YEAR END TECHNICAL REPORT

September 29, 2023, to September 28, 2024

Waste and D&D Engineering and Technology Development

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FIU | Applied Research Center
Florida International University

Addendum:

This document represents one (1) of five (5) reports that comprise the Year End Reports for the period of September 29, 2023 to September 28, 2024 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-EM0005213.

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-2023-800012997-04b-009

Project 2: Environmental Remediation Science and Technology
Document number: FIU-ARC-2023-800013918-04b-006

Project 3: Waste and D&D Engineering and Technology Development
Document number: FIU-ARC-2023-800013919-04b-006

Project 4: DOE-FIU Science & Technology Workforce Development Initiative
Document number: FIU-ARC-2023-800013920-04b-015

Project 5: Long-Term Stewardship of Environmental Remedies: Contaminated Soils and Water and STEM Workforce Development
Document number: FIU-ARC-2023-800013922-04b-005

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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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PROJECT 3 EXECUTIVE SUMMARY

The Waste and D&D Engineering and Technology Development Project (Project 3) focuses on delivering solutions under the waste, D&D and IT/data science areas for the DOE Office of Environmental Management. This work directly supports D&D activities being conducted across the DOE EM complex to include Oak Ridge, Savannah River, Hanford.

During FIU Year 4, the following DOE Fellows directly supported this project: Alejandro De-La-Noval (graduate, Computer Science), Aris Duani Rojas (graduate, Ph.D., Computer Science), Fabiola Rivera-Noriega (undergraduate, Computer Science), and Victor Gonzalez (undergraduate, Mechanical Engineering).

The following ARC researchers are supporting this project and mentoring the DOE-EM Fellows: Himanshu Upadhyay (Ph.D., Engineering/Management, Task 1, 3, 7, 8 & 9, Associate Professor, Electrical and Computer Engineering), Walter Quintero (M.S., Computer Engineering, Task 1 & 3, Research Scientist/IT Team Lead), Santosh Joshi (M.S., Engineering Management, Task 7, 8 & 9, Research Specialist II / AI Team Lead), Clint Miller (MCSA, MCSE, CompTIA Security +, C|EH, Cyber Systems Engineer), Jayesh Soni (Ph.D., Computer Science & Engineering, Task 8, Postdoctoral Associate), Joseph Sinicrope (M.S., Technology Leadership/MBA, Task 2, Research Scientist), Mellissa Komninakis (B.S., Biological Eng./Materials Science & Engineering, Task 2, Research Analyst), Jose Rivera (B.S., Civil Engineering, Research Analyst), Leonel Lagos (Ph.D., PMP®, Mechanical Eng./Civil/Env. Engineering, PI).

This project included the following tasks during the September 29, 2023, to September 28, 2024, period of performance:

Task 1: Waste Information Management System (WIMS) (HQ)

This task provides direct support to DOE EM for the management, development, and maintenance of a Waste Information Management System (WIMS). WIMS was developed to receive and organize the DOE waste forecast data from across the DOE complex and to automatically generate waste forecast data tables, disposition maps, GIS maps, transportation details, and other custom reports. WIMS is successfully deployed and can be accessed from the web address https://emwims.org/. The waste forecast information is updated annually. WIMS has been designed to be extremely flexible for future additions and is being enhanced on a regular basis.

Task 2: D&D Support to DOE EM for Technology Innovation, Development, Evaluation and Deployment

This task provides direct support to DOE EM for D&D technology innovation, development, evaluation, and deployment. Based on high priority operational requirements expressed by DOE EM HQ, the national labs, and site personnel, FIU will expand its research in technology test and evaluation to: 1) Test and evaluate a down-selected foam technology to mitigate contaminant release in the 3D irregular-shaped nuclear piping to support decommissioning activities at F/H labs and across the DOE EM complex; 2) Empirically quantify and validate the effects of fixative technologies on mitigating airborne release fractions (ARF) used in safety basis calculations and the Source Term Formula outlined in DOE-HDBK-3010; and 3) Collaborate with ASTM International E10.03 subcommittee and other DOE-EM stakeholders to update standard specifications and testing protocols for D&D technologies, with a particular emphasis on foam fixatives. FIU will further support the EM D&D program by participating in D&D workshops, conferences, and serving as subject matter experts.

Task 3: Knowledge Management Information Tool (KM-IT) (HQ, SRNL, INL, ANL)

The Knowledge Management Information Tool (KM-IT) is a web-based system developed to maintain and preserve the EM knowledge base. The system was developed by Florida International University's Applied Research Center with the support of the D&D community, including DOE-EM, the former DOE ALARA centers, and with the active collaboration and support of the DOE's Energy Facility Contractors Group (EFCOG). The KM-IT is a community driven system tailored to serve the technical issues faced by the workforce across the DOE Complex. The KM-IT can be accessed from web address http://www.dndkm.org.

Task 7: AI for EM Problem Set (Soil and Groundwater) - Exploratory data analysis and machine learning model for Hexavalent Chromium [Cr (VI)] concentration in 100-H Area (PNNL)

The Hanford Site 100 Areas contain monitoring data for groundwater wells (in situ sensing, water sampling), Hexavalent Chromium (Cr (VI)) pump and treat (P&T) activities (extraction and injection flow rates, weekly Cr (VI) sampling of influent water, etc.), as well as water table levels and river stage monitoring data. Artificial Intelligence (AI) / Machine Learning (ML) algorithms may help in understanding complex hydrogeological processes and interactions among the groundwater wells and the dynamic river stage in the Columbia River using these legacy datasets. ML and Deep Learning (DL) models can be developed to identify patterns, address knowledge gaps, and ultimately predict transport of Cr (VI) in the subsurface of the 100-H Area. The aim of this research task is to develop a robust AI/ML model for long-term monitoring, analysis, and prediction of Cr (VI) contamination in the subsurface of the Hanford Site 100 Areas.

Task 8: AI for EM Problem Set (Soil and Groundwater) – Data analysis and visualization of sensor data from the wells at the SRS F-Area using machine learning (LBNL, SRNL)

This task is focused on the development and deployment of a web-based environmental monitoring system using groundwater sensor data from Savannah River Site (SRS). The Aqua TROLL 500 and Aqua TROLL 200 sensors deployed in the SRS F-Area wells record valuable time series data including water temperature, pH, conductivity, and turbidity, among other water quality parameters. The sensors in each well record measurements hourly, thus generating a large amount of water quality data on a daily basis. FIU aims to enable easy retrieval of in-situ field data collected by the deployed sensors, improve data accessibility by the various SRS stakeholders, and facilitate the adoption of analogous web-based systems by other DOE sites with similar sensor deployments. FIU has created a web-based system that uses the HydroVu API to retrieve the water quality data from the sensors, monitor sensor performance and health, and generate reports that can be viewed via a webpage by an end user. Data derived from the sensors can aid in the detection of broken or low battery sensors, uncharacteristic water quality parameters within the F-Area wells, and other significant environmental anomalies.

Task 9: AI for EM Problem Set (Waste Processing) - Nuclear Waste Identification and Classification using Deep Learning

Identifying the low-level nuclear waste and segregation is a hazardous task for the workforce involved in this activity across the DOE complex. To solve this challenging problem, an AI-enabled Robotic ARM was designed using state-of-the-art technology that can facilitate the identification and segregation of the low-level waste (LLW). Previous work at FIU was focused on developing multiple object detection algorithms with different tradeoffs with respect to data quality, speed, and performance. FIU's current work is focused on researching and implementing multiple k-shot object detection algorithms. K-shot object detection algorithms are Deep Learning models designed to detect new object classes without training.

MAJOR TECHNICAL ACCOMPLISHMENTS

Task 1: Waste Information Management System (WIMS) (HQ)

- Performed day-to-day maintenance and administration tasks to monitor and ensure a consistent high level of performance of the WIMS application, using tools such as Google Analytics and Google Search Console.
- Completed the update of WIMS by incorporating the revised 2024 waste forecast and transportation data provided by DOE HQ into the system (Milestone 2023-P3-D5). The 2024 waste forecast data included 6 waste types, 746 waste streams, 36 reporting sites and 37 disposition facilities. The task was officially completed on May 31, 2024.
- Monitored the WIMS site performance, accessibility and Search Engine Optimization (SEO) using multiple tools that offer insight into the website's overall performance and help identify potential issues before they become a problem.
- Maintained the script for the Google Map API which supports the GIS module to ensure it was compliant with the new version of the API.
- Consistently engaged with the external FIU security team to perform independent testing and with the DOE Fellows to conduct internal testing to ensure that the WIMS application remained secure and reliable.
- Presented a poster based on the WIMS application at the Waste Management Symposia 2024 (WM2024) and submitted a new abstract which was accepted for WM2025.

Task 2: D&D Support to DOE EM for Technology Innovation, Development, Evaluation and Deployment

- Drafted a Research Utilization Update Memorandum on Fire Resilient Fixatives in collaboration with SRNL technical leads on behalf of DOE EM TD. D&D teams at the 235F facility have continued to employ the incombustible fixative for fire hazard mitigation and contamination control throughout the facility. Beyond the usage for specific end state goal achievement, this fixative has also been applied to contaminated areas with large surface areas. Entire rooms have been coated to minimize the spread of contamination in Shielded Areas A, B, C, and 772-1F L156 at the SRS over the ensuing years since the initial hot test at the SRS 235-F PUFF Facility.
- Collaborated with SRNL technical leads to author the document titled "*Radiation Hardened Foam Hot Test Plan-Phase III: Evaluation of FoamBag™ / Endseal Fixative Foams During Application in a Radiological Environment*" (SRNL-STI-2024-00326). It was formally approved for execution by all DOE EM stakeholders.
- Completed a technical progress report titled, *"Foam Technologies for Mitigating Risk During Nuclear Pipe Decommissioning – Containment & Leak Testing"*, document number FIU- FIU-ARC-2023-800013919-04c-005, which will be published on OSTI.
- Developed a peer-reviewed manuscript, *"Determination of Airborne Release Fractions from Loose Powder Contamination under Impact Stress"*, doi:10.1080/00295450.2024.2345945, which was accepted and published in the journal, *Nuclear Technology*.
- Continued to chair the ASTM International E10.03 Subcommittee and led the formal 5-year reapproval and promulgation for 2 international standards in support of the D&D

community: a) E1760, *Guide for Unrestricted Disposition of Bulk Materials Containing Residual Amounts of Radioactivity;* and b) E3191, *Standard Specification for Permanent Foaming Fixatives Used to Mitigate the Spread of Radioactive Contamination,* for renewal and balloting.
- Supported the D&D Roadmap initiative sponsored by DOE EM.

Task 3: Knowledge Management Information Tool (KM-IT) (HQ, SRNL, INL, ANL)

- Published 23 technologies and 63 news articles, updated vendor information, and posted 8 events on the KM-IT platform. In addition, the team kept the content fresh with relevant resources for the community, such as D&D-related training, conferences, and workshops. The content management efforts continue to keep the website current and informative for the D&D community.
- Attended the 2024 Waste Management Symposia where the team hosted a booth to display and demo the D&D KM-IT research on document summarization and using Large Language Model (LLM). The LLM model was deployed successfully on the FIU AI Ops website and will continue to be matured for better results and efficiency.
- Presented a paper at WM2024 based on LLM titled *"Artificial Intelligence Based Nuclear Decommissioning Document Summarization"* which focuses on exploring AI capabilities to summarize D&D documents stored in the D&D KM-IT.
- Developed eight (8) newsletters for mass communication via email to keep users informed of new system features and other related activities. Newsletters were also sent to the registered users of the KM-IT and to the participants of the Waste Management Symposia with news articles and upcoming events.
- Hosted four (4) Tech Talks during this period of performance (in October 2023, and January, April, and July 2024). This involved collaboration with Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Los Alamos National Laboratory (ANL), and Florida International University's Applied Research Center (FIU-ARC) research team to present topics relevant to the DOE EM Complex.
- Gave a presentation to the DOE HQ Knowledge Management Community on June 6, 2024. The presentation topic was on the use of Generative AI in D&D and Infrastructure, using as an example the document summarization mentioned under Subtask 3.4 using the D&D documents in the KM-IT database.
- Ssuccessfully kept the D&D KM-IT application and production environment running with optimal performance. In addition, the team continued to test, maintain, secure and administer the KM-IT system to keep it secure and up to date with industry standards by updating the Secure Socket Layer (SSL), updating the production environment with updates/patches, replacing hardware for optimum performance, and testing the application on a secure network using cyber security tools.

Task 7: AI for EM Problem Set (Soil and Groundwater) – Exploratory data analysis and machine learning model for Hexavalent Chromium [Cr (VI)] concentration in 100-H Area (PNNL)

- Researched and implemented generative AI algorithms to fill in the missing values in the data for reliable modeling. The Generative Adversarial Networks (GANs), Variational AutoEncoders (VAEs), Synthetic Minority Over-sampling Technique for Regression (SMOTER) and Time-series Generative Adversarial Networks (TimeGAN) algorithms are implemented to generate synthetic data using the data files from 100-H area.

- Re-trained the Long Short-Term Memory (LSTM) models with synthetic datasets to evaluate the prediction accuracy.
- Conducted literature review on the attention mechanisms and explainability, specifically focusing on their application to time series datasets with multiple features.
- Conducted research on TabTransformers and various LSTM architectures tailored for tabular datasets.

Task 8: AI for EM Problem Set (Soil and Groundwater) - Data analysis and visualization of sensor data from the wells at the SRS F-Area using machine learning (LBNL, SRNL)

- Hosted a web application (ALTEMISAI) to publish the sensor data reports to authenticated users.
- Implemented stored procedures such as 'TopNClosestSensors' and 'GetLowBatteryOrMissingSensors' to streamline the retrieval of crucial sensor data and identify sensors with low battery levels or missing data, effectively bolstering maintenance processes and sensor data integrity.
- Continued to report missing or low battery sensors to SRNL based on hourly sensor data.
- Analyzed the lab data provided by SRNL and developed ML models using multiple algorithms with hyperparameter optimization to find the models that can best predict the contaminant concentration.

Task 9: AI for EM Problem Set (Waste Processing) - Nuclear Waste Identification and Classification using Deep Learning

- Developed and implemented OWL-ViT for one-shot object detection, enabling accurate detection of previously unseen LLW with minimal training data by leveraging vision transformer-based architectures.
- Created a custom reinforcement learning (RL) algorithm for one-shot object detection, optimizing detection performance through reward-based learning for LLW.
- Adapted YOLOv8 for supervised object detection of low-level nuclear waste, achieving high precision and recall metrics in challenging environments with real-world datasets.
- Designed and deployed an API for seamless model integration with a robotic arm, ensuring real-time inference capabilities without imposing additional hardware requirements on the robotic system.

TASK 1: WASTE INFORMATION MANAGEMENT SYSTEM (WIMS) (HQ)

The Waste Information Management System (WIMS) was developed to receive and organize the DOE waste forecast data from across the DOE complex and to automatically generate waste forecast data tables, disposition maps, GIS maps, transportation details, and other custom reports. WIMS is successfully deployed and can be accessed from the web address https://emwims.org/.

During this period, the team developed a poster titled *"Waste Information Management System with 2022-23 Waste Streams"* which was presented at the WM2024 conference in Phoenix on March 12, 2024. The image in Figure 1 below shows the final version of the poster.

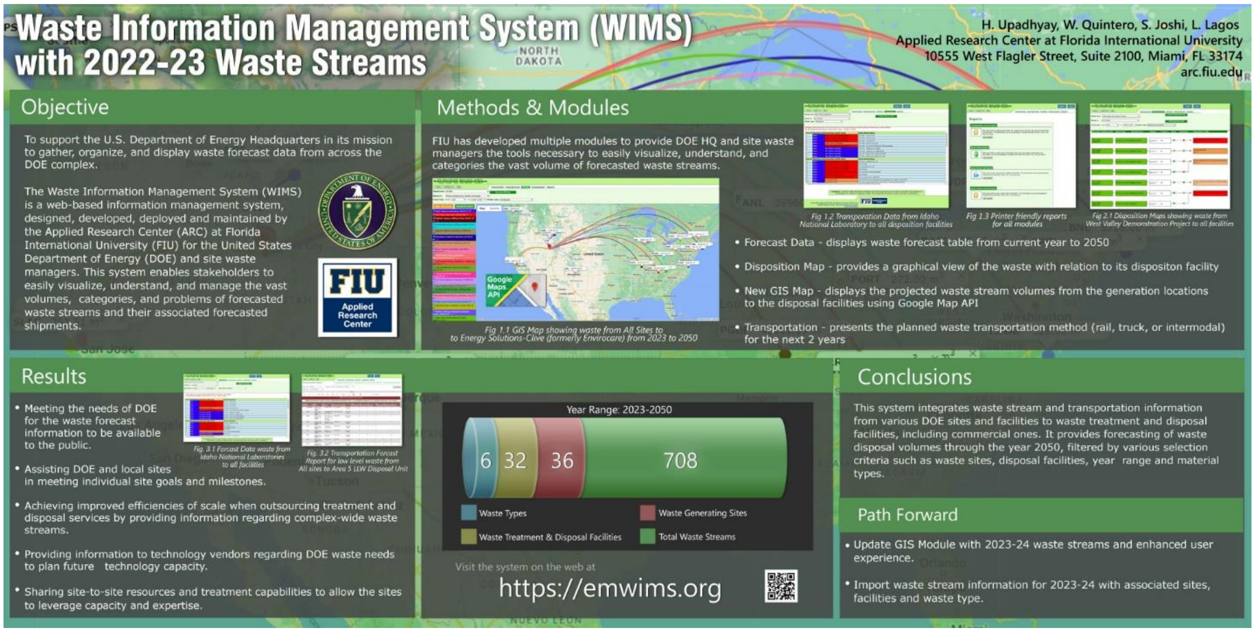


Figure 1. WIMS poster for WM2024 titled *"Waste Information Management System with 2022-23 Waste Streams"*.

The picture below shows the FIU and DOE team presenting the poster, Walter Quintero *(left)* and Dr. Himanshu Upadhyay *(right)*.

Figure 2. FIU-DOE team presenting WIMS poster at WM2024, Walter Quintero *(left)* and Dr. Himanshu Upadhyay *(right).*

Subtask 1.1 WIMS System Administration & Cyber Security – Database Management, Application Maintenance & Performance Tuning

Subtask 1.1: Introduction

This subtask includes the day-to-day maintenance and administration of the application and the database servers. FIU maintains the WIMS application system to ensure a consistent high level of performance. In addition, the database administrators perform routine maintenance in order to keep the WIMS database and server in a stable condition. The WIMS application is also maintained on the web server by the Web Server Administrator. This administrator monitors the network and server traffic and performs changes necessary to optimize the application performance. In addition, as part of this subtask, FIU provides application and database security, as well as Help Desk support to DOE site waste managers, HQ managers and other users who need assistance in using WIMS.

Subtask 1.1: Objectives

The goal of this assignment is to oversee and manage the maintenance of the WIMS application, ensuring it operates according to its design. This requires ongoing commitment from the team to regularly update both the software and hardware, safeguarding the application's resilience. Given the escalating frequency of cyber threats, the FIU team actively maintains the application's security through timely updates. This proactive approach not only mitigates the risk of cyber breaches but also enhances the user experience, enabling the application to run optimally.

Subtask 1.1: Methodology

FIU continued to perform day-to-day maintenance and administration of the application and the database servers to ensure a consistent high level of performance of the WIMS application system. FIU continued to execute certain security tasks, including antivirus engine and definitions updates on both the web and database servers. Other maintenance tasks included Windows OS updates and patches that were applied to the servers running the emwims.org application. This routine maintenance is necessary to keep the WIMS database and server in a stable condition and to monitor the network and server traffic to optimize the application's performance. Updates worth mentioning included:

- Configuration of the Google Map API, mostly involving Google reCAPTCHA verification. This is used by the Google Map API to prevent spamming to their API.
- Update of the disposition map module legend.
- Monitoring of the Google Search Engine console which is used to detect any issues that the site may experience preventing Google to crawl the site.
- Monitoring of the Google Analytics G4 script used to track user traffic. This script was recently changed by Google which introduced new features.

Subtask 1.1: Results and Discussion

FIU continued performing day-to-day maintenance and administration of the application and the database servers to ensure a consistent high level of performance of the WIMS application system. In addition, certain security tasks were constantly executed, including antivirus engine and definition updates on both the web and database servers. Other maintenance tasks included Windows OS updates and patches that were applied to the servers running the emwims.org application. This routine maintenance is necessary to keep the WIMS database and server in a stable condition and to monitor the network and server traffic to optimize the application's performance.

Multiple tools were used to monitor the site performance, accessibility, and Search Engine Optimization (SEO). These tools offer insight into the website's overall performance and can help identify potential issues before they become a problem. The image below (Figure 3) shows a snapshot of the website after running a report which not only shows that the site is performing at an optimal level, but also points out that there are some accessibility issues that need to be addressed. This information was used to prioritize if something needed attention on the site. This report showed improvement when compared to last year. The Best Practice and SEO scores increased to 89 and 92, respectively.

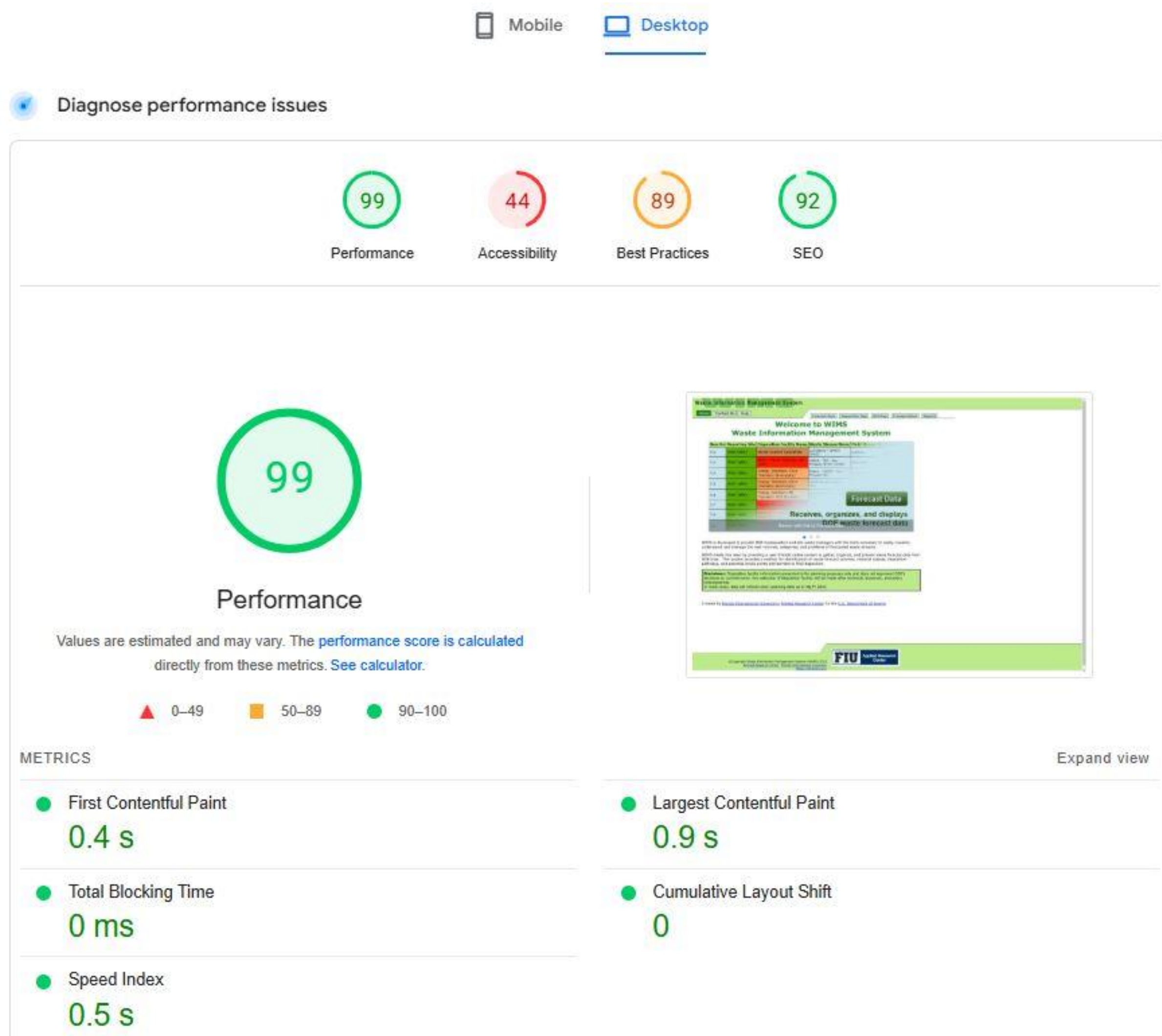


Figure 3. Snapshot report from Google PageSpeed Insights for emwims.org.

Recommendations by the Google Search Console tools were also addressed, such as adding alternative text to images and modifying the code to help with some modern browsers that required a viewport setting in the heading section. These changes helped the page to be compatible with search engines and improved the Search Engine Optimization (SEO) score.

The Google Map API key was also revised after a recent update by testing the GIS module. This API key frequently updates, thus requiring consistent updates of the script configuration with the updated key.

One major effort included the team setting up a development environment to perform the waste stream annual data integration (Subtask 1.2). This new environment was a backup of the current production environment and was used to work on Subtask 1.2 in parallel to the production environment. This way, the WIMS application was able to remain online without any interruption. The specific efforts included creating a virtual machine for development, installing appropriate software (MS SQL and Visual Studio), backing up the application files and the SQL database from production, setting up a remote connection for the team to work on the virtual machine and updating the firewall rules to interact with the applications, such as the Google Map API.

After the waste stream annual data integration (deliverable 2023-P3-D5)was completed, a development and staging environment for the application was created. The development environment was used to import the new waste stream data and to work on the application in parallel to the production application. In addition, a staging environment was created to share the progress with DOE HQ and allow them to provide feedback on the development. After DOE completed the review, the application was moved to production (https://emwims.org/) which completed the deliverable on May 31, 2024. The team then proceeded to clean up the development and staging environment.

FIU also continued to monitor the Google Analytics version 4 (GA4) scripts recently implemented on the site to make sure the application continues to report the website activity properly. GA4 added new reporting features which the team is learning to implement by experimenting with the configuration settings.

In addition, hardware maintenance was conducted by replacing several hard drives on the backup server. The FIU team closely monitors all the hardware that supports the application and keeps track of performance issues and lifetime of the hardware. Any hardware that starts to underperform or is close to its recommended life cycle is replaced to avoid failures.

Finally, an abstract was submitted to the Waste Management Symposia 2025 (WM2025) titled *"Waste Information Management System with 2024-25 Waste Streams"*. WM is held every year in Phoenix, AZ during the month of March. If the abstract is accepted, the team will submit a full paper and poster to present at the conference.

Subtask 1.1: Conclusions

The culmination of these efforts is a robust and secure WIMS web application that consistently performs at its best. By proactively addressing maintenance needs, the team ensures the application's resilience against cyber threats. This not only reduces the likelihood of security breaches but also contributes to an enhanced user experience. The result is a reliable and optimized WIMS application that aligns with its intended design, providing users with a secure and seamless digital experience.

Subtask 1.1: References

Waste Information Management System (WIMS), https://emwims.org/, Applied Research Center, Florida International University.

Subtask 1.2: Waste Stream Annual Data Integration

Subtask 1.2: Introduction

Under this subtask, FIU receives revised waste forecast data as well as transportation data as formatted data files on an annual basis. To incorporate these new files, FIU built a data interface to allow the files to be received by the WIMS application and imported into SQL Server. SQL server is the database server where the actual WIMS data is maintained. This data is typically received from DOE in the April/May timeframe.

Subtask 1.2: Objectives

The objective of this subtask is to consolidate waste forecast information from separate DOE sites and build forecast data tables, disposition maps, and GIS maps on the web. An integrated system was needed to receive and consolidate waste forecast information from all DOE sites and facilities and to make this information available to all stakeholders and the public. As there was no off-the-shelf computer application or solution available for creating disposition maps and forecast data, FIU built a DOE complex-wide, high performance, n-tier web-based system for generating waste forecast information, disposition maps, GIS Maps, successor stream relationships, summary information and custom reports based on DOE requirements.

Subtask 1.2: Methodology

Under this subtask, FIU receives and incorporates the revised waste forecast data files into the system on a yearly basis. The new waste data replaces the existing waste data and becomes fully viewable and operational in WIMS. In March, revised waste forecast data was received from DOE-HQ as formatted data files. To incorporate these new files, a data interface was built to allow these specific files to be formatted for the WIMS application and imported into SQL Server. This data was imported and mapped to the 2024 waste stream structure which then updated the Forecast Data, Disposition map, Successor stream map, Transportation and Reports.

The process begins by backing up the existing production database and application to move to a development environment and testing the development environment in preparation for the data import.

FIU received the 2024 waste forecast data from DOE HQ at the end of March 2024. The data was inspected to make sure it included all the sites and facilities, waste stream types and forecasted dates required for import. The team normalized the data by updating column headings to match the current database schema. The data was imported and reviewed/matched to the original source data sent by DOE HQ. Once this verification process was completed, the team started the development process to make sure each module was able to access the new data. DOE Fellows helped with testing the application modules to make sure everything was working, while the staff continued to address any development issues and make sure the application was running smoothly before moving it back to the production server.

Next, the team began working on validating the data, making sure all the site and facility information matched current data. The data was then normalized prior to its import to the SQL server. Once the data migration to the SQL server was deemed successful, work began on the actual development of the application to consume the new data. The team worked on the development environment so that the production application will not experience any interruptions. The first module worked on was the reporting module. This module was updated to accommodate the new data year range, material and waste type. Once multiple reports were finished, the team started to generate reports to compare their output with the original Excel data received from DOE HQ. The DOE Fellows assisted in this Quality Assurance (QA) process to make sure the results matched the original data provided exactly. The image below shows a sample WIMS report showing waste stream data starting from 2024 from "All Sites" to "Perma-Fix Gainesville". While the DOE Fellows continued to work on this process, the team proceeded to work on the other modules (Forecast Data, Disposition Map, GIS Map and Transportation).

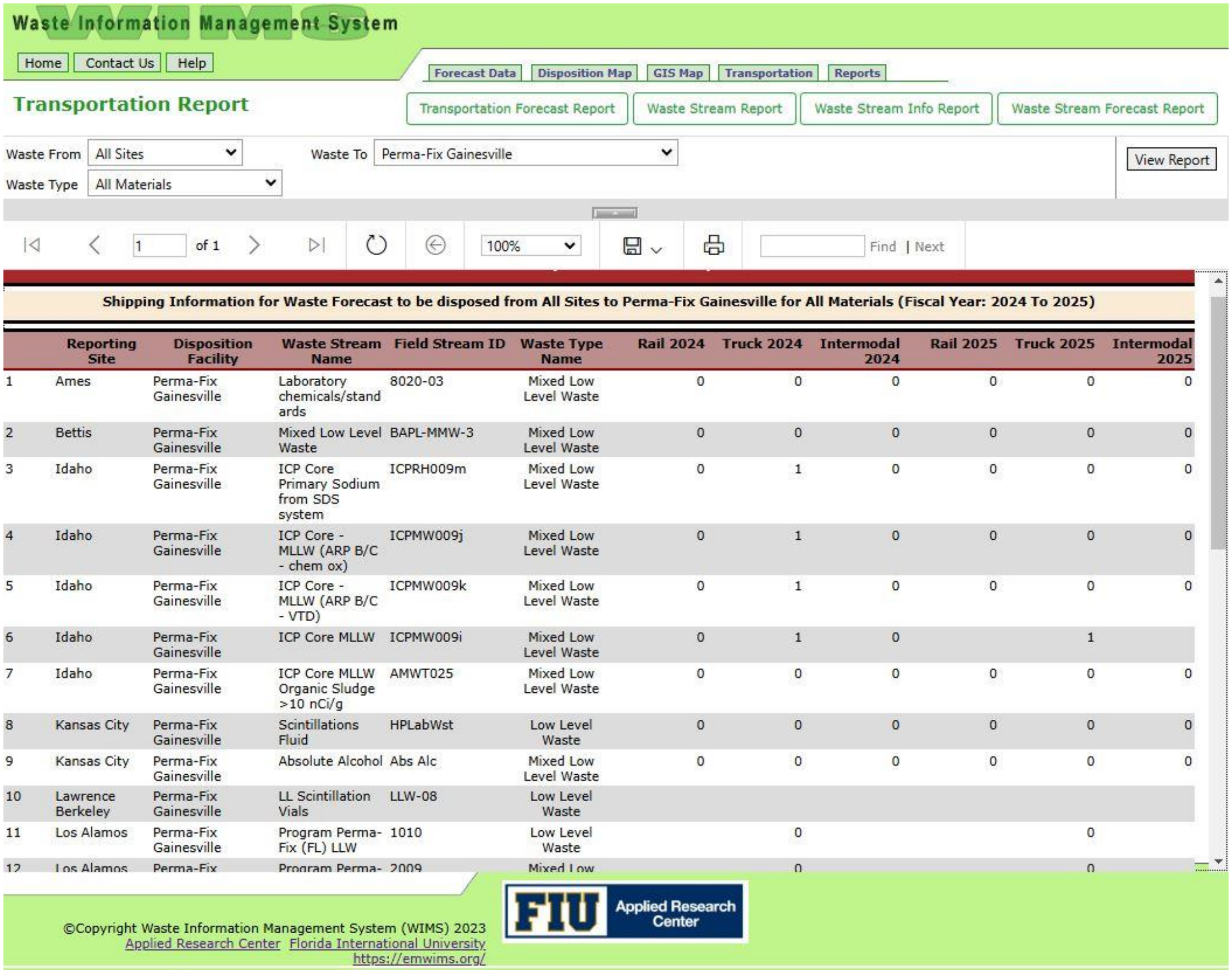


Figure 4. WIMS reporting module showing waste stream data starting from 2024 from "All Sites" to "Perma-Fix Gainesville".

FIU updated the legend on the Disposition Map module to include new treatment codes. The image below shows the new legend under the disposition map for waste streams from “All Sites” to “Clean Harbors” starting in 2024 for all materials.

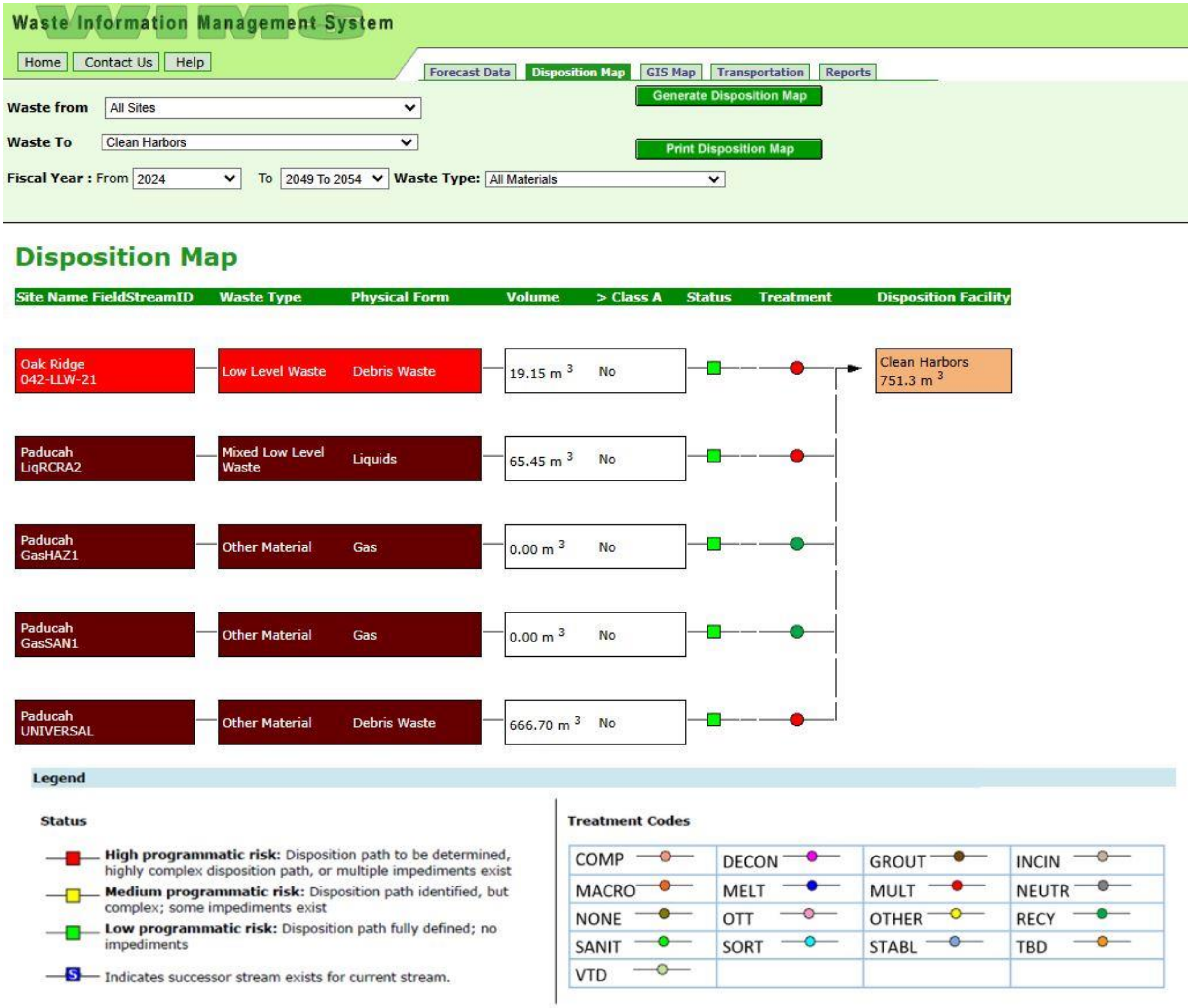


Figure 5. WIMS Disposition Map module with legend for waste streams from "All Sites" to "Clean Harbors" starting in 2024 for all materials.

By the end of April, the team completed the input of the data, development, and enhancement of each of the modules on the development environment. FIU provided DOE HQ with a URL on the staging server for them to review the progress, test the application and provide additional feedback and comments. The DOE Fellows then continued to perform data validation on each of the modules.

Subtask 1.2: Results and Discussion

During the month of May, the development and enhancement of each of the modules was completed after performing an internal review. FIU provided DOE HQ with a URL on the staging server for them to review the progress, test the application and provide additional feedback and comments. FIU addressed the feedback provided from DOE HQ and moved the application to the production server making the new data and application live at http://emwims.org. DOE HQ was notified about the completion of this deliverable (2023-P3-D5 due on May 31, 2024) on May 5, 2023. The following screenshots show the WIMS application running live on the production server. The modules shown are Forecast Data, Disposition Map, GIS Map, Transportation and Reports.

