YEAR-END TECHNICAL REPORT
September 29, 2019 to September 28, 2020

DOE-FIU Science & Technology Workforce Development Initiative for Office of Legacy Management

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Addendum:

This document represents one (1) of five (5) reports that comprise the Year End Reports for the period of September 29, 2019 to September 28, 2020 prepared by the Applied Research Center at Florida International University for the U.S. Department of Energy Office of Environmental Management (DOE-EM) under Cooperative Agreement No. DE-EM0000598.

The complete set of FIU's Year End Reports for this reporting period includes the following documents:

Project 1: Chemical Process Alternatives for Radioactive Waste
    Document number: FIU-ARC-2019-800006470-04b-270

Project 2: Environmental Remediation Science and Technology
    Document number: FIU-ARC-2019-800006471-04b-267

Project 3: Waste and D&D Engineering and Technology Development
    Document number: FIU-ARC-2019-800006472-04b-256

Project 4: DOE-FIU Science & Technology Workforce Development Initiative
    Document number: FIU-ARC-2019-800006473-04b-306

Project 5: DOE-FIU Science & Technology Workforce Development Initiative for Office of Legacy Management
    Document number: FIU-ARC-2019-800012253-04b-003

Each document will be submitted to OSTI separately under the respective project title and document number as shown above. In addition, the documents are 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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PROJECT 5 OVERVIEW

The Department of Energy (DOE) established Legacy Management (LM) 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. Recognizing that LM sites are driven by their unique requirements such as operation and maintenance of remedial action systems, routine inspection and maintenance, and records related activities, Florida International University's Applied Research Center envisions developing a unique program to address LM's goals and preparing and securing the next generation workforce that will be required to accomplish these goals.

Florida International University (FIU), the largest Hispanic serving research-extensive institution in the continental United States, is one of the nation's leading producers of scientists and engineers from underrepresented groups. In 1995, DOE created a unique partnership with FIU to support environmental cleanup technology development, testing and deployment at DOE sites. This partnership spawned a research center at FIU dedicated to environmental research and development (R&D). The center, now known as the Applied Research Center, has tackled and helped solve problems at many DOE sites.

Since 1995, 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. ARC's applied research is performed under the DOE-FIU Cooperative Agreement (under Contract #DE-EM0000598). ARC's applied research, technology development; test & evaluation, and STEM workforce development covers four major areas of environmental cleanup operations: radioactive waste processing, facility decontamination and decommissioning, soil & groundwater remediation and modeling, and information technology (IT) development for environmental management. As discussed, and agreed among DOE EM and LM, FIU infrastructure and expertise developed under the Cooperative Agreement will be leveraged to initiate the pilot program for LM. To this end, the research & student training, will be structured closely following the DOE Fellows program model.

The DOE LM Fellows Program has inducted two (2) minority FIU STEM students during the induction ceremony held in November 2019. The DOE Fellows induction ceremony has been attended by DOE LM officials Mr. Carmelo Melendez, Dr. David Shaffer and Ms. Jalena Dayvault.

DOE LM Fellows have been engaged in research topics investigating the use of apatite for uranium sequestration at the Old Rifle site, and the application of remote sensing technologies at LM sites.

MAJOR ACCOMPLISHMENTS

Major accomplishments of this program to date include:

- Two FIU minority students were competitively selected to become part of the initial cohort of STEM minority students selected for this program and officially inducted during the annual DOE Fellows Induction Ceremony hosted at FIU in November 2019.
- The DOE LM Fellows attended the Waste Management Symposia 2020 and met with Dr. David Shafer to discuss their research topics.
- The DOE LM Fellows were assigned with research tasks studying the uranium contamination at the Old Rifle site and using remote sensing technologies for long-term surveillance of DOE-LM Sites.
- DOE Fellow Olivia Bustillo developed a study plan for the research topic “Use of Apatite for Uranium (U) Sequestration”, which was submitted to DOE LM.
- DOE Fellows Eduardo Rojas drafted a study plan on “Remote Sensing Technologies for LM Sites” and submitted it for review.

TASK 5.1: DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT INITIATIVE FOR OFFICE OF LEGACY MANAGEMENT

TASK 5.1: INTRODUCTION

Florida International University (FIU), the largest Hispanic serving research-extensive institution in the continental United States, is one of the nation's leading producers of scientists and engineers from underrepresented groups. In 1995, the U.S. Department of Energy created a unique partnership with FIU to support environmental cleanup technology development, testing and deployment at DOE sites. This partnership spawned a research center at FIU dedicated to environmental R&D. The center, now known as the Applied Research Center, has tackled and helped solve multiple problems at many DOE sites. The DOE-FIU Science and Technology Workforce Development Program is designed to build upon this relationship by creating a pipeline of minority engineers specifically trained and mentored to enter the DOE workforce in technical areas of need. This innovative program was designed to help address DOE's future workforce needs by partnering with academic, government and DOE contractor organizations to mentor future minority scientists and engineers in the research, development, and deployment of new technologies addressing DOE's environmental cleanup challenges.

TASK 5.1: OBJECTIVES

Under this pilot project, FIU ARC proposed to expand the current DOE EM CA to include a new project (Project #5) within the already established DOE-FIU Cooperative Agreement to support LM's main goals and mission. It is projected that 2 FIU minority students will be competitively selected to become part of an initial cohort of STEM minority students selected for this program. It is also anticipated that half time of a Post-Doctoral Fellow will be needed to directly support and guide the selected students. To ensure that the students will be trained in pertinent technical areas that directly support LM's goals, FIU will work closely with LM management to define high target, high priority technical topics. Based on past performance, skill sets, and infrastructure at FIU, some of the technical areas of concentration may include long-term monitoring; technology identification, selection, testing/evaluation; big data/data analytics; IT tools for knowledge management and transfer; fate and transport modeling of contaminants of concern; and deactivation & decommissioning (D&D). The selected students will present their research in relevant conferences such as the Waste Management Symposia. The students will also participate in a 10-week summer trainingship program at selected LM sites. Students will use the research topics for their dissertation/thesis and publish their research results in appropriate peer-reviewed journals.

