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

Waste and D&D Engineering and Technology Development

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FIU | Applied Research Center
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Addendum:

This document represents one (1) of five (5) reports that comprise the Year End Reports for the period of September 29, 2019 to September 28, 2020 prepared by the Applied Research Center at Florida International University for the U.S. Department of Energy Office of Environmental Management (DOE-EM) under Cooperative Agreement No. DE-EM0000598. Incremental funding under this cooperative agreement resulted in FIU having to execute carryover scope, which was completed in November 2019. The technical information for the carryover scope from FIU Performance Year 9 has therefore also been included in these reports.

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

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

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

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

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

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

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

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PROJECT 3 OVERVIEW

The Waste and D&D Engineering and Technology Development Project (Project 3) focuses on delivering solutions under the waste, D&D and IT 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, Idaho and Portsmouth. This project included the following tasks during the September 29, 2019 to September 28, 2020 period of performance:

Task 1: Waste Information Management System (WIMS)

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 for 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. For FIU Performance Year 10, FIU expanded its research in technology test and evaluation in the following key areas: 1) Evaluate fixative performance when exposed to various stressors (impact, water immersion, thermal/fire, etc.) associated with open air demolition activities and safety basis analysis in response to high priority requirements identified across the DOE complex; 2) Assist SRNL in addressing high priority fire resistant, contamination control and safety requirements in support of DOE EM D&D efforts by conducting test and evaluation of intumescent foams in operational scenarios, such as dismantling contaminated pipework; 3) Assist SRNL in monitoring and analyzing data associated with the FD Intumescent Coating operational test and evaluation in Process Cells #1 and #7 at the SRS 235-F PUFF Facility; 4) Investigate the potential for multi-functional fixatives intended for mercury abatement in support of D&D activities; and, 5) Continue working with ASTM International's E10 and E10.03 Committees to establish performance metrics and uniform testing protocols to support the standards development, testing, evaluation, and deployment of D&D technologies.

Task 3: D&D Knowledge Management Information Tool (KM-IT)

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. The mobile version of the system can be accessed from https://m.dndkm.org.

Task 6: Analysis of Image Data using Machine Learning/Deep Learning and Big Data Technologies

This task is aimed at using Machine Learning/Deep Learning and Big Data Technologies to run analysis of image data. The research focuses on specific LiDAR technology mounted on a robotic platform to be deployed at FIU mock up facilities to develop a pilot-scale infrastructure using machine learning/deep learning and big data technologies for structural health monitoring of facilities. FIU will work closely with SRNL to identify applications at SRS or other DOE facilities.

MAJOR TECHNICAL ACCOMPLISHMENTS

Task 1: Waste Information Management System (WIMS)

- FIU received a new set of waste stream forecast and transportation forecast data from DOE and completed the data import and all the necessary code updates to the back-end and front-end of the application to accommodate the new waste streams.
- FIU completed upgrading the security module with the WIMS Identity Management framework. FIU upgraded the WIMS Report module with the new SQL Server 2017 platform.
- A presentation on WIMS was made at WM2020 featuring the current accomplishments on the project.

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

- Established the first ASTM International Student Chapter in the world at FIU. This was a collaborative effort intended to further the integration of standards-based testing and evaluation for D&D technologies.
- Mr. Joseph Sinicrope was elected as the 2nd Vice-Chairman 2 and Membership Secretary to the ASTM International E10 Committee on Nuclear Technology and Application. He was also selected for a 3-year term on the ASTM International Technical Operations Committee.
- Continued to support SRNL with follow up activities for the intumescent coating fixative hot test and evaluation at the SRS 235-F PuFF Facility. Collaborated with SRNL to develop a final Test Plan for obtaining the final data points related to the FD Incombustible Fixative in the entry hood of Process Cell #1. The SRNL-FIU Final Close-Out Report for this research activity is planned for FY21.
- Developed an approved experimental design to quantitatively ascertain the effects of fixative technologies in immobilizing residual contamination under ideal conditions, as well as exposure to certain impact and environmental stressors. The experimental design was published and uploaded as a Technical Progress Report on OSTI and KM-IT. The data obtained during the experimental phase of this activity will be used to support the update of the DOE-HDBK-3010.
- Developed a concept for a multi-functional polymer intended to assist with Hg abatement.
- Completed the test and evaluation of a down-selected intumescent foam intended to assist with nuclear pipe dismantling and decommissioning activities. The data from this effort was published in a Technical Progress Report and uploaded on OSTI and KM-IT.

