- DOE Fellows attended a Tech Talk on January 29, 2026, hosted by FIU titled “Development of Robotic Tools for Nuclear Decommissioning” by speaker Dr. Leonel Lagos from FIU.

TASK 3: OVERALL CONCLUSIONS & LESSONS LEARNED (FIU YEARS 1 – 5)

The vision of this project is to cultivate a pipeline of highly trained, mission aligned scientists and engineers from FIU’s STEM programs who are prepared to support DOELM’s long-term stewardship responsibilities. Through immersive research experiences, structured mentoring, and targeted technical training, participating students develop the skillsets necessary to contribute to LM’s work in long-term site monitoring, environmental data management, and stakeholder engagement. A total of 6 DOE LM Fellows were officially inducted and exposed to hands-on research, internships, conference participation, professional development, and obtained one (1) graduate and two (2) undergraduate degrees based on the research conducted under this project.

Over this five-year performance period, the project has successfully met its objectives by engaging FIU STEM students in hands-on research directly tied to DOELM priorities. Students were competitively selected as LM Fellows and trained in high priority technical areas such as long-term environmental monitoring, contaminant fate and transport modeling, and technology evaluation. Their work has been integrated into ongoing LM research activities, allowing them to contribute meaningfully to technical tasks while gaining foundational experience in LM’s mission space.

The program has strengthened LM’s future workforce by providing students with opportunities to collaborate with LM site personnel, national laboratory researchers, and technical mentors. Students also presented their findings at national conferences and participated in summer internships. These experiences have given students valuable exposure to real-world stewardship challenges and helped preserve institutional knowledge essential for the long-term management of DOE legacy sites.

While the project has successfully trained a diverse cohort of students, challenges remain in sustaining long-term student engagement due to academic workload, competing opportunities, and evolving career interests. To address these challenges, the program is exploring strategies such as enhanced mentorship, stronger alignment between student research and LM’s evolving technical needs, and expanded career-readiness support to better prepare students for federal hiring pathways and LM-related career opportunities.

Through these efforts, the project continues to advance DOE-LM’s mission by developing a well-prepared, technically capable, and diverse workforce ready to support the long-term protection of human health and the environment at DOE legacy sites.

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APPENDIX A: CONFERENCE PARTICIPATION, PUBLICATIONS, AWARDS, ACADEMIC MILESTONES, & COMMUNITY OUTREACH

CONFERENCE PARTICIPATION

WASTE MANAGEMENT SYMPOSIA, PHOENIX, AZ

Professional Track - Oral and Poster Presentations

Bustillo, O. (DOE LM Fellow), Gudavalli, R. and Gonzalez-Raymat, H. *Characterization of Sediment from the Old Rifle Site.* Waste Management Symposia 2022, Phoenix, AZ, March 6-10, 2022 [Oral and poser presentation].

Student Poster Competition

Bustillo, O. (DOE LM Fellow). *Characterization of Sediment from the Old Rifle Site.* Waste Management 2021 Virtual Conference, Phoenix, AZ, March 8-12, 2021 Virtual. [Student poster].

Rojas, E. (DOE LM Fellow). *Remote Sensing Technology Characterization for LM Sites.* Waste Management 2021 Virtual Conference, Phoenix, AZ, March 8-12, 2021 Virtual. [Student poster].

Cameron, S. (DOE LM Fellow). *Climate Resiliency Studies for Long-Term Surveillance of DOE-LM Disposal Cell Sites.* Waste Management 2023, Phoenix, AZ, February 26 - March 2, 2023 [Student poster].

Coy, T. (DOE LM Fellow). *Climate Resiliency Studies for Long-Term Surveillance of DOE-LM Sites.* Waste Management 2025, Phoenix, AZ, March 9-13, 2025 [Student poster].

Ocampo, V. (DOE LM Fellow). *Hydroxyapatite as a Remedial Agent: Examining Uranium Sorption and Desorption.* Waste Management 2025, Phoenix, AZ, March 9-13, 2025 [Student poster].

Coy, T. (DOE LM Fellow). *Climate Resiliency Studies for Long-Term Surveillance of DOE-LM Sites.* Waste Management 2026, Phoenix, AZ, March 8-12, 2026 [Student poster].

Ocampo, V. (DOE LM Fellow). *Usage of Hydroxyapatite for Uranium Remediation Under Varying Environmental Conditions.* Waste Management 2026, Phoenix, AZ, March 8-12, 2026 [Student poster].

Other Sessions

- Olivia Bustillo (panelist): *Panel Session, "Graduating Students and New Engineers - Wants and Needs - Are Companies Even Listening?"*: Discussed the shift in workplace culture due to Gen Z becoming the majority within the workforce. WM2021, March 8-12, 2021 Virtual.
- Olivia Bustillo & Eduardo Rojas: *Waste Management 2021 post-conference meeting:* Met with Legacy Management leadership (Director, Carmelo Melendez and Site Manager, Jalena Dayvault) to discuss updates on their research and possible future work. WM2021, March 8-12, 2021 Virtual.
- Olivia Bustillo (panelist): *Panel Session, "130B: US DOE National Labs and Academia Successful Partnerships in the Development and Training of STEM Workforce"*: In this panel, Olivia gave a student's perspective on the benefits of universities partnering with national labs

and her personal perspective on current workforce development programs. WM2023, February 26 - March 2, 2023.