TASK 5.1: RESULTS AND DISCUSSION

DOE Fellows Recruitment & Selection

The DOE Fellows Fall 2019 recruitment efforts were conducted to identify and select new DOE Fellows to join the program as part of the Class of 2019. Twelve students were selected for interviews held on October 23-24 2019, from which 2 FIU students were selected to join the program as DOE LM Fellows Class of 2019.

Table 1. DOE Fellows Class of 2019

First Name	Last Name	Major	Degree
Olivia	Bustillo	Environmental Engineering	BS
Beatriz	Perasso	Environmental Engineering	BS

Each new DOE Fellow was assigned to an ARC staff member to serve as their mentor and supervise their LM research work. Orientation for the new DOE Fellows was conducted and the new Fellows completed FIU's Environmental Health & Safety courses required by the university and ARC prior to conducting any work in ARC's lab facilities. The new DOE Fellows also created a brief bio to include on the DOE Fellows website.

DOE Fellows Induction Ceremony

FIU's Science & Technology Workforce Development Program (DOE Fellows program) inducted two (2) very talented FIU STEM students as the first cohort of DOE LM Fellows Class of 2019 on November 7, 2019. The DOE Fellows Induction Ceremony was attended by representatives from DOE-EM, including Mr. Leonard H. O. Spearman Jr. and Mr. Jean Pabon, along with representatives from DOE's Office of Legacy Management, including Mr. Carmelo Melendez. Also in attendance were FIU leadership including the FIU Provost, Executive Vice President and Chief Operating Officer (Dr. Kenneth Furton), FIU's Vice President for Research & Economic Development & Dean of the University Graduate School (Dr. Andres Gil), FIU's Dean of Engineering (Dr. John Volakis), as well as FIU faculty, ARC leadership and staff members, and current and former DOE Fellows.

Table 2. DOE LM Fellows Inducted During November 2019 Induction Ceremony

DOE Fellow	Degree	Major Area of Study
Olivia Bustillo	BS	Environmental Engineering
Beatriz Perasso	BS	Environmental Engineering

Figure 1. DOE LM Fellows Class of 2019 with Mr. Carmelo Melendez and Dr. Leonel Lagos.

Figure 2. DOE LM Fellows and officials during 2019 induction ceremony. (L to R: Mr. Carmelo Melendez, Ms. Jalena Dayvault, Beatriz Perasso, Olivia Bustillo, Dr. Leonel Lagos and Dr. David Shafer).

Figure 3. DOE LM Fellow Olivia Bustillo receiving certificate and pin during 2019 induction ceremony.

Figure 4. DOE LM Fellow Beatriz Perasso receiving certificate and pin during 2019 induction ceremony.

Mr. Leonard Spearman, Jr., Senior Advisor to the Assistant Secretary (EM), was one of the keynote speakers for the induction ceremony. Mr. Spearman from DOE-EM, Mr. Melendez from DOE-LM and the other distinguished guests had the opportunity to participate in morning tours of the ARC research laboratories. Tours of the ARC facilities included visits to the radiological laboratory; multi-functional indoor testing facility; the GIS, modeling & simulation laboratory; the soil and groundwater laboratory; the environmental technology laboratory; and the robotics and sensors laboratory.

Figure 5. DOE LM officials visiting FIU laboratories during the lab tours.

DOE Fellows Conference Participation

Waste Management Conference 2020

DOE LM Fellows Olivia Bustillo and Eduardo Rojas attended the Waste Management Symposia in Phoenix, Arizona from March 8-12, 2020. The Waste Management Symposium is the world's largest conference on radioactive waste management & disposal, decommissioning, packaging & transportation, facility siting and site remediation

At the Waste Management Symposia, DOE Fellows and mentors, Dr. Ravi Gudavalli and Mr. Anthony Abrahao, met with David Shafer from the Office of Legacy Management (LM) to discuss the scope of the research. Two research topics that FIU will be supporting include: a study of the use of apatite injection for sequestering uranium (U) in groundwater and an evaluation of suitable remote sensing imagery techniques and how to relate them to the different environmental characteristics present in current LM sites.

Figure 6. DOE Fellows at WM 2020.

TASK 5.1: CONCLUSIONS

This project is successfully meeting its objectives by providing research training and mentoring for students from underrepresented groups on environmental problems at DOE LM.

TASK 5.2: USE OF APATITE FOR URANIUM SEQUESTRATION AT OLD RIFLE SITE

TASK 5.2: INTRODUCTION

The Office of Legacy Management (LM) is charged with managing former 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. In many of these LM sites, uranium was removed as part of the cleanup process, and former mines and waste piles were capped. Uranium remaining in the subsurface under the capped waste piles was predicted to be flushed by natural groundwater flow. However, still today uranium has persisted at elevated concentrations in groundwater much longer than predicted. Uranium poses severe potential health hazards to humans and the environment. When unmonitored in the environment, uranium has the potential to affect the quality of surface water, groundwater, and food supplies. This is a toxic chemical that can lead to acute health effects such as kidney damage and various forms of cancer.