The current application features updates to the Forecast Data, Disposition map, Successor stream map, Transportation and Reports modules. The 2024 waste stream data covers 37 sites and 37 disposition facilities for a combined total of 746 waste streams. The images below show several screenshots of the WIMS application modules.

The image below shows the Forecast Data module with data from "All Sites" to "Lawrence Livermore National Laboratory" from year "2024" to "2049 to 2054" for all material waste types.

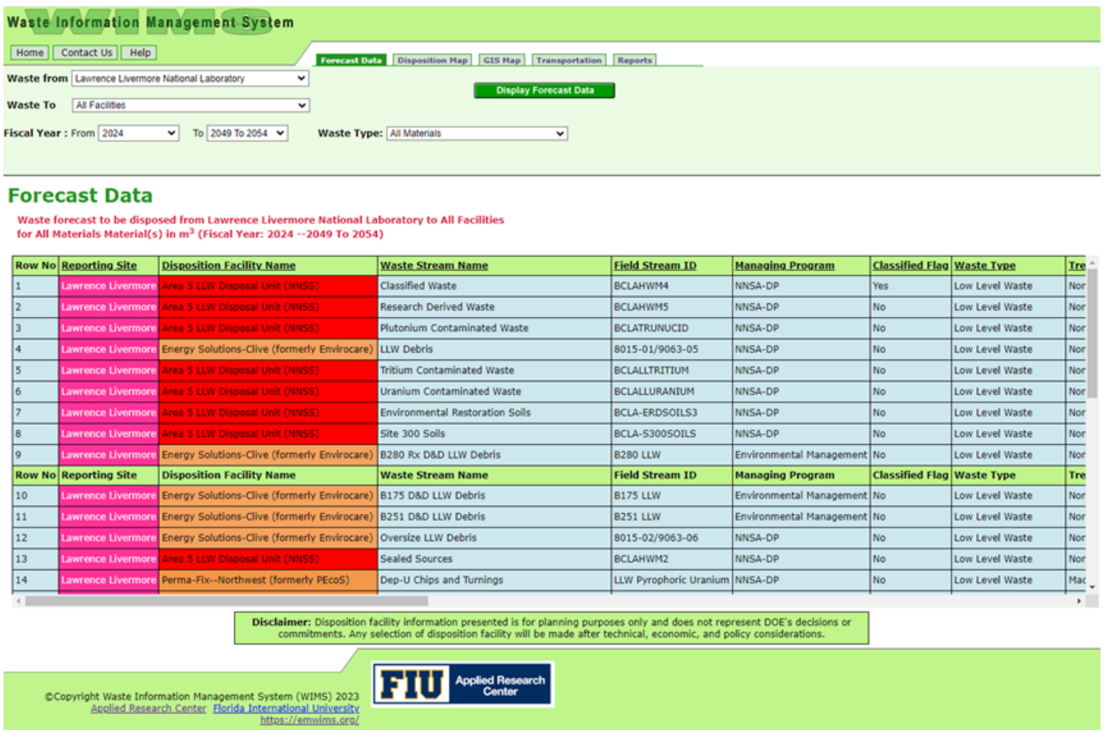


Figure 6. WIMS Forecast Data module showing waste streams from Lawrence Livermore National Laboratory to all facilities.

The image below shows the Disposition Map module with data from "Ames Laboratory" to "All Facilities" from year "2024" to "2049 to 2054" for all material waste types. Notice that total waste is grouped by disposition facilities.

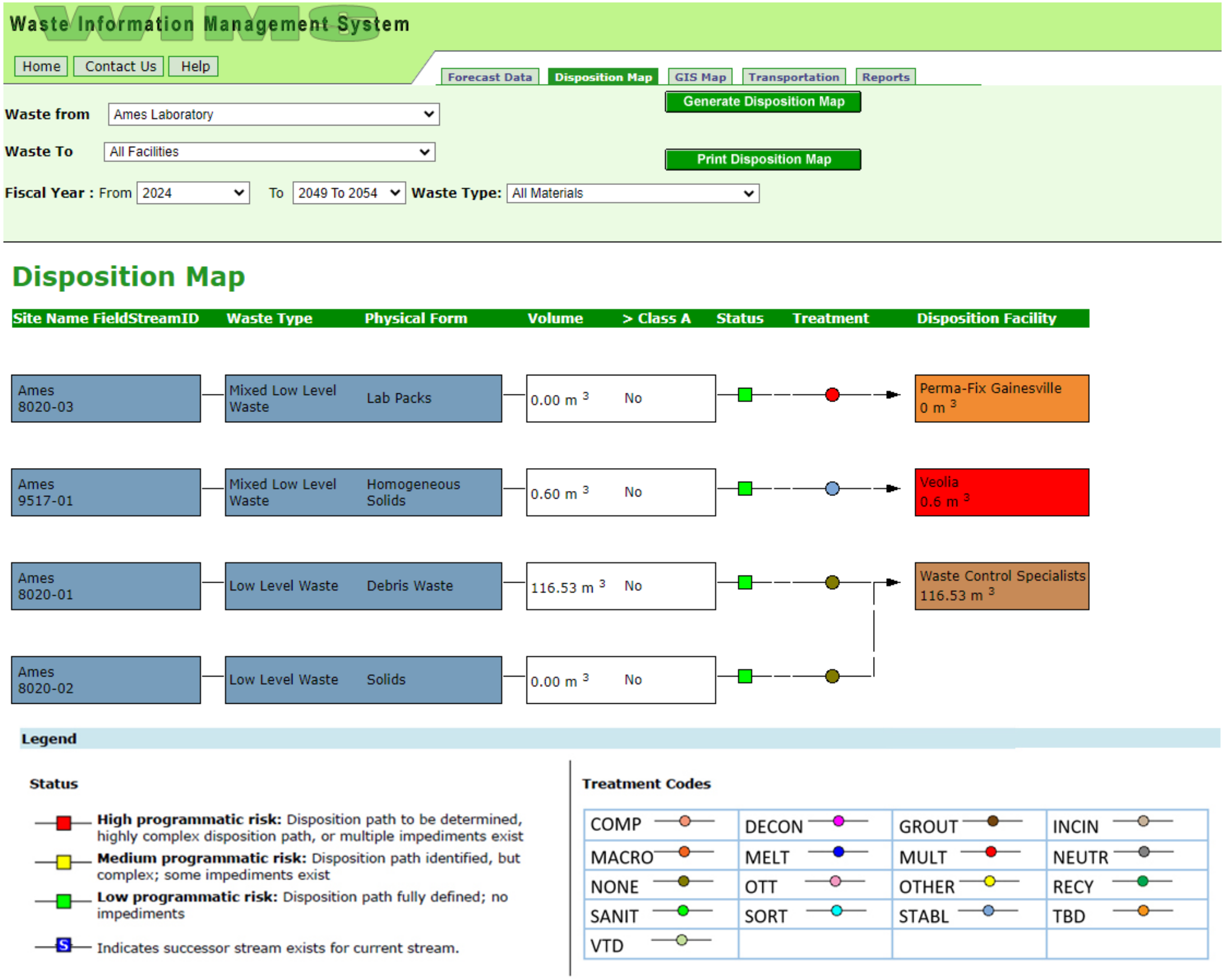


Figure 7. WIMS Disposition Map module showing waste streams from Ames Laboratory to all facilities with updated treatment code legend.

The following image below shows the GIS Map module with data from "Los Alamos National Laboratory" to "All Facilities" from year "2024" to "2049 to 2054" for all material waste types. The GIS map shows the multiple disposition locations across the country with the total volume. The list of disposition locations is also shown on the left side banner which can be used to filter the data on the map.

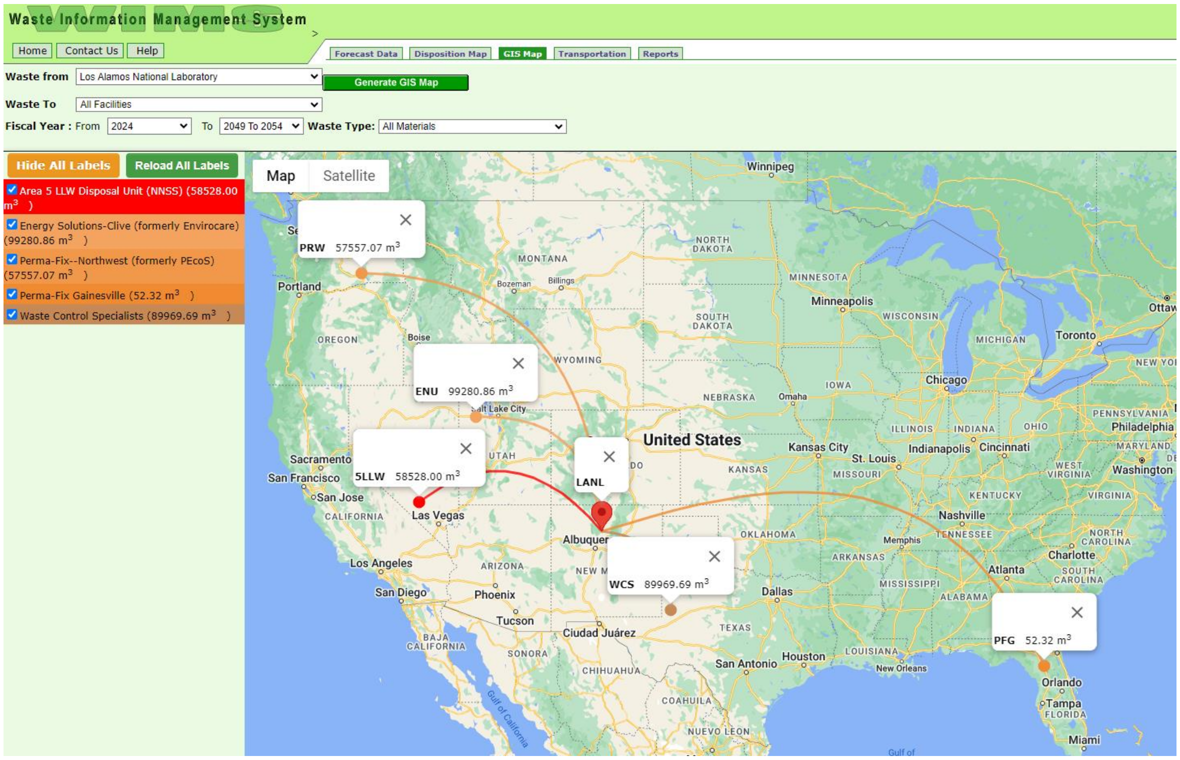
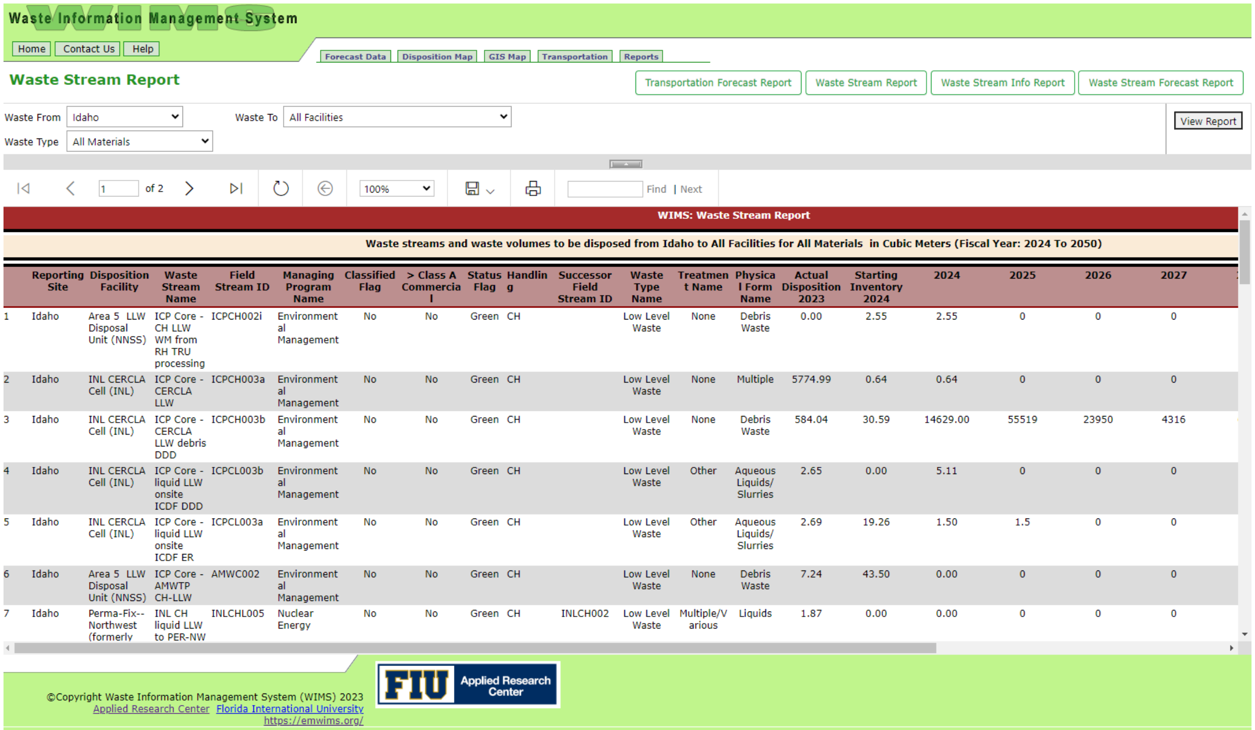


Figure 8. WIMS GIS Map module with data from “Los Alamos National Laboratory” to “All Sites”.

This next image shows the Transportation module with data from the “Naval Reactor Facility” to “All Facilities” for all material waste types. This module lists the mode of transportation to be used (Rail, Truck, Intermodal) for the next few years (2024, 2025).

Figure 9. WIMS Transportation module with data from “Naval Reactor Facility” to “All Facilities”.

Finally, the image below shows the Report module (Waste Stream Report) with data from “Idaho” to “All Facilities” for all material waste types. Note that the report module supports export of any report to multiple formats (Word, Excel, PowerPoint, PDF and more).



	Reporting Site	Disposition Facility	Waste Stream Name	Field Stream ID	Managing Program Name	Classified Flag	> Class A Commercial	Status Flag	Handling	Successor Field Stream ID	Waste Type Name	Treatment Name	Physical Form Name	Actual Disposition 2023	Starting Inventory 2024	2024	2025	2026	2027
1	Idaho	Area 5 LLW Disposal Unit (NNSS)	ICP Core - CH LLW WM from RH TRU processing	ICPCH002i	Environmental Management	No	No	Green	CH		Low Level Waste	None	Debris Waste	0.00	2.55	2.55	0	0	0
2	Idaho	INL CERCLA Cell (INL)	ICP Core - CERCLA LLW	ICPCH003a	Environmental Management	No	No	Green	CH		Low Level Waste	None	Multiple	5774.99	0.64	0.64	0	0	0
3	Idaho	INL CERCLA Cell (INL)	ICP Core - CERCLA LLW debris DDD	ICPCH003b	Environmental Management	No	No	Green	CH		Low Level Waste	None	Debris Waste	584.04	30.59	14629.00	55519	23950	4316
4	Idaho	INL CERCLA Cell (INL)	ICP Core - liquid LLW onsite ICDF DDD	ICPCL003b	Environmental Management	No	No	Green	CH		Low Level Waste	Other	Aqueous Liquids/ Slurries	2.65	0.00	5.11	0	0	0
5	Idaho	INL CERCLA Cell (INL)	ICP Core - liquid LLW onsite ICDF ER	ICPCL003a	Environmental Management	No	No	Green	CH		Low Level Waste	Other	Aqueous Liquids/ Slurries	2.69	19.26	1.50	1.5	0	0
6	Idaho	Area 5 LLW Disposal Unit (NNSS)	ICP Core - AMWTP CH-LLW	AMWC002	Environmental Management	No	No	Green	CH		Low Level Waste	None	Debris Waste	7.24	43.50	0.00	0	0	0
7	Idaho	Perma-Fix--Northwest (formerly	INL CH liquid LLW to PER-NW	INLCHL005	Nuclear Energy	No	No	Green	CH	INLCH002	Low Level Waste	Multiple/Various	Liquids	1.87	0.00	0.00	0	0	0

Figure 10. WIMS Report module (Waste Stream Report) with data from "Idaho" to "All Facilities".

After publishing the updated 2024 waste stream data from DOE to the production server, the team has continued to monitor the performance of the website modules and reports and has since made minor tweaks to address display issues (updating HTML and CSS code). The team will continue to monitor the site and will address any other issues that may arise.

Below is the list of the 36 supported sites on WIMS.

- Ames Laboratory
- Argonne National Laboratory
- Bettis Atomic Power Laboratory
- Brookhaven National Laboratory
- Energy Technology Engineering Center
- Fermi National Accelerator Laboratory
- Hanford Site-RL
- Hanford Site-RP
- Idaho National Laboratory
- Kansas City Plant
- Knolls Atomic Power Laboratory - Kesselring
- Knolls Atomic Power Laboratory - Schenectady
- NG Newport News
- Norfolk Naval Shipyard
- Nuclear Fuel Services, Inc. (cleanup site)
- Oak Ridge Reservation
- Pacific Northwest National Laboratory
- Paducah Gaseous Diffusion Plant
- Pantex Plant
- Pearl Harbor Naval Shipyard
- Portsmouth Gaseous Diffusion Plant
- Portsmouth Naval Shipyard
- Princeton Plasma Physics Laboratory
- Puget Sound Naval Shipyard
- Sandia National Laboratories – NM
- Savannah River Site
- Separations Process Research Unit
- Stanford Linear Accelerator Center

• Lawrence Berkeley National Laboratory • Lawrence Livermore National Laboratory • Los Alamos National Laboratory • Naval Reactor Facility • Nevada National Security Site	• Thomas Jefferson National Accelerator Facility • Waste Isolation Pilot Plant • West Valley Demonstration Project

Below is the list of the 37 supported facilities on WIMS.

• 200 Area Burial Ground • 746-U Landfill • Area 5 LLW Disposal Unit • Area 5 MLLW Disposal Cell • Area G (LLW disposal) (LANL) • Clean Harbors • Commercial TBD • E-Area Disposal (SRS) • EMWMF Disposal Cell (ORR) • Energy Solutions - Clive (formally Envirocare) • Energy Solutions - TN (formally GTS Duratek) • ERDF (HANF) • Heritage Liverpool (Ohio) • Impact Services-TN • INL CERCLA Cell (INL) • Integrated Disposal Facility (HANF) • New RH LLW Vaults (INL) • Omega Waste Logistics • ORNL Liquid LLW System	• OSWDF (Portsmouth) • Paducah CERCLA • Perma-Fix Gainesville • Perma-Fix--Diversified Scientific Services, Inc. • Perma-Fix--Northwest (formally PEcoS) • Perma-Fix/Materials & Energy Corp • Remote Waste Disposition Project (INL) • River Metals • RMW Trenches (MLLW/LLW) (HANF) • RMW Trenches/IDF (HANF) • RWMC (LLW disposal) (INL) • Siemens • Smokey Mountain Solutions • To Be Determined • Unitech • US Ecology-Idaho • Veolia • Waste Control Specialists

Subtask 1.2: Conclusions

WIMS continues to successfully accomplish the goals and objectives set forth by DOE. WIMS has replaced the historic process of each DOE site gathering, organizing, and reporting their waste forecast information utilizing different database and display technologies. In addition, WIMS meets DOE's objective to have the complex-wide waste forecast information available to all stakeholders and the public in one easy-to-navigate system. The data includes low-level and mixed low-level radioactive waste forecast data supplied by all DOE programs in addition to transportation information. After a final review, the FIU team published the 2024 stream data (6 waste types, 746 waste streams, 36 reporting sites and 37 disposition facilities) and application to the production server running live at https://emwims.org/. DOE HQ was notified about the completion of this deliverable (2023-P3-D5 due on May 31, 2024).

Subtask 1.2: References

Office of Environmental Management (DOE-EM), https://www.energy.gov/em/office-environmental-management, U.S. Department of Energy.

Waste Information Management System (WIMS), https://emwims.org/, Applied Research Center, Florida International University.

TASK 2: D&D SUPPORT TO DOE EM FOR TECHNOLOGY INNOVATION, DEVELOPMENT, EVALUATION AND DEPLOYMENT

Subtask 2.1: Development of Uniform Testing Protocols and Standard Specifications for Fixative Technologies in Support of Complex-wide D&D Activities

Subtask 2.1: Introduction

The U.S. Department of Energy's Office of Environmental Management (DOE EM) has taken a leading role in investing in the research and development (R&D) of critical technologies to support the safe and efficient decommissioning of legacy nuclear facilities. To facilitate the complex-wide deployment and adoption of those technologies from the laboratory to end users, and to maximize return on investment of government-sponsored R&D projects, DOE EM proactively solicits and evaluates initiatives intended to enhance achievement of these goals. Given that standards-based testing and evaluation is a critical enabler to the successful transition and deployment of D&D technologies from the lab to the end user, FIU continued to actively participate in ASTM International's E10 and E10.03 Committees to develop and promulgate uniform performance metrics and testing protocols for D&D technologies.

Subtask 2.1: Objectives

Under this task, FIU ARC continues to actively participate in ASTM International's E10 and E10.03 Committees to develop and promulgate uniform performance metrics and testing protocols for D&D technologies, with a particular emphasis on fixatives and foams. This activity directly supports the planned operational deployment of those technologies on site, as well as establishes the groundwork for updating the DOE-HDBK-3010. Providing a uniform certification methodology for fixative technologies has been deemed an essential goal under this activity.

Subtask 2.1: Methodology

Leveraging the fixatives research and development activities being led by Savannah River National Laboratory (SRNL) and Florida International University's Applied Research Center (FIU ARC) on behalf of DOE EM's Office of Infrastructure and D&D, a collaboration with ASTM International's E10 Committee and E10.03 Subcommittee has been established to develop, codify, and promulgate consensus-based standard specifications and uniform testing practices. This initiative captures the advancements made in experimental design formulation for fixative technologies during the test and evaluation phases of designated activities across the DOE EM complex. An FIU researcher serves as the Chair and a SRNL researcher serves as the Vice-Chair, with other national lab representatives joining as voting members. As testing protocols for various fixative technologies (e.g.: permanent, foam, decon gels, etc.) are developed and proven, they are subsequently introduced to the E10.03 Subcommittee for review, balloting, approval, and promulgation as an international standard for the D&D community.

Subtask 2.1: Results and Discussion

As highlighted above in the achievements section, two benchmark standard specifications for the D&D community were updated and reapproved over this reporting period. Specifically, E1760, *Guide for Unrestricted Disposition of Bulk Materials Containing Residual Amounts of Radioactivity;* and E3191, *Standard Specification for Permanent Foaming Fixatives Used to Mitigate the Spread of Radioactive Contamination,* was submitted for renewal and balloting.

The formal balloting for ASTM E3191 closes on December 4, 2024. This standard is important as it is being used to guide the testing and evaluation of foam fixatives being considered for potential use in support of an F/H lab decommissioning project. This standard specification has served as a guiding document for the testing and evaluation of the foam technologies being investigated as potential plugs in support of the F/H lab decommissioning project of the piping in the courtyard. Additional performance requirements identified during this project have been incorporated into the updated standard specification by the E10.03 Fixatives Working Group. It will be used to assist in the evaluation of the hot demo of the foam technology at F/H labs tentatively scheduled in 2027.

Subtask 2.1: Conclusions

The ASTM International E10.03 Subcommittee will continue pursuing further testing protocol and standards development for fixatives and other technology categories associated with D&D, creating consensus-based standards for D&D technologies that are not only aligned with technical specifications, but also account for the safety, regulatory, and operational requirements encountered during D&D activities. Addressing existing shortfalls through standards will provide credibility, yield a significant return on investment, and allow all types of D&D technologies (robotics, fixatives, characterization, decontamination, demolition, etc.) to be developed, tested, evaluated, and compared to a set of uniformly accepted metrics.

International standards and testing protocol development plays a critical role in successful technology development and deployment programs. These standards lay the groundwork for setting the necessary conditions to successfully test, evaluate, compare, transition, and employ technologies in support of D&D activities in the highly regulated, safety conscience, risk adverse industry in which work is done. Universally accepted standards are essential in building the bridge to full field deployment of new technologies. This is particularly relevant when working at the higher ends of the TRL readiness scale and addresses many concerns on the part of all stakeholders – from researchers and developers to end users, regulatory agencies, and the public.

Subtask 2.1: References

ASTM International. (2016). *E1760-16(2024) Standard Guide for Unrestricted Disposition of Bulk Materials Containing Residual Amounts of Radioactivity.* Retrieved from https://doi.org/10.1520/E1760-16

ASTM International. (2017). *E3104-17(2023) Standard Specification for Strippable & Removable Coatings to Mitigate Spread of Radioactive Contamination.* Retrieved from https://doi.org/10.1520/E3104-17

ASTM International. (2017). *E3105-17(2023) Standard Specification for Permanent Coatings Used to Mitigate Spread of Radioactive Contamination.* Retrieved from https://doi.org/10.1520/E3105-17

ASTM International. (2018). *E3191-18 Standard Specification for Permanent Foaming Fixatives Used to Mitigate Spread of Radioactive Contamination.* Retrieved from https://doi.org/10.1520/E3191-18

ASTM International. (2019). *E3190-19 Standard Practice for Preparation of Fixed Radiological/Surrogate Contamination on Porous Test Coupon Surfaces for Evaluation of Decontamination Techniques.* Retrieved from https://doi.org/10.1520/E3190-19

ASTM International. (2021). *E3283-21 Standard Practice for Preparation of Loose Radiological/Surrogate Contamination on Nonporous Test Coupon Surfaces for Evaluation of Decontamination Techniques.* Retrieved from https://doi.org/10.1520/E3283-21

Subtask 2.2: Test and Evaluation of Down-selected Intumescent Foams/Foam Plug Technologies to Mitigate Contaminate Release during Nuclear Pipe Dismantling in Support of a Hot Demo at F/H Labs

Subtask 2.2: Introduction

FIU, in collaboration with SRNL, continued investigating COTS technologies that could be used to immobilize or isolate, or both, dispersible contamination deposited within 3-dimensional void spaces, such as pipes, gloveboxes, and HVAC systems, that would be difficult to otherwise coat with conventional 2-dimensional fixatives. One such scenario was identified by the F/H Laboratory Decommissioning Project Team. By FY '27, the F/H Laboratory Deactivation Project Team plans to remove all the buried pipework, shown in Figure 11. The piping length to be removed is about 250 feet and will be cut to 5' lengths so it may be disposed to B-25. The site team is interested in investigating whether the application of certain down-selected foam technologies could enhance engineering controls to mitigate the risk of contaminant release and reduce costs.

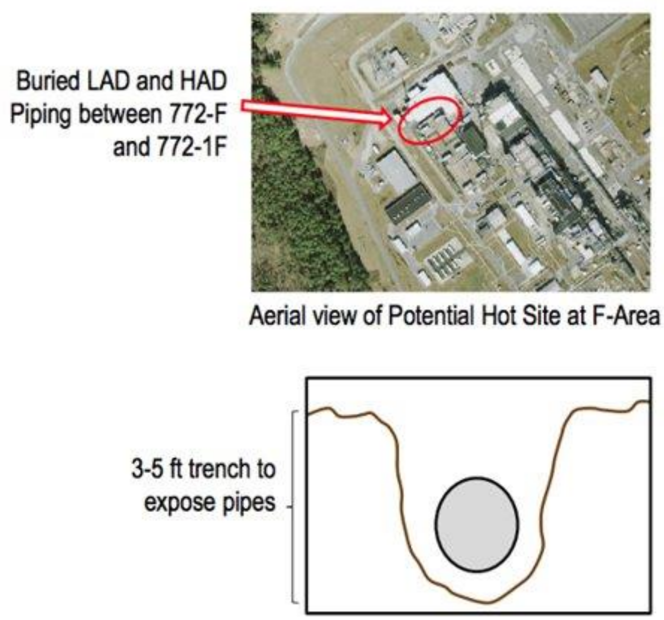


Figure 11. Buried pipe removal site at F/H Labs.

The basic premise in employing the selected technology is to create an air and watertight, lightweight foam plug using an expandable foam that can be applied via established hot tap procedures prior to the actual dismantling of the pipes, thereby allowing workers to cut into sealed pipes rather than open pipes, as depicted in Figure 12. The foam plugs can be placed at 5' increments to mirror the planned packaging and transportation procedures and serve as an added engineering control to isolate gross / residual contamination within the pipe segment. The foam technology would be applied during the normal course of the hot tap process.

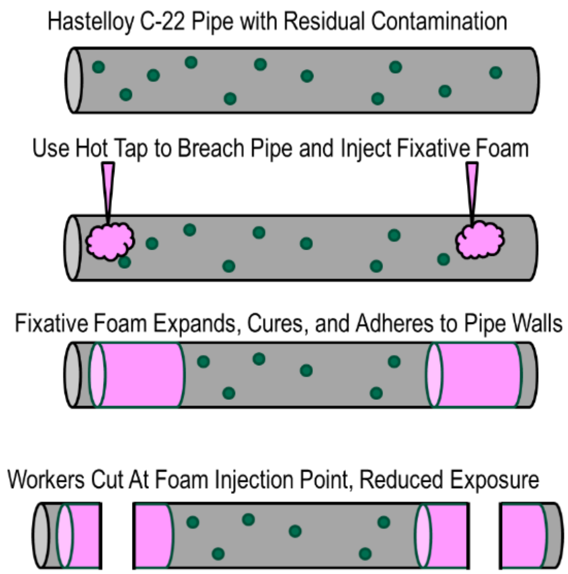


Figure 12. Operational concept for employing foam technology.

During this performance year, the Radiation Hardened Foam Cold Demo Test Plan was executed. This document outlined the test objectives and implementation plan for a down-selected foam fixative technology intended to facilitate activities in support of the Savannah River Site (SRS) F/H labs' D&D efforts. It is a collaborative effort between SRNL, FIU, and the SRS F/H labs' team intended to test and evaluate the potential of a polyurethane foam in mitigating the release of contamination during dismantling operations on radioactively contaminated piping in legacy facilities. The cold demo test plan addresses specific requirements highlighted by site and safety personnel and will be executed in FIU's Outdoor Test and Evaluation Facility using a mock-up that replicates the operational conditions at the proposed hot test location at the F/H labs. Results from the cold test plan will inform the hot test at the F/H labs, which will use the foam fixative to confine and/or isolate residual contamination within a 3-dimensional void space of Hastelloy C-22 piping designated for removal from the site and transported to a proper disposal facility.

Subtask 2.2: Objectives

The initial focus of testing for the foam technologies centered on characterizing certain mechanical and thermal properties that could impact their effectiveness as a 3D fixative in Hastelloy C-22 pipes. Specifically, testing addressed the following objectives:

1. Evaluation of the adhesion and bonding properties of the foams to Hastelloy C-22 piping.
2. Evaluation of the adhesion and bonding properties of the foams to Hastelloy C-22 piping under various moisture conditions.
3. Determination of the heat profile of the foams during curing in Hastelloy C-22 piping.
4. Evaluation of the impact of thermal stressors on cured foams.
5. Initial assessment of the foams' compatibility during application with established hot tap procedures for nuclear pipe dismantling.
6. Evaluation of off-gas characteristics and volatility during curing.

7. Evaluation of the impacts of temperature and humidity on the foams via environmental chamber testing.

Test objectives 1-5 were conducted at FIU, with objectives 6-7 being conducted at SRNL. Over the course of the past year, FIU and SRNL have hosted several periodic updates with the F/H Labs Decommissioning Team and DOE EM HQ.

Subtask 2.2: Methodology

Foam Technology Description

There were two COTS foams selected from Steve Vick International for evaluation in Phase II. Foambag^{TM} has been in use in the UK in gloveboxes at Sellafield and meets the UK gas industry technical standard T/SP/E/59. The FoamBag^{TM} holds resin foam in place as it expands. At full expansion, the foam seeps through the semi-porous panels of the bag to form an adhesive seal with the pipe.

Figure 13. Depiction of Foambag™ technology, which holds the resin foam in place as it expands and seeps through the semi-porous panels of the bag to form an adhesive seal with the pipe.

The second technology is similar to the original Foambag^{TM} product, but it uses a different resin called Endseal. Preliminary testing will be done with this product, which will be referred to as "Endseal" moving forward. This foam has a better chance of generating a seal up to 45 psi and can be modified to meet specific project requirements, per the manufacturer.

Evaluation of the adhesion and bonding properties of the foam plug to Hastelloy C-22 piping

Adhesion capabilities of the foam to Hastelloy C-22 piping will ultimately decide whether a foam fixative plug can confine and immobilize residual contamination in piping prior to transportation and disposition. The adhesion test will assess if any potential incidental impact could cause the FoamBag^{TM} foam to delaminate from Hastelloy C-22 piping, causing the release of contamination. The tensile adhesion and compressive and shear properties of the foam itself have been baselined by FIU and SRNL in accordance with ASTM D1623: *Test method for tensile adhesion properties of rigid cellular plastics,* ASTM D1621: *Standard Test Method for Compressive Properties of Rigid Cellular Plastics*, and ASTM D3574E: *Foam Tension Testing*. Furthermore, FIU and SRNL previously developed a series of testing practices specifically designed to evaluate the foam's ability to perform and function as a permanent plug in a pipe under normal operating conditions and when exposed to a variety of environmental and impact stressors. Using the MTS Criterion series 43 Tensile Tester with compression plates, shown in Figure 14, the amount of force required to push a foam plug out of a 3" D x 14" L pipe segment was determined.

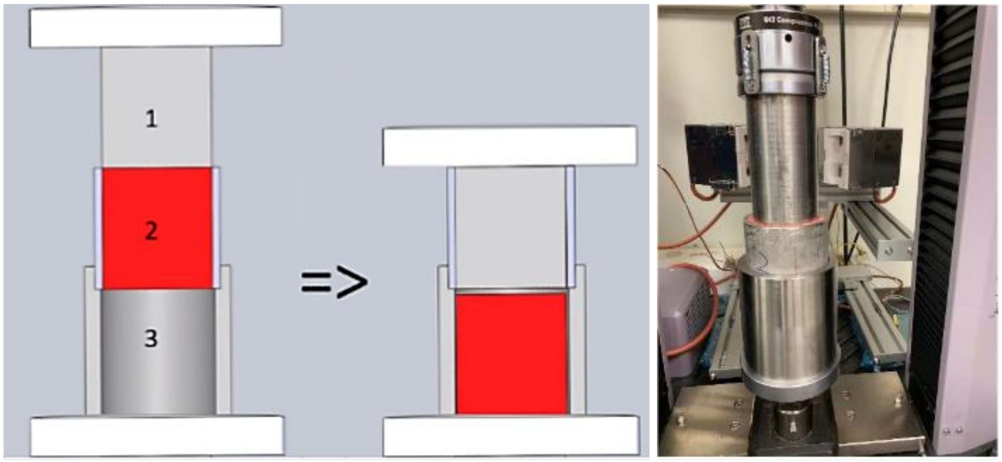


Figure 14. Plug strength test schematic (left) and plug strength testing for pipe samples using the "plunger – bucket" method on an MTS testing device (right).

Determination of the heat profile of the foam during curing in Hastelloy C-22 piping

Section 7.10 of *ASTM E3191-18: Standard specification for permanent foaming fixatives used to mitigate spread of radioactive contamination* states that "the foaming fixative shall not generate heat sufficient to compromise any of the components within the enclosure to which it is applied". Site personnel also expressed an interest in documenting the external pipe temperature profile during the curing process to further ensure worker safety during handling.

Determining the heat profile inside the pipe during the foam curing process involved inserting four Extech TP870 Type K thermocouples at varying depths into the Hastelloy C-22 pipes (Figure 15) and connecting them to an Extech SDL200 datalogger for 24 hours to determine the internal temperature of the foam while curing (Figure 16). Simultaneously, to measure the external pipe temperatures during the curing process, the FLIR E53 thermal imaging camera was employed to achieve this objective. The FLIR E53 has the capacity to measure object temperatures up to 1200°F, has a thermal sensitivity of < 0.07°F (40 mK), and a measurement accuracy of ± 2%. The supplemental FLIR software provides insight in terms of temperature data analysis. The multi-spectral Dynamic imaging (MSX) mode was used for all image analysis. MSX mode overlays both the thermal and digital images together and provides a more detailed thermal image for the external pipes.

Figure 15. Pipe with thermocouples at varying depths.

Figure 16. Extech equipment *(far left and center)* and FLIR E53 thermal imaging camera *(far right)*.

Evaluation of resistance to thermal stressors

The purpose of this test is to evaluate the resistance of foam technologies in sustaining exposure to extreme thermal stressors that may be present during the pipe cutting evolution at F/H Labs, especially if a torch is selected as the preferred method.

Though not specifically developed to test and evaluate polyurethane foams and their resistance to thermal stressors, the IEC 60695-11-10 Flammability Standard has been identified as a potential "near fit / best fit" standard after extensive discussions between FIU and SRNL researchers. The standard specifies small-scale laboratory test procedures intended to compare the burning behavior of plastics and foams when vertically or horizontally oriented test bar specimens are exposed to a flame ignition source, displayed in Figure 17 and Figure 18. The objectives of the Phase II thermal stressor test are to conduct a modified version of the IEC 60695-11-10 Flammability Test (both horizontal and vertical methods), a 30-minute direct exposure test of the foams to a 2000°F propane flame, and a mass loss test through exposure to incremental temperatures in a muffle furnace.

Two test methods are described. Method A is a horizontal burning test and is intended to determine the linear burning rate of materials under specific test conditions. Method B is a vertical burning test and is intended to determine whether materials self-extinguish under specific test conditions.

1. Method A - Horizontal Test
    - **Step 1:** Original length of sample is recorded.
    - **Step 2:** The sample is supported in a horizontal position.
    - **Step 3:** A flame is applied to the end of the specimen for 30 seconds then removed. Time of flame application will be recorded.
    - **Step 4:** Once sample is cooled, new length of sample will be recorded.
    - **Step 5:** Repeat this test for all six samples.

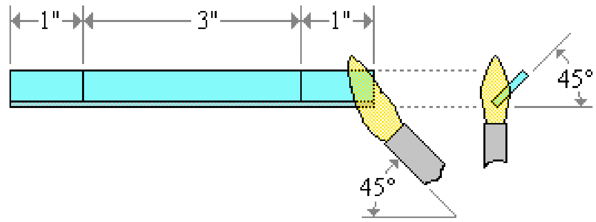


Figure 17. Horizontal flame test per IEC 60695-11-10.