Task 3: D&D Knowledge Management Information Tool (KM-IT)

- FIU continued its outreach and marketing efforts by attending WM2020 and presenting a poster on D&D research on KM-IT.
- The application and infrastructure were upgraded to new industry standards. The application framework was upgraded to the latest version of .NET, and the hardware was virtualized.
- A total of 268 technologies were added to the D&D KM-IT technology module and four (4) newsletters were sent to D&D KM-IT users.

Task 6: Analysis of Image Data using Machine Learning/Deep Learning and Big Data Technologies

- FIU continued its object detection and anomaly detection efforts for the structural health monitoring of the DOE infrastructure.
- FIU team implemented deep learning-based YOLOv3 (You Only Look Once V3) architecture, which is a near real-time object detection mechanism suitable for streaming videos, static videos, and still images.
- For the anomaly detection subtask, the FIU team implemented a One Class Classifier (OCC), which is a hybrid approach with a combination of Auto Encoder (AE) and Convolutional Neural Network (CNN).

TASK 1: WASTE INFORMATION MANAGEMENT SYSTEM (WIMS)

Task 1: Executive Summary

For Task 1, FIU has developed a Waste Information Management System (WIMS) 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 data and other displayed reports. This system offers a single information source to allow interested parties to easily visualize, understand, and manage the vast volumes of the various categories of forecasted waste streams in the DOE complex. 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.

During this reporting period, 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. Additionally, FIU continued to perform certain security tasks, including antivirus engine and definitions updates on both the web and database servers. Windows OS updates and patches were also applied to the servers running the application. FIU also performed routine maintenance in order to keep the WIMS database and server in a stable condition and monitored the network and server traffic to optimize the application performance.

During the first quarter, FIU submitted an abstract for the 2020 Waste Management Symposia capturing the research and efforts on WIMS during 2019. The abstract titled "*Waste Information Management System with 2019-20 Waste Streams"*. The abstract was accepted on October 1, 2019 for a poster presentation during the conference, which was held in Phoenix, Arizona. During the month of October 2019, FIU began writing the full paper for this abstract. The details of the abstract presentation are below:

Abstract: 20491 Waste Information Management System with 2019-20 Waste Streams
Session: LLW/ILW Characterization - Posters (3.1b)
Date: Tuesday
Time: 8:00 AM - 11:35 AM

FIU submitted the full paper titled *"Waste Information Management System with 2019-20 Waste Streams"* to WM2020 on November 15, 2019. In November, FIU also prepared a WIMS presentation for DOE upon the request of Jonathan Kang. The presentation included an overview of WIMS and its features. It also contained screenshots of each of the modules with description and capabilities.

FIU presented the WIMS project at WM2020 on March 10, 2020 in Phoenix, AZ. The presentation captured the WIMS effort, accomplishments and future work. It also contained information about artificial intelligence (AI) technologies that can be used to produce better forecasting estimates. The presentation was well received by attendees and there were multiple questions from the audience especially in the areas of AI. The picture below shows Dr. Himanshu Upadhyay presenting the WIMS application at the Waste Management Symposia on March 10, 2020 in Phoenix, AZ.

Figure 1. Himanshu Upadhyay presenting WIMS at Waste Management on March 10, 2020.

During the last quarter, one major Subtask 1.2 (WIMS Identity Management) was completed. Details of this accomplishment is listed in the following sections. Also during this period, the FIU team presented the research efforts performed on this task to DOE HQ officials and DOE Site POCs on August 25-26, 2020. This presentation consisted of accomplishments to date and plans for future work. The presentation shared with the team can be downloaded from the DOE Research website maintained by FIU at https://doeresearch.fiu.edu/.

Subtask 1.1: Integration of New Waste Stream and Transportation Data into WIMS

Subtask 1.1: Introduction

Under this subtask, FIU receives revised waste forecast data and 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 1.1: Objectives

The objective of this task 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 is needed to receive and consolidate waste forecast information from all DOE sites and facilities and to make this information available to all stakeholders and to 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 1.1: Methodology

FIU receives revised waste forecast data and transportation data as formatted data files from DOE EM 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. Once integrated, reviewed and verified, the new waste data replaces the existing/previous waste data and becomes fully viewable and operational in WIMS.

FIU received the data from DOE HQ during the month of March 2020.

Subtask 1.1: Results and Discussion

Once the new annual waste forecast dataset was received from DOE EM, the team worked on importing the data into the development database environment and updated the application to consume the new waste stream data. Changes were made to the front-end and back-end of the application to accommodate new data that was imported into the database. The team completed updating the Forecast, Disposition Map, GIS Map and Transportation Map modules with the new waste stream data. All changes made in the development environment were moved to staging for the DOE to review.