Several studies proved that injection of apatite into groundwater have shown to sequester uranium. Apatite, or hydroxyapatite (HA), has been used as a means to sequester uranium in areas where contaminant levels exceed the amount permitted, such as maximum contaminant limit (MCL). Apatite is a versatile tool regarding the immobilization of uranium, as it can potentially be used for both ex situ (as a sorbent for pump and treat systems) and in situ (as a permeable reactive barrier or source area treatment). The DOE's Old Rifle Site in Colorado, which was once a uranium mill processing facility that operated throughout the late 1970's, has implemented a hydroxyapatite permeable reactive barrier (PRB) to remediate uranium. Although the facility has since been demolished and the uranium mill tailings have been moved to a disposal cell, the site is still contaminated with low levels of uranium. Using apatite to remediate uranium has proved effective at this site as well as the Hanford, WA site (Rigali et al. 2018). DOE-LM has implemented an in situ hydroxyapatite (HA) Permeable Reactive Barrier to remediate uranium at the Old Rifle site in Colorado (Szecsody et al. 2016). While this process has proved to be effective, a better understanding of the uranium removal mechanisms behind the interaction is required.

FIU in collaboration with DOE-LM is investigating the use of apatite injection for sequestering uranium (U) in groundwater. Specifically, FIU is investing the mechanism of U removal from groundwater using apatite as well as the environmental factors that influence the stability of that removal. The data obtained will help fill the knowledge gaps of the mechanisms involved in the removal of U and the stability of the removal, and assist DOE-LM remediate uranium in the site where uranium is present.

TASK 5.2: OBJECTIVES

The purpose of this study is to identify the mechanisms of uranium removal by apatite and the stability of uranium removal under various environmental conditions (such as pH, ORP, etc.). The specific objectives of this research include the following:

- Determine the mechanism of Uranium removal from groundwater by apatite
- Study the environmental factors that influence the stability of U removal over time

A three phase approach has been designed to identify the mechanisms of uranium removal. The first phase focuses on studying the synthesis, formation kinetics, and characterization of apatite by mixing calcium, citrate and phosphate solutions. Phases two and three studies the interaction of uranium with apatite during and after formation of apatite and will study the mechanisms behind the interaction/sequestration. The mechanisms behind the interaction/sequestration of uranium and apatite could include adsorption of uranium on to apatite, precipitation of U-phosphate surface phases, phosphate precipitates coating uranium surface phases, or surface complexation. This year, the research has focused solely on the first phase of the experiment including the synthesis, kinetics, and characterization of hydroxyapatite.

TASK 5.2: METHODOLOGY

Materials:

This study utilized a solution containing sodium citrate, calcium chloride, and a phosphate solution. The phosphate solutions used in the experiment include trisodium phosphate, ammonium dihydrogen phosphate, disodium phosphate, and monosodium phosphate.

Synthesis and Characterization Studies:

Synthesis of hydroxyapatite experiments consisted of creating stock solutions of calcium, phosphate, and citrate. Different Ca:Citrate:P ratio samples were created to determine the optimum ratio for maximum yield of hydroxyapatite. Since HA takes between 3.5 to 5.3 weeks to form, the samples were monitored for 6 weeks before being prepared for analysis (Zsecsody et al. 2017). Throughout the 6 weeks, the pH was measured regularly and 200µL aliquots were collected at regular intervals. Aliquots were centrifuged at 2700 RPM for 30 minutes and supernatant was extracted to be analyzed via ICP-OES to measure aqueous concentrations of Ca and P. At the end of 6 weeks, remaining supernatant was removed and samples were placed in an oven at 30°C until drying was complete. Dried solids were stored in small scintillation vials and solids were analyzed through the XRD instrument. In between running the samples, they were stored in a desiccator for preservation.

XRD analysis:

A Bruker D2 PHASER XRD instrument was used for characterization of the hydroxyapatite solids that formed throughout the experiments. The sample was packed flat on to a sample holder (Figure 7) and analyzed via XRD from a 2θ value of 5-90˚ with a 0.05° step size. Observed X-ray diffraction patterns were matched to the International Centre for Diffraction Data’s power diffraction file database (PDF).

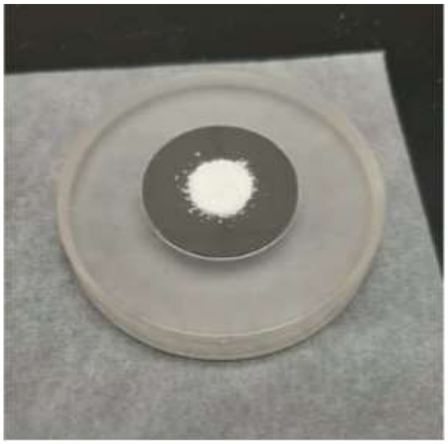

Figure 7. Hydroxyapatite powder on sample holder for XRD analysis

TASK 5.2: RESULTS AND DISCUSSIONS

FIU conducted preliminary experiments to synthesize hydroxyapatite by mixing calcium, citrate, and phosphate solutions, as shown in Table 3. The target pH for precipitation of hydroxyapatite the samples was approximately 7.5, however the pH of trial A solution was observed to be 11.59. A trial B, with similar concentration, was prepared; however, the pH of this set was adjusted to 7.5 using 0.1M HCL. The sample that was pH adjusted managed to maintain a pH of 7.5, however, as shown in Figure 8, this sample did not form a crystalline solid which indicated no formation of apatite. The sample that was not adjusted began to form an amorphous solid, but the final pH was about 11.59, which is not optimal for apatite formation.

Table 3. Composition of Trial Hydroxyapatite Samples Prepared

	Trial A	Trial B
Calcium Concentration	20 mM	
Citrate Concentration	50 mM	
Phosphate Concentration	20 mM	
Phosphate Salts	trisodium phosphate	
pH adjusted	No	Yes
pH	11.59	7.5

Figure 8. Apatite solution adjusted to 7.5 (left) and apatite solution without pH adjustment (right). Red circle shows white amorphous solids being formed.