2. Method B - Vertical Test
    - **Step 1:** Support the sample in a vertical position.
    - **Step 2:** Apply the flame to the bottom of the specimen for 10 seconds and then remove it until the flaming stops and record time.
    - **Step 3:** Reapply the flame for another ten seconds, remove, and record time until the flame extinguishes.
    - **Step 4:** Repeat this test for all six samples.

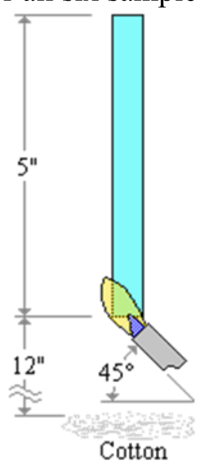


Figure 18. Vertical flame test per IEC 60695-11-10.

Pneumatic and Hydrostatic Containment Testing

The experimental schematic, outlined in Figure 19, depicts the setup that was used to test the foam plug's ability to seal the pipe and contain any residual radioactive contamination. Pressures used were 10-30 psi.

During containment testing, each pressure level was held for 5 minutes. Immediately at the start of testing, at 1 min, and at 5 min marks, soap water was applied on both ends of the pipe. If bubbles were present, then the system was not "closed" (i.e., there was leakage/there was loss of containment).

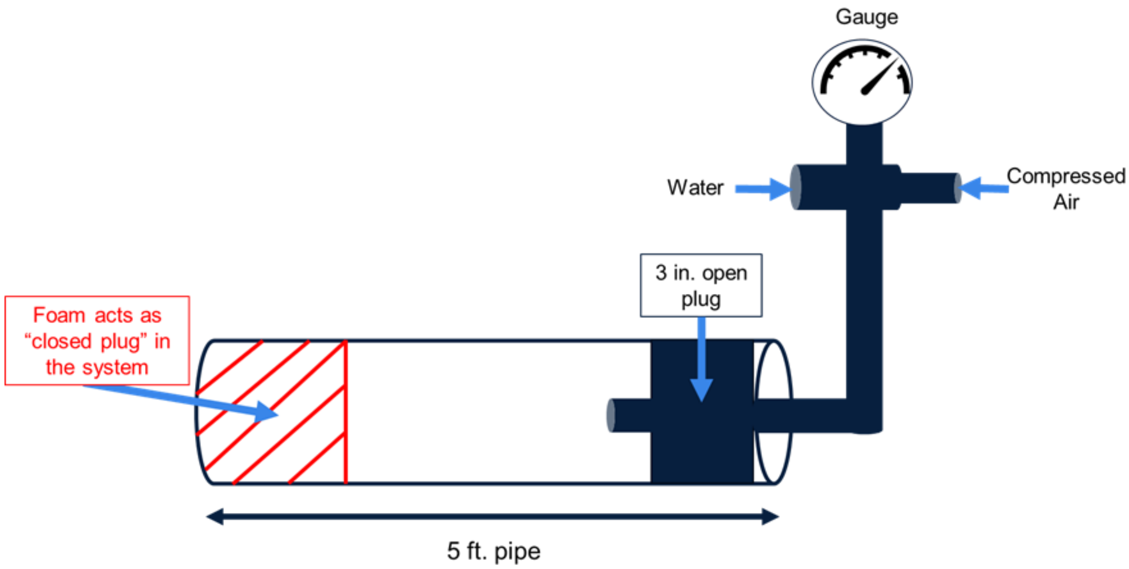


Figure 19. Experimental design for containment test.

Subtask 2.2: Results and Discussion

Table 1 below provides a summary of the test and evaluation results to date. Note that these results are in direct response to the specific testing parameters identified by the site for their pipe decommissioning and removal project. ***It is not intended to be viewed as an all-encompassing test and evaluation of the technologies for other potential applications where they may very well be perfectly suited.*** A strategic take away throughout this process is that COTS foam technologies are exceptionally versatile and warrant further investigation for their potential applicability to other D&D problem sets.

Table 1. Summary of Results

Foam Technology	Curing Time	Max Curing Temp.	Average Plug Strength	Adhesion to Wetted Surface	Fire Retardant	Environmental Chamber	Headspace	Hot Tap Compatible
Hilti	1-3 mins	276°F	7,733 lbf	888 lbf	YES	PASS	PASS	NO
FoamBag	15-45 mins	277°F	9,684 lbf	4,741 lbf	YES* With Exolit AP750 Additive	In Progress (SRNL)	In Progress (SRNL)	YES

Endseal	15-45 mins	180°F	16,032 lbf	In Progress	YES* With Exolit AP750 Additive	TBD (SRNL)	TBD (SRNL)	YES

The Hilti CP-620 foam technology was previously disqualified as a potential solution for nuclear pipe decommissioning for several reasons. The Hilti foam has an extremely fast cure time, which does not allow for sufficient working time. As defined in ASTM E3191 Section 7.2, *"the foaming fixative shall exhibit a working time sufficient to meet a realistic application rate"*. Hilti also had very poor adhesion to wetted pipe surfaces. Due to the uncertainty of the condition of the piping, there is a possibility that there is some residual moisture there. Furthermore, the current packaging of this foam makes it completely incompatibile with hot tap procedures.

Determination of the heat profile of the foam during curing

Internal curing temperatures for the FoamBag™ reached a maximum temperature of 276.8°F (136°C). This peak temperature occurred within 12 minutes of application (expected since the foam technology cures slightly slower, thereby increasing working time) and began to steadily decrease 3 minutes after, depicted in Figure 20.

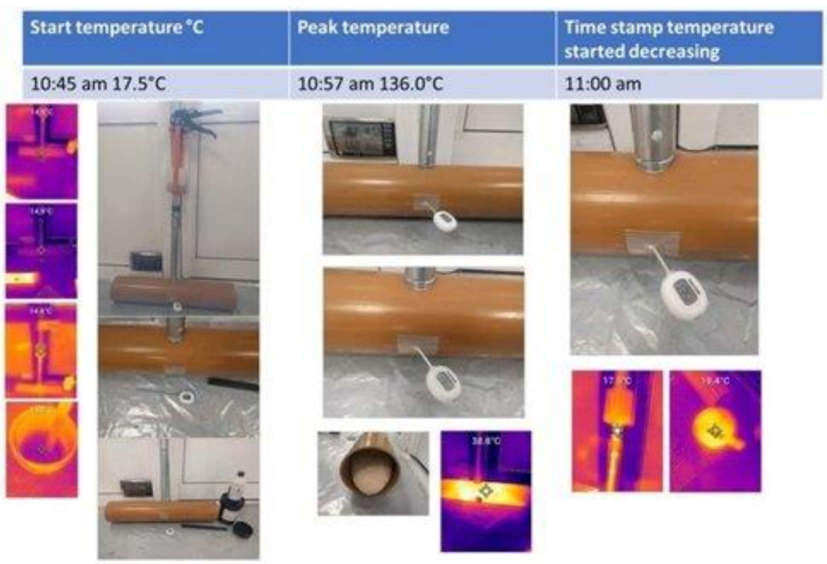


Figure 20. FoamBag™ curing temperature profile.

Endseal's curing temperature was monitored using the leftover foam mixture in the mixing bucket, shown in Figure 21. Temperature was measured with (2) Type K thermocouples, denoted as "T1" and "T2", and the Extech datalogger. The maximum temperatures reached during curing were 161.5°F for T1 and 162.3°F for T2. This is significantly lower than the curing temperature of the FoamBag™, which was about 277°F. It is important to note that these experiments did not include the fire retardant additive Exolit, which may affect the temperatures. A more substantive analysis is ongoing to further characterize Endseal and FoamBag™ curing temperature profiles, which will include the Exolit additive at different ratios.

Figure 21. Initial testing of curing temperature of Endseal foam.

Evaluation of the adhesion and bonding properties of the foam plug to Hastelloy C-22 piping

As highlighted in Figure 22 below, FoamBag™ displayed excellent adhesion and bonding characteristics when applied to dry surfaces of Hastelloy pipes. This observation remained consistent regardless of the time lapse associated with the testing, as there was no notable difference in plug strength data whether tested 24 hours or 96 hours after curing. For the FoamBag™, the average failure load was an average of 9683.61 ± 3104.29 lbf. The results for the FoamBag™ were promising under moisture conditions. The average failure load was significantly better than Hilti when applied to wet Hastelloy C-22 pipe segments, with an average of 4741.61 lbf with a standard deviation of ± 2012.95 lbf. Although this value is lower than when applied to dry surfaces, it is still considered adequate as a temporary engineering control during cutting and removal of the pipes.

Preliminary testing with Endseal showed a significant increase in its adhesion and bonding to Hastelloy piping. Although only a few samples have been tested so far, the average failure load was 16,032 lbf. This is almost 2x higher than the baseline results for FoamBag™. A full series of plug strength tests are still ongoing for Endseal.

Evaluation of resistance to thermal stressors

On its own, the FoamBag™ and Endseal technologies failed both test methods under the IEC 60695-11-10 Flammability Standard used by FIU ARC. As seen in Figure 22, FoamBag™ has no inherent fire-retardant capabilities and, as such, is flammable when exposed to certain thermal stressors such as a direct flame. To address this deficiency, ARC researchers identified a COTS fire-retardant additive called Exolit AP-750. Exolit AP-750 is characterized by the vendor as a non-halogenated flame retardant based on ammonium polyphosphate as its main component, which develops its effectiveness through phosphorus/nitrogen synergism. It differs in its mode of action from non-phosphorus-based flame retardants by achieving its effect through intumescence. Materials containing Exolit AP 750 will intumesce on exposure to flame. The carbon-rich foam layer formed will protect the polymer and in many cases the substrate through its heat-insulating effect, reducing further oxygen access and preventing dripping in case of a thermoplastic based formulation. Beyond the primary effects on fire behavior such as reduction of flame propagation rate, rate of heat release, dripping behavior, residual lengths of test specimens after flame tests etc., positive secondary fire effects such as low smoke density, no release of corrosive off-gases, lower formation of toxic smoke gases are also present and of great interest. Again, additional testing is required, but initial results support the hypothesis that the fire-retardant capabilities of FoamBag™

and Endseal can be significantly enhanced with the addition of the Exolit AP-750. When mixed with foam to Exolit ratios of 1:1, 2:1, and 3:1 ratios, FoamBag^{TM} and Endseal samples performed similarly to the Hilti intumescent foam technology. An insulating char was formed immediately upon exposure to a direct flame and overall flame and smoke propagation were negligible. A focus for the research activity's future work is to conduct more comprehensive tests of foam and Exolit ratios.

Figure 22. FoamBag^{TM} flammability comparison with (left sample) and without (right sample) the Exolit AP-750 additive.

Pneumatic and Hydrostatic Containment Testing

FoamBag plug with Exolit AP 750 fire retardant additive had no pressure leakage at 25 psi and 35 psi at 5 minutes each, even after being subjected to a direct flame from a Bernzomatic propane torch. In Figure 23A, the direct flame was applied directly to the Foambag + additive plug for 4 minutes, where the maximum flame temperature recorded was about 3400°F. In Figure 23B, the FoamBag + additive plug intumesced, causing the plug to self-extinguish when the flame was removed and creating a thermal insulating barrier. In Figure 23C, the plug was still relatively intact underneath the thermal insulating char. Even though the initial results were promising, overall, the containment leak testing was inconsistent with the Foambag technology (with and without the Exolit additive), where some plugs failed at pressures as low as 10 psi.

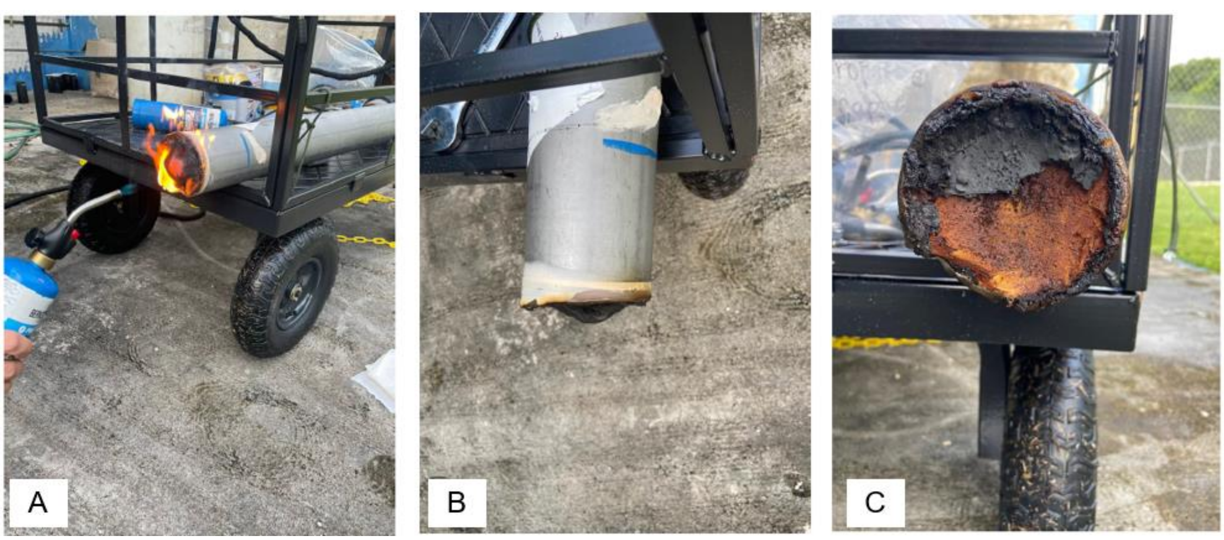


Figure 23. Foambag^{TM} + additive plug exposed to fire stress before containment leak testing with compressed air.

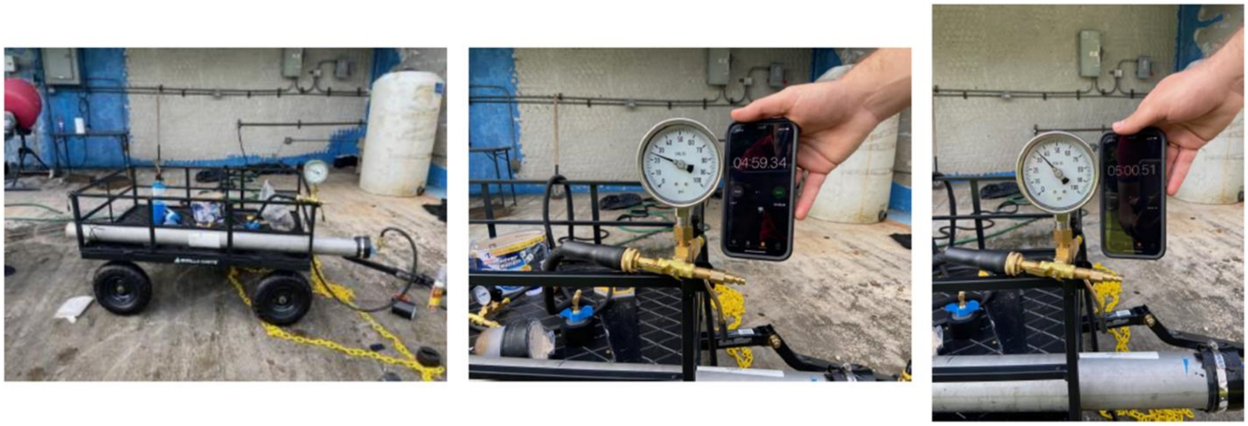


Figure 24. Foambag™ + additive containment leak test after applying thermal stress at pressures up to 35 psi.

The containment testing (without thermal stress) with Endseal produced more consistent foam plugs. The pneumatic and hydrostatic results are shown in Table 2 and Table 3. Endseal foam plugs passed both containment scenarios which were performed up to pressures of 20 psi with no leakage detected. Endseal also provided more consistent containment than Foambag, making it more reliable.

Table 2. Endseal Pneumatic Leak Testing Results

Pneumatic Testing											
10 PSI				15 PSI				20 PSI			
Time (min)	Pressure Drop on Pressure Gauge?	Foam Plug - Bubbles?	Closed Plug - Bubbles?	Time (min)	Pressure Drop on Pressure Gauge?	Foam Plug - Bubbles?	Closed Plug - Bubbles?	Time (min)	Pressure Drop on Pressure Gauge?	Foam Plug - Bubbles?	Closed Plug - Bubbles?
0	No	No	No	0	No	No	No	0	No	No	No
1	No	No	No	1	No	No	No	1	No	No	No
5	No	No	No	5	No	No	No	5	No	No	No
* small leak noticed by bubbles present where the digital gauge was connected.				* small leak noticed by bubbles present where the digital gauge was connected.				* small leak noticed by bubbles present where the digital gauge was connected.			

Table 3. Endseal Hydrostatic Leak Testing Results

Hydrostatic Testing											
10 PSI				15 PSI				20 PSI			
Time (min)	Pressure Drop on Pressure Gauge?	Foam Plug - Bubbles?	Closed Plug - Bubbles?	Time (min)	Pressure Drop on Pressure Gauge?	Foam Plug - Bubbles?	Closed Plug - Bubbles?	Time (min)	Pressure Drop on Pressure Gauge?	Foam Plug - Bubbles?	Closed Plug - Bubbles?
0	No	No	No	0	No	No	No	0	No	No	No
1	No	No	No	1	No	No	No	1	No	No	No
5	No	No	No	5	No	No	No	5	No	No	No
* small leak noticed by bubbles present where the digital gauge was connected.				* small leak noticed by bubbles present where the digital gauge was connected.				* small leak noticed by bubbles present where the digital gauge was connected.			

Subtask 2.2: Conclusions

Based on the specific project parameters associated with the F/H Lab Decommissioning efforts of the Hastelloy C-22 pipes in the courtyard, it was decided that future testing will continue with Foambag and Endseal technologies. Both have great potential to meet the operational requirements for the F/H Lab Decommissioning Project, and discussions have commenced to set it on a trajectory that results in a hot demo at the SRNL Test Bed in Aiken, S.C. The focus of effort for this research activity over the next year are contained in the recently approved test plan, ***"Radiation Hardened Foam Hot Test Plan-Phase III: Evaluation of FoamBagTM / End Seal Fixative Foams During Application in a Radiological Environment"*** **(SRNL-STI-2024-00326)** with some key objectives outlined below. All stakeholders will continue to collaborate closely, and modifications will be made, as required, depending on additional requirements and/or the results of testing.

1. Finalize containment and leak testing on intact and fire-stressed plugs in Hastelloy C-22 piping using hydrostatic and pneumatic pressure testing protocols, as initial results have been generally positive.
2. Determine the optimal ratio of Exolit AP-750 fire retardant additive to foam that balances resistance to thermal stressors with adhesion and bonding properties of the foam plugs to Hastelloy C-22 piping under dry and wet surface conditions.
3. Investigate functionalization of foams for radiation shielding and mercury abatement.
4. Confirm impacts of curing on internal pipe pressure.
5. Confirm application procedures for installation of foam plugs are hot tap compatible under operating conditions expected during dismantling.

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Subtask 2.3: Certifying Fixative Technology Performance when Exposed to Impact Stressors as Postulated in Contingency Scenarios Highlighted in Safety Basis Documents

Subtask 2.3: Introduction

Department of Energy (DOE) facilities undergoing decontamination and decommissioning (D&D) activities struggle with safety concerns of residual radioactive contamination leftover after gross decontamination efforts have concluded. Regulations, such as the DOE-HDBK-3010, *“Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities”*, provide some direction on appropriate factors for dealing with the residual contamination. However, this directive has not been updated since 1994, with much of the data originating from studies performed in the 1970s and does not account for new technological advances. As such, overly conservative or lenient airborne release fractions (ARFs) in the Source Term Formula are applied that either require the implementation of challenging operational restrictions and costly nuclear safety controls or pose serious safety concerns to the public and environment.

The Source Term Formula is a linear equation used to calculate the amount of radioactive material, in grams or curies, that could be released[1]. This equation is mainly used for safety and environmental analyses and considerations. Some of the major challenges include: (1) inaccurate Source Term calculations; (2) inaccurate safety controls; and (3) failure to provide new data to corroborate results from over 30 years ago. This concern was also identified in recent studies published by Hubbard et. al., where ARFs from nuclear fires were reevaluated for surrogate liquid and solid contaminants.

The handbook provides the postulated ARF coefficients based on the contaminant form and accident scenario. Specifically, the ARF coefficient is defined as an approximation of radioactive material suspended in air that can be transported as a result of physical stresses from an accident. Airborne particles are specified as having an aerodynamic equivalent diameter (AED) greater than 10 µm. Many stressors of interest are outlined in both the DOE-HDBK-3010 and the Basis of Interim Operations (BIO), where impact scenarios are highlighted in many nuclear facilities. Impact accidents can be as minor as an item dropping in a hot cell or as significant as a natural disaster that causes larger falling debris. For instance, in the event of a seismic release, powder contamination may experience a free-fall spill, vibration-shock, air turbulence from impact, and/or resuspension.

Under this subtask, FIU focused on the development of a standardized experimental design for impact stress with modern equipment and the process of reevaluating historical data for powder contamination under this specific stress. Additionally, fixative performance was evaluated when exposed to impact stressors associated with safety basis analysis in response to high priority requirements identified across the DOE complex. This research effort has the added benefit of potentially providing essential data points on the positive effects of fixative technologies on mitigating airborne release fractions, respirable fractions, and resuspension rates used in safety basis calculations and the Source Term Formula outlined in DOE-HDBK-3010.

Subtask 2.3: Objectives

1. **Develop and validate experimental design for the quantification of contamination release during impact stress.**
   This objective focuses on the experimental methodology for impact stress and includes four main aspects: surrogate contaminant, impact test chamber, collection of released particulates, and analysis.

2. **Reevaluate ARF coefficients for powder contaminants under impact stress.**
   This approach will either confirm or dispute the original ARFs for powder contamination as determined in the DOE-HDBK-3010. Since there have been new technological advances in analytical techniques, it is possible that the coefficients in the present version of the handbook are outdated and do not accurately reflect the airborne release.

3. **Determine ARF coefficients for fixative materials under impact stress.**
   This objective focuses on investigating the ARFs for fixatives applied over powder contamination under impact. Initially, two polymer fixatives will be used as a starting point to provide data to substantiate the Fixative State for this stressor. Based on previous research conducted, the use of fixatives should produce much lower ARFs.

Subtask 2.3: Methodology

Throughout numerous DOE nuclear facilities, there are many different types of substrates to which the fixatives may be applied. However, these initial experiments only consider non-porous substrates (stainless steel coupons). All testing is performed on: (1) coupons without a fixative as a baseline and to confirm the original data for ARFs for powder contaminants under impact, and (2) two fixatives (FD and PBS) as a starting point to provide data to substantiate the fixative/polymer state under impact. There are four main aspects to this experimental methodology: surrogate contaminant, impact test chamber, collection of released particulates, and analysis.

Surrogate Contaminant and Controlled Contamination of Test Coupons

Cesium chloride (CsCl) is the surrogate contaminant used as it is a non-radioactive soluble powder and contains a unique chemical element that will be detectable in the analysis component. It is essential that the coupons are weighed before and after contaminant application, to quantify the initial amount of contamination prior to any stressor for proper release measurements. Another main aspect is to be able to uniformly contaminate the test coupons for all experiments. Previous work and existing standards, such as ASTM E3283-21 "*Standard Practice for Preparation of Loose Radiological/Surrogate Contamination on Nonporous Test Coupon Surfaces for Evaluation of Decontamination Techniques*", are being leveraged for this design.

A small known quantity of CsCl was used to create a solution in deionized water. The contaminant solution was mixed homogenously and then applied to 304-stainless steel coupons at different points. 10 µL drops of contaminant solution were stippled in a pattern towards the center of the coupon, per ASTM E3283, which created a uniform distribution and reduced the risk of run-off at the edge of the coupon. The coupons were undisturbed while the solvent was allowed to evaporate, shown in Figure 25. After evaporation, the coupons were weighed to initially quantify the amount of contaminant present. The fixative could then be applied and cured to the manufacturer's requirements. The coating thickness was confirmed using the Defelsko PosiTector 6000. The Defelsko PosiTest LPD pin-hole detector is used, where appropriate, to confirm that there are no small cracks/holes in the coating application before all testing.

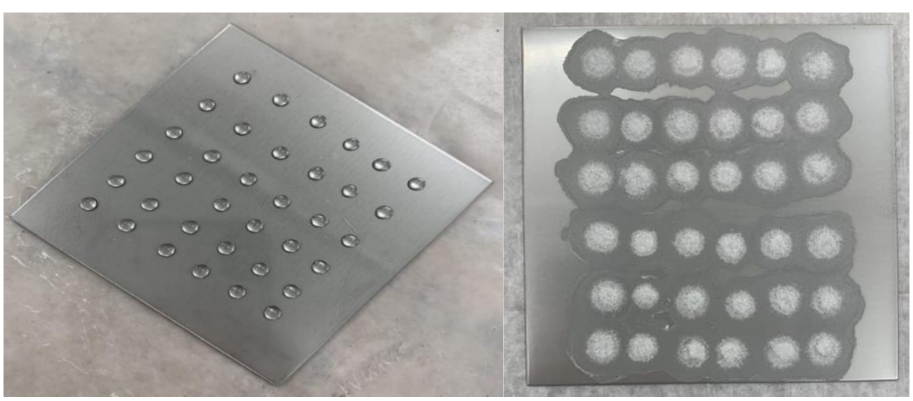

Figure 25. Stippled contaminant solution on 304-SS coupon (left) and after solvent evaporation (right).

Impact Stressor

BYK-Gardner PF-5546 Extra Heavy-Duty Impact Tester, shown in Figure 26, has a maximum force of 320 in-lb and is used to evaluate impact resistance and determine the exact point of failure and/or establish pass/fail specifications. It specifically complies with ASTM D2794, "Standard Test Method for Resistance of Organic Coatings to the Effects of Impact". While this method was not originally designed to test for contamination release, it establishes a standard method to test a coating's response to rapid deformation. The coupons are required to have the following dimensions: 3.0" length, 3.0" height; and 0.024" width. Additionally, an acrylic housing assembly was placed around the device which will allow for artificially contaminated coupons to be tested for release fractions.

Figure 26. BYK-Gardner PF-5546 Extra Heavy-Duty Impact Tester.

Contamination Release Collection

In order to quantify a total release, effective collection methods must be used to ensure accuracy of the data. Collection of released contamination includes airborne and any particulates that may have resettled on the stressor apparatus or test chamber surfaces. Mixed cellulose ester (MCE) filter cassettes and an air-sampling pump were used to collect any suspended airborne particulates. Any contamination that has settled on the walls of the test chamber or stress apparatus can be collected using sampling wipes. Then the filters and wipes are dissolved in an acidic medium for the analysis process. The experimental setup is displayed in Figure 27.

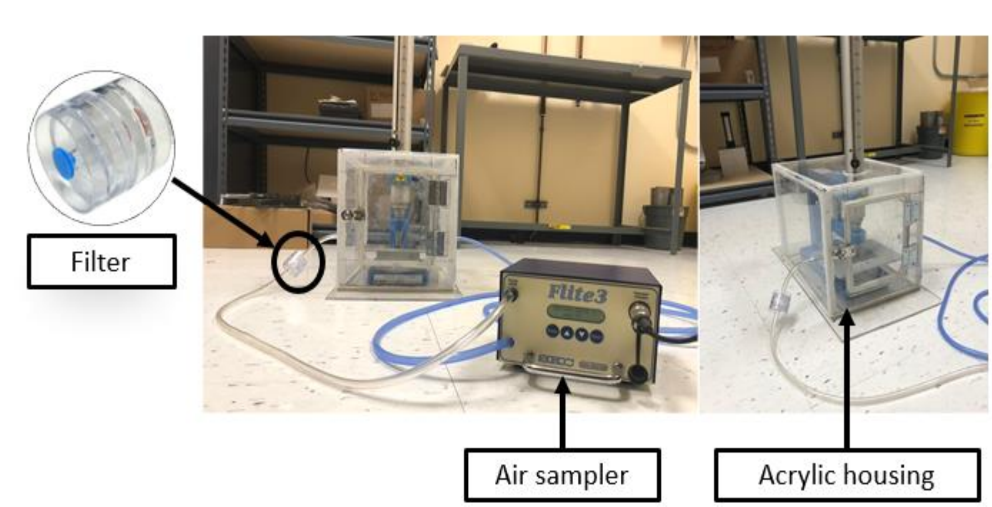

Figure 27. Impact tester with acrylic impact housing and Flite 3 901-3011 air sampler setup.

Analysis

After collecting the released contaminant, it can be analyzed using mass spectrometry, depicted in Figure 28. The surrogate contamination has a unique signature that can be detected using ICP-MS. Mass spectroscopy detects charged particle impacts following a deflection by a magnetic field that separates ions by mass/charge ratios. Carefully tracked dilutions or dissolutions are required to correctly determine the amount of collected contaminant. These analysis methods will detect only the specified element in the surrogate (Cesium), which is imperative in certifying and quantifying fixative performance.

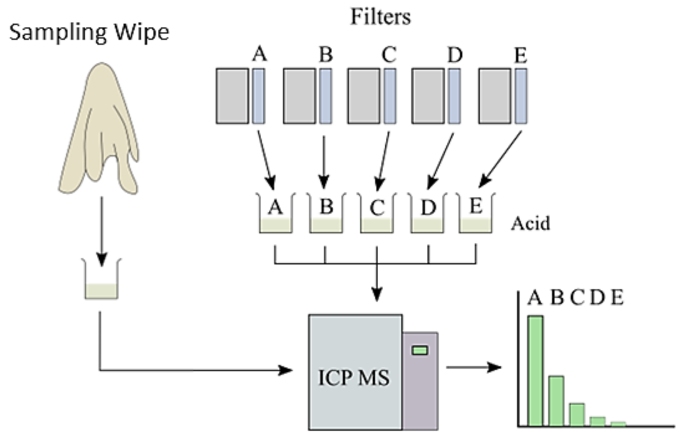

Figure 28. Collection and analysis process.

Subtask 2.3: Results and Discussion

It is important to note that preliminary tests were performed to ensure that there were no interferences with naturally occurring cesium or components in the stainless-steel coupons. This included exposing several sampling wipes to the lab environment and placing the coupons in acid for a specified time before ICP-MS analysis. All samples were prepared using the same methodical procedures previously described. In addition, efforts to eliminate possible cross-contamination were implemented, such as periodic changing of tubing and running blank samples through the impact chamber.

Varying force levels were tested with the surrogate powder contamination to encompass a sufficient range. Control samples with the same sample preparation but not subjected to any impact were included in the analysis. A minimum of six coupon samples were used for each force level to account for any outliers that may arise during testing. The respective averages for each impact force tested up to maximum are shown in Table 4.

Table 4. Average Airborne Release Fractions for Baseline Powder Contamination under Impact Stress

	Impact Force (in-lb) / (kg-cm)	Average Airborne Release Fraction	Standard Deviation
Powder	320 / 368	2.27E-04	2.76E-04
	240 / 276	1.08E-04	1.69E-04
	200 / 230	1.05E-05	2.77E-06
	160 / 184	6.32E-07	2.43E-07
Total Average		**3.47E-04**	

In addition, testing proceeded on contaminated coupons with fixatives to determine the impact on ARFs. The impact forces used are at varying intervals from 160 in-lb to 320 in-lb (maximum).

ICP-MS testing was completed on impact samples for FD coating. The results, displayed in Table 5, show a significant reduction in the ARFs for powder contaminants. This data provides supporting evidence that a different ARF coefficient should be implemented for fixatives in the DOE-HDBK-3010.

Table 5. Average Airborne Release Fractions for FD Coating under Impact Stress

	Impact Force (in-lb) / (kg-cm)	Average Airborne Release Fraction	Standard Deviation
FD	320 / 368	4.46E-08	4.48E-08
	240 / 276	2.61E-08	9.88E-09
	200 / 230	1.92E-08	1.15E-08
	160 / 184	1.52E-08	7.32E-09
Total Average		**5.25E-07**	

Similarly, FIU performed ICP-MS testing on the additional PBS-coated samples. The results are shown in Table 6. The average ARF for PBS was similar to the results of the FD-coated samples, 1.10e-6 and 5.25e-7 respectively. Overall, this lower ARF for fixative coatings further confirms the idea of a "fixative" state, which should be considered in the DOE-HDBK-3010 so that this reduction can be credited in safety basis calculations.

Table 6. Average Airborne Release Fractions for PBS Coating under Impact Stress

	Impact Force (in-lb) / (kg-cm)	Average Airborne Release Fraction	Standard Deviation
PBS	320 / 368	4.06E-07	1.62E-07
	240 / 276	3.08E-07	1.13E-07
	200 / 230	2.28E-07	1.26E-07
	160 / 184	1.61E-07	3.66E-08
Total Average		**1.10E-06**	

Subtask 2.3: Conclusions

As the number of nuclear facilities undergoing demolition and D&D activities increases, there is an overwhelming need for additional safety measures. However, the guiding documents for safety basis analyses are outdated and do not accurately reflect advancements in new materials and technologies. The data collected during this performance year regarding the ARFs for surrogate powder contamination under impact were characterized and reevaluated. Most of the work previously performed lacked sufficient detail to completely replicate the experiments and there was a considerable amount of uncertainty in the measurements and the impacts applied may not have been comparable to a real-world scenario. Therefore, to address the need for repeatability, a standardized process for applying impact stress was developed using an ASTM-rated impact tester. MCE filters and an air sampler were utilized to capture any airborne release, with 80 cycles to ensure sufficient collection of particulates. The filters were then leached and/or dissolved in nitric acid and diluted, if necessary, for ICP-MS analysis. Based on the analysis presented, the ARF for powder contamination under impact produced an average ARF of about 3.5e-04, which reconfirmed the validity of the value presented in the DOE-HDBK-3010, 4e-04. These initial results for fixatives establish an ARF that is less than that of a liquid contaminant, as shown in Figure 29, which supports the idea of a fixative/polymer state.

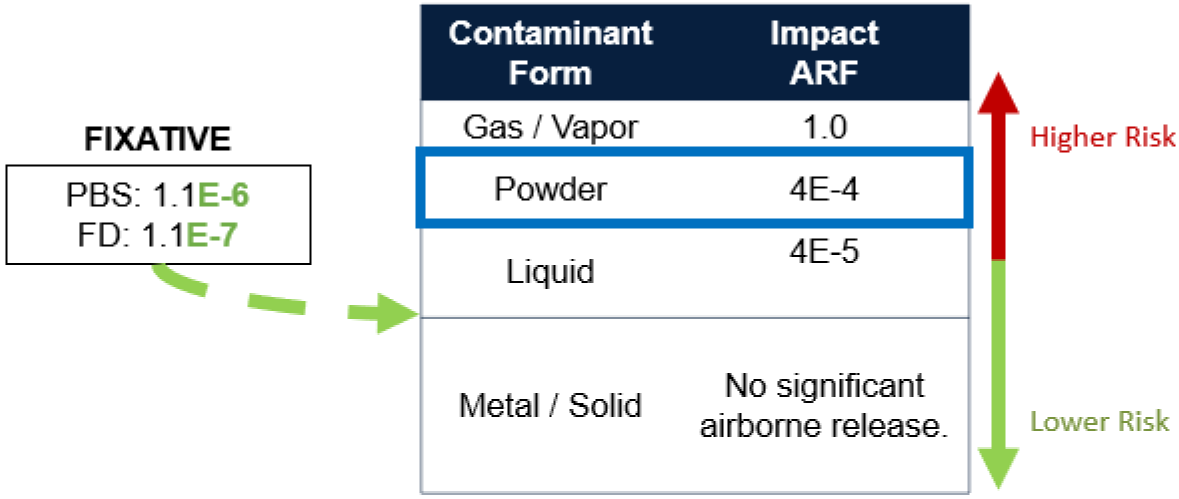

Figure 29. DOE-HDBK-3010 ARF coefficients for various contaminant forms under impact stress. Initial data indicates a fixative state with an ARF less than a liquid contaminant.

FIU will continue collaboration with SRNL and other sites to leverage ASTM practices and principles to further define operational parameters. FIU will proceed with any additional testing required to quantify release and the performance of fixative technologies to support and update the DOE-HDBK-3010. Various substrate types and/or thicknesses will be considered for future testing.

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Subtask 2.5: Digitalization in Decommissioning (NEW)

Subtask 2.5: Introduction

Decommissioning of a nuclear facility is a sophisticated and lengthy process that is initiated once the facility permanently ceases all operations, due to a variety of internal and external factors including reaching the end of the facility's operating life (usually 40-60 years for newer plants) and cleaning, storing, and disposing of radioactive contaminants and byproducts of nuclear reactions. To summarize, the general process involves surveying the facility and decontaminating it to reduce radioactivity, dismantling the structures and machinery, removing contaminants such as irradiated material and spent fuel cells and disposing/storing them properly, and releasing the property to be repurposed. However, in many cases the final step involves a method known as "entombment", where the facility is encased in a durable structure such as concrete. This method is usually required when the on-site radioactive material is not fully removed or decontaminated.

The focus of this subtask is to digitalize this decommissioning process, more specifically the initial step which involves site characterization and surveying the nuclear facility for damage to finalize plans for removal and disposal of radioactive material. As the planning process involves professionals having to physically enter these facilities with building schematics and proper PPE, it risks exposure to radioactivity and other hazardous materials. The amount of time spent in the facility increases this risk, and while the risk dramatically decreases due to decontamination and removal of the toxic waste, the presence of radionuclides (unstable elements that release radiation) still induces risk. To minimize the risk of exposure and other occupational hazards, the use of autonomous mobile robotic platforms configured with a 3D laser scanner is implemented in order to eliminate the need for a human presence in the site characterization step of the decommissioning process. The robotic platform, Boston Dynamic's quadrupedal robot Spot, will be programmed with autonomous navigation software and fitted with visualization hardware to localize itself based on its surroundings, and navigate unknown frontiers based on its own procedurally generated map, all while performing sequential 3D point cloud scans using the scanner, the Trimble X7. Preliminary research on the use of alternative scanners is ongoing, mainly due to the stationary aspect of the X7, meaning that it can only scan while mounted securely and immobile. The scanner uses LiDAR (Light Detection and Ranging) technology, which uses a series of lasers sent out from the device to measure variable distances between it and its surroundings. The individual points on which the lasers bounced off are gathered in one file to generate a digital twin of the range of the scan.