In April, the team worked on importing the data into the development database environment and updated the application to consume the new waste stream data. Changes were made to the front-end and back-end of the application to accommodate new data that was imported into the database.

Finally, in May, the team completed updating the Forecast, Disposition Map, GIS Map and Transportation Map modules with the new waste stream data, ensuring all the feedback from DOE HQ was incorporated. After a final review, the FIU team moved the application from the staging server to the production server and made all the data live at https://emwims.org/. This subtask (2019-P3-M4) which was due on May 29, 2020, was actually completed ahead of schedule in early May and is now marked as complete. The figures below show a few screenshots representing the new data from 2020.

Figure 2. WIMS Disposition Map module showing forecast data from Brookhaven National Laboratory to all facilities from 2020 to 2050.

Figure 3. WIMS GIS Map module showing forecast data from Idaho National Laboratory to all facilities from 2020 to 2050.

As of the end of this period, the WIMS application supported the following waste types:

- All Materials
- Unknown
- Low Level Waste
- Mixed Low Level Waste
- 11e.(2) Byproduct Material
- Other Material

In addition, the waste can be forecasted among 36 sites and 33 disposition facilities. The names of each of the locations are listed below.

Table 1. List of Sites and Facilities Supported by WIMS

	SITES		FACILITIES
1	Ames Laboratory	1	200 Area Burial Ground (HANF)
2	Argonne National Laboratory	2	746-U Landfill(Paducah)
3	Bettis Atomic Power Laboratory	3	Alaron
4	Brookhaven National Laboratory	4	Area 5 LLW Disposal Unit (NTS)
5	Energy Technology Engineering Center	5	Area 5 MLLW Disposal Cell (NTS)
6	Fermi National Accelerator Laboratory	6	Clean Harbors
7	Hanford Site-RL	7	Commercial TBD

8	Hanford Site-RP	8	E-Area Disposal (SRS)
9	Idaho National Laboratory	9	EMWMF Disposal Cell (ORR)
10	Kansas City Plant	10	Energy Solutions-Clive (formerly Envirocare)
11	Knolls Atomic Power Laboratory - Kesselring	11	Energy Solutions-TN (formerly GTS Duratek)
12	Knolls Atomic Power Laboratory - Schenectady	12	ERDF (HANF)
13	Lawrence Berkeley National Laboratory	13	Impact Services-TN
14	Lawrence Livermore National Laboratory	14	INL CERCLA Cell (INL)
15	Los Alamos National Laboratory	15	Integrated Disposal Facility (HANF)
16	Naval Reactor Facility	16	New RH LLW Vaults (INL)
17	Nevada Test Site	17	Omega Waste Logistics
18	NG Newport News	18	OSWDF(Portsmouth)
19	Norfolk Naval Shipyard	19	Paducah CERCLA
20	Nuclear Fuel Services, Inc. (cleanup site)	20	Perma-Fix Gainesville
21	Oak Ridge Reservation	21	Perma-Fix--Diversified Scientific Services, Inc.
22	Paducah Gaseous Diffusion Plant	22	Perma-Fix--Northwest (formerly PEcoS)
23	Pantex Plant	23	Perma-Fix/Materials & Energy Corp
24	Pearl Harbor Naval Shipyard	24	Remote Waste Disposition Project (INL)
25	Pacific Northwest National Laboratory	25	River Metals
26	Portsmouth Gaseous Diffusion Plant	26	RMW Trenches (MLLW/LLW) (HANF)
27	Portsmouth Naval Shipyard	27	RMW Trenches/IDF (HANF)
28	Princeton Plasma Physics Laboratory	28	RWMC (LLW disposal) (INL)
29	Puget Sound Naval Shipyard	29	Siemens
30	Sandia National Laboratories - NM	30	Smokey Mountain Solutions
31	Savannah River Site	31	TA 54/Area G (LLW disposal) (LANL)
32	Stanford Linear Accelerator Center	32	To Be Determined
33	Separations Process Research Unit	33	Waste Control Specialists
34	Thomas Jefferson National Accelerator Facility		
35	Waste Isolation Pilot Plant		
36	West Valley Demonstration Project		

Subtask 1.1: 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 application to the production server running live at https://emwims.org/. This subtask (2019-P3-M4) was completed ahead of schedule in early May and is now marked as complete.

Subtask 1.1: 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.

Subtask 1.2: WIMS Identity Management

Subtask 1.2: Introduction

During FIU Performance Year 10, FIU will incorporate an identity management module to allow users to be authenticated. This feature will control user access, capture user interaction with the system, and manage the user accounts. This module will allow users to register, login to the system, and create a profile, as well as allow system administrators to control access based on assigned roles. This task is to take advantage of the Microsoft.Net framework upgrades done to the application in the previous year.