In order to create a hydroxyapatite solution with a pH of approximately 7.5, the other trial experiments contained samples in which the phosphate solution was created with three different phosphate salts, instead of only trisodium phosphate that was used in the experiment (Table 4). (Zsecsody et al. 2017). These samples had varying calcium, citrate, and phosphate concentrations, however the ratio was constant. After two weeks, amorphous particles started to form in the sample with 40 mM Ca, 100 mM Citrate and 45 mM phosphate indicating higher concentration of components are needed for the reaction occur. The amorphous solids within the samples began to appear more crystalline as the time progressed (Figure 9).

Table 4. Composition of samples prepared with three phosphate salts

	Scenario 1	Scenario 2
Calcium Concentration	20 mM	40 mM
Citrate Concentration	50 mM	100 mM
Phosphate Concentration	22.5 mM	45 mM
Phosphate Salts	ammonium dihydrogen phosphate, disodium phosphate, monosodium phosphate	
pH	7.50	7.40

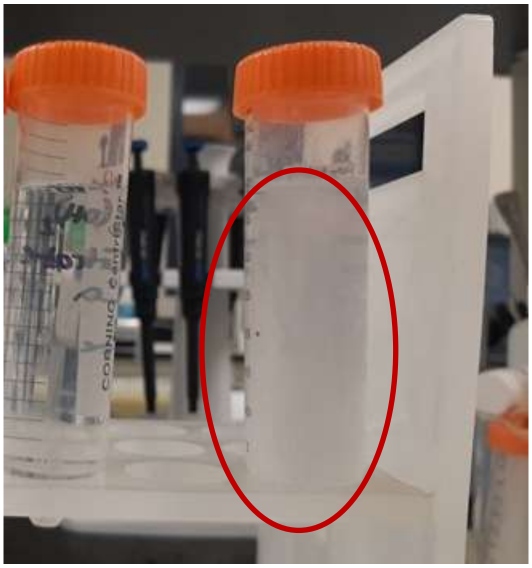

Figure 9. Apatite solution with three phosphate salts and 50mM citrate, 22.5M PO_4, 20mM calcium (left); apatite solution with three phosphate salts and 100mM citrate, 45mM PO_4, 40mM calcium (right).

Hydroxyapatite formation studies were conducted in triplicates, to ensure reproducibility, with varying ratios of citrate, calcium and phosphate solution (Table 5). Samples were allowed to equilibrate for 6 weeks to complete precipitation of HA before preparing the samples for characterization. Throughout 6 weeks, pH was measured and aliquots were taken three times a week. The aliquots were then centrifuged and the supernatant was extracted to remove solids. The solids and supernatant were then placed in the refrigerator for future analysis. Scenarios 2 and 3 (pictured below) began to form an amorphous solid within the first two weeks of the experiment before crystalline solids began forming (Figure 10). Scenarios 4 and 5 (not pictured) also followed a similar trend of formation. Furthermore, the supernatant that was collected will next be analyzed via ICP-OES to measure the concentrations of Ca and P. This data will be used to quantify the change in elemental concentration during the experiment. In addition, the remaining solids will be analyzed via SEM-EDS.

Table 5. Composition of Hydroxyapatite Samples Prepared

	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Calcium Concentration	40 mM	80 mM	80 mM	40mM
Citrate Concentration	100 mM	200 mM	100 mM	100 mM
Phosphate Concentration	45 mM	90 mM	45 mM	90 mM
pH	7.33 - 7.40	7.24 - 7.27	6.94 - 6.97	7.28 - 7.30

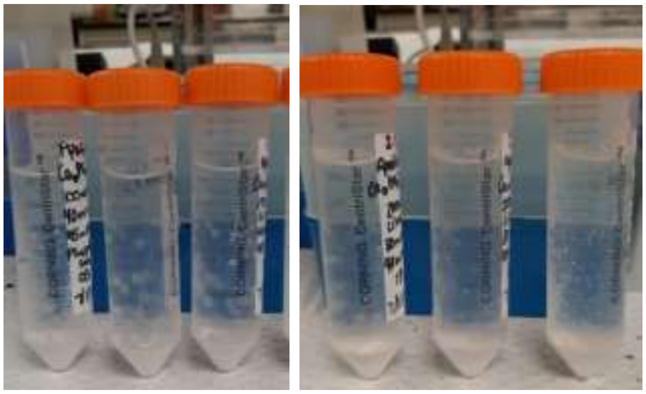

Figure 10. (L-R): Apatite formation experiment samples showing scenario 2 and scenario 3.

Dried apatite samples (Figure 11) were characterized via XRD and observed patterns (Figure 12) are being matched with a known database of minerals to confirm the formation of HA. Once all of the samples have been analyzed and their patterns have been matched to determine the characteristics of the solids that formed, the optimal Ca:Citrate:P ratio can be determined. This ratio will be subsequently used in the experiments to explore the interaction of uranium and hydroxyapatite. Thus far, the XRD data from the HA analysis support that the samples had formed hydroxyapatite. One of the XRD patterns obtained from the XRD instrument displayed peaks that were possibly due to impurities in the sample, so that sample was washed twice with deionized water, dried, and then analyzed again for comparison.