Subtask 2.5: Objectives

1) **Integrate the 3D LiDAR scanner with the autonomous mobile robot and import both autonomous navigation and frontier exploration software.**
   This objective prioritizes the physical and software integration aspects of the robot platform and laser scanner configuration, as it is required to begin official autonomous testing in both simulated and real-world environments.
2) **Develop 3D models and nuclear facility "walkdowns" using the gathered 3D point cloud data.**
   This objective is partially accomplished using third-party 3D modeling programs capable of accepting and editing the exported and post-processed point cloud files. The more prevalent research is into how to produce higher quality scans using the software as well as how to develop the 3D environment for use in a professional setting.
3) **Develop and implement radiation detection and recording features for additional data collection.**
   As another facet of the overall research project, detection and overlaying of ambient radiation in the nuclear facility onto its digital twin is beneficial to professionals who will be entering to remove any remaining hazardous material as part of the decommissioning process.

Subtask 2.5: Methodology

The focus of the research was directed to testing the individual devices in both solitary and combined configurations, with different testing variables such as terrain, time constraints, quality control, and methods of manipulation. For the Spot quadrupedal robotic platform, maneuverability testing was conducted in different terrains with no additional payloads and with the entire Trimble setup mounted on it. As for the Trimble X7, scanning was performed using different complex environments with ample variation in structure, terrain, and lighting, including but not limited to vehicle parking tunnels, office rooms on campus, a concrete bay area, and construction sites at varying levels of completion. While not completely officiated, radiation and simulation testing are undergoing the planning stage, in which autonomous navigation and frontier exploration software is being imported into the Spot CORE I/O external computer payload to pilot the robotic platform, as well as research into radiation detection hardware and software which will provide the option to overlay the data onto the 3D point cloud data captured during deployment.

Subtask 2.5: Results and Discussion

Objective 1

Initial steps to accomplish proper integration between the Trimble X7 and the Spot quadrupedal robot required literature review on the basic functions of 3D laser scanners and the correlation between the Spot robot's mechanical and computer systems. With the X7, scanning is done via a separate device with proprietary software installed to set scan parameters such as scan distance, level of detail, lighting conditions, etc. As the final project is meant to function autonomously, a separate computer was required to run the scanning software while being connected to both the Spot and the X7. The Spot CORE external computer payload was chosen as the midpoint of both devices to run not only the scanning software, but also the autonomous navigation software required in the future after sufficient progress in the physical integration was made. Because of the arm attachment that both Spot robots had at the time of the project's start, custom mounting designs were made in order to attach the Trimble X7 to the Spot physically, with Spot movement and Trimble X7 scanning being accomplished with two separate devices running their respective software (Figure 30).

Figure 30. Physical and digital designs for preliminary X7 mount.

Using this preliminary configuration for the Spot and X7, carefully surveyed stress testing was conducted in flat terrain environments to determine the overall structural capacity of the Spot with a new payload attachment. The chosen physical design featuring the curved prongs on either side of the flat base was based on a similar design specifically made as the direct mount for the Trimble

X7 onto the Spot robot, manufactured with Boston Dynamics and titled the "Spot Defender". While preparations were being made to acquire this mount for the project, the intermediary design was used to showcase the Spot at engineering conferences. With the Spot Defender, an additional Spot CORE payload and Velodyne real-time LiDAR scanner were purchased to aid in the autonomous navigation and frontier exploration side of the research project. Testing parameters were altered and expanded to include the entire payload configuration on a new Spot robotic platform, one without an arm attachment to provide additional space for installation (Figure 31). Testing included piloting the spot with the separate controller in difficult terrain environments such as outdoors over unstable ground and up and down stairs.

Figure 31. Finalized Spot/Trimble X7 complete payload configuration.

As for the digital integration between the payloads to the Spot, implementation of the autonomous navigation and frontier exploration software is ongoing, largely due to the stall in progress from the Spot CORE external computer payload. With the CORE received with the purchase of the Spot Defender mount, issues with the administration authentication as well as the termination of the support of the update and factory reset software by Boston Dynamics caused the programming of the CORE to slow in its progress. In order to find an alternative, the payload was swapped for a newer model titled the Spot CORE I/O (Figure 32), which is still supported by Boston Dynamics. Authentication is still ongoing with the CORE I/O due to its previous use with prior research projects impeding the upload and configuration of the navigation software required for the current project.

Figure 32. Spot CORE and CORE I/O Comparison.

Physical testing using this finalized configuration has slowed due to consistent use with little to no error in maneuverability of the Spot with the additional payload attachments. This configuration has been showcased at various nuclear and engineering conferences and conventions since its assembly, such as the ETEBA BOTC 2024 Conference in Knoxville, TN, as well as the American Nuclear Society's Winter meeting in Orlando, FL.

Objective 2

The development of 3D digital twins of scanned environments using the Trimble X7 has progressed considerably during the past year of research and development. Initial literature review and testing with the X7 consisted of understanding the limitations of the scanning software, as the current program being used (FieldLink) offers a wide range of features one can manipulate to alter the time taken per scan, the level of detail captured, the range of points gathered per scan, etc. Both stationary and mounted tests were conducted, with the X7 being supported by both the accompanying tripod as well as the Spot robot. With both methods of scanning, there is no considerable difference in quality or smoothness of the data, therefore it can be inferred that the Trimble X7 suffers little to no negative effects from scanning from a mobile robotic platform (Figure 33).

Figure 33. Comparison between mounted scan picture and resulting digital twin.

From the post-processed and refined scans exported from the FieldLink software, further editing and refining is completed using the Autodesk ReCap software, which allows users to edit individual sections of points, smooth errant data, and create animated slide shows to use as intermediary "walkdowns" of the scan. The program allows users to take screen captures of the camera view, which it stitches together and provides animated transitions where the camera "flies" to the subsequent scene. While this level of detail and ease of use is not the desired quality for this objective, it serves as a useful precursor for demonstrations and showcasing at conferences. Autodesk ReCap also provides a simple dimensioning feature, allowing users to measure distances between two individual points within the scan. Overall, this software will be used going forward for both the project's development and for initial deployment once the project reaches that stage of near completion. As for the scans captured using the X7 and refined using ReCap, various environments were chosen to test the adaptability of the LiDAR scanner, which can be seen in the following figure (Figure 34).

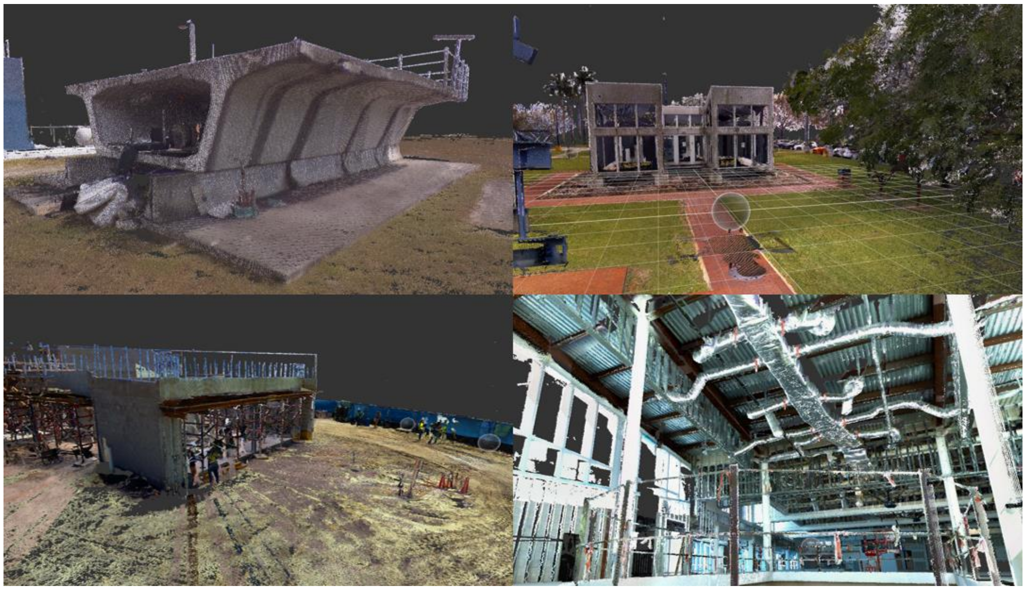


Figure 34. 3D point cloud scans of concrete bay area (top left), FIU solar house (top right), FIU chapel construction site (bottom left), and Doral center construction site (bottom right).

The quality of scans, as described above, are consistent and do not display any major issues between individual scans in a larger project. Smaller errors are prevalent, however, in the form of failed automatic registration between subsequent scans, as well as the issue with the X7 being a stationary laser scanner. For the registration, the error can be replicated in specific scenarios where the distance between scans in a project are too far for the X7 to reach with its lasers, or when the secondary scan is captured in a different lighting or in a different open room than the primary. The most obvious causes for this registration error are the variable conditions mentioned that affect the scanning sequence, which are remedied by introducing mental checks and written documentation to the device operators to develop the habit of checking conditions between scans to reduce the possibility of a registration error. As for the stationary scanning issue, there is a larger issue that is embedded in the X7's general function, as it may be a high-fidelity 3D point cloud scanner, however with the added limitation of requiring precise conditions prior to scanning. The way that the X7 scans is as such: it begins a pre-scan calibration to ascertain its position in space using its rotating cameras, it conducts the scan, compiles the point cloud data, transfers it to the empty file created beforehand, and it displays it on the separate device. The pre-scan calibration saves its position prior to scanning, so any movement during the ensuing scan disrupts it, resulting in no data being compiled or transferred. While the simplest solution to this problem is to not move the Spot while scanning, it introduces a time limit to the entire deployment of the Spot/X7 configuration, as the Spot robot only has a battery life of two hours. For larger environments, the risk of the Spot losing power before the digital twin is complete is larger as well. To combat this, discussions with Trimble are being held to devise a method for dynamic scanning, as well as research into alternative 3D laser scanners that provide dynamic scanning as a primary feature.

Objective 3

Development of the radiation detection and recording features of the Spot/X7 research project is still in the initialization phase, as much of the required hardware and software setup to begin proper testing is still in development, primarily the autonomous navigation. During the months of April and June, progress was made with simulated testing using a standard Geiger-Müller counter in a controlled 5m x 5m area. The simulation, based on solid angle fraction and Poisson distribution, successfully identified randomly placed 1 mCi samples of C0-60 and Cs-137, generating a detailed radiation map (Figure 35). Manned testing of the Spot with the installed Geiger-Müller counter has also been conducted to determine the range of detection of the counter as well as the Spot's capability to withstand radiation, albeit a miniscule amount harmless to humans for safety purposes. Additional testing further in the year expanded the controlled simulated area to a 16ft x 16ft section, however progress in that section of the project slowed and focus shifted towards autonomous programming and software packages necessary for Spot navigation and frontier exploration in simulated environments.

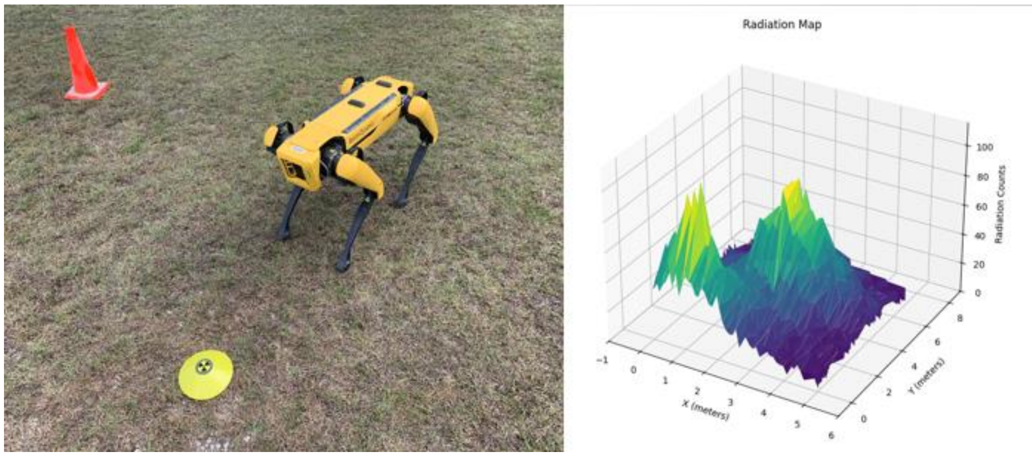


Figure 35. Image of radiation detection test and resulting 3D map.

Subtask 2.5: Conclusions

With the given results and inferences made during discussion with project members, other DOE fellows, and mentors, it was concluded that the Spot and Trimble X7 produce consistent and positive results in their respective aspects of the project, which complement each other when in the final configuration shown. The quadrupedal robotic platform, Spot, is fully capable of maintaining balance and power when traversing difficult terrain environments with additional payload attachments, which allows the Trimble X7 to capture high-fidelity scans of its environment to be used for reference and decommissioning purposes. The Trimble X7 shows little to no major errors with scanning within the given parameters of the FieldLink software, with the registration and stationary issues being solved or mitigated with implemented systems and additional research. Lastly, the radiation detection and recording feature of the Spot/X7 configuration shows steady progress towards final implementation and deployment, with research into the overlaying of said radiation data onto the digital twin still ongoing. Overall, progress in all objectives is steady, however official deployments have not been scheduled. Primary focus is on the installation and testing of the autonomous navigation and frontier exploration software, as well as the installation of the FieldLink software onto the CORE I/O to initiate scans from a connected computer.

Subtask 2.5: References

[1] I. Karanta. (2024). *Hazards and Risks of Nuclear Decommissioning – The Big Picture* [Online]. Available: https://www.decomm.fi/2021/11/23/hazards-and-risks-of-nuclear-decommissioning-the-big-picture/#:~:text=An%20understanding%20of%20the%20hazards,of%20money%20may%20be%20lost.

[2] NEI. (2016, Aug.). *Decommissioning Nuclear Power Plants* [Online]. Available: https://www.nei.org/resources/fact-sheets/decommissioning-nuclear-power-plants

[3] Trimble Inc. (2020, Jan.). *Trimble X7 3D Laser Scanner User Guide* [Online]. Available: https://geomatika-smolcak.hr/wp-content/uploads/2020/01/UserGuide_X7.pdf

[4] U.S. NRC. (2020, Jun. 8). *Decommissioning Process* [Online]. Available: https://www.nrc.gov/waste/decommissioning/process.html

[5] World Nuclear Association. (2022, May 3). *Nuclear Fuel Cycle: Decommissioning Nuclear Facilities* [Online]. Available: https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/decommissioning-nuclear-facilities#:~:text=Newer%20plants%20are%20designed%20for,made%20available%20for%20other%20uses.

TASK 3: KNOWLEDGE MANAGEMENT INFORMATION TOOL (KM-IT) (HQ, SRNL, INL, ANL)

Subtask 3.4: Content Management

Subtask 3.4: Introduction

Content Management includes publishing D&D technologies and QA/QC of existing content in the system. This is accomplished with the assistance of DOE Fellows who do most of the data mining across the system. Addition of vendors, lessons learned, best practices, D&D news, and conferences are also a part of content management.

In addition, FIU started to use technology documents from the Technology module to train a Generative AI model that uses a Large Language Model (LLM) to transform extensive documents into brief summaries.

Subtask 3.4: Objectives

The objective of this effort is for FIU to continue to publish additional technologies, vendors, and lessons learned on the KM-IT platform in addition to other relevant resources for the community, such as D&D-related training, conferences, and workshops to maintain fresh and informative content on the website. In addition, FIU plans to train a Generative AI model that uses a LLM to perform document summarization to assist with populating content on the Technology Module.

Subtask 3.4: Methodology

FIU used factsheets, conference material (agenda, proceedings, brochures, etc.), vendor website, publications, DOE newsletters, and other sources to continue to publish additional technologies, vendors and lessons learned on the KM-IT platform. In addition, the team used other relevant resources for the community, such as D&D-related training, seminars, and workshops to share information with the D&D community. The team also used website data analytics on the D&D KM-IT website and looked for anomalies, spikes in traffic, and other information that should be addressed. By using data analytics, the developers and team members can focus on critical issues affecting the website. It can also provide great insight into features that should be enhanced and/or added to the website based on user behavior.

For document summarization, FIU is using Generative AI Large Language Model (LLM) for uniform identification of key points to ensure consistency of the results. The image below shows the Retrieval Augmentation Generation (RAG) sequence diagram process. Here we see the documents are fed to the Embedding Model which then sends document embeddings to a Vector Database. When the user queries the application by sending a prompt requesting information, the prompt is sent to the model and the Vector DB, which then generates a message to the Large Language Model (LLM). This message is composed of the prompt, query and enhanced context from the user. The LLM streams a generative text response back to the user completing the cycle.

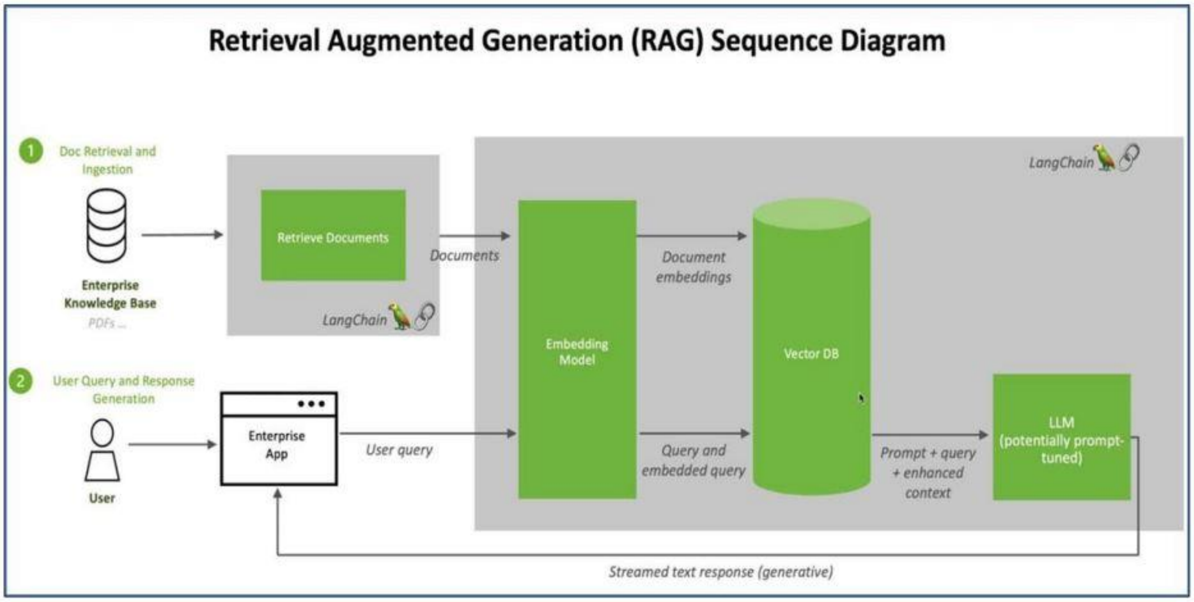


Figure 36. Retrieval Augmented Generation (RAG) sequence diagram.

Subtask 3.4: Results and Discussion

In Year 4, FIU continued to publish additional technologies, vendors, and lessons learned on the KM-IT platform in addition to other relevant resources for the community, such as D&D-related training, conferences, and workshops. There were 23 technologies published on the D&D KM-IT website. Below is the list of technologies published during this period including title, description, and link to the technology on the D&D KM-IT website.

1. GemmaCert Cannabis Analyzer Professional
2. Workstation for Laser Testing of Single Event Effects (SEE) on Radiation Hardened Semiconductor
3. Gorilla Strengthen Glass Laser Cutting System; Model ASP-Gorilla-201
4. Tucsen Dhyana 95
5. Corroscan Capacitance 2D Imaging
6. ASP-WN03RA200H 200mm Diameter High Precision Rotation Stages
7. T690 AC/DC (HV) LED Optical & Electrical Tester
8. T716 SMD LED Taping Optical & Electrical Analyzer
9. T770 Dual Stations LED Optical & Electrical Tester
10. T68X High Power LED Tester
11. Spectral Light Meter SRI2000 UV Illuminance Spectrometer (250nm - 850nm)
12. UVC Spectroradiometer SRI-4000UVC
13. Juno USB Laser Power Meter
14. S3 Soil Sorting System
15. TAWARA_RTM Water Treatment Plant Radiological and Nuclear Threat Detection System
16. EF-4000 Energy Absorption Low-Density Foam
17. Mobile Packet Monitor
18. Fork Detector (IAEA)

19. Passive Neutron Slab Counter
20. Far Field Gamma Monitor
21. ODAS- a cutting-edge drone mapping and surveying solution
22. Brolga-002 Mobile Cold Spray System
23. Apex Exoskeleton

The following image shows the technology ASP-WN03RA200H 200mm Diameter High Precision Rotation Stages on the D&D KM-IT website. This technology belongs to the vendor Allied Scientific Pro. When a new technology is added to the KM-IT, a technology page is created to contain the technology description, benefits, comments, and pictures. When the user clicks on the picture, the image of the technology is enlarged as seen in the image below.

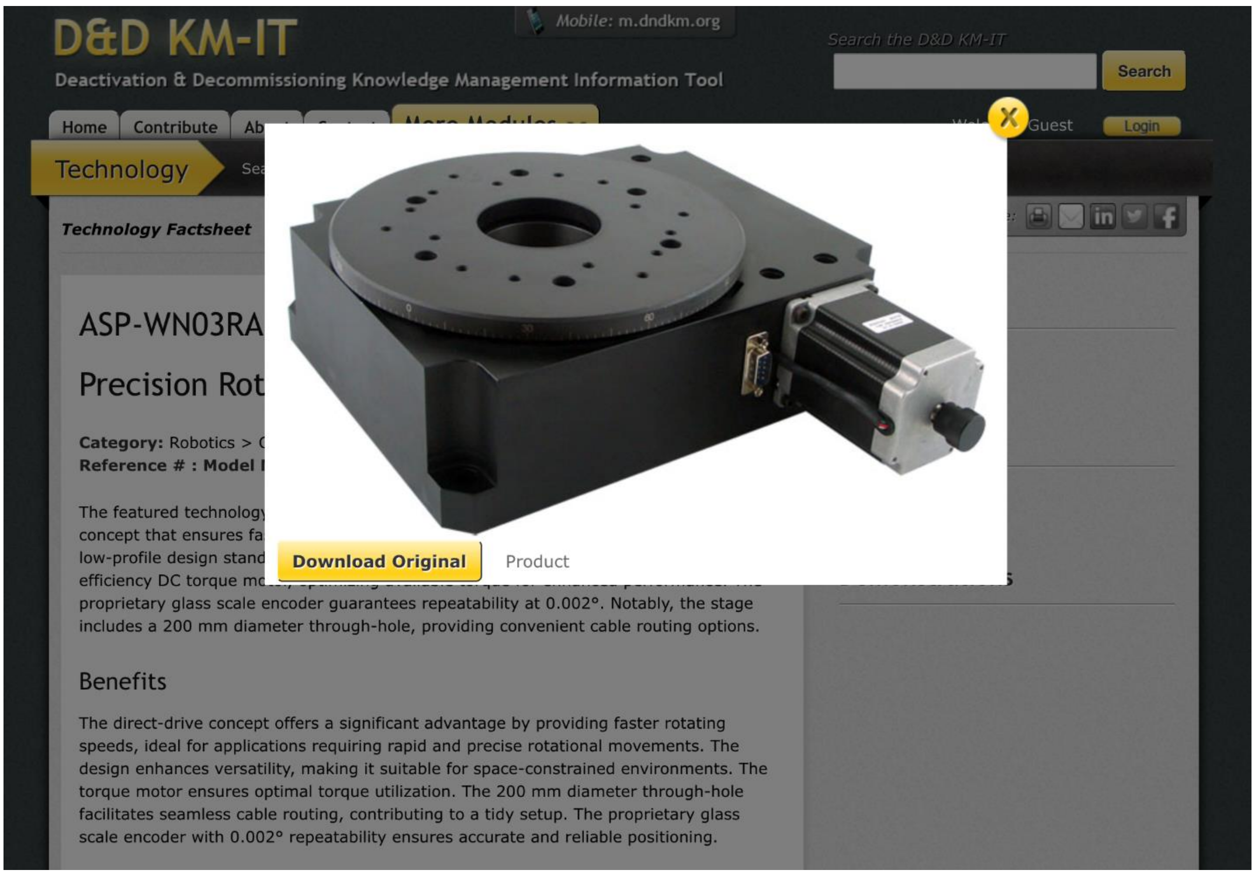


Figure 37. Technology LaserBlast ™ Cleaning System 100 Watts on the D&D KM-IT from vendor Allied Scientific Pro.

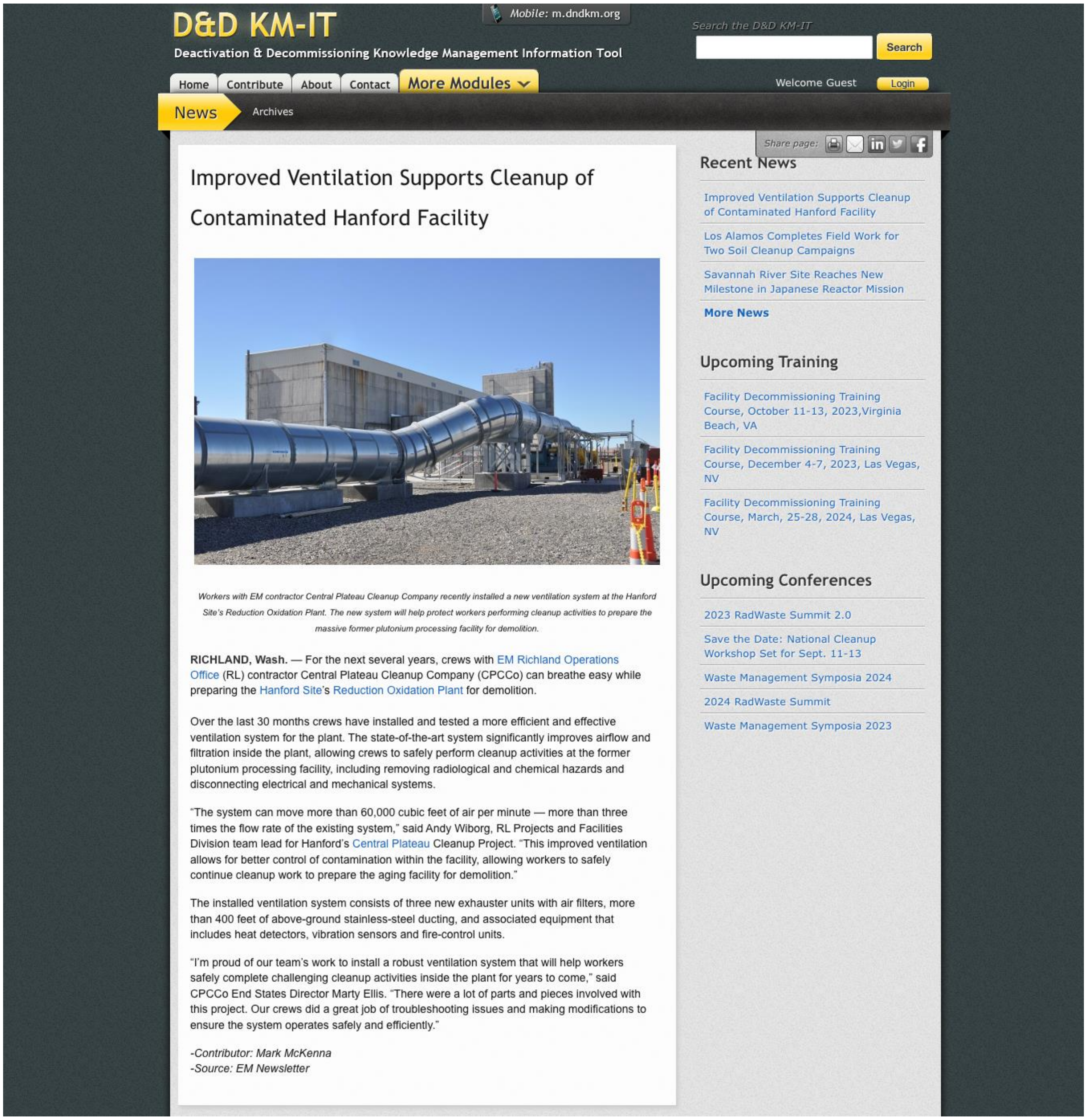
During this period, the team focused on adding news articles and events relevant to the D&D community. The team added 63 articles to the news module of the KM-IT. The source of the articles was mainly from the EM Newsletter. The complete list of news is archived on the KM-IT at the following URL - https://www.dndkm.org/News/NewsDefault.aspx. The following articles were added to the website.

1. Radiation-Detecting Drone Soars Over Portsmouth for Collaborative Testing
2. 'Big Dig' Milestone: Ventilation System Shaft Reaches Final Depth at WIPP
3. 2023 Priorities Update: West Valley Achieves Main Plant Demolition Milestone

4. Teams Upgrade Hanford's Effluent Treatment Facility
5. EM Worker Safety is Central to Wearable Robotics Team Efforts
6. New Reliable Source to Supply Nitrogen to Idaho Waste Treatment Facility
7. DOE, FIU Welcome New Fellows Into Program to Help Build EM Workforce
8. Idaho Site Makes Demolition Progress in Advance of Placing Landfill Cover
9. Oak Ridge Crews Prep Reactor Facility for Demolition at ORNL
10. West Valley Removes Legacy Waste, Setting Stage for More Cleanup Success
11. Team's Solution Ensures Integrity of Radioactive Material Containers at SRS
12. Savannah River Site Reaches New Milestone in Japanese Reactor Mission
13. Los Alamos Completes Field Work for Two Soil Cleanup Campaigns
14. Oak Ridge Keeps Pace of Progress in 2023
15. Paducah Removes 1 Million Pounds of Hazardous Refrigerant in 2023
16. Improved Ventilation Supports Cleanup of Contaminated Hanford Facility
17. Oak Ridge Sets Big Goals for 2024
18. Los Alamos Contractor Surpasses Small Business Goals for Fiscal Year 2023
19. WIPP Begins Mining New Waste Disposal Panel for First Time in Decade
20. Japan Delegation Visits EM Sites for Information Exchange
21. Footprint Continues Shrinking Near Former Hanford Processing Facility
22. West Valley Removes 40,000-Pound Tank for Main Plant Demolition
23. Hanford Plant Installs Startup Heaters in Second Melter
24. Idaho Demolition Project Reaches Toward Recycling, Sustainability Goals
25. West Valley Crews Safely Demolish Former Waste Packaging Area
26. West Valley Employs Video Technology to Improve Waste Tank Inspection
27. Oak Ridge Disposal Facility Enters Next Phase of Construction
28. Waste Management Wrap-up: From Cleanup to Clean Energy
29. Hanford Lab Prepares for More Hot Work and Tank-Waste Treatment
30. Savannah River Site Team's Creative Solution Furthers Tank Waste Retrieval
31. Hanford Plant Brings Second Melter Online
32. EM Crews Complete Repairs on Oak Ridge's Tallest Stack
33. Waste Isolation Pilot Plant Plans More Infrastructure Upgrades
34. EM's Carlsbad Office Sends Tool to Hanford to Boost Waste Certification Work
35. Los Alamos Public Forum Engages Community on Chromium Project
36. Oak Ridge Completes First Phase of New Disposal Facility Project
37. West Valley Ships Eight Large Legacy Waste Containers for Disposal
38. EM Team Takes Part in Inaugural Workshop, New Facility for Robotics, AI
39. West Valley Clears One Large Component After Another from Main Plant
40. Oak Ridge Welcomes New Class of Summer Interns
41. U-233 Processing in Oak Ridge Exceeds EM Priority Goal
42. Collaborative Research and Development Supports Hanford Waste Vitrification
43. SRS Completes Construction Milestone on Next Mega-Size Disposal Unit
44. Photo Project to Help Document Hanford's Historic T Plant
45. Perfect Fit: Crews Assemble Cask Storage System

46. EM Priority Update: Oak Ridge Makes Headway Toward Y-12 Building Knockdown
47. Oak Ridge Completes Largest Soil Remediation Project at ETTP
48. SRS Contractor Welcomes Largest Class of Interns in Liquid Waste Program History
49. Paducah Tests Drones for Emergency Response
50. Hanford Drains Last Reactor Fuel Storage Basin
51. Oak Ridge Team Member Wins Award for Contributions Across EM Complex
52. Construction on Test Bed Initiative Advancing Hanford Tank Waste Mission
53. Crews Remove Reactor, Advance Major Deactivation Project at ORNL
54. Idaho Crews Level Largest Building on Cold War Landfill
55. Hanford Stabilizes Last Reactor Fuel Storage Basin
56. Idaho Crews Improve Safeguards for Spent Nuclear Fuel in Storage
57. EM MSIPP Achievement Workshop Attracts 245 Participants as Program Marks 10th Year
58. A Heavy Lift: Savannah River Site Finishes Heavy Water Moderator Sampling
59. Oak Ridge Contractor Builds on Intern Program Success
60. Olympic-style First: Hanford Contractors Pass the Glass
61. Interns Gain Valuable Experience Helping EM Fulfill Cleanup Mission in Idaho
62. Idaho Crews to Ensure Integrity of Waste Drums with Unique Technology
63. Risk Reduction Continues Near Former Hanford Processing Facility

The images below are screenshot samples of the articles recently added to the website. The new module on the D&D KM-IT also has an archive of past articles that can be accessed at the following URL: https://www.dndkm.org/News/NewsDefault.aspx.



D&D KM-IT

Deactivation & Decommissioning Knowledge Management Information Tool

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Improved Ventilation Supports Cleanup of Contaminated Hanford Facility

Workers with EM contractor Central Plateau Cleanup Company recently installed a new ventilation system at the Hanford Site's Reduction Oxidation Plant. The new system will help protect workers performing cleanup activities to prepare the massive former plutonium processing facility for demolition.

RICHLAND, Wash. — For the next several years, crews with EM Richland Operations Office (RL) contractor Central Plateau Cleanup Company (CPCCo) can breathe easy while preparing the Hanford Site's Reduction Oxidation Plant for demolition.

Over the last 30 months crews have installed and tested a more efficient and effective ventilation system for the plant. The state-of-the-art system significantly improves airflow and filtration inside the plant, allowing crews to safely perform cleanup activities at the former plutonium processing facility, including removing radiological and chemical hazards and disconnecting electrical and mechanical systems.

"The system can move more than 60,000 cubic feet of air per minute — more than three times the flow rate of the existing system," said Andy Wiborg, RL Projects and Facilities Division team lead for Hanford's Central Plateau Cleanup Project. "This improved ventilation allows for better control of contamination within the facility, allowing workers to safely continue cleanup work to prepare the aging facility for demolition."

The installed ventilation system consists of three new exhauster units with air filters, more than 400 feet of above-ground stainless-steel ducting, and associated equipment that includes heat detectors, vibration sensors and fire-control units.

"I'm proud of our team's work to install a robust ventilation system that will help workers safely complete challenging cleanup activities inside the plant for years to come," said CPCCo End States Director Marty Ellis. "There were a lot of parts and pieces involved with this project. Our crews did a great job of troubleshooting issues and making modifications to ensure the system operates safely and efficiently."

-Contributor: Mark McKenna
-Source: EM Newsletter

Recent News

- Improved Ventilation Supports Cleanup of Contaminated Hanford Facility
- Los Alamos Completes Field Work for Two Soil Cleanup Campaigns
- Savannah River Site Reaches New Milestone in Japanese Reactor Mission
- **More News**

Upcoming Training

- Facility Decommissioning Training Course, October 11-13, 2023,Virginia Beach, VA
- Facility Decommissioning Training Course, December 4-7, 2023, Las Vegas, NV
- Facility Decommissioning Training Course, March, 25-28, 2024, Las Vegas, NV

Upcoming Conferences

- 2023 RadWaste Summit 2.0
- Save the Date: National Cleanup Workshop Set for Sept. 11-13
- Waste Management Symposia 2024
- 2024 RadWaste Summit
- Waste Management Symposia 2023

Figure 38. News item titled *"Improved Ventilation Supports Cleanup of Contaminated Hanford Facility"* added to the D&D KM-IT website.

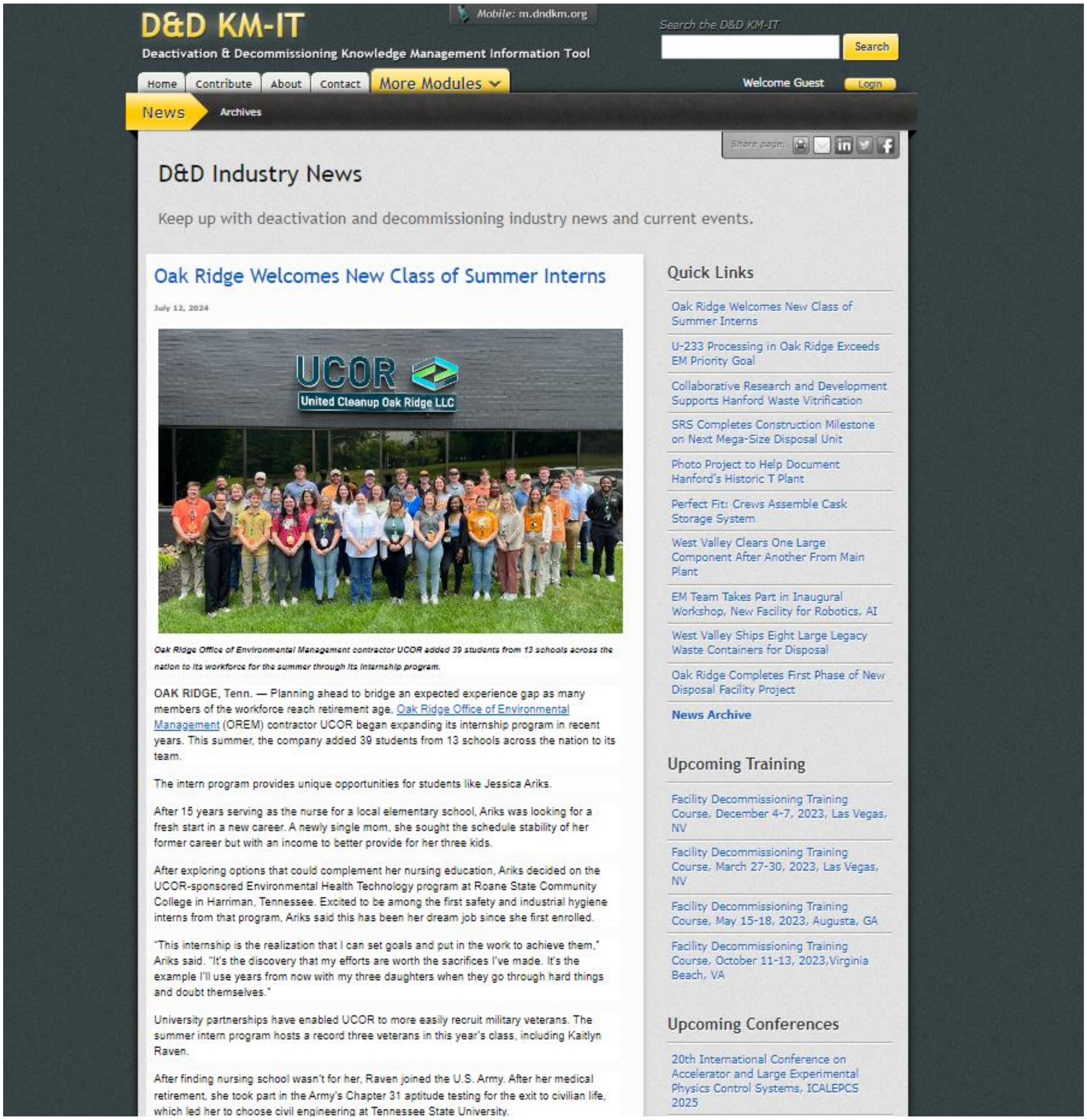


Figure 39. News article on the D&D KM-IT titled "*Oak Ridge Welcomes New Class of Summer Interns*".