Subtask 1.2: Objectives

Upgrading the authentication module of the WIMS application to Identity Management will result on a stable account management module and a better user experience for users. So of the more specific benefits among other include.

1. Increased user experience and cybersecurity of the user accessing the system.
2. Create a muti-layer security access to prevent unauthenticated access.
3. Provide a module for user to manage their own account profile including password reset.

Subtask 1.2: Methodology

This new task incorporates an identity management module to allow users to be authenticated. This feature is designed to control user access, capture user interaction with the system, and manage the user accounts. This module allows users to register, login to the system, and create a profile, as well as allow system administrators to control access based on assigned roles.

In April, the team started to setup the development environment for this task. This environment consisted of backing up the existing production WIMS application to the development environment where the backend code was to be updated to use identity management. This environment consisted of a backup of the existing database as well so that it can be upgraded to include the tables that will contain the user credentials, roles and login information. This was a delicate upgrade since the existing database was altered to accommodate these changes.

The typical authentication process is shown in the following figure, where the client requests a resource from the server. The server in turn, requests authentication from the client (such as username and password). The client sends the credentials to the server at which point the credentials are verified. The server will then grant the client access to the resource originally requested.

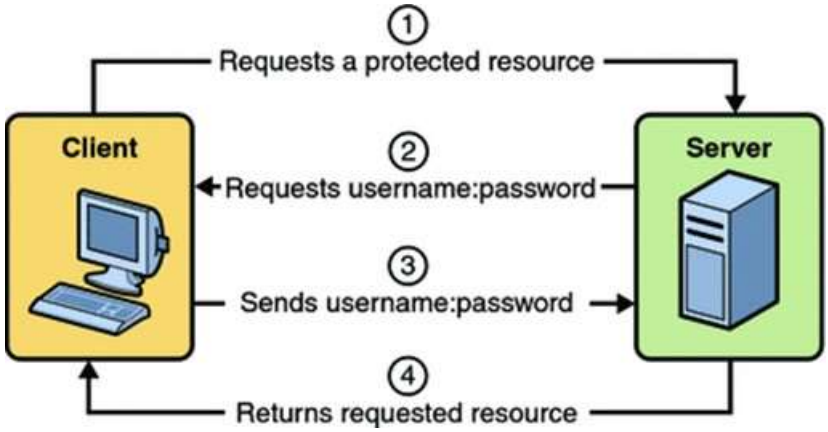

Figure 4. Typical authentication process.

In June, the team continued researching the integration of the identity management framework with the existing .NET framework that the WIMS application is built on. The team started implementing database changes on the development environment. The following figure shows the database tables created when the identify framework was deployed with default settings. These tables contained information about the user, the group to which they belong and their role on the application. The focus during this period was creating these tables on the existing WIMS application and adding the necessary Graphical User Interface (GUI) for user management.