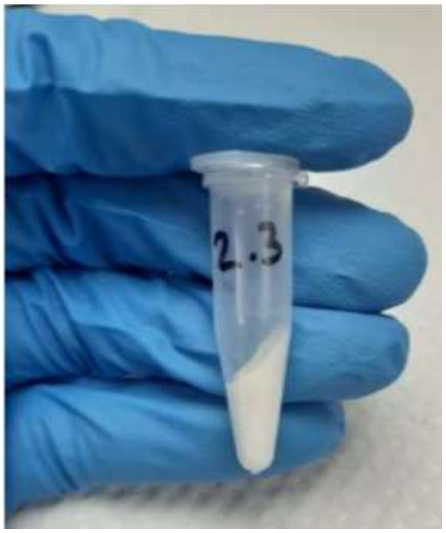

Figure 11. Dried hydroxyapatite sample used for characterization.

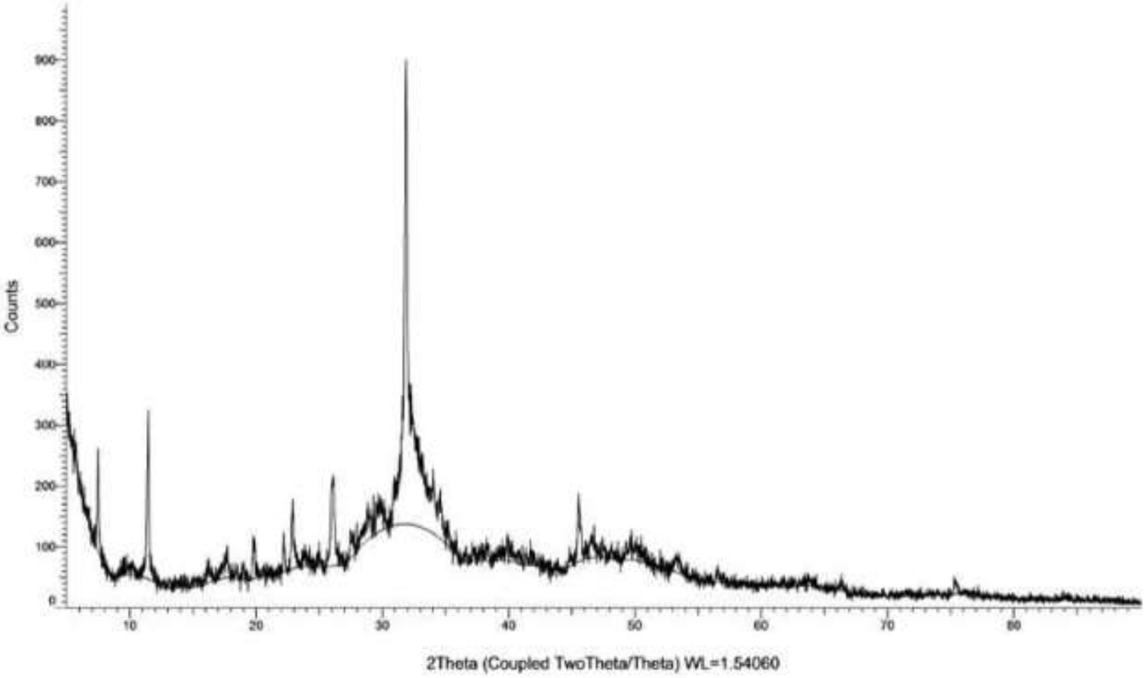

Figure 12. Synthesized Hydroxyapatite XRD pattern.

TASK 5.2: CONCLUSIONS

Based on preliminary results, synthesis with a combination of phosphate salts resulted in formation of hydroxyapatite. The synthesis, kinetics, and characterization experiments are being concluded. From the current experiment, scenario 3 appears to precipitate the most solid and has the potential to be the optimal ratio for following experiments.

TASK 5.2: REFERENCES

Rigali, Mark, et al. “Performance of an In Situ Hydroxyapatite Permeable Reactive Barrier at the Old Rifle Uranium Processing Mill Site.” 2018.

Szecsody, JE, et al. “Use of a Ca-Citrate-Phosphate Solution to Form Hydroxyapatite for Uranium Stabilization of Old Rifle Sediments: Laboratory Proof of Principle Studies.” Mar 2016.

Szecsody, JE, et al. “Influence of Ca-Citrate-Phosphate Mixtures on Rifle Sediment Treatment for Uranium Remediation.” Aug 2017.

TASK 5.3: REMOTE SENSING TECHNOLOGIES FOR LONG-TERM SURVEILLANCE OF DOE-LM SITES

TASK 5.3: INTRODUCTION

Fulfilling the Department of Energy's post-closure responsibilities and ensuring the future protection of human health and the environment poses a considerable long-term challenge. In this scenario, remote sensing technologies can be effective tools for informed decision-making as geospatial data and trends are taken into account so that managers can base their decisions on more accurate information.

A fast-growing trend in remote sensing surveys uses on-demand photogrammetric analysis and LiDAR scans deployed by autonomous robotics platforms. These technologies provide a cost-effective, centimeter-level precision with a shorter time frame compared to traditional methods. Three-dimensional mapping strategies provide valuable data, such as orthomosaic maps, 3D point clouds, volumetric measurements, slope monitoring, erosion trends, digital surfaces, and terrain models. However, the choice (or combination) of methods is situational and depends on factors such as time, budget, and capturing conditions, among others.

DOE-LM has used LiDAR to measure changes in landfill profiles and disposal cells at Old Rifle and Mexican Hat sites. These changes in LiDAR profiles could be early indicators of erosion of the cell cover or compaction of waste. Sites that endured maintenance issues can benefit from LiDAR surveys, such as Rocky Flats Landfill slumping, Grand Junction Disposal volumetric estimation, and Mexican Hat Disposal erosion issues.

Florida International University (FIU), in collaboration with the U.S. Department of Energy's Office of Legacy Management (DOE-LM), is investigating robotic platforms and remote sensing methods suitable for long-term monitoring of DOE-LM sites considering their environmental characteristics.