In addition, the team added events relevant to the community like the Waste Management Symposia and D&D facility decommissioning training. All the events added to the KM-IT can be found on the Training module of the website at: https://www.dndkm.org/Training/TrainingDefault.aspx.

The screenshot below shows the sample entry for Waste Management Symposia 2025 which will be held in Phoenix in March 2025.

Figure 40. Waste Management Symposia 2025 event entry on the D&D KM-IT.

FIU made some progress training a LLM using D&D KM-IT technology documents and have deployed this model on the FIU AI Ops website. This website is a collection of AI tools available to the public. The following screenshot shows a screenshot of the landing page of FIU AI Ops.

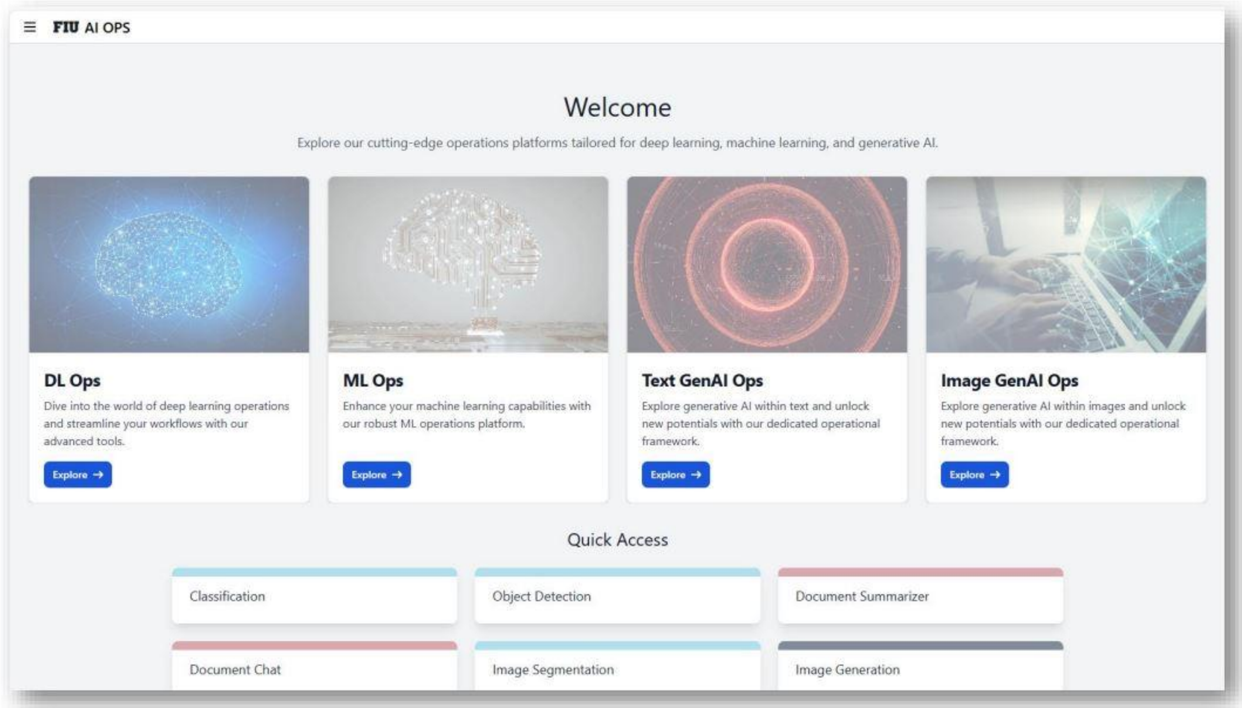


Figure 41. FIU AI Ops website.

The following screenshot shows the document summarization LLM at work. In this instance, the user has uploaded a document titled *"136-1476-Linear Motion.pdf"* to the application. This document is sent to the LLM and the response includes a summarization of the document. The title, description, benefits and limitations are automatically generated by the LLM and displayed back to the user. Therefore, it does not matter how long the document is, the application will read it and send a summary within a second. This model is continuing to be improved for better results and efficiency.

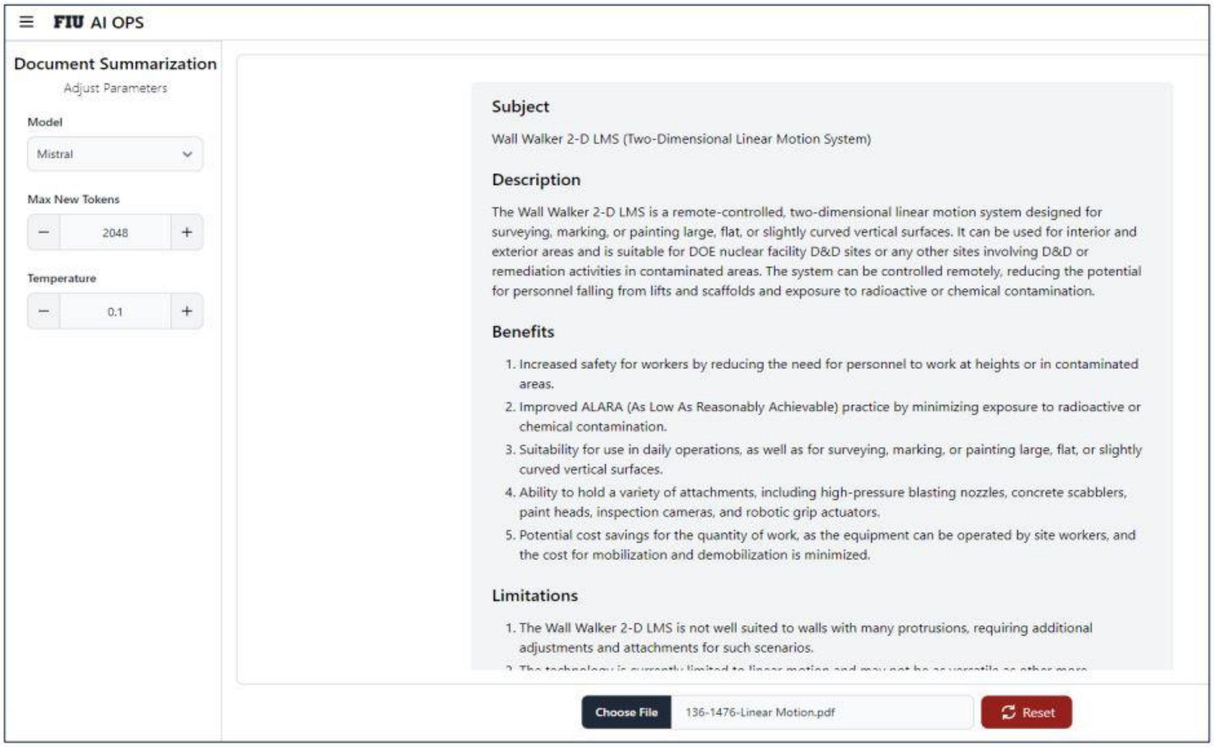


Figure 42. Document summarization sample using a Technology module document from D&D KM-IT.

Content management has allowed the D&D KM-IT to increase its content. The graph below (Figure 43) summarizes the growth over the years. As of September 2024, the system had 1,608 D&D technologies, 1,195 registered users, 1003 D&D vendors, and 111 subject matter specialists.

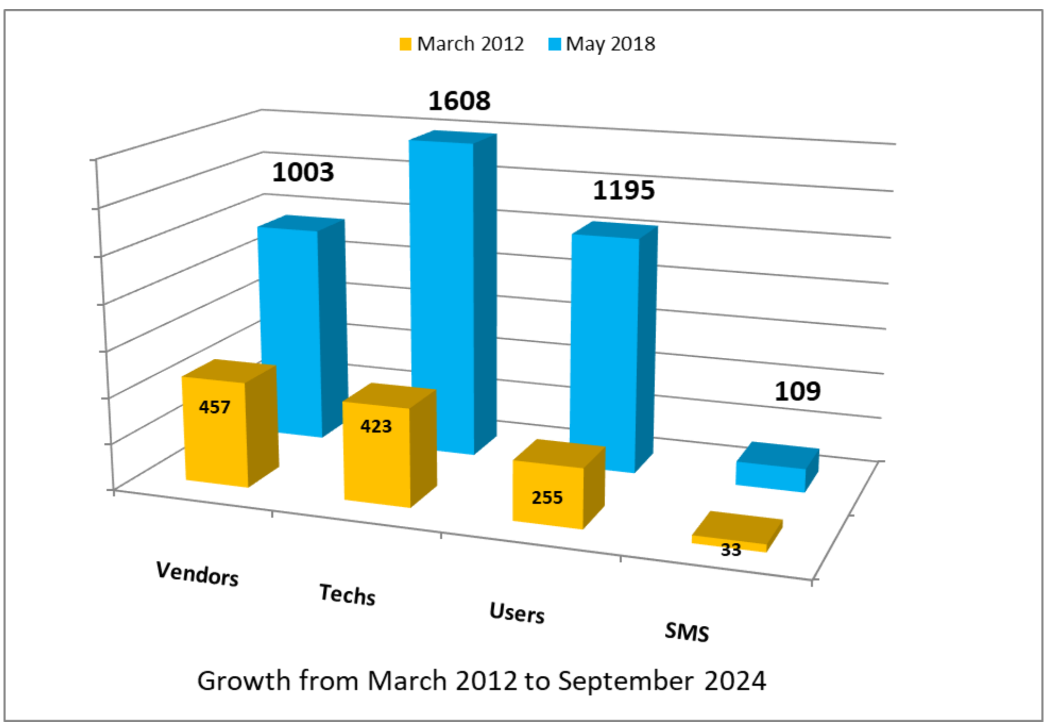


Figure 43. Number of vendors, technologies, users, and SMS as of September 2024.

FIU achieved the abovementioned objectives by publishing 23 technologies, 63 news items and 7 events on the D&D KM-IT website over the past year. In addition, website data analytics captured key metrics that helped the FIU developer focus on specific issues on the website. The content management efforts continue to keep the website current and informative for the D&D community.

The LLM model was deployed successfully on the FIU AI Ops website and will continue to be matured for better results and efficiency. A paper was presented based on this research at the Waste Management Symposia 2024 titled *Artificial Intelligence Based Nuclear Decommissioning Document Summarization"* which focuses on exploring AI capabilities to summarize D&D documents stored in the D&D KM-IT.

Subtask 3.4: References

Deactivation & Decommissioning Knowledge Management Information Tool (D&D KM-IT), https://dndkm.org/, Applied Research Center, Florida International University.

Google Analytics, https://analytics.google.com, Google Analytics, Google Inc.

Google Search Console, https://search.google.com/search-console/, Google Search Console, Google Inc.

Subtask 3.5: Marketing and Outreach

Subtask 3.5: Introduction

This task involves reaching out to sites/national labs to increase KM-IT user involvement as well as presentations at conferences and collaboration with other organizations involved in D&D. In addition, the team focuses on increasing engagement from DOE sites and national labs on D&D KM-IT by a series of methods such as Tech Talks, public and internal newsletters.

Some specific activities for outreach and marketing of KM-IT include the following:

<u>Newsletters and Mass Communications</u>**:** Newsletters and online promotions are a great way to bring waves of traffic to the website. By using the registered users as recipients, users are kept up to date on new features and content on the D&D KM-IT.

<u>Conferences and Workshops</u>**:** Participation and presentations of KM-IT at industry conferences boost awareness of the website and its capabilities to the target users. FIU has presented KM-IT at conferences, such as the Waste Management Symposia, through a combination of oral and poster presentations as well as individual and small-group demonstrations and workshops hosted in the exhibition hall. At these events, the site features can be explained in detail and participants can share their feedback and ideas.

<u>User Support and Ad Hoc Specialized Reports:</u> This task includes supporting KM-IT users with a help desk role to resolve issues on a day-to-day basis, as well as developing specialized reports using the KM-IT system for unforeseen data requests from DOE or the EM community of practice.

Subtask 3.5: Objectives

The objective of this task is to reach the D&D community and educate them on the features available on the D&D KM-IT system. There are many industry leaders who work at various DOE sites and national labs that can benefit greatly from the capabilities that the system has to offer. In many cases, these individuals are not aware of the system, so by doing outreach and marketing, the system usage can be promoted while helping the D&D community meet their knowledge management needs.

Marketing and outreach are critical for the self-sustainability of the system as it introduces the system to subject matter experts who may not be aware of its features and capabilities. This task increased the footprint of the D&D KM-IT in the community by allowing users to discover the capabilities of the D&D KM-IT.

Subtask 3.5: Methodology

This task is an ongoing process that is executed over the course of the year. When new features or content is added to the system, DOE is notified and others in the industry are reached via email to get feedback and comments. This is done not only to communicate with DOE regarding accomplishments and milestones, but also to involve other leaders in the industry in the process of spreading the word about D&D KM-IT. When sending newsletters, FIU uses the D&D KM-IT as its recipients. Currently, there are 1,195 registered users in the system. FIU has also used the public distribution list provided by the Waste Management Symposia (WMS) to make announcements about the D&D KM-IT training workshop typically held at the FIU booth during WMS.

FIU uses a third-party application/service called Mailchimp to send newsletters to a large distribution list. This service supports email stats like opened emails and read emails, and it also tracks clicks. However, for official announcement of milestones and deliverables, FIU uses a typical email system to notify its stakeholders. During the course of this year, several emails were sent to DOE notifying them about new features, such as the development of a sub-module on the KM-IT platform to highlight current EM research efforts and activities in support of D&D. The team also updates flyers, postcards and factsheets to promote the D&D KM-IT.

Figure 44. Multiple marketing and outreach materials used to promote the D&D KM-IT (postcards, flyers, factsheets, and newsletters).

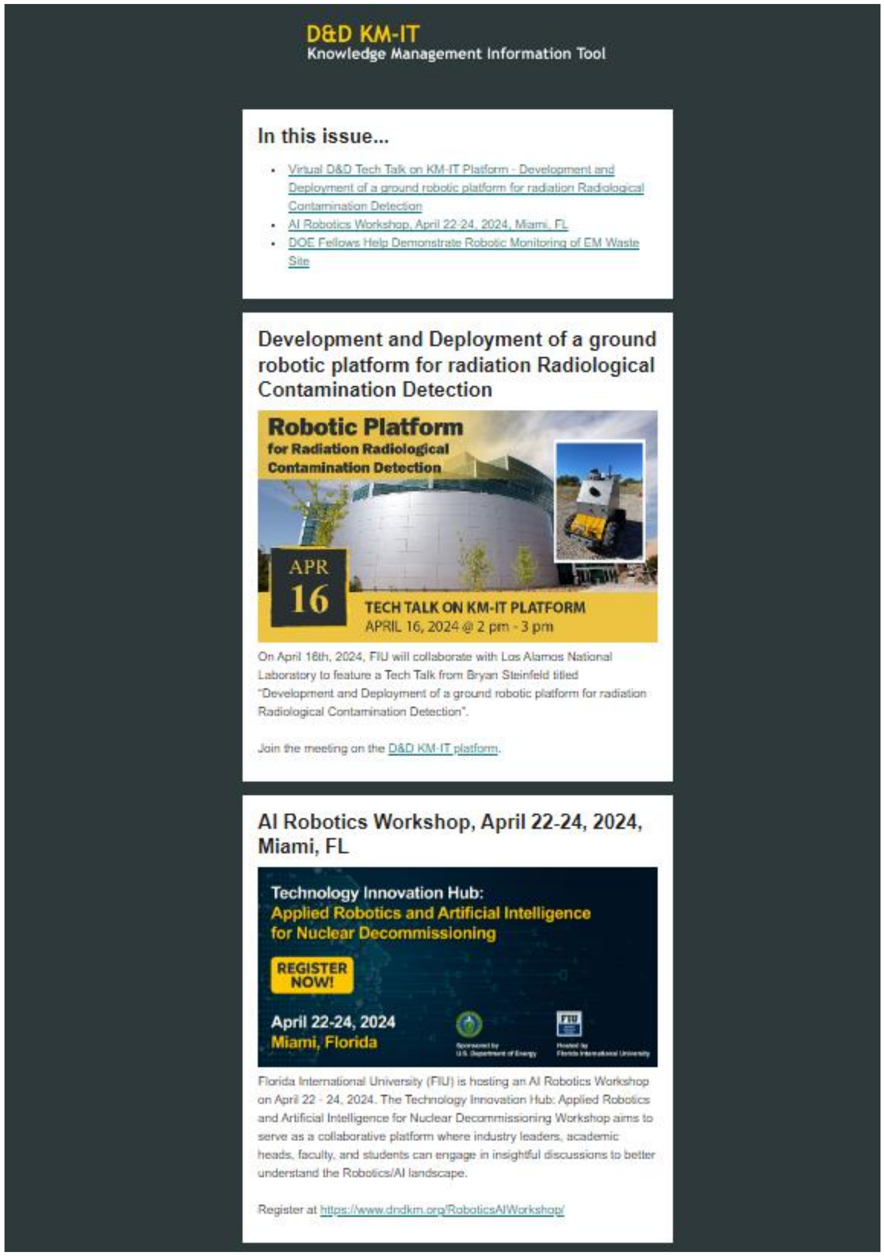
Subtask 3.5: Results and Discussion

As part of the marketing and outreach efforts, the team presented a paper at Waste Management Symposia 2024 based on the research focused on exploring AI capabilities to summarize D&D documents stored in the D&D KM-IT. The title of the paper was *"Artificial Intelligence Based Nuclear Decommissioning Document Summarization"*.

During this period, FIU prepared several newsletters that were sent to its registered users. Here are the titles and content of some of the newsletters sent:

- AI Robotics Workshop - To inform users of the AI Robotics Workshop help at FIU during April 2024. This newsletter included information about the venue, registration procedures, presentation, agenda and remote zoom information.
- D&D KM-IT April Newsletter – The topics of this newsletter included:
    - Virtual D&D Tech Talk on KM-IT Platform - Development and Deployment of a Ground Robotic Platform for Radiological Contamination Detection
    - AI Robotics Workshop, April 22-24, 2024, Miami, FL
    - DOE Fellows Help Demonstrate Robotic Monitoring of EM Waste Site
- D&D KM-IT April Tech Talk – Newsletter sent to registered users reminding them to join the April Tech Talk.
- D&D KM-IT May Newsletter – The topics of this newsletter included:
    - Virtual D&D Tech Talk on KM-IT Platform - AI/ML Research support for Advance Long-Term Environmental Monitoring Systems (ALTEMIS)
    - Tech Talks recording available on the D&D KM-IT
    - DOE Fellows Help Demonstrate Robotic Monitoring of EM Waste Site
- D&D KM-IT July Newsletter – The topics of this newsletter included:
    - A Case Study: The Strategic Integration of Consensus Standards to Facilitate Fixative Technology Development, Deployment, and Acceptance
    - LM Emphasizes Importance of Future Workforce Development and Partnership in DOE-FIU Program
    - EM Team Takes Part in Inaugural Workshop, New Facility for Robotics, AI
    - Los Alamos Public Forum Engages Community on Chromium Project
- D&D KM-IT July Tech Talk – Newsletter sent to registered users reminding them to join the July Tech Talk.
- D&D KM-IT October Newsletter – This newsletter is being prepared and will be sent in the first week of October. The topics of this newsletter included:
    - Significance of Resilient Analytics in Achieving the Energy Resilience of Microgrids
    - FIU-DOE End-of-Year Review
    - FIU Student's Summer Internships Impact at Hanford Site

The following images show screenshots of a few newsletters sent during this period.



D&D KM-IT
Knowledge Management Information Tool

In this issue...

- Virtual D&D Tech Talk on KM-IT Platform - Development and Deployment of a ground robotic platform for radiation Radiological Contamination Detection
- AI Robotics Workshop, April 22-24, 2024, Miami, FL
- DOE Fellows Help Demonstrate Robotic Monitoring of EM Waste Site

Development and Deployment of a ground robotic platform for radiation Radiological Contamination Detection

Robotic Platform
for Radiation Radiological Contamination Detection
APR 16
TECH TALK ON KM-IT PLATFORM
APRIL 16, 2024 @ 2 pm - 3 pm

On April 16th, 2024, FIU will collaborate with Los Alamos National Laboratory to feature a Tech Talk from Bryan Steinfeld titled "Development and Deployment of a ground robotic platform for radiation Radiological Contamination Detection".

Join the meeting on the D&D KM-IT platform.

AI Robotics Workshop, April 22-24, 2024, Miami, FL

Technology Innovation Hub:
Applied Robotics and Artificial Intelligence for Nuclear Decommissioning
REGISTER NOW!
April 22-24, 2024
Miami, Florida

Florida International University (FIU) is hosting an AI Robotics Workshop on April 22 - 24, 2024. The Technology Innovation Hub: Applied Robotics and Artificial Intelligence for Nuclear Decommissioning Workshop aims to serve as a collaborative platform where industry leaders, academic heads, faculty, and students can engage in insightful discussions to better understand the Robotics/AI landscape.

Register at https://www.dndkm.org/RoboticsAIWorkshop/

Figure 45. D&D KM-IT newsletter sent in April 2024.

Figure 46. Newsletter prepared to promote the January Tech Talk and sent to D&D KM-IT users prior to the event.

Figure 47. D&D KM-IT Newsletter to be sent in June 2024.

In addition, a newsletter and other promotional graphics were prepared to announce FIU's presence at Waste Management 2024. The image below shows a sample promotional graphic used on social media to announce FIU's participation at WM2024. This sample post had the booth number and basic information about FIU's participation in the conference. This announcement was posted across FIU's ARC social media outlets (Facebook, LinkedIn and Twitter).

Figure 48. Promotional graphic for announcing FIU participation at WM2024 on social media.

In total, 10 newsletters were developed:

- Four newsletters were targeted at promoting Tech Talks.
- Three newsletters were sent to KM-IT users with news articles and events.
- Two newsletters to promote a Robotic AI Workshop
- One newsletter was specifically targeted to promote the FIU participation at WM2024.

Finally, an abstract to Waste Management 2025 (WM2025) titled *"Large Language Model based D&D ChatBot on Knowledge Management Information Tool" was submitted*. WM is held every year in Phoenix, AZ during the month of March. The abstract was accepted, so the team will have the opportunity to share this research with the community. Also, during this conference, the capabilities and features of the D&D KM-IT are demonstrated at the FIU booth. This allows the team to get feedback from the D&D community, encourage users to register with the system, and become subject matter experts.

In addition, printed marketing material was updated and printed which included 5"x7" postcards that were distributed at WM2024. One of the postcards included information about FIU-ARC focus areas which included D&D KM-IT; the second was an updated D&D KM-IT postcard; and the third which was created to promote an AI Robotics Workshop, was printed and posted on D&D KM-IT. The images below show the postcards generated and printed.

Figure 49. 5”x7” postcards used as marketing material and distributed at WM2024, which included one with FIU-ARC focus areas, an updated D&D KM-IT postcard, and one promoting the upcoming AI Robotics Workshop in April 2024. The postcards were also posted on D&D KM-IT.

Finally, FIU gave a presentation to the DOE HQ Knowledge Management Community on June 6, 2024. The presentation topic was on the use of Generative AI in D&D and Infrastructure, using as an example the document summarization mentioned under Subtask 3.4 using the D&D documents in the KM-IT database. The image below shows a few screenshots of the virtual meeting attended by Dr. Inés Triay, Dr. Leonel Lagos, Dr. Himanshu Upadhyay and Mr. Walter Quintero.

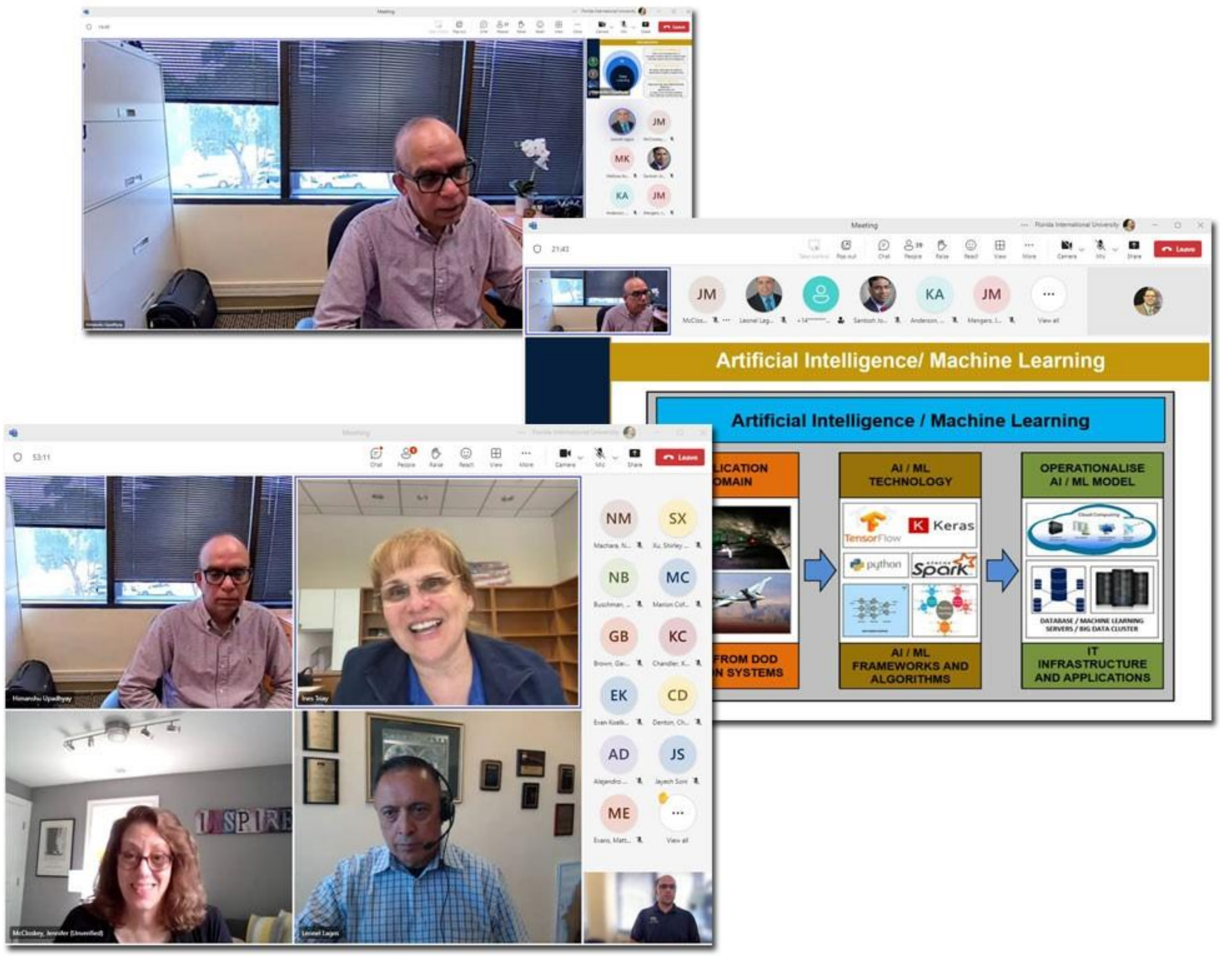


Figure 50. FIU presentation to the DOE HQ Knowledge Management Community on June 6, 2024.

Subtask 3.5: Conclusions

Outreach and marketing are critical elements towards the long-term sustainability of this knowledgebase and are essential for the long-term strategic vision of D&D KM-IT. Moving forward, FIU will continue to participate in industry conferences (such as Waste Management Symposia) and other workshops to demonstrate and promote the KM-IT system. This allows for collaboration with other centers, facilities, and DOE sites to increase usage and subject matter specialist participation. In addition, FIU will continue to develop newsletters for mass communication via email to keep users informed of new system features and other related activities.

Subtask 3.5: References

Deactivation and Decommissioning Knowledge Management Information Tool (D&D KM-IT), https://www.dndkm.org/, Applied Research Center, Florida International University.

Subtask 3.6: D&D KM-IT System Administration & Cyber Security

Subtask 3.6: Introduction

D&D KM-IT system administration is an ongoing task, which involves day-to-day administration of servers that house the KM-IT databases and web applications. This task includes updating patches and OS fixes, updating antivirus engines and definitions, updating drivers and assuring that the network (firewall, routers and switches) is working properly. This task also involves securing the network infrastructure where the D&D KM-IT is deployed, secured, and maintained at FIU's research facility, as well as conducting routine cyber security tasks to test the network's vulnerability.

Subtask 3.6: Objectives

The objective of this task is to enhance the overall security and efficiency of the D&D KM-IT infrastructure by implementing robust system administration practices and proactive cybersecurity measures. This includes managing and maintaining server environments, ensuring proper configuration of network devices, monitoring system performance, and applying security patches to prevent vulnerabilities. The goal is to safeguard sensitive data, protect against cyber threats, and ensure business continuity by identifying and mitigating risks, optimizing system performance, and ensuring compliance with industry security standards. Through effective system administration and vigilant cybersecurity management, FIU aims to reduce the risk of data breaches and minimize potential disruptions to the system.

Subtask 3.6: Methodology

To achieve the objective of enhancing system administration and cybersecurity, the methodology involves an ongoing comprehensive, multi-step approach. First, an assessment of the D&D KM-IT infrastructure is conducted to identify vulnerabilities, followed by a risk analysis to evaluate potential threats. System administration practices are then implemented, including proper configuration management, user access controls, and continuous system monitoring. Cybersecurity measures, such as regular patch management, firewalls, and encryption, are deployed to protect systems and data. An incident response plan and disaster recovery strategies are established to ensure quick recovery from potential breaches. Finally, the process includes continuous evaluation and adaptation to emerging threats, ensuring that the D&D KM-IT infrastructure and cybersecurity posture remains effective and up-to-date.

Subtask 3.6: Results and Discussion

During this period, the team performed several tasks. One of them included running a Google PageSpeed Insight report for the D&D KM-IT website shown below (Figure 51). This report captured issues that could improve the website's speed, such as eliminating the render-blocking resources by caching or reducing the amount of Cascading Style Sheet (CSS) files or compressing them. There was a significant improvement in the score for all the metrics from the same report last year.

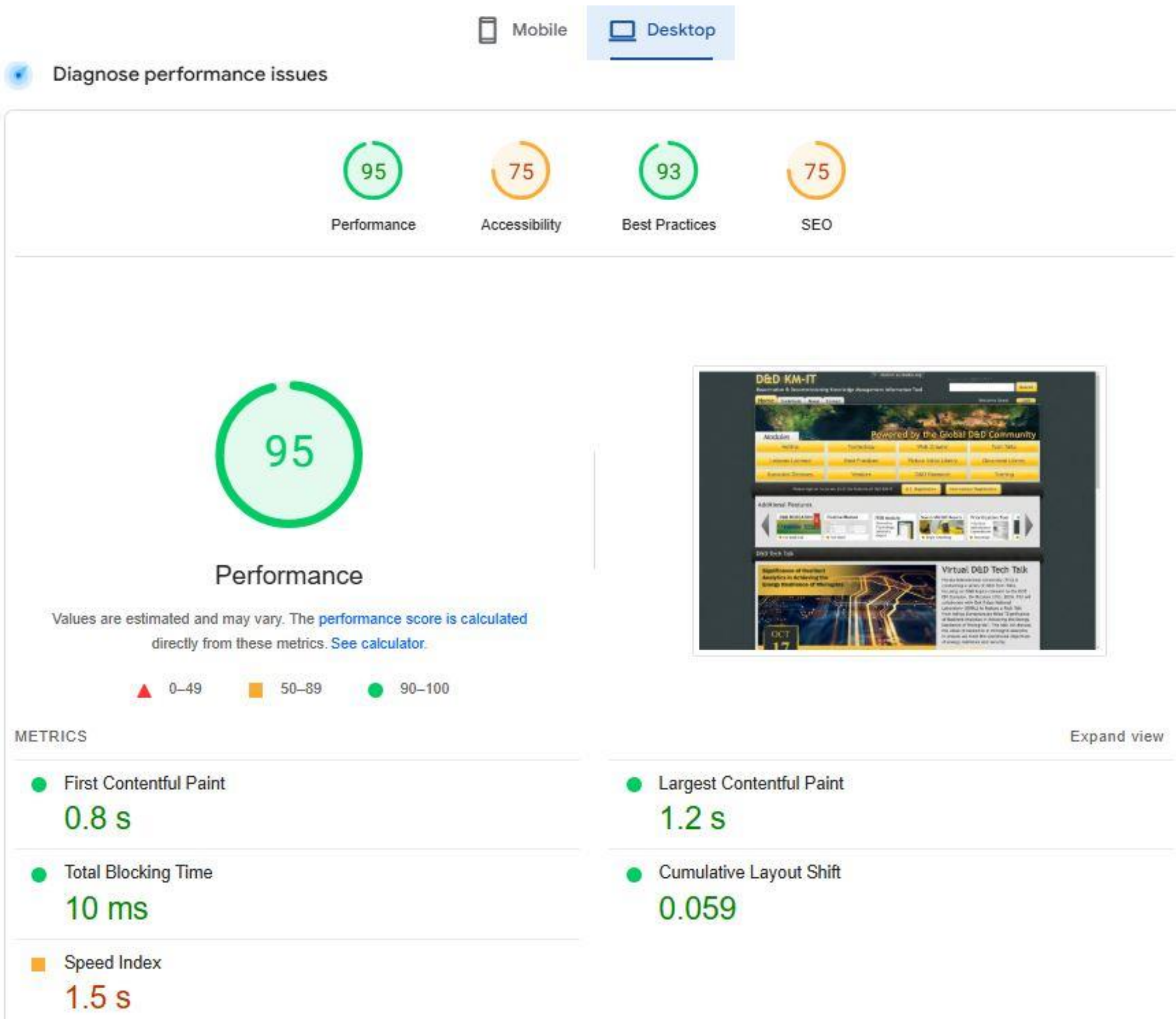


Figure 51. Snapshot report from Google PageSpeed Insights for dndkm.org.

The team addressed some recommendations from Google PageSpeed and other tools that help improve the performance of the application. Some of the specific tasks performed during this period included:

- Migration of the production server to a new environment was completed to remain compliant with security policies from the University and to implement the best security practices. This process involved migrating the database and web server to new servers with the latest operating system. The staff is finishing some configuration and testing to ensure that all the modules are working properly. One of the modules that still needs to be finalized is Global Search which uses dtSearch software to crawl the site. The template that shows the result is not displaying the results correctly and the team is debugging this before making this entire application live. Once the testing is complete, the domain will be redirected to this new environment.
- Migration of both the web server and the database server to virtual machines has been completed, utilizing a Linux hypervisor known for its robust stability and performance. This change represents a strategic move away from HyperV virtual machines, which were previously used but were found to be less stable and efficient compared to their Linux-based counterparts. By choosing Linux hypervisors, the team has opted for a virtualized environment that offers greater reliability and control. These hypervisors are designed to

handle high workloads and provide enhanced stability, reducing the risk of crashes or performance bottlenecks. They also offer a wider range of customization options, allowing the team to fine-tune the virtual machines to meet specific needs.

- Monitor the Google Analytics version 4 (GA4) to make sure the new script implemented on the website is reporting correctly. So far, the new GA4 script running on the website appears to be reporting properly. The new features available with this script are also being explored to see what can be utilized to improve the site's performance.
- New hardware upgrades to keep the application reliable. These upgrades included hard drive replacement and battery backup power upgrades.
- Monitoring of the new virtual machines running the KM-IT application (database and web app) using Linux hypervisor. The Linux hypervisor provided a more stable performance than HyperV virtual machines.
- FIU completed the integration of the production environment of the collaboration tools with the new updated version of the framework running on updated servers. This update was necessary to meet the university security requirements. The collaboration tools support multiple modules on the D&D KM-IT (news, events, workshops, and training).
- Updated the index on the DTSearch application. The team updates the index manually to monitor that the index updates successfully. The index is updated regularly to make sure new content added to the site is added to the index. The DTSearch is used on the Global Search module and individual search modules.

FIU also monitors the website reporting with Google Analytics (GA). The image below shows a quick snapshot of the period from October to September 2024. The site averages about two thousand users per month with the top module being the Technology Module.

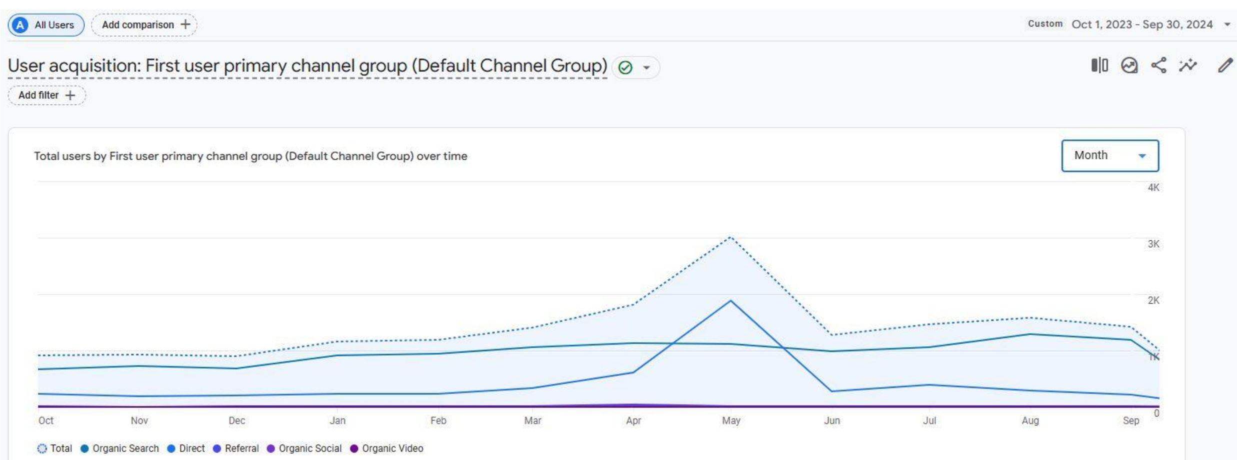


Figure 52. Number of users visiting the D&D KM-IT during Jul – Sep, 2023.