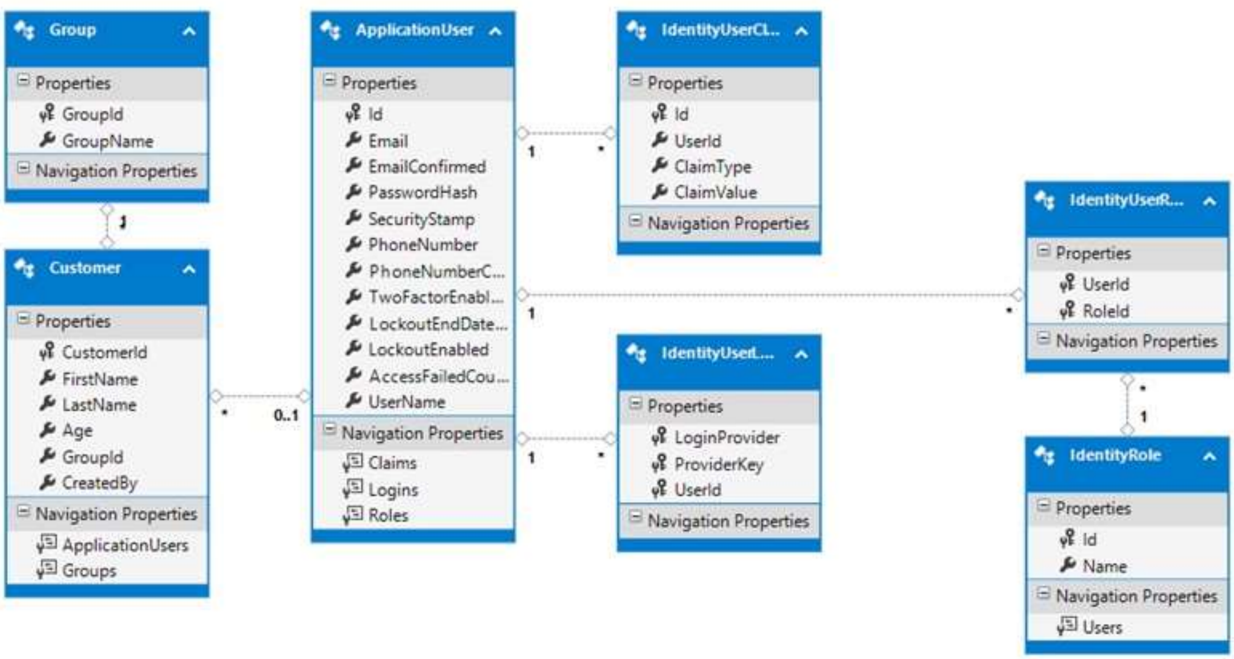

Figure 5. Sample identity management tables created on the database with default values.

The next step was to make the code changes to the application, starting with configuration settings to create tables and store procedures in the database to support identity management, in addition to creating multiple pages on the application to support registration, login, role management, and more user management tasks. Finally, the application had to undergo unit testing and integration testing before being moved to the production server where both the application and database are replaced. This task was due on July 31, 2020.

Subtask 1.2: Results and Discussion

The team followed industry standards for this implementation, which was completed on July 31, 2020. The completion of this task makes the WIMS application more secured. It also allows users to have their own profile and administrators to control user roles. It also provides an environment for developers to maintain the application more efficiently moving forward. . The WIMS application is running on a production server and can be accessed at https://emwims.org/. A screenshot of the WIMS application is shown below with the identity management functionality buttons (Register & Login) at the top right corner.

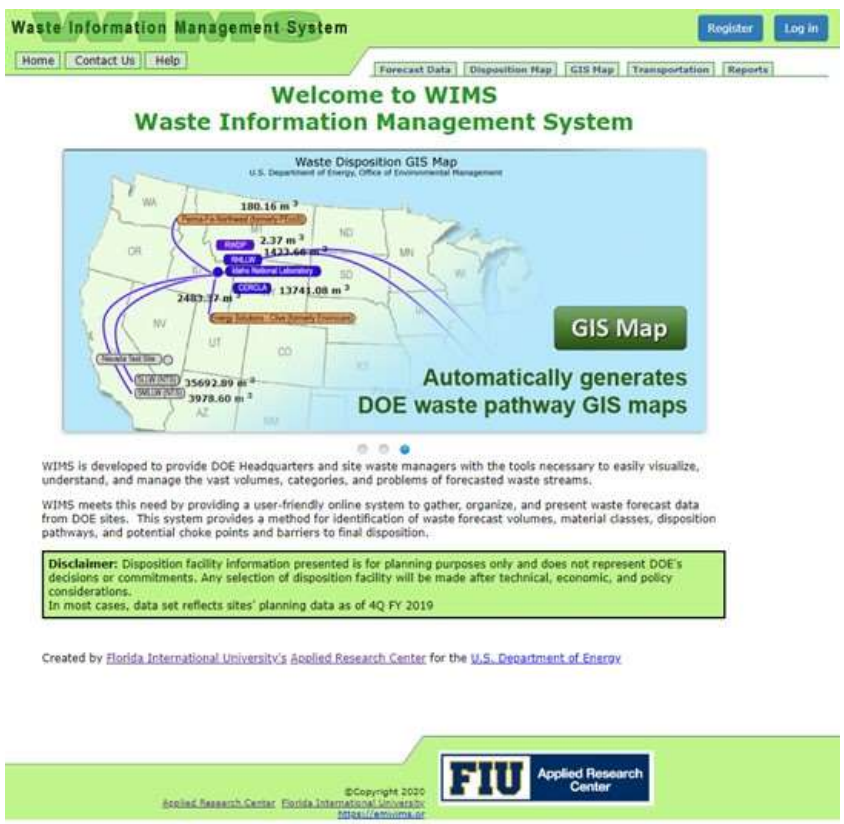

Figure 6. WIMS application showing Register and Login buttons at the top right corner, which are part of the identity management module.

Subtask 1.2: Conclusions

During this period of performance, FIU incorporated an identity management module to allow users to be authenticated and take advantage of the new framework 4.6 that was implemented during the previous year. This feature is designed to control user access, capture user interaction with the system, and manage the user accounts. This module will allow users to register, login to the system, and create a profile, as well as allow system administrators to control access based on assigned roles. As a result, the WIMS application is more secure while providing a better user experience.