The study will prepare the foundation for potential continued collaborations in employing geospatial data analysis frameworks assisted by Artificial Intelligence driven by Machine Learning. The frameworks will provide DOE-LM sites with tools for tracking long-term effects on land cover and land use dynamics and issues related to climate change, resilience, and extreme weather events, helping to detect maintenance issues early on. Thereby, the FIU study contributes to the 2020-2025 Strategic Plan by adhering to Goal 4: Sustainably manage and optimize the use of land and assets and address severe weather events.

TASK 5.3: OBJECTIVES

This study's primary goal is to compile a matrix containing the appropriate remote sensing technology adequate for surveying specific features present in DOE-LM sites across the country. The investigations will pursue the following objectives:

- Compile current land feature characteristics of DOE-LM sites across the U.S., such as arid, semi-arid, wet, semi-wet environments, vegetated or barren lands, elevation, topography, and weather.

- Investigate specific needs in DOE-LM sites for remote sensing data collection, combining data from questionnaires addressed to site manager, visits, existing publicly available aerial photography from DOE-LM, and on-demand in-house surveys.
- Evaluate commercially available robotic systems, state-of-the-art in remote sensing technologies suitable for UAVs, UGVs, and wearables.

In the first year, this study will mainly focus on photogrammetry and LiDAR remote sensing applications using autonomous unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs). Even though UAVs are popular remote sensing tools, when battery life is a concern, especially in vast areas, a ground platform or wearable system might be better suited. A ground system has fewer constraints with payload capacity and can even be gas-powered.

Another aspect of this study is engaging the DOE-LM's Fellow in hands-on training and professional development activities exploring areas of interest related to remoting sensing applied to site monitoring, such as mobile platforms for sensor delivery, optimal mission planning for imaging acquisition, sensor integration, in-house surveys and field validation, photogrammetry and LiDAR mapping frameworks, intelligent point cloud management algorithms, object detection techniques, and artificial intelligence focusing on topics related to statistical learning and remote sensing.

TASK 5.3: METHODOLOGY

FIU worked with DOE-LM personnel, national laboratory contacts, and collaborators from industry and academia to identify shortcomings of the baseline approach and past research efforts. In the study, FIU used two UAVs, shown in Figure 13 in in-house fights and surveys. The DJI Phantom 3 is a small quadcopter couple with a gimbal camera suitable for photogrammetry surveys. The DJI S1000 is a larger octocopter with improved flight performance and better loading capacity (about 30 lbs), essential in carrying a LiDAR mapping system and supporting embedded computers.

Figure 13. FIU's photogrammetry (left) and LiDAR (right) mobile mapping systems.

The in-house mapping surveys worked as a testbed to evaluate remote sensing techniques, sensors, mission planning patterns, and collect data for testing geospatial analysis software. The aerial surveys were also used to contextualize the research and training efforts of the DOE-LM Fellow. The efforts included the integration of a mid-range high-resolution imaging LiDAR into the large

UAV. Table 6 shows the specifications of the procured LiDAR that will be used throughout the study.

Table 6. LiDAR specifications.

Model	**Ouster OS1**
Weight (g)	455
Beams	32
Temperature (c)	-20 to +50
Vertical FOV (^{o})	45
Range (m)	120
Precision (cm)	+- 1.5 to 5
Points per second	2,621,440
Rotation Rate (Hz)	10 or 20
Power (W)	14-20
Vertical Resolution (^{o})	0.01
Horizontal Resolution (^{o})	0.01

TASK 5.3: RESULTS AND DISCUSSIONS

In this performance period, most of the efforts were dedicated to preparing the foundation necessary to carry on the study and proposing a cohesive study plan relevant to DOE-LM needs. The efforts included a comprehensive literature review in remote sensing, the characterization of major DOE-LM sites, hands-on training, preliminary in-house fights, and finally, the LiDARselection and procurement, as well as starting the LiDAR integration into a UAV preparing for in-house scans.

The literature review summarized relevant state-of-the-art imaging technologies, basically mid-range LiDAR imaging systems, and several camera types such as thermal, multispectral, 3D, depth, and tracking cameras, including fundamental concepts in image interpretation and geospatial data management in a document provided by the Sandia National Laboratory. The efforts also included the precision versus coverage and adequacy of using ground, airborne, spaceborne based platforms, and guidelines in acquiring remote sensing data using multi-rotor versus fixed-wing UAVs.

The review is focused on applications using photogrammetry and LiDAR mapping, depending on a particular use case and time, budget, and capturing conditions, among others. LiDARs are active sensors suitable for surveying narrow structures such as power lines or telecom towers and mapping areas below tree canopies. In contrast, photogrammetry uses passive cameras better for projects that require visual data such as construction inspections, asset management, and agriculture. Lastly, we explore the popular supporting software for autonomous systems, mission planners, and custom builds using the Robot Operating Systems (ROS) software frameworks.

Regarding the DOE-LM site characterization, FIU continued characterizing selected Legacy Management site conditions and its corresponding geographical setting via the Land Use Classification Systems from the United States Geological Survey (USGS), which provides standardization for categorizing land use. The classification levels range from general to specific uses. Our characterization selected levels suitable for remote sensing applications. The classification includes identifying weather conditions and wind speeds to consider remote platforms best suited for their location. The compilation encompasses all CERCLA/RCRA, NWPA, D&D, and FUSRAP sites, including different environmental characteristics also classifying them according to land features, vegetation, elevation and weather conditions, and type of contamination at the sites, including radiological, chemical, and hazardous materials.

During the same period, FIU started the in-house integration of the LiDAR to our high payload octocopter in a setup similar to the one illustrated by Figure 14.