Subtask 3.6: Conclusions

The team has successfully kept the D&D KM-IT application and production environment running with optimal performance. After all the hardware and software updates were done, the application did not experience any outages. As a result, the application continues to be more reliable because of the routine maintenance performed on the environment where the application is running.

Subtask 3.6: References

Deactivation and Decommissioning Knowledge Management Information Tool (D&D KM-IT), https://www.dndkm.org/, Applied Research Center, Florida International University.

Subtask 3.8: KM-IT Tech Talks

Subtask 3.8: Introduction

The FIU team met with DOE EM prior to the start of the period of performance to discuss opportunities to promote the D&D KM-IT across the DOE sites and facilities. Several topics were discussed, and one was the development of a Tech Talk series where scientists performing D&D-related work would present their research to the community. Several Tech Taks were conducted during the previous period and due to their success, this task continues to introduce the D&D community with cutting edge research being performed by subject matter experts.

Subtask 3.8: Objectives

The objective of the Tech Talks is to provide a platform for scientists to share their D&D research with the community. By using the KM-IT platform, FIU can promote the KM-IT application through newsletters, flyers and event websites. The goal is to increase the engagement of DOE sites and facilities by participating in the Tech Talks as a presenter or attendees.

Subtask 3.8: Methodology

The FIU team organized D&D-focused Tech Talks every quarter on the D&D KM-IT platform. FIU collaborated with national laboratories and/or DOE sites to identify and present technical topics of interest to the community where scientists can present their research. The Tech Talks were performed virtually using an online meeting platform (Microsoft Teams). The event information, including schedule and archive of previous Tech Talks were hosted on the D&D KM-IT. The team promoted Tech Talks via newsletters, website, emails, and flyers developed by FIU. The Tech Talks were recorded, and the video was uploaded to YouTube and archived on the KM-IT platform supporting the next generation of scientists and engineers.

Subtask 3.8: Results and Discussion

FIU conducted four Tech Talks during this period where the team collaborated with national laboratories and/or DOE sites/facilities to identify and present technical topics of interest to the community. The Tech Talks were conducted virtually using an online meeting platform (Microsoft Teams) which was accessible through the KM-IT platform. The Tech Talks were promoted via newsletters sent to the registered user of the KM-IT and other recipients. The user had to register prior to attending the event using Microsoft Forms (Figure 53).

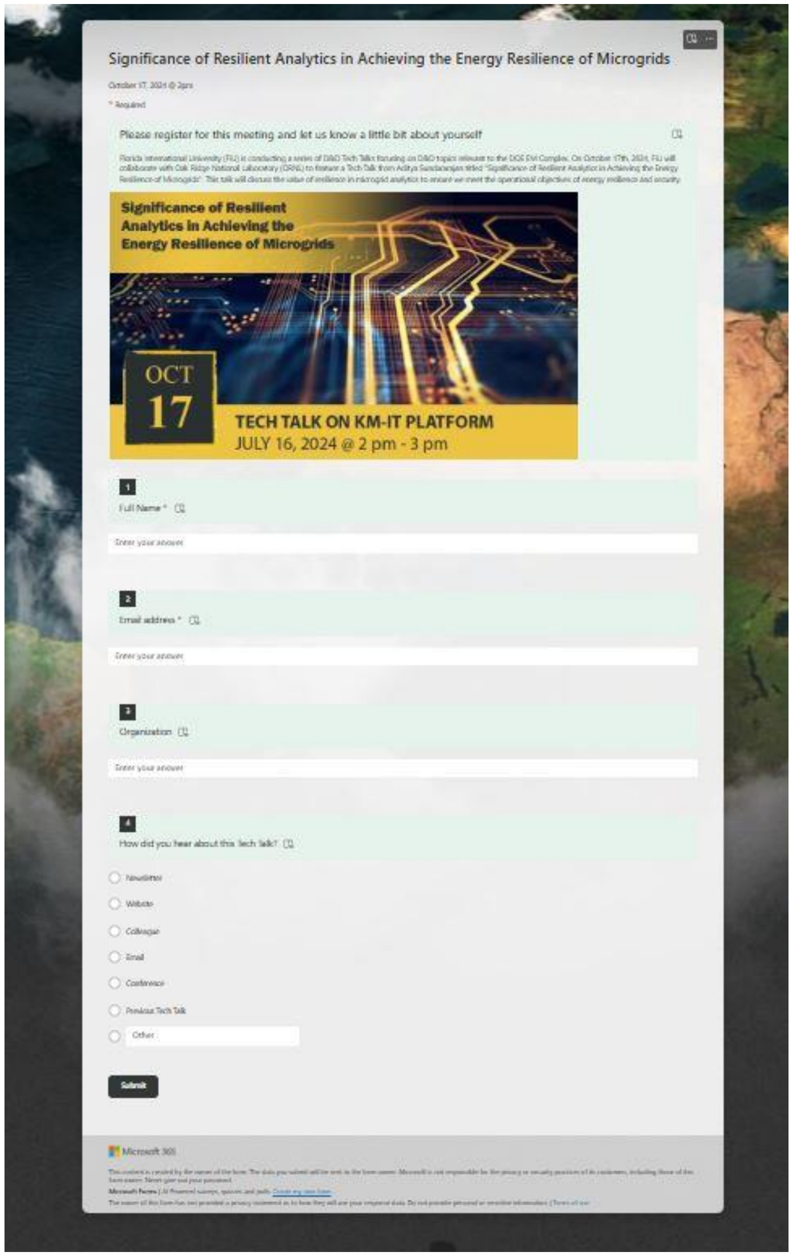


Figure 53. Tech Talk registration form using Microsoft Forms.

The team started this period by hosting a Tech Talk on October 1, 2023, titled "*Natural Language Processing for Event Discovery, Extraction, and Inferential Forecasting*". This Tech Talk featured Dr. Thomas Danielson from Savannah River National Laboratory who presented his research on Natural Language Processing for Event Discovery, Extraction, and Inferential Forecasting. An event webpage was created at https://www.dndkm.org/TechTalk/ and the video recording of the Tech Talk was published on YouTube and embedded on the website. The image below shows the Tech Talk website.

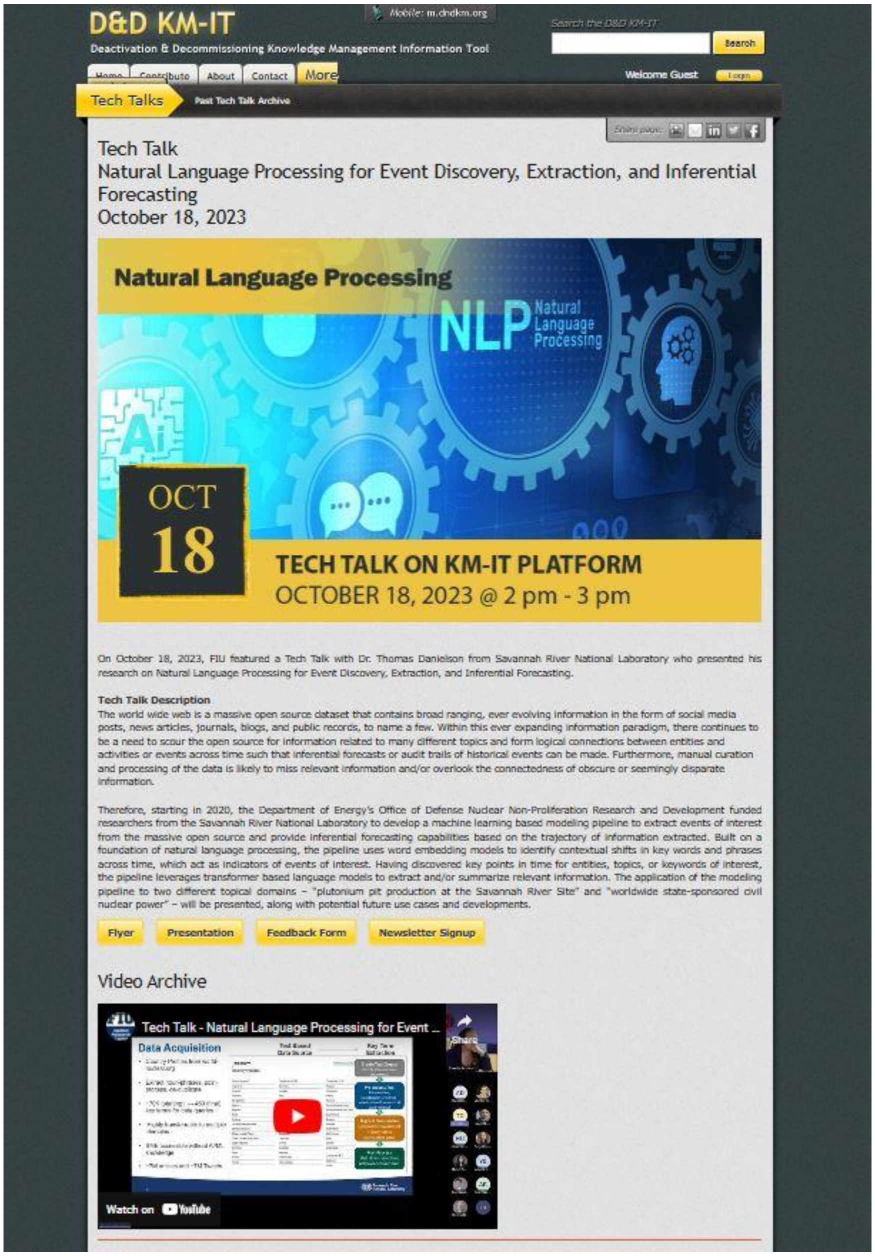


Figure 54. October Tech Talk event webpage.

On January 16th, 2024, FIU collaborated with Pacific Northwest National Laboratory (PNNL) to feature a Tech Talk with Dr. Hilary Emerson and Dr. Jim Szecsody titled "*Uranium Characterization and Remediation at the Hanford Site*".

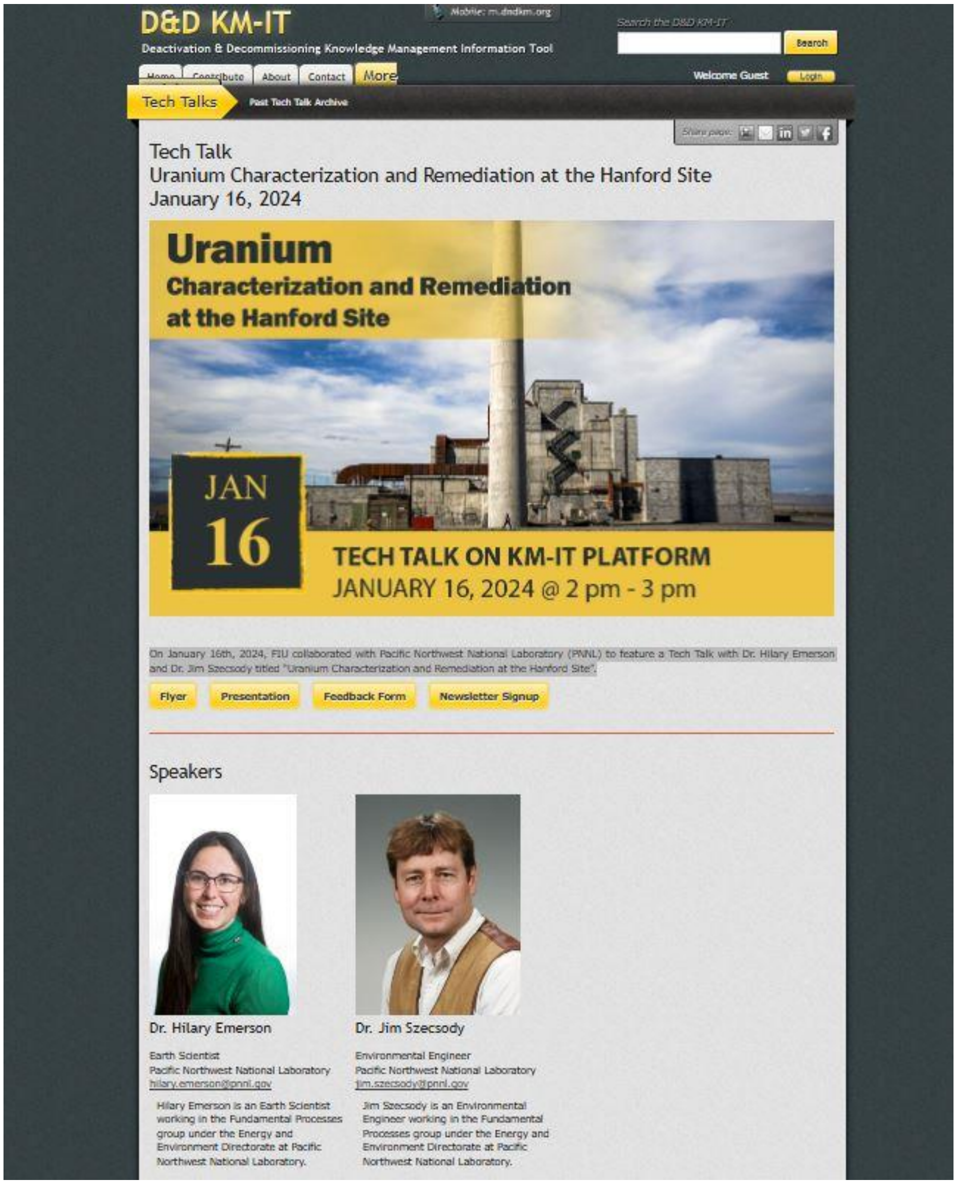


Figure 55. Webpage for Tech Talk hosted on January 16 titled "Uranium Characterization and Remediation at the Hanford Site".

Depending on the topic, these tech talks were attended by various organizations. The tag cloud below shows the participant organizations that attended the Tech Talk on July 16, 2024.

Figure 56. Organizations that attended the Tech Talk on July 16, 2024.

In addition, the team prepared graphics and flyers to promote the event. The following two images show the banner that the team prepared for one of the events. This material is used in emails newsletters, websites, and social media.

Figure 57. D&D KM-IT Tech Talk banner for the next event on July 16, 2024.

The image below shows the flyer of the Tech Talk on January 16th, 2024.

Figure 58. Tech Talk flyer for January 2024.

During the month of April, FIU collaborated with Los Alamos National Laboratory to feature a Tech Talk from Bryan Steinfeld titled "*Development and Deployment of a ground robotic platform for radiation Radiological Contamination Detection*". This Tech Talk was hosted virtually on the D&D KM-IT framework on April 16, 2024. The image below is a screenshot of the Tech Talk event website which includes the information about the Tech Talk (title, description and speaker's picture and bio).

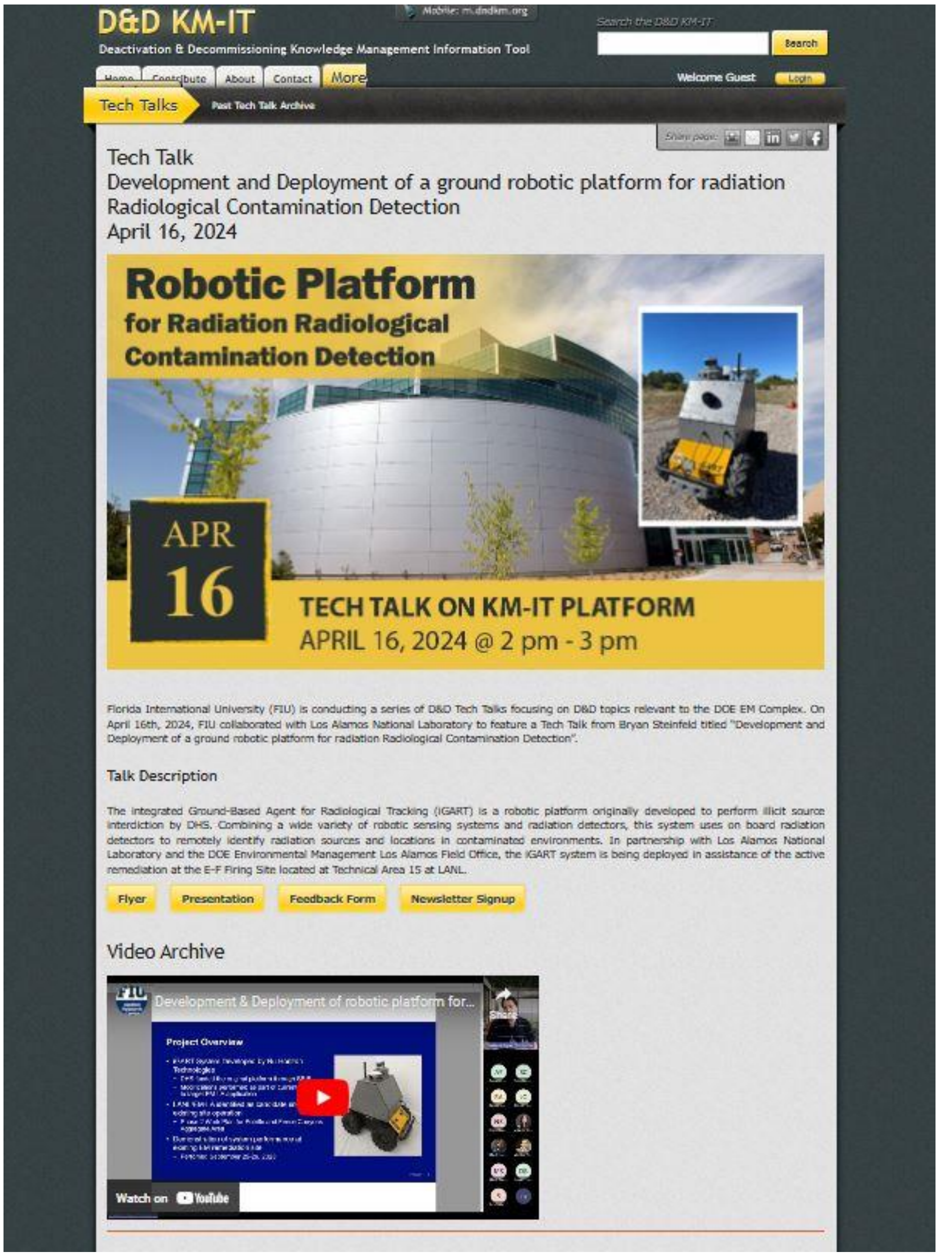


Figure 59. D&D KM-IT Tech Talk event webpage hosted on April 16, 2024.

The final Tech Talk hosted during this period was on July 18, 2024 titled *"A Case Study: The Strategic Integration of Consensus Standards to Facilitate Fixative Technology Development, Deployment, and Acceptance"* presented by Joseph (Joe) Sinicrope. Joe is a Research Scientist at FIU's Applied Research Center leading the efforts of testing, evaluation, deployment of COTS-based technologies for DOE D&D activities.

Figure 60. KM-IT Tech Talk webpage conducted on July 16, 2024.

In summary, the following Tech Talks were conducted during this period.

- October 18, 2023, Natural Language Processing for Event Discovery, Extraction, and Inferential Forecasting
  - Topic – Discussing the value of resilience in microgrid analytics to ensure we meet the operational objectives of energy resilience and security
  - Collaborator – FIU, Oak Ridge National Laboratory (ORNL)
  - Speaker – Dr. Aditya Sundararajan
  - Deliverable - 2023-P3-D1
- January 16, 2024, Uranium Characterization and Remediation at the Hanford Site
  - Topic – Uranium Characterization and Remediation at the Hanford Site
  - Collaborator – Pacific Northwest National Laboratory (PNNL)

- Speaker – Dr. Hilary Emerson and Dr. Jim Szecsody
- Deliverable - 2023-P3-D3

- April 16, 2024, Development and Deployment of a ground robotic platform for radiation Radiological Contamination Detection
  - Topic – Ground robotics platforms for radiation detection
  - Collaborator – Los Alamos National Laboratory
  - Speaker – Dr. Bryan Steinfeld
  - Deliverable - 2023-P3-D4
- July 16, 2024, A Case Study: The Strategic Integration of Consensus Standards to Facilitate Fixative Technology Development, Deployment, and Acceptance
  - Topic – The Strategic Integration of Consensus Standards to Facilitate Fixative Technology Development, Deployment, and Acceptance
  - Collaborator – FIU
  - Speaker – Joseph (Joe) Sinicrope
  - Deliverable - 2023-P3-D7

All Tech Talk recordings were uploaded to YouTube on the FIU-ARC YouTube channel. The image below shows a screenshot of one of the recordings on YouTube. These videos are embedded into the KM-IT Tech Talk website.

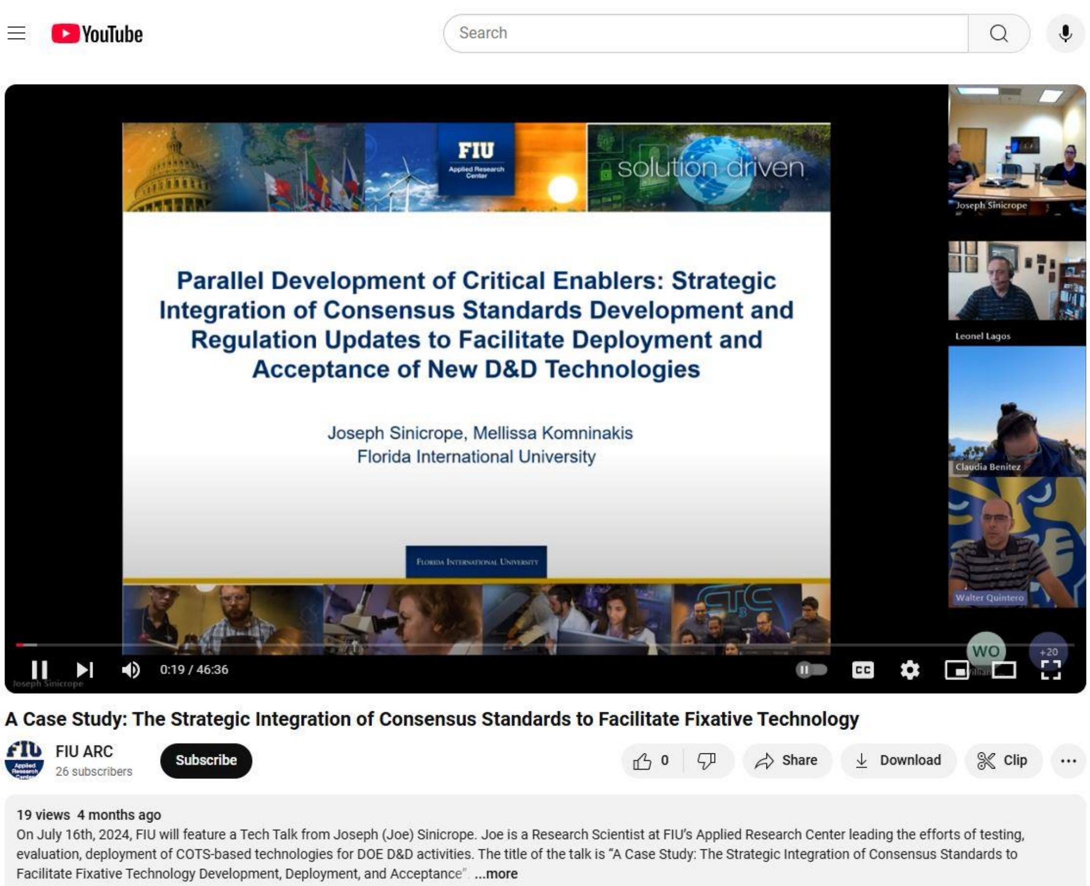


Figure 61. Tech Talk recording from February uploaded to the YouTube platform.

The following screenshot shows the embedded video on the KM-IT website after they are uploaded to YouTube. All the past Tech Talks can be viewed at https://www.dndkm.org/TechTalk/.

Figure 62. Tech Talk recording uploaded to YouTube and embedded on the KM-IT website.

Subtask 3.8: Conclusions

These Tech Talk events allowed subject matter experts (SMEs) to share their knowledge and experience with DOE EM sites and stakeholders. These were virtual one-hour events, which included one or two guest speakers on relevant topics of interest to the community. The events were recorded and published on D&D KM-IT (https://www.dndkm.org/TechTalk/) along with other associated material such as the agenda, presentation slides and lessons learned for post-event viewing as well.

Subtask 3.8: References

Deactivation and Decommissioning Knowledge Management Information Tool (D&D KM-IT), https://www.dndkm.org/, Applied Research Center, Florida International University.

Microsoft Forms, https://forms.office.com/, Microsoft Form, Microsoft Corporation.

TASK 7: AI FOR EM PROBLEM SET (SOIL AND GROUNDWATER) - EXPLORATORY DATA ANALYSIS AND MACHINE LEARNING MODEL FOR HEXAVALENT CHROMIUM [CR (VI)] CONCENTRATION IN 100-H AREA (PNNL)

This task is focused on conducting research on the extended dataset from the U.S. Department of Energy's (DOE's) Hanford Site 100 Areas to explore spatiotemporal relationships between groundwater (GW) Chromium (Cr (VI)) concentration points. Previously processed data for consistent daily samplings modeled with recurrent neural networks (RNNs) provided favorable predictions. However, the previous data preprocessing involved simple imputation results with little variability. To produce higher quality daily samples, FIU employed generative AI techniques to fill in the missing values in the data for reliable modeling. The Generative Adversarial Networks (GANs) [1], Variational AutoEncoders (VAEs) [2], Synthetic Minority Over-sampling Technique for Regression (SMOTER) [3], and Time-series Generative Adversarial Networks (TimeGAN) [4] algorithms will be implemented to generate synthetic data using the data files from 100 area. Previously implemented Long Short-Term Memory (LSTM) [5] models will be re-trained with synthetic datasets to evaluate the prediction accuracy.

Task 7: Introduction

The U.S. Department of Energy's (DOE's) Hanford Site 100 Areas contain monitoring data for groundwater wells (in situ sensing, water sampling), Hexavalent Chromium (Cr (VI)) pump and treat (P&T) activities (extraction and injection flow rates, weekly Cr (VI) sampling of influent water, etc.), as well as water table levels and river stage monitoring data. Artificial Intelligence (AI) / Machine Learning (ML) algorithms may help in understanding complex hydrogeological processes and interactions among the groundwater wells and the dynamic river stage in the Columbia River using these legacy datasets. ML and Deep Learning (DL) models can be developed to identify patterns, address knowledge gaps, and ultimately predict transport of Cr (VI) in the subsurface of the 100-H Area. The aim of this research is to develop a robust AI/ML model for long-term monitoring, analysis, and prediction of Cr (VI) contamination in the subsurface of the U.S. Department of Energy's (DOE's) Hanford Site 100 Areas. AI/ML algorithms can leverage high-performance computing to predict the spatial and temporal distribution of Cr (VI) and help in identifying any spatiotemporal relationship in the dataset. AI/ML models have already been previously developed; however, modeling is performed on sparse data with the missing values on a given day for multiple wells. This imputation is administered via a rolling average window in which the daily values are interpolated. This method produces intervals of constant values for all wells due to infrequent sampling of wells. Using generative AI models, those intervals of missing values could be replaced with more variable data that would add confidence to predictions calculated from previous time series modeling.

Task 7: Objectives

The overarching goal of this research is to couple long-term monitoring of the hexavalent chromium (Cr (VI)) concentration with AI/ML models to identify temporal and spatial relationships of subsurface chromium transport that reduces uncertainties in the conceptual site model (CSM). To aid modeling with authentic data, the objectives for this year involved creating synthetic data that captures the underlying distribution, variability, and behavior of the actual data from the Hanford groundwater wells.

Task 7: Methodology

Conditional Generative Adversarial Network (CGAN):

The CGAN network architecture is the default variant for GANs. It operates by the joint training of two sub-networks training in competition with each other. The networks are referred to as a generator and a discriminator, respectively. The generator network is trained to generate data from noise, while the discriminator network is trained to classify whether the data produced by the generator is real or false. Hence, the generator takes normally distributed noise as input while the discriminator takes the generated data together with the real data as input.

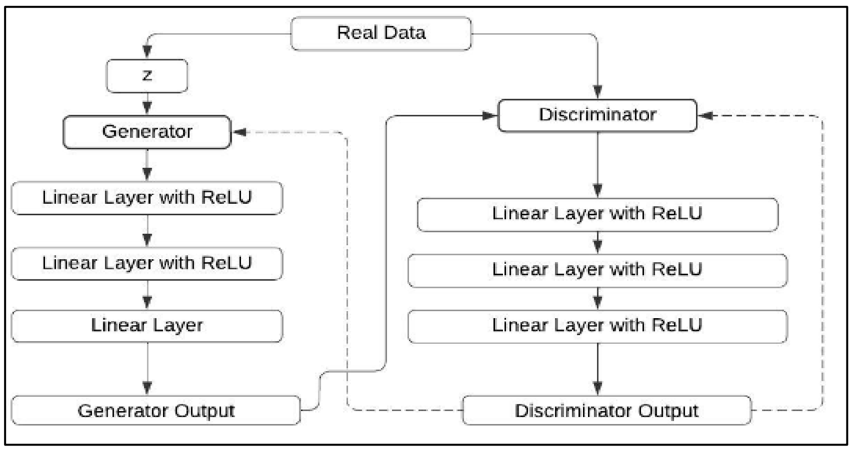


Figure 63. CGAN Model Architecture.

Variational AutoEncoder (VAE):

A VAE builds atop the standard AutoEncoder network architecture**.** An AutoEncoder takes input and compresses it down into its latent representation.

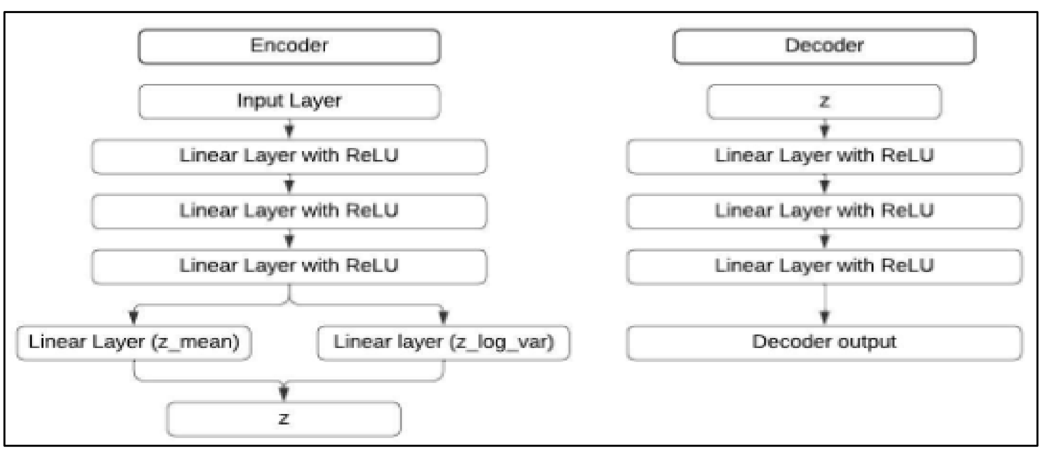


Figure 64. VAE Model Architecture.

As input passes through layers during encoding, it is capturing important features as a byproduct of dimensionality reduction. It then takes the latent representation and decodes back into its original form, thus focusing on data reconstruction. A VAE adds variability to the consistent mapping between the real data and the latent space by mapping inputs into a probability distribution rather than a learned latent representation. In a VAE, the decoder is sampling from the latent distribution when generating new data.

Synthetic Minority Over-sampling Technique for Regression (SMOTER):
SMOTER attempts to balance class distributions. It aims to balance class distributions by generating synthetic samples for the minority class. After generating synthetic instances, those synthetic instances that are misclassified by their nearest neighbors from the majority class are removed, thus refining the quality of the synthetic samples produced. This editing process helps to mitigate the risk of overfitting that can occur with overly aggressive oversampling, leading to a more effective balancing of class distributions while preserving the underlying characteristics of the minority class. Out of the four-solutions team implemented for synthetic data generation, SMOTER is the only one that is not a model, but rather a statistical technique.

Time-series Generative Adversarial Networks (TimeGAN):
TimeGAN is a GAN based framework to generate realistic time-series data in sequential data with different observed behaviors.

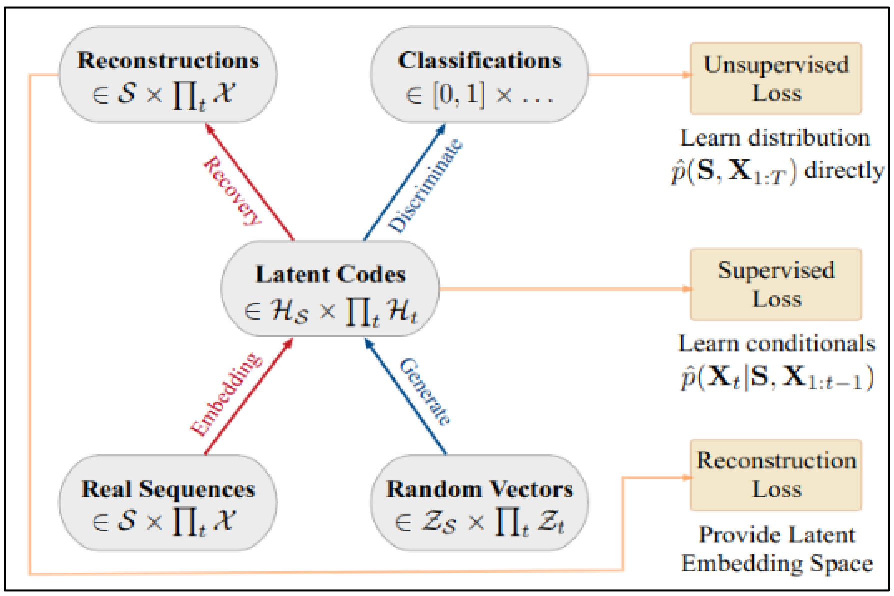


Figure 65. TimeGAN model architecture.

TimeGAN incorporates a supervised loss calculated by comparing generated sequences to ground truth data within a latent space. This latent space captures the stepwise conditional distributions of the sequence data. We are thus mainly dealing with three losses, those being the reconstruction loss, unsupervised loss, and the supervised loss. Joint training for encoding, generation, and sequencing is accomplished by training the embedding and recovery to minimize the combination of the reconstruction and supervised losses and training the generator to minimize the combination of supervised and adversarial losses.

Time-agnostic Models and TimeGAN Comparison:
The time-agnostic models do not account for the sequential or temporal nature of the data. For the time-agnostic models, there is a need to model the Hanford well time series data on small enough intervals of time. The bigger the interval used, the more samples that can be captured in time-agnostic modeling. The cost comes at having higher error in our generated data, as values at the

beginning of the time series are generally higher than those at the end due to clean-up efforts at the Hanford. An interval length of one month was decided upon for preferred balance of available samples for training and sequencing error minimizing. The month with the highest amount of available original well samples from December 2015 with 157 samples was selected as representative input data to benchmark the generative models. The data generated using the time-agnostic methods undergo Train Synthetic Test Real (TSTR) evaluation for synthetic quality comparison. This method uses a second evaluative model that is trained on synthetic data which provides predictions on a validation set of the data.

The TimeGAN on the other hand takes sequence position into account, discarding the need to split the time series into windows. When evaluating the performance of TimeGAN-generated data, we model on a particular well's time series and compare how close the synthetic time series is to the original, expecting some variation within the results. The well 199-D5-32 time series with the highest amount of available original values was chosen as input in TimeGAN.

Task 7: Results and Discussion

Real and Synthetic Data Distributions:
Using the synthetic datasets produced from our time-agnostic methods, the team performed the comparison by inspecting the provided range of values by each method.

Table 7. Value Ranges for the Cr [VI] Concentration

Dataset	Minimum	Maximum
Original	1.5	288.0
Interpolated	0.8	321.5
GAN-Generated	1.2	141.0
VAE-Generated	31.3	45.9
SMOTER	1.5	288.0
Combined	1.2	288.0

The datasets used in our comparison includes the original data unaltered, the interpolated data from previously mentioned processing using rolling averages, the GAN-generated data, the VAE-generated data, the SMOTER re-balanced data, and a "combined" dataset which takes the GAN-generated data and adds it to the original data. The combined dataset represents the effectiveness of the synthetic data working together with the original data. In terms of value ranges for the datasets, SMOTER values were in a range similar to the original data. As SMOTER rebalances rather than creates new data, this is an expected behavior.

A more reliable visualization of distribution is shown in Figure 66, it depicts the probability density functions (PDF) of each dataset. In this case, the SMOTER dataset is not the closest matching to the original as SMOTER rebalancing attempts to center this PDF. Indeed, the closest PDF that a dataset exhibit belongs to the combined data and the GAN-generated data. VAE-generated data, on the other hand, is limited to a narrow-exaggerated window. In practicality, the VAE data generation is limited to sample for only two wells, despite the training data having over 100 unique wells.

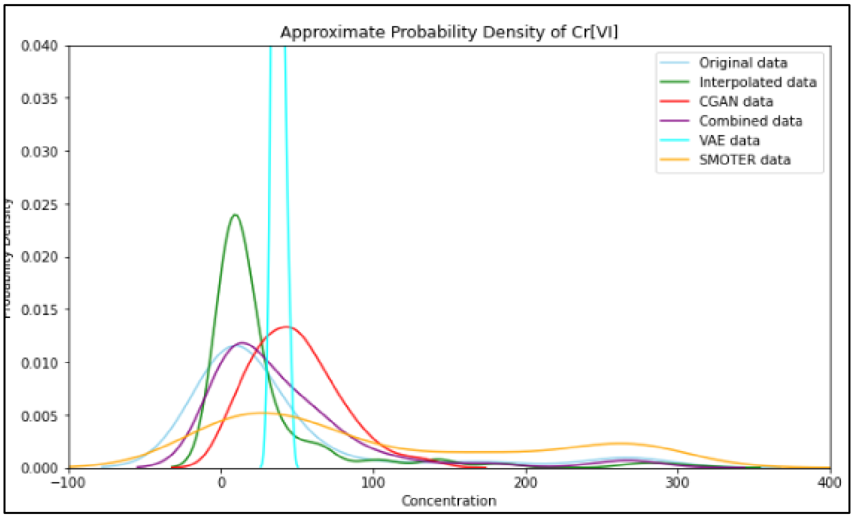


Figure 66. The approximate probability densities of Cr[VI] for each synthetic dataset.