Subtask 1.2: References

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

ASP.NET Identiy Overview [Web log post] Retrieved November, 2020 from https://docs.microsoft.com/en-us/aspnet/identity/overview/

Subtask 1.3: Upgrade of WIMS Report Server & Report Function

Subtask 1.3: Introduction

The current WIMS report module was based on SQL Server 2005 infrastructure. This task focused on upgrading the server to SQL Server 2017. The WIMS report module, including forecast data, waste stream and transportation reports, were upgraded using the SQL Server Data Tools 2017. These reports were configured to run on the latest reporting server using advanced components and published over the web to be accessible to the users through a variety of web browsers.

Subtask 1.3: Objectives

The main objective of this task was to stabilize the WIMS report server and report module functionality with the latest version of the SQL reporting server. By upgrading to the new SQL Server 2017, the WIMS application will be able to provide a more stable report module and user experience. In addition, the reports can be downloaded in multiple formats like XML, CSV, TIFF, PDF, web archive or Excel.

Subtask 1.3: Methodology

FIU started by updating the reporting server software on the SQL Server. Next, FIU upgraded each of the current reports and made the necessary modifications to make them compatible with the new version. Next, all necessary configurations were applied to the system to make it compatible with the existing reports. Finally, the reporting module was fully tested before moving the module to the production server for full public access.

Subtask 1.3: Results and Discussion

The reporting server software on the SQL server has been updated using the following methodology:

- The reporting server software was updated on the SQL Server.
- Each of the current reports were upgraded and the necessary modifications made to make them compatible with the new version of the SQL Server.
- All necessary configurations were applied to the system to make it compatible with the existing reports.
- Finally, the reporting module was fully tested before moving the module to the production server for full public access at https://emwims.org/Reports

The screenshot below shows the reporting module on WIMS.