- Olivia Bustillo: *Speed Networking Event*: A one-on-one conversation between students and professionals, where the students had an opportunity to talk with a professional for several minutes and then rotate tables to talk with professionals from other companies. This provided great networking experience and exposure to the students as well as the companies. WM2023, February 26 - March 2, 2023.
- Olivia Bustillo: *Waste Management's 1st Annual Job Fair:* This provided an opportunity to meet and talk with representatives from many different companies and learn about careers within each organization. This was greatly beneficial for Ms. Bustillo, who was graduating in the summer of 2023 and wanted to learn about potential opportunities as she would be entering the workforce. WM2023, February 26 - March 2, 2023.
- Valeria Ocampo: *The Long-term Stewardship (LTS) Day:* Organized by the DOE Office of Legacy Management. WM2024, March 10-14, 2024.

DOE-FIU COOPERATIVE AGREEMENT ANNUAL RESEARCH REVIEW

- September 14-15, 2021: DOE Fellows presented their research accomplishments during the Annual FIU Research Review.
- September 24, 2023: Shawn Cameron participated in the Annual FIU Research Review held on with DOE-HQ and site POCs and presented his research accomplishments on Task 2 - "Climate Resiliency and Long-Term Surveillance of DOE-LM Disposal Cells".

AWARDS

BEST POSTERS/PRESENTATIONS

Waste Management Symposia

- Olivia Bustillo (DOE Fellow) and Ravi Gudavalli – Best poster and presentation: Session 095, Track 7 - Environmental Remediation (7.1) – *Interaction of Hydroxyapatite and Uranium in Groundwater at the Old Rifle Site to Facilitate Site Remediation.* Waste Management Symposia 2023, Phoenix, AZ, February 26 - March 2, 2023.
- Valeria Ocampo (DOE Fellow) – 1st Place: Undergraduate Student Poster Competition for poster *"Hydroxyapatite as a Remedial Agent: Examining Uranium Sorption and Desorption.",* Waste Management 2025, Phoenix, AZ, March 9-13, 2025. Her poster included experimental data from FIU ARC's research and her DOE-LM internship in Grand Junction, CO.

FIU ARC DOE Fellows Poster Competition 2023

- Shawn Cameron (DOE Fellow) – 3rd Place: 17th Annual DOE Fellows Poster Competition. The award was presented to him during the DOE Fellows induction ceremony on Nov. 8, 2023.

ASME 'SUPERIOR PAPER' AWARDS

Bustillo, O., Gudavalli, R. and Gonzalez-Raymat, H. *Interaction of Hydroxyapatite and Uranium in Groundwater at the Old Rifle Site to Facilitate Site Remediation.* Waste Management Symposia 2023, Phoenix, AZ, February 26 - March 2, 2023.

ROY G. POST FOUNDATION SCHOLARSHIP RECIPIENTS

- DOE Fellow Shawn Cameron was awarded a Roy G. Post Foundation scholarship and presented a poster based on his DOE-LM research on Sunday, Feb. 26, 2023, during Session 039 Posters: Roy G. Post Scholarship 2023 Winners.

DOE FELLOW & MENTOR OF THE YEAR AWARDS

"DOE Fellow of the Year" and **"Mentor of the Year"** awards are presented during the DOE Fellows Induction Ceremonies which are held annually at FIU's Modesto Maidique Campus.

- Olivia Bustillo - DOE Fellow of the Year (2021).

PRESIDENTIAL MANAGEMENT FELLOW (PMF) AWARD

- Olivia Bustillo - Presidential Management Fellow (PMF) Class of 2023.

ACADEMIC MILESTONES

The following DOE-LM Fellows (undergraduate and graduate) have supported the research conducted under Project 5 over the contractual performance period and have graduated with either bachelor's or master's degrees from FIU.

- Olivia Bustillo – B.S., Environmental Engineering; Accepted a position at Drummond Carpenter after graduation.
- Eduardo Rojas – B.S., Mechanical Engineering; Accepted a position as a Temporary Research Assistant at Florida International University's Applied Research (ARC) Center.
- Shawn Cameron – M.S., Mechanical Engineering; Accepted a position as an Engineering Intern at UCOR followed by an MSIPP Post Graduate Fellowship at Savannah River National Laboratory (SRNL).

APPENDIX B: FIU QUARTERLY AND YEAR END REPORTS AND ANNUAL RESEARCH REVIEW PRESENTATIONS

The following documents for the Cooperative Agreement (CA) between the U.S. Department of Energy's Offices of Environmental and Legacy Management and the Applied Research Center at Florida International University represent the research conducted by FIU during the current CA's period of performance, and are available at FIU ARC's DOE Research website https://doeresearch.fiu.edu/SitePages/Welcome.aspx

1. FIU Quarterly Reports
2. FIU Year End Reports
3. FIU Annual Research Review Presentations