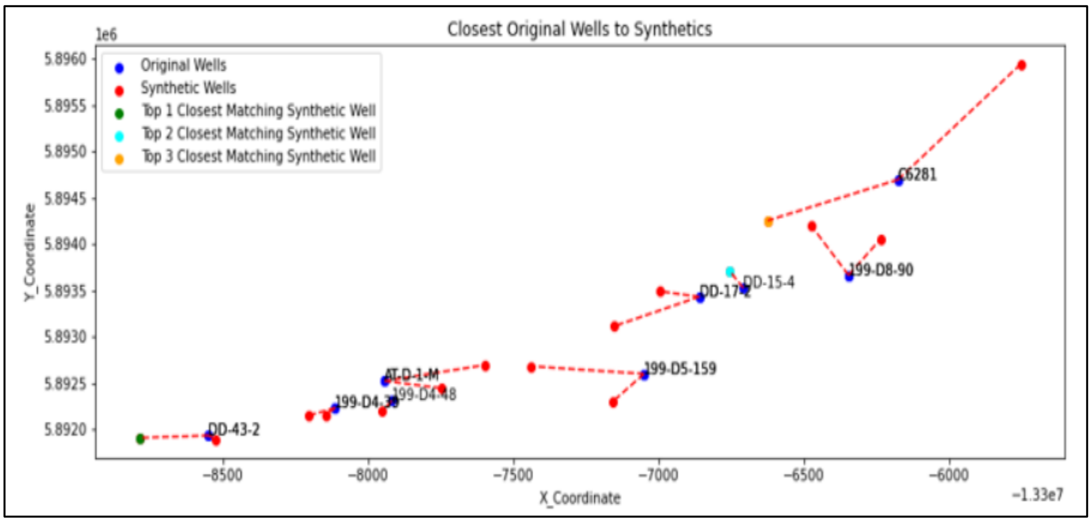


Figure 67. Placement of synthetic wells in relation to their closest original well.

The CGAN is generating data which is closer in distribution than any of the time-agnostic solutions. Figure 67 above shows how the synthetic well data matches the original spatially.

The team visualized TimeGAN generated data distribution using principal component analysis (PCA) and t-distributed stochastic neighbor embedding (TNSE) and compared them to the original as shown in Figure 68. PCA and TNSE can be used to reduce data into lower dimensions, in this case, 2 dimensions for the purpose of visualization. Although TimeGAN-generated distributions do not match very well using TSNE, they do match more similarly when using PCA, although it is not a total match as the synthetic data likes to focus on one section of space while the original distribution sprawls out more. This disconnect could be explained by outlying values in the original time series.

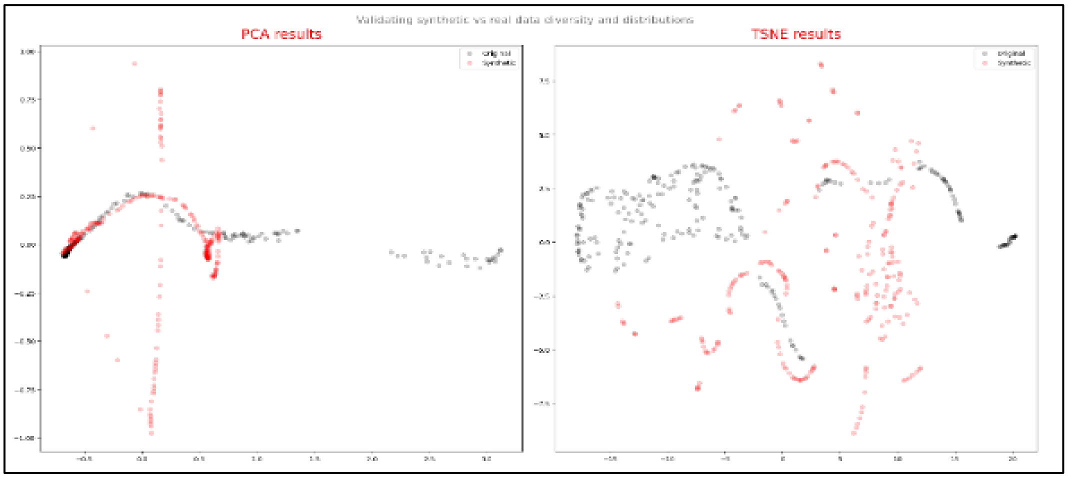


Figure 68. Spatial distribution of well 199-D5-32 time series using PCA and TSNE.

Synthetic Data Performance Comparison:

The comparison of metrics of synthetic data generation using different algorithmic is shown below.

Table 8. TSTR results for datasets on Gradient Boosting model.

Dataset	MSE	MAE	R^2
Original	153.79	8.67	0.98
Interpolated	7560.43	44.45	-0.44
GAN-Generated	5850.33	43.62	-0.12
VAE-Generated	5493.29	48.49	-0.05
SMOTER	4152.12	30.16	0.21
Combined	764.04	15.85	0.85

The Gradient Boosting model was used as an evaluative model when performing TSTR on time-agnostic model generated synthetic datasets. As shown in Table 8, none of the synthetic datasets could outperform the original with a 98% R^2 score. However, the combined data shows the 85% R^2 score. Thus, in a case where the original data is not enough, having CGAN generate more data to mix in with the original satisfies requirements without too much loss in authenticity.

The performance of the TimeGAN data was evaluated by comparing how close the generated sequences were to the original time series, as shown below.

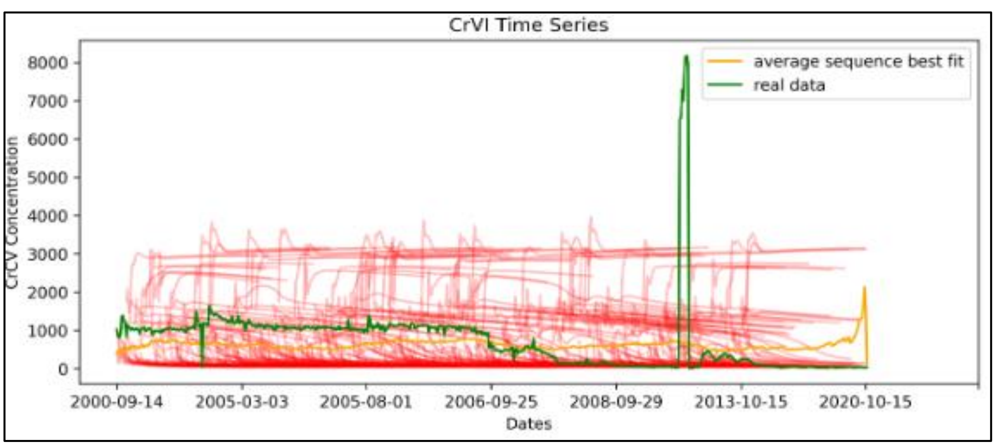


Figure 69. Generated sequences of well 199-D5-32 time series and resulting average time series.

The TimeGAN used recurrent units to capture sequence position and hence it takes the sequences of samples. In order to reduce all the overlapping sequences down to one, the average of all the samples in a given time step is taken to construct the average best fit sequence to compare to the real data. The generated sequences themselves are noisy, and between an established upper and lower bound. The best fit sequence shows in two places where it is too far from the original, despite the need for variability in generated data. One of the two places is at the end of the time series, which seems to show an increase in concentration whereas the real time series shows a decreasing behavior. The other place is during an outlying spike that happens in the real time series around the 2010 to 2012 timeframe. This inability to capture this outlying spike in values could explain the previously mentioned discrepancy in the distribution resulting from PCA reduction.

Model Evaluation using Synthetic Datasets:

Using the best generative model from the time-agnostic methods, we filled all the missing values for every Hanford 100 HRD area well from 2015 to 2019 with data generated from training GAN on every monthly window making up the time span. After concatenating all the newly filled records for each month to give one single time series, the LSTM model re-training was performed to evaluate the performance of the synthetic dataset. There are two model instances of LSTM; one is trained on the interpolated data, and one is trained on the generated synthetic data. Metrics from prediction on a testing split focusing on the year 2019 are shown below.

Table 9. Performance metrics for LSTM model on target well 199-D5-101 using previously processed (interpolated) data and the newly generated synthetic data.

Dataset	MSE	MAE	RMSE
Interpolated	7.69	2.53	2.77
Synthetic	179.82	13.15	13.41

A detailed comparison of the two prediction results is shown below.

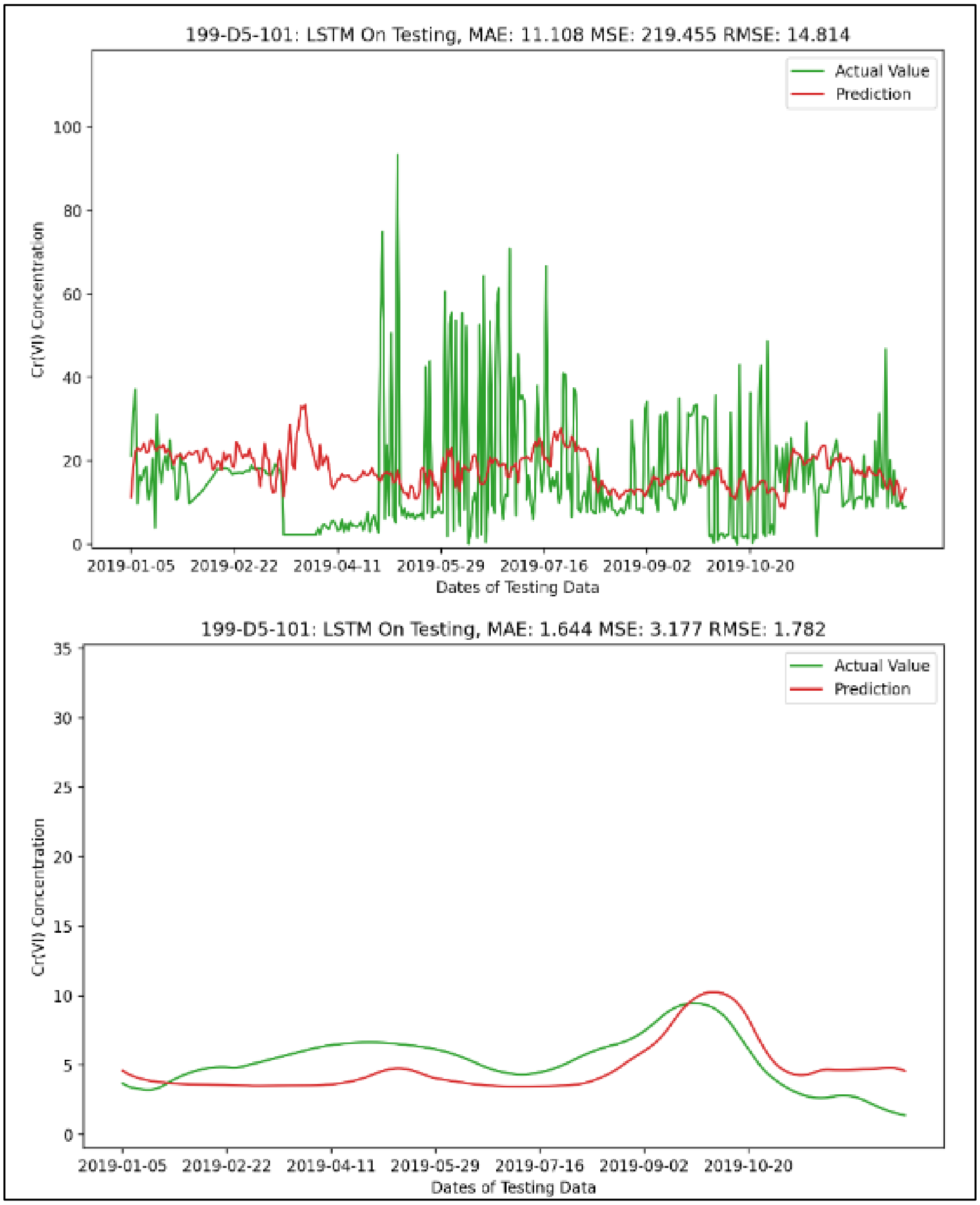


Figure 70. Best model prediction performance on target well 199-D5-101 with synthetic data (top) and interpolated data (bottom).

Task 7: Conclusions

In summary, the synthetic data does not perform better than previous results using rolling mean imputation for the input's missing values. Whether authentic in real distribution or not, the synthetic data is much noisier than the interpolated data. Granted, the average infilling naturally produces very smooth curves. This results in a simpler function for a model to approximate than the function displayed by the synthetic data, hence the exaggerated prediction spikes displayed in the synthetic prediction instance.

Task 7: References

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TASK 8 AI FOR EM PROBLEM SET (SOIL AND GROUNDWATER) - DATA ANALYSIS AND VISUALIZATION OF SENSOR DATA FROM THE WELLS AT THE SRS F-AREA USING MACHINE LEARNING (LBNL, SRNL)

Task 8: Introduction

This task is focused on implementation of a web-based platform leveraging groundwater sensor data from the Savannah River Site (SRS). The Aqua TROLL 500 and Aqua TROLL 200 sensors installed at SRS generate continuous time series data on various water properties, including temperature, pH, conductivity, turbidity, and battery status. Currently, 22 wells equipped with these sensors deliver hourly measurements, producing substantial amounts of data daily. FIU has undertaken the initiative to enhance the accessibility of this data for diverse stakeholders at SRS while also promoting its adoption at other DOE sites with similar sensor networks. To achieve this, FIU has developed a web system that collects sensor readings nightly, processes the data, and displays the results on an intuitive web interface. The platform delivers essential insights such as alerts for malfunctioning sensors, low battery warnings, and reports on key parameters like pH, turbidity, and conductivity for individual wells or subsets of wells. By integrating these functionalities, the web system provides stakeholders with an effective tool for monitoring and managing groundwater well data at SRS and potentially at other DOE locations, supporting data-driven decision-making and resource management.

Task 8: Objectives

The main objective of this task is to support the long-term monitoring goal of the ALTEMIS project. A web system was developed to manage and utilize data collected by the Aqua TROLL 500 and Aqua TROLL 200 sensors deployed in the F-Area of the SRS. This was achieved by storing the sensor data, extracting key information about water properties in the wells and sensor statuses via the HydroVu API, and presenting this information to stakeholders through a secure, user-friendly webpage that requires login and authentication for access. Additionally, AI models were developed using the data received from SRNL and the prediction results published on the ALTEMISAI website.

Task 8: Methodology

The ALTEMIS AI Website was developed as a centralized platform for hosting and managing sensor data collected from the SRS. The primary focus of the platform is to provide stakeholders with easy access to vital sensor metrics, such as readings, battery status, and other relevant information, while maintaining secure user access and robust data management capabilities.

Platform Design and Development:

The website was designed with user accessibility and data integrity in mind, utilizing a modern technology stack to ensure functionality, scalability, and security:

- **Front-End Development:** The interface was built using .NET, HTML5, Bootstrap, JQuery, JavaScript, and CSS to create a responsive, intuitive user experience.

- **Back-End Architecture:** The platform is supported by a MySQL database for data storage and management and uses Microsoft Reporting Service for generating and delivering detailed reports.
- **Deployment:** The platform is accessible via the URL https://altemisai.org, allowing authenticated users to interact with the system online.

Key Functionalities:

1. **Sensor Data Reporting**
   The ALTEMIS AI Website facilitates the generation, visualization, and downloading of sensor data reports, empowering users to derive insights from real-time and historical data. Key features include:
   - **Report Generation:** Users can specify parameters such as Station ID/Well, Sensor Type, and Date Range to generate customized reports.
   - **Real-Time Data Access:** The platform provides an intuitive interface for viewing real-time and historical sensor data.
   - **Export Capabilities:** Reports can be downloaded in multiple formats, including PDF and CSV, for offline use and further analysis.

2. **User Management**
   Ensuring secure access and maintaining system integrity are critical aspects of the platform. To achieve this, the ALTEMIS AI Website includes:
   - **User Approval:** Administrators can evaluate and authorize new user accounts to maintain controlled access.
   - **User Removal:** The ability to delete user accounts ensures that only active, authorized users retain access.
   - **Password Management:** Support for resetting user passwords enhances usability and security.

By integrating these features, the ALTEMIS AI Website serves as a reliable, efficient tool for stakeholders to manage and analyze SRS sensor data while ensuring robust user authentication and data management processes.

The homepage of the ALTEMIS AI Website acts as a welcoming gateway for users, offering a concise overview of the platform's features and facilitating easy navigation. It is designed to ensure a seamless user experience by providing clear and direct access to critical functionalities.

Home page:

1. **Navigation Bar:**
   A top navigation bar provides links to essential sections of the website, including:
   a. **About:** A detailed explanation of the website's purpose and functionality.
   b. **Reports:** Access to the reporting module for authenticated users.
   c. **Contact:** Information for user assistance and support.

2. **Login and Registration:**
   a. **Login:** Secure access to the report module for existing users.
   b. **Registration:** A streamlined process for new users to create an account.

3. **Purpose and Context:**
   The homepage includes a brief description of the website's purpose, emphasizing its role in managing SRS sensor data and providing reports. A disclaimer ensures users are aware of the website's intended use.

4. **Contact Information:**

   Easy access to contact details ensures users can quickly reach out for support or inquiries.

The design and functionality of the homepage reflect the platform's commitment to accessibility, security, and clarity, setting the tone for an efficient user experience throughout the website.

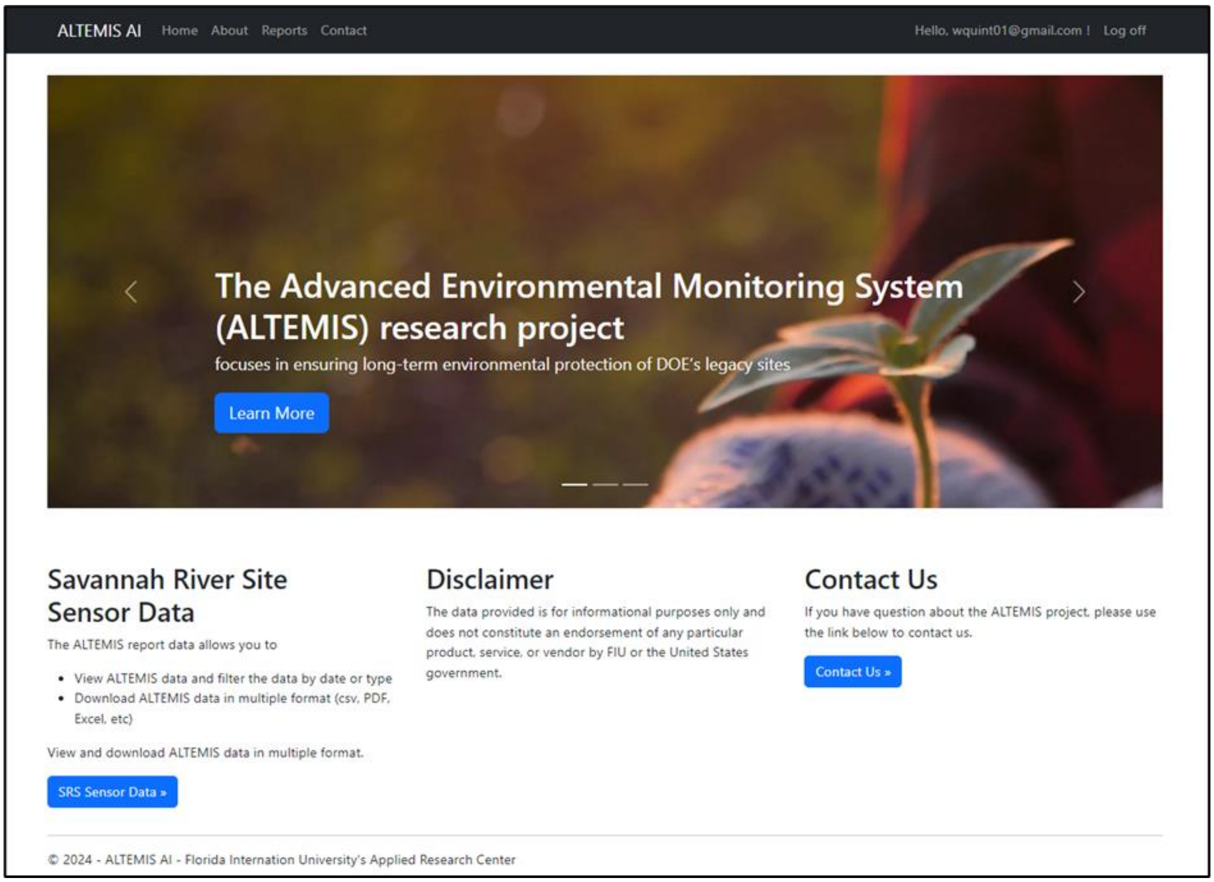


Figure 71. ALTEMIS AI Home page.

About Page:

The About Page offers detailed information about the website, its purpose, and the team behind it. This page explains in detail the data collection process and the overall objective of the project.

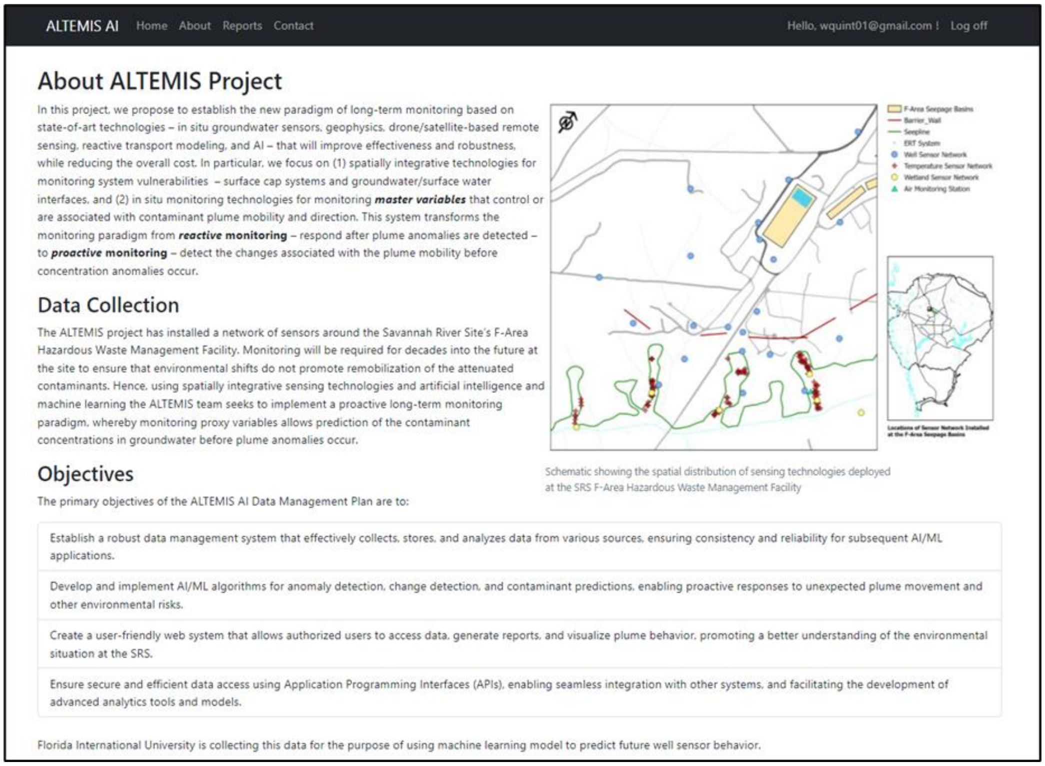


Figure 72. ALTEMIS AI About page.

Reports Page:

This page is the central hub for accessing sensor data reports. Users can generate, view, and download reports through a user-friendly interface that supports various filters and display options. This page is secure, and only authorized users can gain access. Users must be logged in or registered to access this page, which can be done from the top navigation.

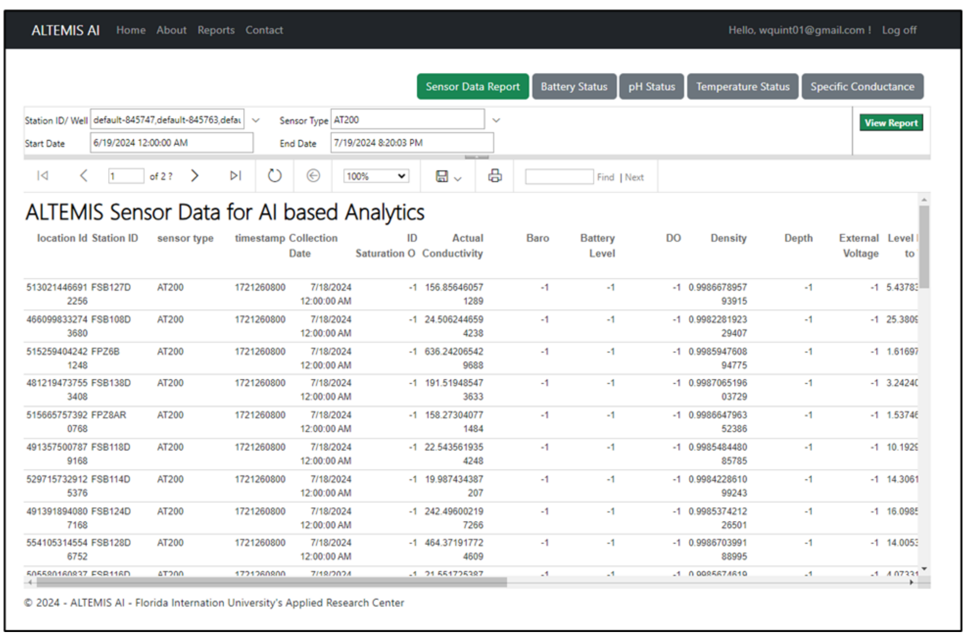
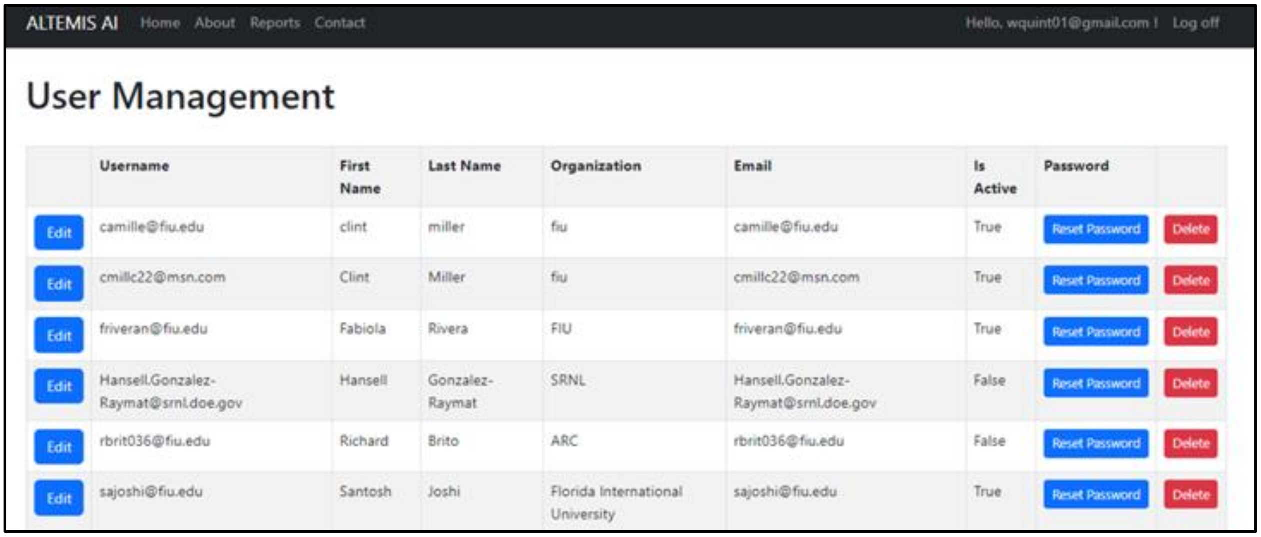


Figure 73. ALTEMIS AI report module showing sensor data report.

User Management Page:

The user management page is accessible to administrators and provides tools for managing user accounts, including approval, deletion, and password reset functionalities.



ALTEMIS AI Home About Reports Contact Hello, wquint01@gmail.com ! Log off

User Management

	Username	First Name	Last Name	Organization	Email	Is Active	Password	
Edit	camille@fiu.edu	clint	miller	fiu	camille@fiu.edu	True	Reset Password	Delete
Edit	cmillc22@msn.com	Clint	Miller	fiu	cmillc22@msn.com	True	Reset Password	Delete
Edit	friveran@fiu.edu	Fabiola	Rivera	FIU	friveran@fiu.edu	True	Reset Password	Delete
Edit	Hansell.Gonzalez-Raymat@srnl.doe.gov	Hansell	Gonzalez-Raymat	SRNL	Hansell.Gonzalez-Raymat@srnl.doe.gov	False	Reset Password	Delete
Edit	rbrit036@fiu.edu	Richard	Brito	ARC	rbrit036@fiu.edu	False	Reset Password	Delete
Edit	sajoshi@fiu.edu	Santosh	Joshi	Florida International University	sajoshi@fiu.edu	True	Reset Password	Delete

Figure 74. ALTEMIS AI website user management module.

Back-end SQL stored procedures with integrated Python Scripts:

Store SRS F-Area Sensor Data:

A python script was implemented to retrieve the SRS F-Area sensor data through the HydroVu API and store data in the ALTEMISAI database at FIU. The script uses python packages like requests and json to query the HydroVu API and retrieve the sensor data. The script retrieves the assigned access token to be able to interact with the HydroVu API. It sends a request to obtain all sensors at all locations. The script parses through multiple pages of data to do this. Then, for each location, the script uses a GET request to retrieve the water properties measured by the corresponding sensors. In case of failure, the script waits a set time and retries up to a set maximum retries. After this step, preprocessing is performed on the data to convert IDs into name, standardize units of measurement, among other data formatting steps.

The script uses python packages like pyodbc to establish database connections to the ALTEMISAI database. This connection can be used to query tables and assess if the ALTEMISAI database is behind the HydroVu API in its sensor measurements. For example, if the most recent row in the database for well FSB138D is from two hours ago, then only the last two hours of measurements should be retrieved from the HydroVu API and added to the database for well FSB138D. And if another well is out of sync with the HydroVu API by five hours, then only those last five hours of data should be retrieved and added to the database. This ensures that only the needed sensor measurements are retrieved from the HydroVu API and added to the database, which removes all possible redundancy of getting or adding the same data twice.

Once a subset of the data is retrieved, the script inserts the data into the ALTEMISAI database using SQL INSERT statements. The data is stored in three tables: SRS_SensorData, SRS_SensorMetadata, and SRS_SensorUnits. The SRS_SensorData table stores information relating to the location, sensor type, timestamp, and all the sensor readings like temperature, pH, conductivity, turbidity, etc. The SRS_SensorMetadata table stores the information about the latitude, longitude, and well where the sensor is located. The SRS_SensorUnits table stores the units of measurements for each reading parameter from the sensors.

Extract Information from the SRS F-Area Sensor Data:

The most basic form of information that can be extracted from the stored sensor data is the different rows based on the condition. A stored procedure was implemented SensorData_GetSensorDataByDateRangeAndWellNameAndSensorType, which queries the SRS_SensorData table for specific wells and sensors within a time range.

```sql
USE [ALTEMISAI]
GO
/****** Object:  StoredProcedure [dbo].[SensorData_GetSensorDataByDateRangeAndWellNameAndSensorType]    Script Date: 3/14/2023 2:55:06 PM ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO

ALTER PROCEDURE [dbo].[SensorData_GetSensorDataByDateRangeAndWellNameAndSensorType]
    @StartDate datetime = null,
    @EndDate datetime = null,
    @WellName nvarchar(50) = null,
    @SensorType nvarchar(50) = null
AS
BEGIN
    SET NOCOUNT ON;

    SELECT * FROM SensorData
    WHERE (@StartDate IS NULL OR COLLECTION_DATE >= @StartDate)
    AND (@EndDate IS NULL OR COLLECTION_DATE <= @EndDate)
    AND (@WellName IS NULL OR STATION_ID = @WellName)
    AND (@SensorType IS NULL OR sensor_type = @SensorType)
END
```

Figure 75. Screenshot of SQL stored procedure for efficiently accessing and filtering rows in the SRS_SensorData table.

Additional information that can be extracted from the stored data is relating to the specific water properties of the data. To retrieve this information, a stored procedure was implemented SRS_SensorData_GetValuesOverTime. This stored procedure provides information about the depth to water, pH, total dissolved solids, turbidity, temperature, depth, specific conductance, etc. for a given location and sensor for a given period of time.

Other important and valuable information provided for the SRS personnel are the alerts. For example, if the battery level in a sensor is too low, it would be beneficial for someone to be notified. If the pH in a well is too low, it would also be beneficial to notify someone. This removes the need for a human to frequently check the sensor measurements while allowing for human response when something unexpected or undesired activity happens. FIU implemented a stored procedure SRS_SensorData_LatestSensorAlertReportByColumn that finds the most recent sensor measurement parameter for a well and evaluates if it falls below a threshold. This stored procedure works on battery level, pH, temperature, depth to water, and specific conductivity. It makes use of a custom function called that finds the closest N sensor readings to a given date.

For example, let well A have the following readings for battery level for a given time period: 20, 15, 10, 5, 30. Let well B have the following readings for battery level for a given time period: 20, 15, 10, 5. Then, an alert will be sent for well B but not well A, since the most recent reading in well A shows that the battery has been charged. This considers the interactions of SRS employees with the sensors where alerts are sent, if the most recent battery level reading falls below threshold.

Other information extracted from the stored data includes the sensors that are broken or malfunctioning. To retrieve this information, a stored procedure SRS_SensorData_GetLowBatteryOrMissingSensors was implemented. This stored procedure identifies sensors that should be reporting information, but not doing so, which would require the attention of someone at SRS F-Area, or sensors which have low battery and about to lose power, which would also require the attention of someone at SRS F-Area. Figure 6 shows the implementation of the stored procedure. The stored procedure also makes use of the function called TopNClosestSensorsByColumn.

```sql
CREATE PROCEDURE [dbo].[SRS_SensorData_GetLowBatteryOrMissingSensors]
    @BatteryLevel float = 100,
    @StartDate datetime = null,
    @EndDate datetime = null
AS
BEGIN
    SET NOCOUNT ON;

    DECLARE @BatterySensors TABLE (
        [StationId] [nvarchar](50) NULL,
        [SensorType] [nvarchar](50) NULL,
        [BatteryLevel] [float] NULL
    );
    DECLARE @MissingSensors TABLE (
        [StationId] [nvarchar](50) NULL,
        [SensorType] [nvarchar](50) NULL
    );


    INSERT INTO @MissingSensors
    SELECT M.StationID, M.SensorType FROM SRS_SensorMetadata AS M WHERE NOT EXISTS
    (SELECT 1 FROM SRS_SensorData AS D WHERE M.StationID = D.StationID AND M.SensorType = D.SensorType AND
    (@StartDate IS NULL OR D.CollectionDate >= @StartDate) AND (@EndDate IS NULL OR D.CollectionDate <= @EndDate))



    INSERT INTO @BatterySensors SELECT [StationId],[SensorType],[Column] FROM dbo.TopNClosestSensors('BatteryLevel',@EndDate, 1);

    SELECT [StationId],[SensorType] FROM @MissingSensors
    UNION
    SELECT [StationId],[SensorType] FROM @BatterySensors AS B WHERE (BatteryLevel >= 0 AND BatteryLevel <= @BatteryLevel)

END
GO
```

Figure 76. Screenshot of SQL stored procedure for identifying low battery or missing sensors.

AI/ML Model Development:

FIU worked on model development and analysis, enhancing our predictive capabilities and providing crucial insights into sensor performance. Research was conducted on ensemble algorithms such as bagging, stacking, and boosting, aiming to improve overall model performance by combining predictions from different models. A new ensemble algorithm that leverages both local and global patterns for predictions was successfully implemented. The implementation of the Multilayer Perceptron model was completed, focusing on the evaluation of various hyperparameters, including the number of hidden layers and activation functions. A Decision Tree algorithm was implemented with the best configuration of the hyperparameter optimization.

The visualization code was successfully implemented to plot the residuals of the models' predictions, which was essential in assessing whether the models were genuinely learning from the data or merely memorizing it.

Additionally, the team researched state-of-the-art methods for approximating the Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of continuous variables. These techniques are expected to provide deeper insights into dataset distributions and enhance the accuracy of future analyses. A new preprocessing algorithm was also implemented to transform dataset vectors, reducing noise and improving overall model performance by leveraging possibilities in multidimensional vector spaces.

After analyzing various models, it was determined that the best-performing model achieved an error margin of 1600 pCi/L, which is minimal compared to the safety threshold of 20,000 pCi/L.

Task 8: Results and Discussion

The table below illustrates the sensors that were missing or were with a low battery during a week of April 2024, and the sensors that were missing or with the low battery during a week of May 2022.

Table 10. Output of the SRS_SensorData_GetLowBatteryOrMissingSensors (April 2024)

StationId	SensorType
FAI12D	AT500
FAI3B	AT500
FAI7	VuLink
FAI9D	AT500
FPZ8AR	VuLink
FSB128D	VuLink
FSB135D	AT200
FSB135D	VuLink
FSB91D	AT200
FSB91D	VuLink
FSB99D	VuLink

Table 11. Output of the SRS_SensorData_GetLowBatteryOrMissingSensors (May 2022)

StationId	SensorType
FAI12D	AT500
FAI3B	AT500
FAI9D	AT500
FSB135D	AT200
FSB135D	VuLink
FSB91D	AT200
FSB91D	VuLink

The above cases show the potential use of the web system, where SRS stakeholders are no longer required to constantly monitor the sensors or the wells, but instead receive notifications on the sensor status, battery status etc., which will help address the issue.

Task 8: Conclusion

The development and deployment of the web system for managing groundwater sensor data from the SRS has been successfully completed. This system leverages data collected by Aqua TROLL 500 and Aqua TROLL 200 sensors, which provide critical time-series measurements such as temperature, pH, conductivity, turbidity, and battery levels. With 22 wells generating hourly data, the system addresses the challenge of managing and analyzing large volumes of information daily.

FIU has developed a comprehensive solution that improves accessibility and usability of this data for stakeholders at SRS and paves the way for adoption at other DOE sites with similar sensor deployments. The web system automates nightly data acquisition, processes relevant information, and presents it through an intuitive, user-friendly interface. Key functionalities include real-time sensor status alerts, such as broken sensor and low battery notifications, and detailed reports on parameters like pH, turbidity, and conductivity. Moreover, the system accounts for historical well treatments by incorporating date-based filtering, allowing users to efficiently compare water properties before and after specific interventions. Deployed as an online platform, the system is accessible to authorized users, enabling seamless monitoring from any location. This provides stakeholders with a robust, efficient tool for tracking and analyzing groundwater well data, supporting informed decision-making and resource management at SRS and beyond.