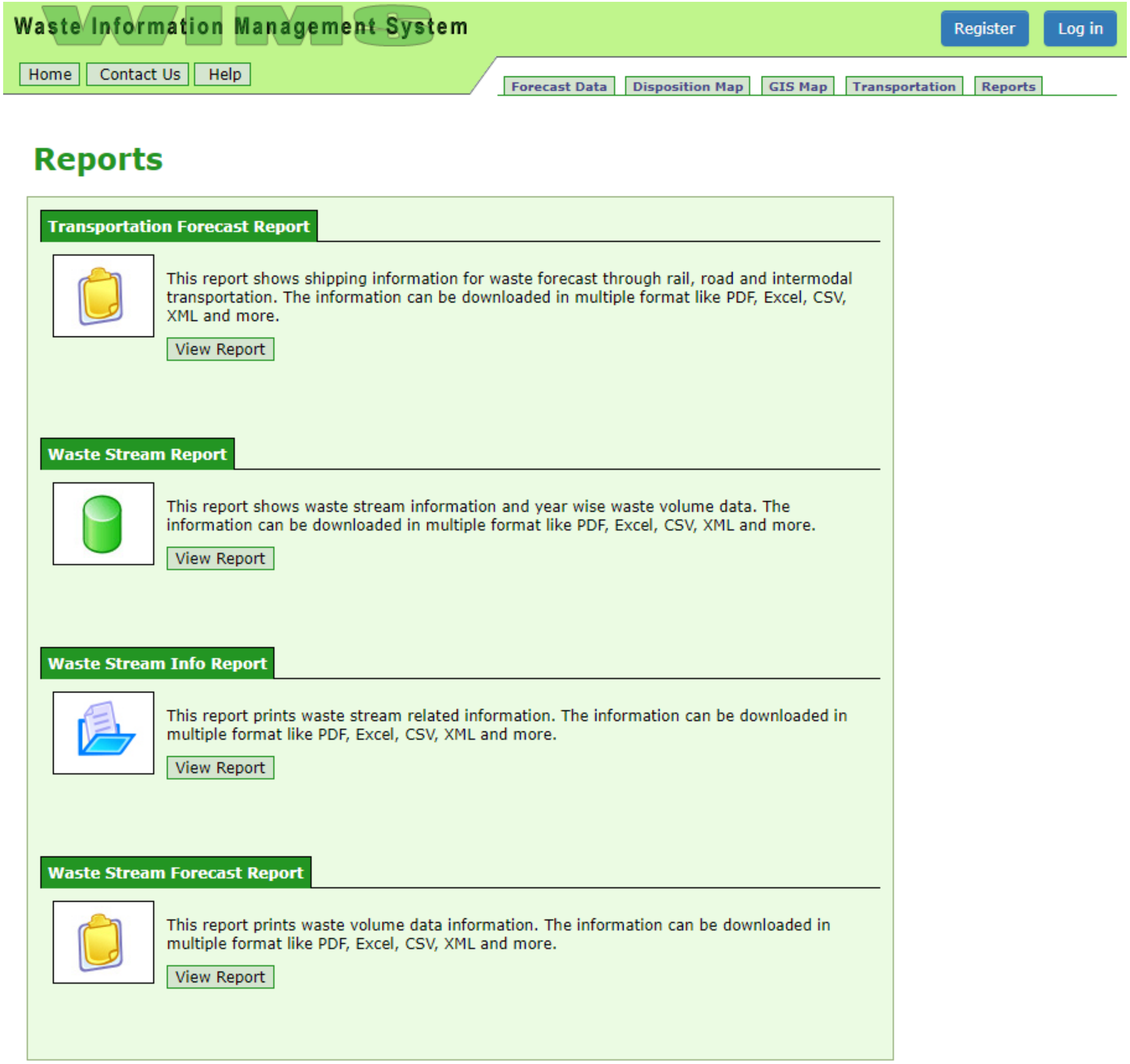

Figure 7. WIMS Report Module available at https://emwims.org/Reports.

The following screenshot is a sample report from the WIMS module.

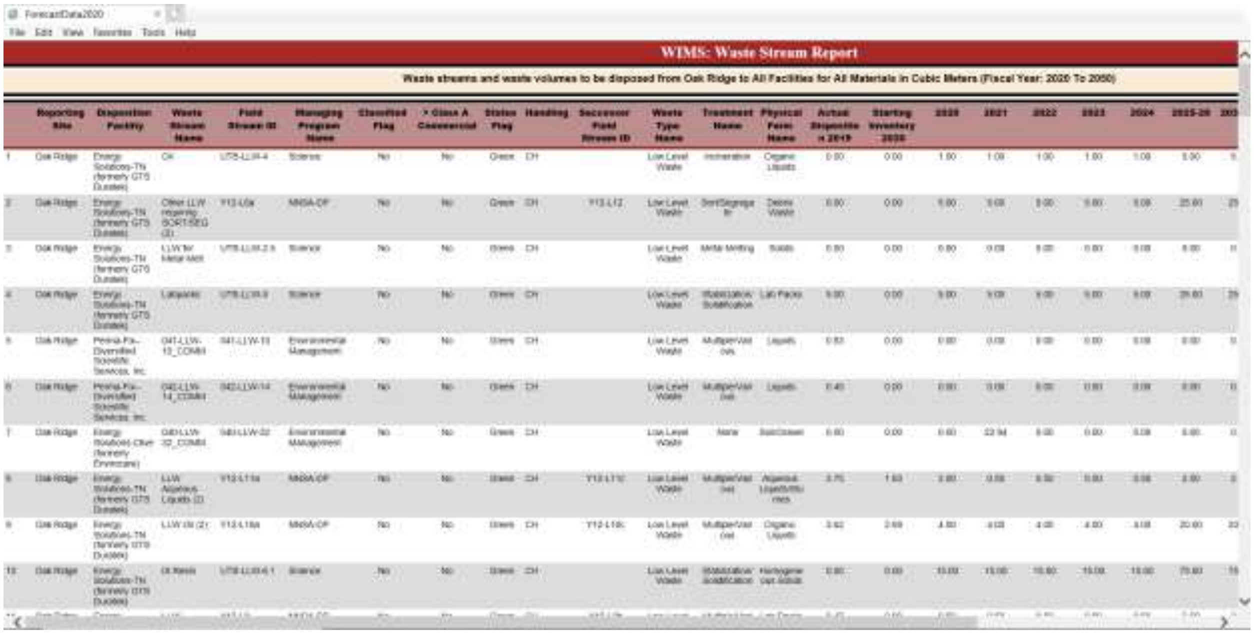

Figure 8. Waste streams and waste volumes to be disposed from Oak Ridge to All Facilities for All Materials in Cubic Meters (Fiscal Year: 2020 To 2050).

Subtask 1.3: Conclusions

FIU went over each of the current reports to make them compatible with the new version of the reporting server. The report module was tested using the latest data available and published after successful testing. This task (2019-P3-M2) was completed and the report module can be directly accessed at https://emwims.org/Reports.