Figure 14. FIU's UAV LiDAR mapping systems conceptual design.

To evaluate the setup, FIU simulated the conceptual design using the Robotic Operating Systems (ROS) toolset. The virtual model was used to assist in the performance evaluation of the mapping system beforehand. Figure 15 illustrates the system's mapping potential, in which a virtual UAV carries the selected multichannel LiDAR while scanning a synthetic environment capturing its environment producing virtual point clouds.

Figure 15. Simulated UAV (left), point cloud results (middle), and synthetic environment (right).

Figure 16 shows preliminary laboratory test results of the procured Ouster OS1-32 LiDAR, as well as the DJI S1000 UAV setup. The DOE Fellow has led the LiDAR's integration efforts into the UAV, a valuable hands-on experience involving designing and testing mechatronic systems, sensors, embedded hardware, and supporting software.

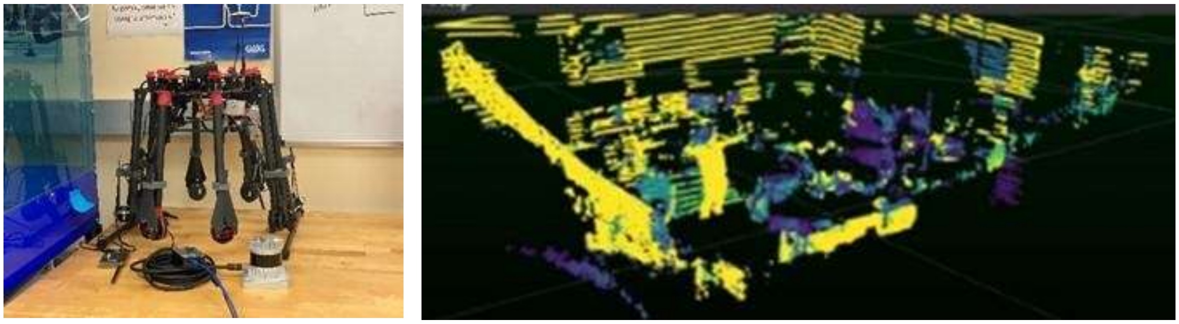

Figure 16. LiDAR and DJI S1000 UAV (left) and preliminary LiDAR testing (right).

Autonomous GPS-assisted flights using the DJI Phantom 3 quadcopter were also conducted, preparing for aerial photogrammetric land studies. As shown in Figure 17, the consumer-grade UAV equipped with a 4k gimbaled camera is ideal for collecting aerial photography.

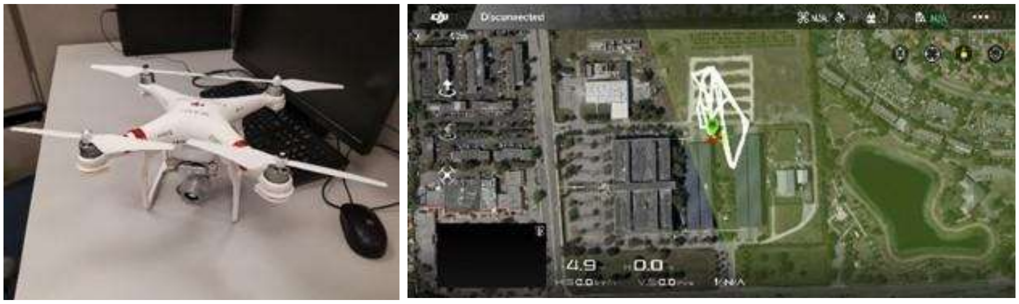

Figure 17. DJI Phantom 3 quadcopter (lef) and in-house planned flight mission (right).

Figure 18 shows sample images of in-house flights. The team plans to use the collected imagery data and the Pix4D software to generate three-dimensional topographic maps.

Figure 18. In-house aerial imagery data.

The hands-on training focused on learning about UAV systems and their main components. As sketched in Figure 19, the main components are the flight controller, GPS, IOSD, Camera, Receiver, ESC, Motor, Video Transmitter, and Video Receiver.

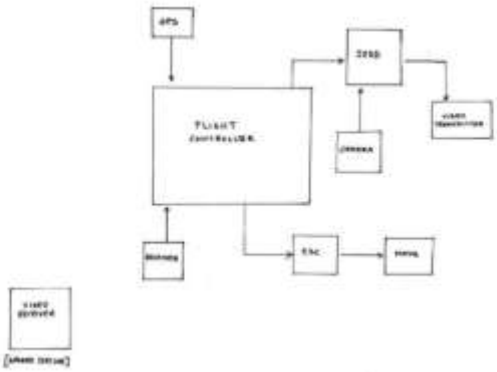

Figure 19. Typical main components in UAV systems.

The DOE Fellow, Eduardo Rojas, received practice lessons in flying UAVs, including the fundamentals of radio controls, takeoff, in-flight, and landing procedures using flight simulators and physical models.

Figure 20. DOE Fellow, Eduardo Rojas, pictured during various UAV flying practice sessions.

FIU also examined potential flight planner software suitable for surveying outdoor missions guided by a GPS autonomously. Finally, the the DOE-LM Fellow presented his research progress during the DOE-FIU Cooperative Agreement Annual Research Review held on August 25, 2020.

TASK 5.3: CONCLUSIONS

In this performance period, the foundation necessary to carry on the study was prepared, and a cohesive study plan relevant to DOE-LM needs was proposed. In the upcoming period, efforts to integrate the procured LiDAR into the octocopter aircraft will be finalized, and comparison tests to evaluate point cloud data generated by LiDAR and photogrammetry will be designed, considering relevant aspects to surveying DOE-LM sites.