Task 8: References

[1] Operator's Manual Aqua Troll 500. In-Situ. (2024). https://in-situ.com/pub/media/support/documents/at500-manual.pdf

[2] Aqua troll 100/200 operator's Manual. In-Situ. (2024). https://in-situ.com/pub/media/support/documents/Aqua_TROLL_100-200_Manual.pdf

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TASK 9: AI FOR EM PROBLEM SET (WASTE PROCESSING) - NUCLEAR WASTE IDENTIFICATION AND CLASSIFICATION USING DEEP LEARNING

Task 9: Introduction

Handling low-level nuclear waste presents significant hazards for the workforce across the Department of Energy (DOE) complex. To address this critical challenge, an AI-enabled robotic arm has been developed using state-of-the-art technology to identify and segregate low-level waste (LLW) efficiently. Previous research focused on creating multiple object detection algorithms, balancing trade-offs in data quality, speed, and performance. Building on this foundation, the current work advances this field by exploring and implementing k-shot object detection algorithms—deep learning models capable of detecting new object classes with minimal or no additional training. This innovative approach aims to enhance the adaptability and effectiveness of waste segregation systems in complex environments.

Task 9: Objectives

This task is focused on identification and segregation of LLW using classification and object detection algorithms and models. This research supports the FIU Robotics team working on the segregation of LLW in appropriate waste disposal containers using a robotic manipulator.

Task 9: Methodology

The task of identifying and classifying nuclear waste can be interpreted as an object detection problem. In object detection, the model should find where an object is present (identifying) and find what the object is (classifying). Some of the object detection algorithms implemented include zero-shot, one-shot, and few-shot algorithms. The zero-shot object detection algorithm detects objects in an image given a word query. One-shot object detection algorithm detects objects in an image given a single image query. And lastly, few-shot object detection algorithm detects objects in an image given multiple image queries, like 5, 10, 30 images. Furthermore, these models do not require additional training or labeling of the images, which means that, to detect a new LLW, only a few images can be used to train the model to detect the new object class.

To implement one-shot object detection, a custom vision transformer was implemented to extract features from images and turn them into vectors. The main idea is that similar images should have similar vectors in both direction and magnitude. The vision transformer was trained using supervised contrastive loss as well as binary cross entropy as part of hyperparameter optimization to find the best mapping from images to vectors. Based on the results, the supervised contrastive loss leads to better results with respect to cosine similarity metrics, despite having a slower convergence rate than binary cross entropy.

The vision transformer was implemented, as shown in Figure 77 below, with an input image size of 224x224 and an output vector of shape 1024, using 12 encoder blocks with 12 attention heads each. Implemented a reinforcement learning environment, where pixels in images are represented as vertices in a graph and actions in the environment are vertex cuts that remove vertices (pixels) from the image.

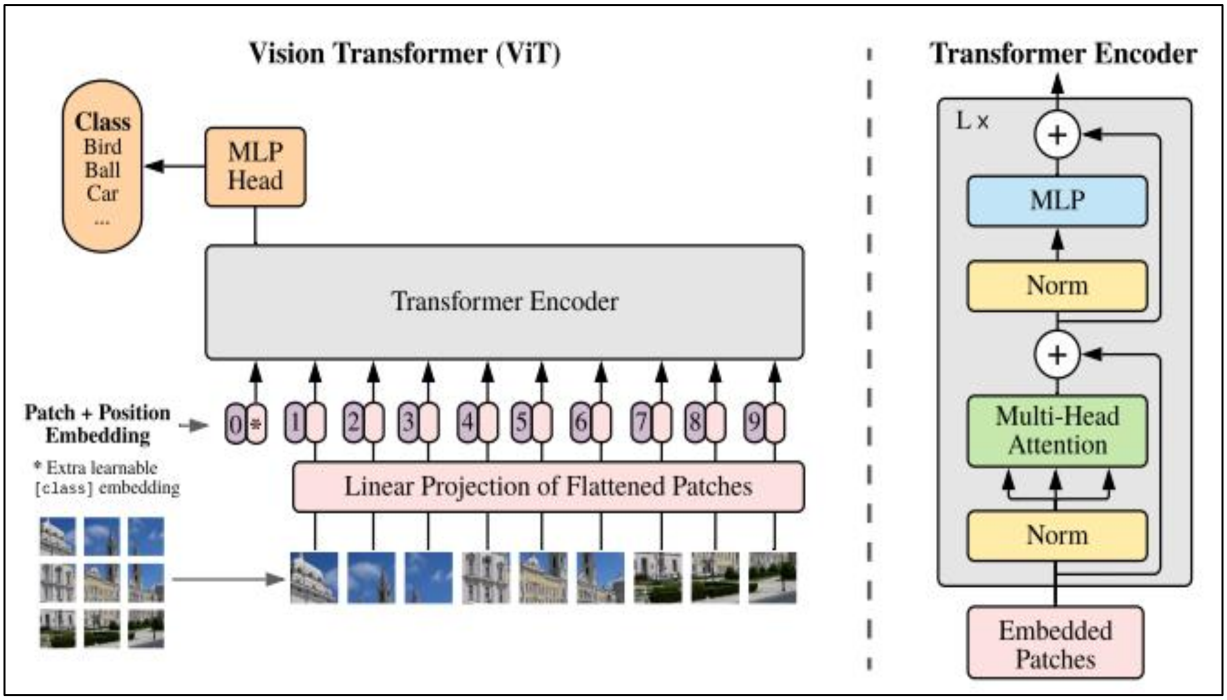

Figure 77. Illustration of the vision transformer architecture.

To create an agent that can perform in this environment, a Proximal Policy Optimization algorithm (PPO) was implemented that learned how to remove areas from the images using the similarity between the query image and the different connected components of the target image. The idea is to approach the one-shot object detection problem as a sequential decision-making problem of removing search spaces. This PPO algorithm was trained on different hyperparameter combinations of general advantage estimation, reward discounts, value function clipping and discounts, etc.

As shown in Figure 78 below, the neural network takes embeddings of the query as input and the target images generated by the custom vision transformer. These embeddings are mapped to a single real number that determines how good being in that state is, where that measure is indicative of how close the target image with eliminated areas is to the query image.

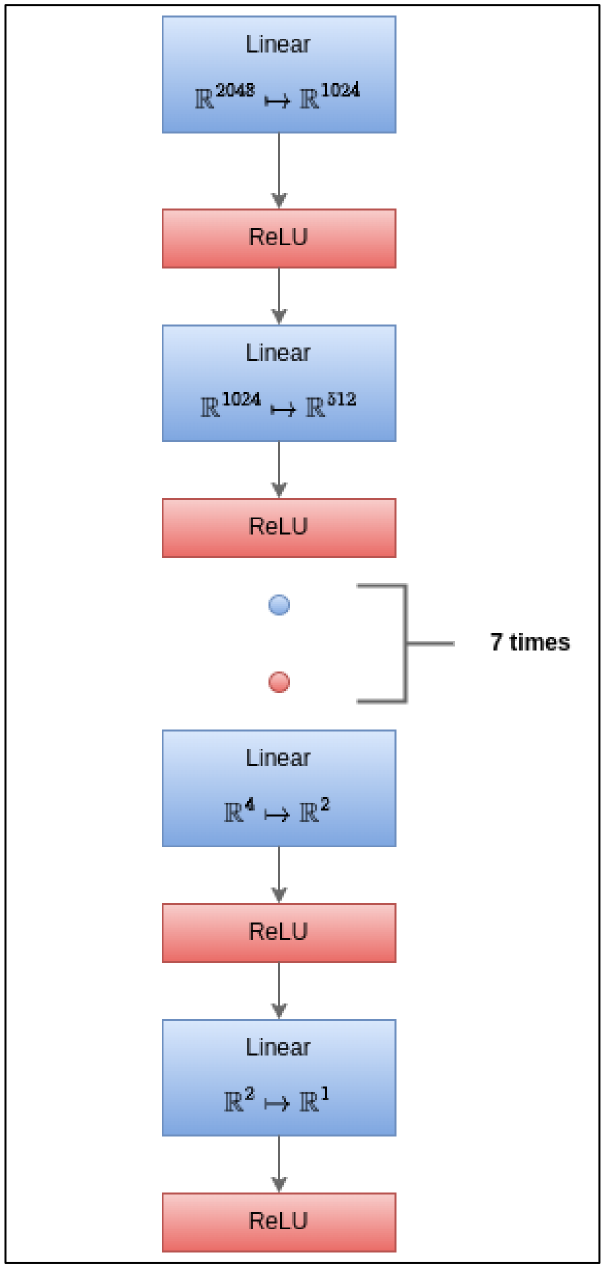

Figure 78. Visualization of the neural network that calculates the value of being in each state.

As shown in Figure 79 below, a neural network was implemented to take embeddings of the query and target images as input and convert it to a 224 x 224 tensor with values between 0 and 1 indicating the probability of removing that pixel from the screen. The variance of each action was calculated using a multivariable Bernoulli distribution.

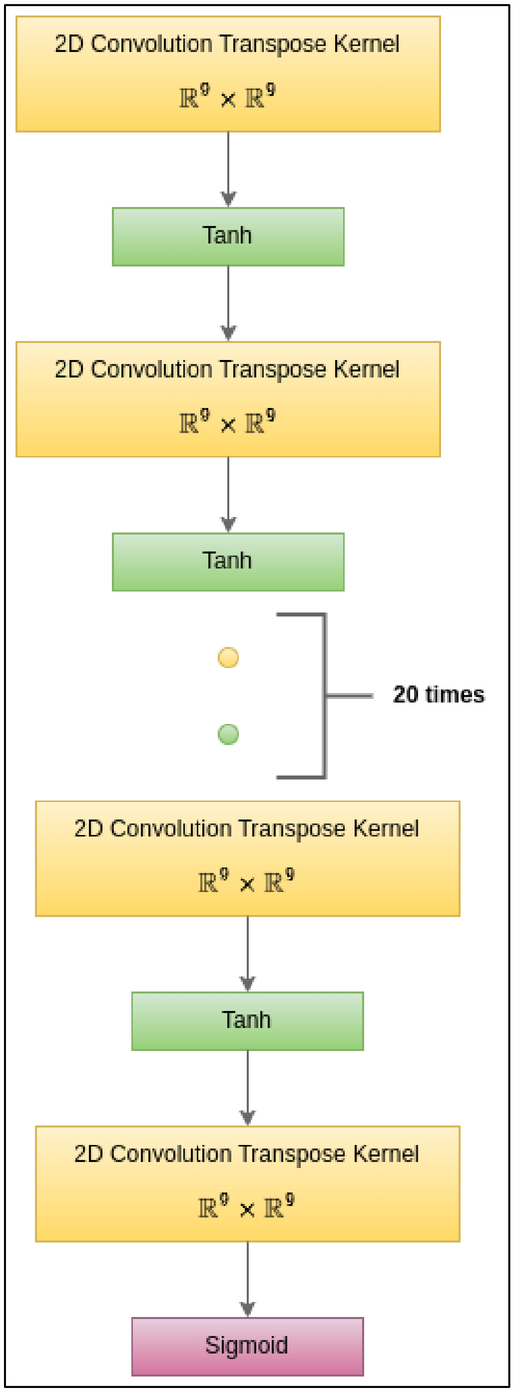

Figure 79. Visualization of the neural network that calculates the action for a given state.

These two neural networks constituted the agent, which learned how to remove chunks from an image using the PPO algorithm. While training the PPO algorithm on the previously discussed environment, where image pixels are vertices and actions are vertex cuts on the graph for an image of size 224 x 224 (the standard size used in vision transformers), the probability of taking a random action for a given policy is represented by the following formula.

$$\frac{1}{2}^{224 \cdot 224} = \frac{1}{2}^{50176} \approx 0 .$$

As such, the environment was changed to predict a continuous action on x, y, w, h and a corresponding variance for each variable. Additionally, FIU experimented with different reward functions for the agent, where the Intersection over Union (IoU) of the ground truth and the predicted boxes could be used as a reward for the agent, but the signal is only useful when the agent generates from the connected component.

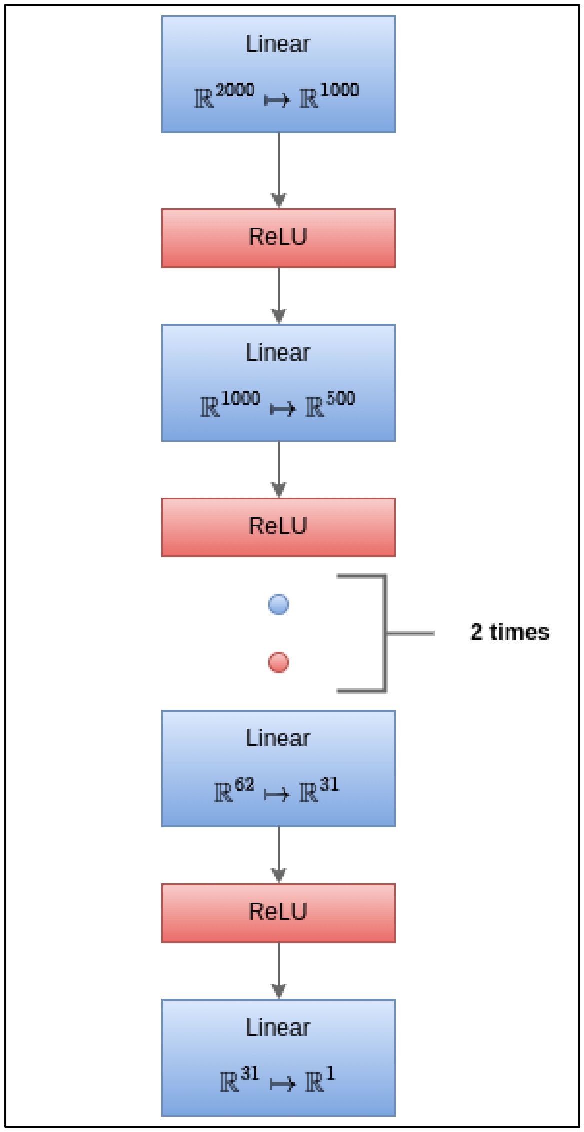

Figure 80. Visualization of the neural network that calculates the value of each state.

The neural network takes the embeddings of the query as input and the target images from the custom vision transformer, and outputs a real number indicating the value of being in each state.

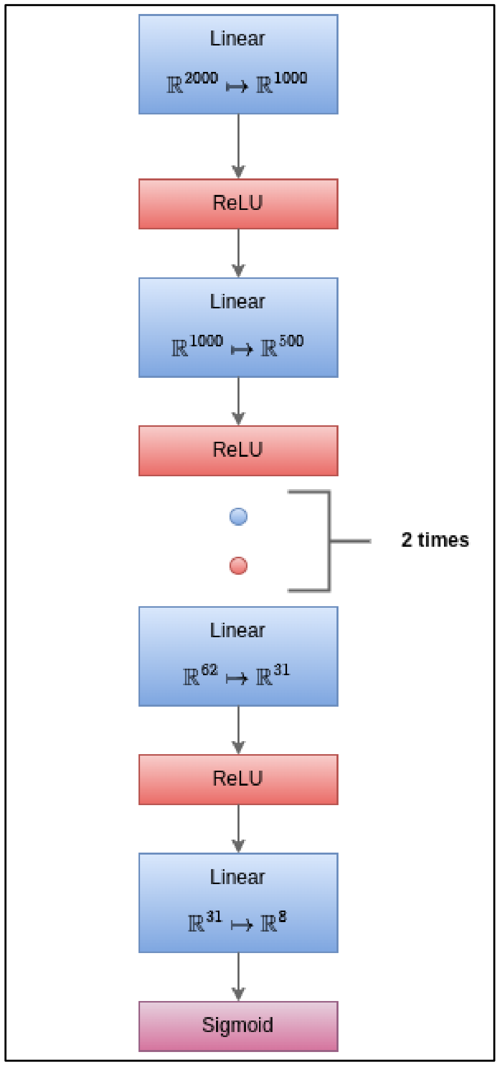

Figure 81. Visualization of the neural network that calculates the action for a given state.

As shown in Figure 81 above, a neural network was implemented to predict the mean probability of removing the rectangle, given by x, y, w, h between 0 and 1, and those values are then adjusted to the size of the image. The neural network also predicts a variance for each of x, y, w, and h, and then an action is sampled using the mean probability and mean variance from a normal distribution.

These two networks form the agent that predicts rectangles to be removed from an image using the PPO algorithm.

Good results were obtained by using a PPO algorithm to predict bounded boxes, but it took a long time to converge to a good trajectory of actions for a single sample. The bounding box removal problem was changed to a vertical and horizontal cut problem on the image. The idea is that, at every time-step, the agent chooses the vertical or horizontal cut and the location that would make the target image most closely resemble the query image. This was implemented in a greedy algorithm manner, where choosing the best action at each timesteps leads to the globally optimal action. The greedy algorithm property is made true for this environment because the reward function uses the ground truth bounding boxes during training by considering the IoU between the different parts of the cut and the target bounding box that matches the query image. To find the best action for a given instance, contextual bandits from Reinforcement Learning were implemented. The team implemented the algorithm to find the best place to cut for a given image and trained greedy algorithm with contextual bandits on different datasets.

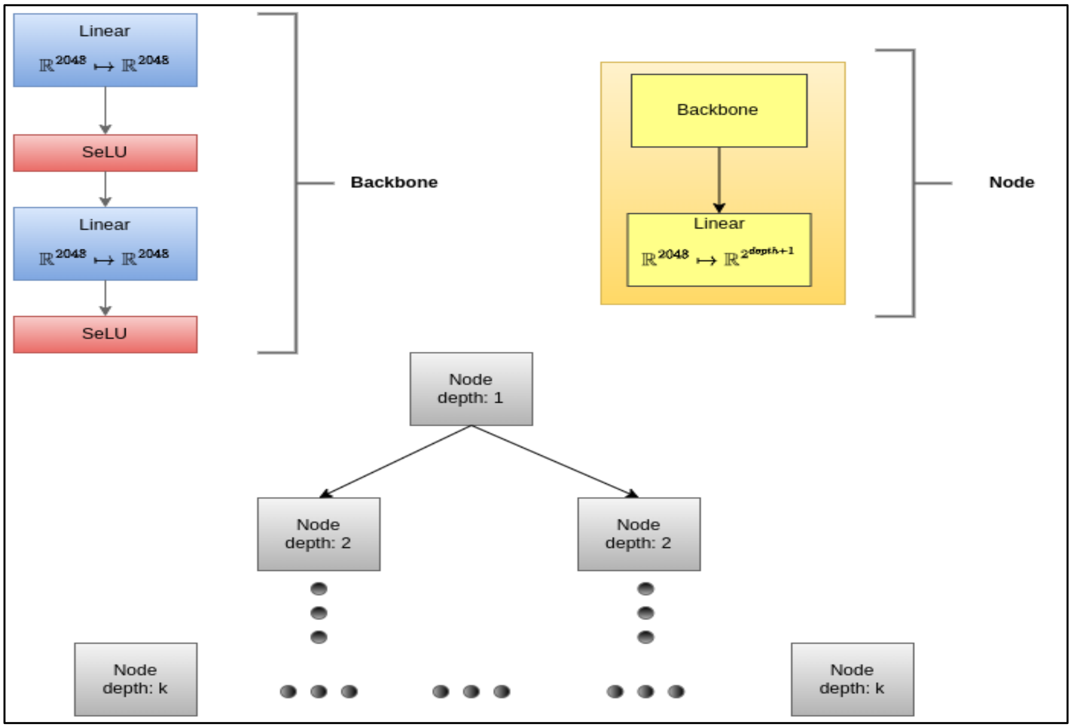

Figure 82. Visualization of the architecture using contextual bandits for continuous actions.

As shown in Figure 82, new architecture passes the input images through a vision transformer to generate embeddings, and then these embeddings are passed through an architecture consisting of a backbone and an output at a given depth. The idea is to determine where through the tree the input image goes, where the leaves of the tree output the action with some variance. Each action is a number between 0 and 2, where numbers between 0 and 1 refer to a horizontal cut at a certain percent of an image, and numbers between 1 and 2 refer to a vertical cut at a value – 1 percent of an image. With this, it is possible to remove chunks of images with the least possible actions, which allows the reinforcement learning algorithm to learn better. If each action is optimal at each timestep, there is no need for the agent to worry about the consequences of the current action in its future state.

Even though the results were passable, and the speed was faster than the previous PPO implementation, the models still took a long time to learn to detect base objects. The large amount of data is needed for the training to detect base objects since that's where the models learn how to detect unseen objects.

As an alternative, the team implemented a script that constructs object prototypes for the De-ViT model. These prototypes are vectors that capture the description of an object through numbers. A script was developed that uses these prototypes to detect objects in an image. This is achieved by splitting an image into patches and those patches into prototypes. The image prototypes can then be matched with previously constructed object prototypes. When an object prototype matches closely with an image path prototype, that patch of the image is given the object class of the object prototype. The models are tested on the YCB dataset, which is a dataset meant for robotic manipulation tasks.

The team also benchmarked the implementation on the Visual Object Classes (VOC) dataset, which contains images of 20 objects that are different in shapes, textures, colors, sizes, etc. This dataset does not support pixel masks, so scripts and classes were implemented to support the conversion between bounding boxes and pixel masks. The advantage of this implementation is that, to add a new object to detect, it is possible to label the bounding box without knowing the level of detail of a pixel mask and still able to obtain acceptable results. This makes it easier to detect new objects. The results were successfully replicated.

The team then benchmarked the implementation on Common Object in Context (COCO) dataset which contains 80 objects, 20 of those are the same objects found in the VOC dataset, and the results were successfully replicated.

In conclusion, the De-ViT is a few-shot object detection model that can be used to detect current and future LLW without additional training or labeling efforts.

Model Deployment:
Executing computer vision models on robotic hardware can trigger significant delays in inference speed. A new architecture that can allow for fast inference speed regardless of the hardware on the robotic arm was developed. The only requirement on the robot hardware is the ability to interact with an API.

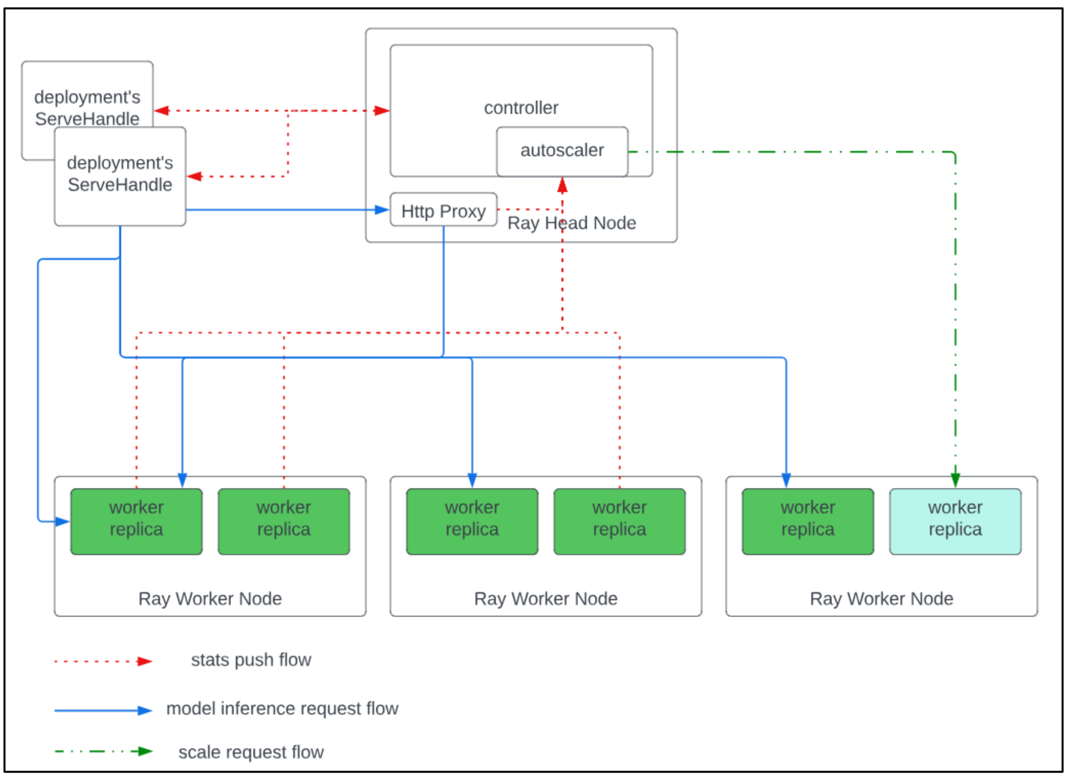

Figure 83. Illustration of the new system architecture for deploying computer vision models.

Figure 83 above shows the new architecture, where the client applications can call ServeHandle part of the API to consume the computer vision models. On the background, the new system can create multiple worker nodes to handle simultaneous requests. This allows multiple robotic applications to use the same deep learning models without delays in prediction. Another benefit of the new system is that training can also be distributed, which allows the models being trained to converge to the same solution faster. If the dataset contains N samples, N/k samples can be split between all k backend nodes at the same time, greatly reducing the training time.

Task 9: Results and Discussion

The team implemented a distributed training script for previously developed image classification algorithms. These algorithms include VGGNet, ResNet, InceptionNet, EfficientNet, and custom CNNs. To better train these models and make use of the distributed architecture, the team implemented an automated hyperparameter optimization script. This script searches through different activation functions, learning rates, image augmentations, number of epochs, etc. to find the model that yields the best performance on the given validation set.

Additionally, a prediction script was implemented. The prediction script serves the models as part of an API, where there can be more than one copy of the same model running at the same time.

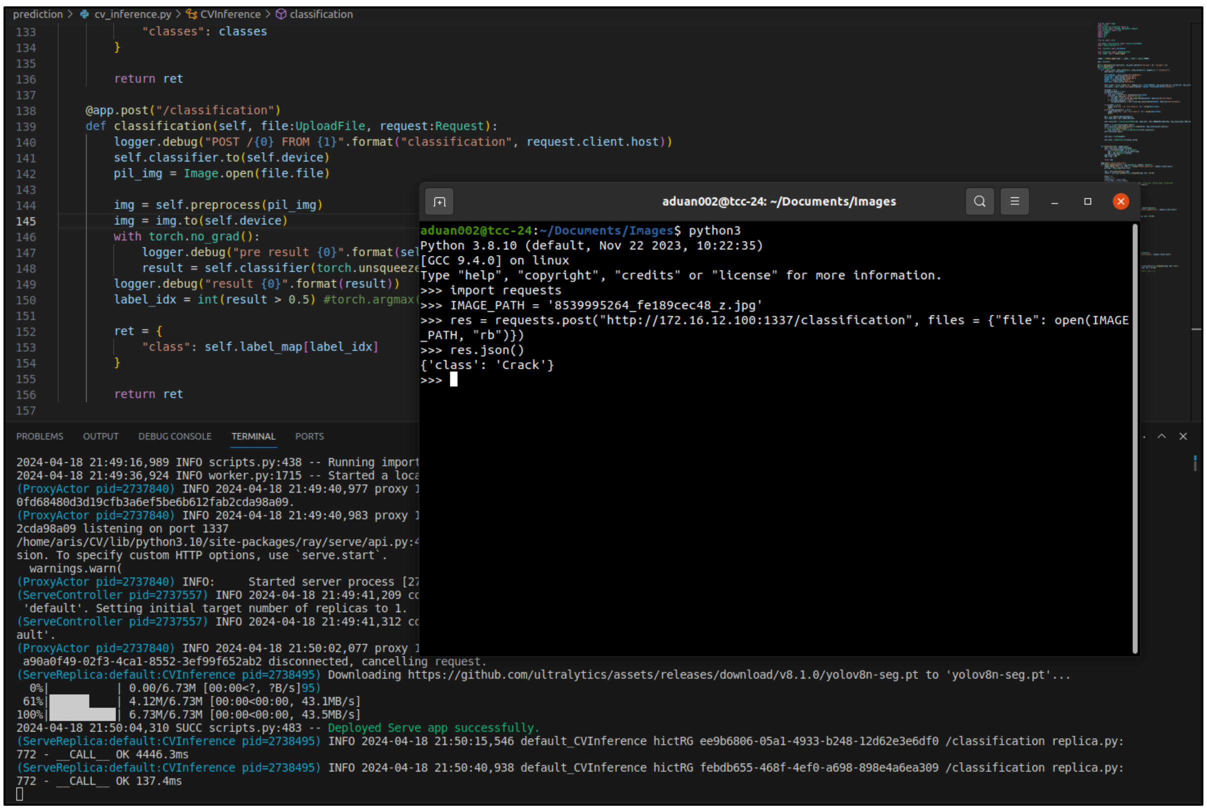

Figure 84. Example of the new server and its response for the client for the image classification algorithms.

As shown above, the client can send a request to the server by using the "classification" endpoint and passing in an image as an argument. The server handles all the processing of the image and responds with a JSON file that contains the class of the image.

The team implemented a distributed training script for new object detection and instance segmentation algorithms. These algorithms are YOLOv8 for object detection and instance segmentation. Previous work on this task involved the development of YOLOv7 models to detect LLW. Since then, the family of YOLO algorithms added YOLOv8, which has many improvements over YOLOv7, which include code and architectural optimizations. This allows YOLOv8 to have better performance under the same inference speeds than YOLOv7 and other YOLO-like models.

As shown in Figure 85 below, YOLOv8 exhibits higher mAP than YOLOv7 for the COCO dataset, where the number of parameters nearly translates to inference speed. The COCO dataset contains 80 classes, which implies that YOLOv8 will provide excellent performance on the LLW detection task.

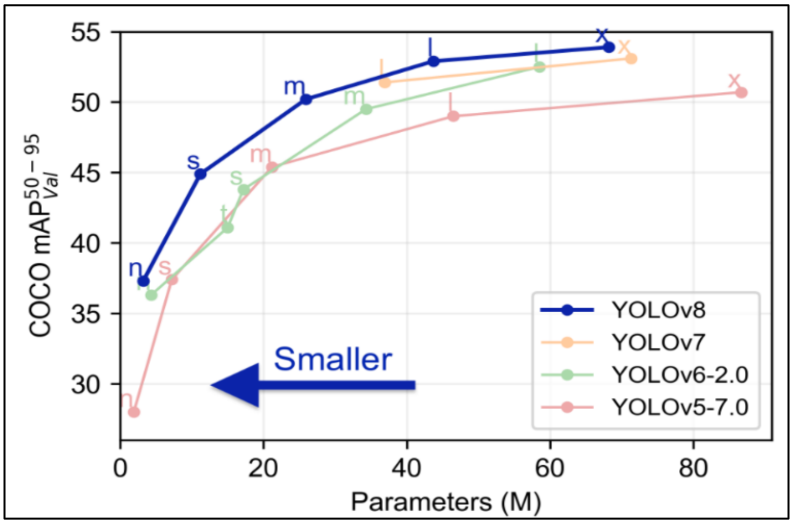

Figure 85. Benchmark of YOLOv8 versus YOLOv7 and previous versions of YOLO.

Additionally, an automated hyperparameter optimization script for the YOLOv8 algorithms was implemented. The script searches through different learning rates, momentums, batch sizes, number of epochs, as well as many data augmentations like saturation changes, translations, rotations, shears, mosaics, etc. The script identifies the model that has the best performance (highest mAP) on the validation set and reports this for use in the API section of the architecture.

A prediction script for instance segmentation and object detection using YOLOv8 was developed. The script can allow multiple models in the GPU to listen in for requests from an application and it can quickly respond with the bounding boxes or convex polygons, confidence on the predictions, and the object names.

```
Python 3.8.10 (default, Nov 22 2023, 10:22:35)
[GCC 9.4.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> import requests
>>> IMAGE_PATH = 'desk_with_items.jpg'
>>> res = requests.post("http://172.16.12.100:1337/object_detection", files = {"file": open(IMA
GE_PATH, "rb")})
>>> res.json()
{'boxes': [[0.210018590092659, 0.3519173264503479, 0.5752139091491699, 0.7731780409812927], [0.
5632666945457458, 0.24517571926116943, 0.8174163103103638, 0.5606846213340759], [0.184084579348
56415, 0.8401548266410828, 0.2771536707878113, 0.9687780737876892], [0.5192590951919556, 0.3771
199584007263, 0.5710033774375916, 0.6469805836677551], [0.013507151976227776, 0.6325163841247559
, 0.18105144798755646, 0.7435790300369263], [0.2401612251996994, 0.6000815629959106, 0.53518366
31365967, 0.7097572684288025]], 'conf': [0.9462347030639648, 0.8755932450294495, 0.816422402858
7341, 0.7740946412086487, 0.3063468635082245, 0.29099366068840027], 'classes': ['laptop', 'tv',
 'cell phone', 'bottle', 'book', 'keyboard']}
>>> 
```

Figure 86. Example of the response for the client for the object detection algorithm.

As shown in Figure 86 above, the client can send a request to the server by using the "object_detection" endpoint and passing in an image as an argument. The server handles all the processing of the image and responds with a JSON file that contains the different classes of the images, normalized coordinates of the bounding boxes, and confidence scores of the predictions. The bounding box predictions are normalized to allow for different image sizes.

Figure 87. Example of response for the client for the instance segmentation algorithm.

Similarly, a request can be sent from the client to the server using the “instance_segmentation” endpoint and passing an image as an argument. The server completes the request and responds with a JSON that contains different instance object predictions, the confidence in the predictions, and a series of (x,y) points that form a polygon around the object. As shown in Figure 87 above, there are many points per object, but this allows for precise predictions that provide the information to the robot arm about the object's shape to guide the physical picking up of the object.

Figure 88. Visualization of the predictions of YOLOv8 for instance segmentation.

As shown in Figure 88 above, YOLOv8 for instance segmentation and object detection can predict cans accurately and with great precision, even in the presence of unrelated objects.

Task 9: Conclusions

In conclusion, managing low-level nuclear waste remains a critical challenge for the DOE due to the significant hazards it poses to the workforce. By leveraging AI-enabled robotic systems, this work builds on prior advancements in object detection algorithms to improve the efficiency and safety of waste segregation processes. The exploration and implementation of k-shot object detection algorithms represent a pivotal step forward, enabling these systems to rapidly adapt to new object classes with minimal training. This innovation not only enhances the adaptability of waste segregation systems but also underscores the transformative potential of AI in addressing complex, high-risk environmental challenges.

Task 9: References

[1] Dosovitskiy, A., Beyer, L., Kolesnikov, A., Weissenborn, D., Zhai, X., Unterthiner, T., Dehghani, M., Minderer, M., Heigold, G., Gelly, S., Uszkoreit, J., & Houlsby, N. (2021, June *An image is worth 16x16 words: Transformers for image recognition at scale*. arXiv.org. https://arxiv.org/abs/2010.11929

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[5] Zhang, X., Wang, Y., & Boularias, A. (2024, March 7). *Detect everything with few examples*. arXiv.org. https://arxiv.org/abs/2309.12969

CONFERENCE PARTICIPATION, PUBLICATIONS, AWARDS & ACADEMIC MILESTONES

Professional Conference Presentations and Proceedings

- W. Quintero, H. Upadhyay, S. Joshi, L. Lagos, Waste Information Management System with 2023-24 Waste Streams, Waste Management Symposia, Phoenix, AZ, March 2024.
- H. Upadhyay, J. Soni, W. Quintero, S. Joshi, L. Lagos, Artificial Intelligence Based Nuclear Decommissioning Document Summarization, Waste Management Symposia, Phoenix, AZ, March 2024.
- Masudur R. Siddiquee, Aurelien O. Meray, Zexuan Xu, Hansell Gonzalez-Raymat, Thomas Danielson, Himanshu Upadhyay, Leonel E. Lagos, Carol Eddy-Dilek, and Haruko M. Wainwright, Machine Learning Approach for Spatiotemporal Multivariate Optimization of Environmental Monitoring Sensor Locations, Artif. Intell. Earth Syst., 3, e230011,
- https://doi.org/10.1175/AIES-D-23-0011.1.
- Duani Rojas, A., Lagos, L., Upadhyay, H. *et al.* AI-based detection and identification of low-level nuclear waste: a comparative analysis. *Neural Comput & Applic* **36**, 21061–21072 (2024). https://doi.org/10.1007/s00521-024-10238-7
- Mellissa Komninakis, Joseph Sinicrope, James C. Nicholson, Bryan Torres, Nicholas Espinal, "*Determination of Airborne Release Fractions for Fixative Technologies under Impact Stress for D&D Activities*", Waste Management Symposia, Phoenix, AZ, March 2024 (oral presentation). *NOTE: Awarded "Superior Rating", only 91 papers received this honorable recognition at WM2024 from the 530+ papers submitted.
- Bryan Torres, Joseph Sinicrope, Mellissa Komninakis, Nicholas Espinal. "*Developing and Testing Radiation Resistant High Density Polyurethane Foam"*, Waste Management Symposia, Phoenix, AZ, March 2024 (poster presentation).
- Mellissa Komninakis, Joseph Sinicrope, James C. Nicholson, Philip Moore, Yolanda Rodriguez, Leonel Lagos, Dainela Radu. "*Determination of Airborne Release Fractions from Loose Powder Contamination Under Impact Stress*". Nuclear Technology, 1-9, June 2024. doi:10.1080/00295450.2024.2345945.
- Joseph Sinicrope chaired the ASTM International E10.03 Subcommittee in January and June of 2024.

Awards

- Joseph Sinicrope received the Peter D. Hedgecock Award from ASTM International for his sustained superior performance and contributions to standards development in support of the E10 Committee on Nuclear Technology and Applications.

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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/SitePages/Welcome.aspx

FIU Year 4 Annual Research Review Presentations:

1. FIU Research Review - Project 1
2. FIU Research Review - Project 2
3. FIU Research Review - Project 3 - D&D IT ML
4. FIU Research Review - Project 4
5. FIU Research Review - Project 5
6. FIU Research Review - Project 4-5 – Carlos Rios
7. FIU Research Review - Project 4-5 – Fellow Aris
8. FIU Research Review - Project 4-5 – Fellow Aubrey
9. FIU Research Review - Project 4-5 – Fellow Melissa
10. FIU Research Review - Project 4-5 – Fellow Ocampo
11. FIU Research Review - Project 4-5 – Fellow Victor
12. FIU Research Review - Project 4-5 – Fellow Theophile
13. FIU Research Review - Wrap Up - Project 1
14. FIU Research Review - Wrap Up - Project 2
15. FIU Research Review - Wrap Up - Project 3 – D&D IT ML
16. FIU Research Review - Wrap Up - Project 4
17. FIU Research Review - Wrap Up - Project 5