The study's primary focus will continue to be on photogrammetry and LiDAR. However, other ground platforms and wearables will be considered. The compilation efforts regarding the different environmental characteristics of DOE-LM sites will be finalized, sorting information requested from the sites and managers.

FIU will continue engaging the DOE-LM Fellow in training and professional development activities, focusing on GIS, image interpretation toolsets, object detection techniques, and artificial intelligence.

ACKNOWLEDGEMENTS

Funding for this research was provided by U.S. DOE Cooperative Agreement #DE-EM0000598. Office of Legacy Management provided the funding for FIU Project 5 this year. During this period of performance, three (3) new DOE LM Fellows were hired and participated in the new pilot program between DOE LM and FIU. The FIU researchers and STEM students are grateful to DOE LM for initiating this new program at FIU.

APPENDIX

The following documents are 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

FIU Year 10 Annual Research Review Presentations:

1. FIU Research Review - Project 1
2. FIU Research Review - Project 2
3. FIU Research Review - Project 3 - DnD
4. FIU Research Review - Project 3 - IT
5. FIU Research Review - Project 4 - 5
6. FIU Research Review - Project 4 - DOE Fellow Derek Gabaldon
7. FIU Research Review - Project 4 - DOE Fellow Gisselle Gutierrez-Zuniga
8. FIU Research Review - Project 4 - DOE Fellow Aurelien Meray
9. FIU Research Review - Project 4 - DOE Fellow Jeff Navidad
10. FIU Research Review - Project 4 - DOE Fellow Silvina De Pietro
11. FIU Research Review - Project 5 - DOE Fellow Olivia Bustillo
12. FIU Research Review - Project 5 - DOE Fellow Eduardo Rojas
13. FIU Research Review - Wrap Up - Project 1
14. FIU Research Review - Wrap Up - Project 2
15. FIU Research Review - Wrap Up - Project 3 - DnD
16. FIU Research Review - Wrap Up - Project 3 - IT
17. FIU Research Review - Wrap Up - Project 4 - 5

In addition, the following documents have been uploaded to OSTI.gov:

Date Submitted to OSTI (mm/dd/yyyy)	OSTI ID	*STI PRODUCT TITLE:	Publication/ Issue Date
09/09/2020	1658912	PROJECT TECHNICAL PLAN - Project 1: Chemical Process Alternatives for Radioactive Waste	12/13/2019
09/09/2020	1658920	Literature Review of Adhesion Mechanisms For Mobile Platforms	4/10/2020
09/15/2020	1660375	Summary of Testing for the Miniature Rover with Integrated UT Sensor	7/24/2020
09/15/2020	1660379	Initial Testing for the H-Canyon Study	8/14/2020
09/15/2020	1660434	FIU PROJECT 1: Chemical Process Alternatives for Radioactive Waste	8/25/2020
09/15/2020	1660389	PROJECT TECHNICAL PLAN - Project 2: Environmental Remediation Science & Technology	12/13/2019

09/15/2020	1660396	FIU PROJECT 2: Environmental Remediation Science & Technology	8/25/2020
09/16/2020	1660534	PROJECT TECHNICAL PLAN - Project 3: Waste and D&D Engineering and Technology Development	12/13/2019
09/16/2020	1660535	EXPERIMENTAL DESIGN: Quantifying / Certifying the Effects of Radiological Fixating Materials & Technologies ISO Source Term Calculations and Open Air Demolition	1/31/2020
09/16/2020	1660536	FIU PROJECT 3: Waste and D&D Engineering and Technology Development	8/25/2020
09/16/2020	1660539	PROJECT TECHNICAL PLAN - Project 4: DOE-FIU Science and Technology Workforce Development Program	12/13/2019
09/16/2020	1660538	Subtle Process Anomalies Detection using Machine Learning Methods	12/20/2019
09/16/2020	1660543	Neptunium (IV) Diffusion through Bentonite Clay	12/20/2019
09/16/2020	1660544	Amplicon Sequencing Assessment to Measure Microbial Community Response from Heavy Metal Contaminated Soils in Savannah River Site, Tims Branch Watershed	12/20/2019
09/16/2020	1660714	An Assessment of Long-Term Monitoring Strategies and Developing Technologies	12/20/2019
09/16/2020	1660717	Mechanical Properties Permanent Foaming Fixatives for D&D Activities	12/20/2019
09/16/2020	1660721	Contributing to the DOE EM 4.1 and 4.12, Office of Groundwater and Subsurface Closure	12/20/2019
09/17/2020	1660918	Double Shelled Tank Visual Inspections	12/20/2019
09/17/2020	1660919	H-6bR Water density Stratification Investigation	12/20/2019
09/17/2020	1660921	2D Dam-Break Analysis of L Lake and PAR Pond Dams Using HEC-RAS	12/20/2019
09/17/2020	1660922	Plutonium Migration from Estuary Sediments (Ravenglass, UK)	12/20/2019
09/17/2020	1660923	FIU PROJECTS 4 & 5: DOE-FIU Science and Technology Workforce Development Program	8/25/2020
09/17/2020	1660925	PROJECT TECHNICAL PLAN - Project 5: DOE-FIU Science and Technology Workforce Development Initiative for Office of Legacy Management (NEW)	12/13/2019

09/17/2020	1660926	DOE-FIU Science and Technology Workforce Development Initiative for Office of Legacy Management	4/30/2020
09/18/2020	1661159	Biotic dissolution of autunite under anaerobic conditions: effect of bicarbonates and Shewanella oneidensis MR1 microbial activity.	Environmental Geochemistry and Health/12/19/2019. https://doi.org/10.1007/s10653-019-00480-7