Subtask 1.3: References

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

SQL Server Reporting Services [Wikipedia] Retrieved November, 2020 from https://en.wikipedia.org/wiki/SQL_Server_Reporting_Services

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

Task 2: Executive Summary

In support of the DOE-FIU Cooperative Agreement under Project 3 (Waste and D&D Engineering and Technology Development), Task 2 (D&D Support for Technology Innovation, Development, Evaluation and Deployment), the FIU Applied Research Center (ARC) continued its focus on research activities related to identifying, testing and evaluating commercial-off-the-shelf (COTS) intumescent material technologies as fire resistant fixative solutions that have a high potential to: 1) successfully address postulated contingency scenarios outlined in Basis for Interim Operations (BIO) / Safety Basis documents across the complex; and, 2) demonstrate a high probability of transitioning to an operational test and evaluation in a radioactive environment on site. This approach resulted in an intumescent coating technology being deployed in the Entry Hood to Process Cell 1 and Process Cell 7 at the SRS 235-F PUFF Facility. The performance of the material has been monitored in the SRS 235-F process cells over this reporting period (Year 10), as have control coupons resident at FIU ARC. A final Test Plan, coordinated among SRS, SRNL, DOE, and ARC was recently completed, and operational planning to acquire thickness measurements of the fixative technology in the entry hood of Process Cell #1 is being finalized. Execution of this activity, to include the final report, is expected in FY'21.

The potential application of intumescent technologies to support D&D activities across the complex has also led to the identification of another COTS intumescent foam technology that has demonstrated initial promise during proof-of-concept experiments this year in addressing an operational requirement for a rigid, fire resistant fixative technology to immobilize and/or isolate residual contamination within a 3-dimensional void space of various volumes at sites across the complex. An operational concept was developed and proposed using the intumescent foam technology as an internal barrier, or "plug", prior to cutting contaminated pipework during dismantling and demolition operations on nuclear sites. Phase I of this research activity involved down selecting a potential intumescent foam against some initial operational parameters outlined in ASTM E3191-18, Standard Specification for Permanent Foam Fixatives, specifically developed by the ASTM International E10.03 Subcommittee to support this broader activity. These included: 1) the ability to immobilize contamination and fill 3D spaces; 2) fire resistance to extreme temperatures and thermal stressors; 3) ability to withstand certain environmental factors such as water; 4) mechanical properties such as rigidity and adhesion to ensure the material can act as a "plug" in piping and not be adversely affected when exposed to expected impact stressors; and, 5) confirmation of temperature profiles related to curing and uniform application of the material. The research plan for the next phase is to develop, in close collaboration with SRNL and site personnel, an operationally-focused test plan designed to directly evaluate the technology in terms of immediate, high priority requirements from safety basis personnel in order to conduct an operational test and evaluation on a DOE EM site by FY'22. This approach mirrors the highly successful phased test and evaluation model employed by ARC and SRNL for the intumescent coating technology deployed in support of the SRS 235-F PUFF Facility.

Finally, another noteworthy result of the overall research portfolio has been the engagement with ASTM International's E10.03 Subcommittee on Radiological Protection for Decontamination and Decommissioning of Nuclear Facilities and Components. This collaboration has resulted in five

(5) universally-recognized standards for fixative technologies since its inception. These standards have been referenced in Test Plans across the DOE EM complex, and have the potential to produce institutional impacts by providing essential data that could be used in revising DOE directives and handbooks. One such example is DOE-HDBK-3010, which serves as the primary reference used for calculating the Material-at-Risk (MAR) and Source Term, and by extension is used as the guiding document for certifying the impacts of fixative technologies. Project 3 D&D developed an extensive experimental design that will be tested and evaluated on fixative technologies, with the explicit intent of quantifying the effectiveness of these technologies in mitigating contaminant release under a variety of stressors (impact, water, etc.). These results could be used to update the aforementioned DOE Handbook and provide relevant data points for site personnel and decision makers as they select fixative technologies to mitigate the potential of release during D&D activities. Both of these initiatives – the robust integration of standards-based test and evaluation and the DOE-HDBK-3010 update – have been identified throughout the complex as critical enablers to facilitating the acceptance and adoption of fixative technologies.

Subtask 2.1: Uniform Testing Protocols and Performance Metrics for D&D

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. In order 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. One such case study emerged and involved the successful deployment of an intumescent fixative technology in support of the SRS 235-F PuFF Facility Risk Reduction Program. A detailed analysis confirmed that a critical enabler and key contributor to this effort was a deliberate, methodical approach to leverage an international, consensus-based standards organization from the onset. There is a substantial body of literature that supports the crucial role of standards in technology programs across all phases of development - from concept, to deployment, to large-scale diffusion - in other industries. Formal standards are the result of a consensual negotiation process carried out by producers, regulators, end users and other interested stakeholders in a voluntary process within standardization organizations (WTO, 2011). Therefore, standard setting is often viewed as a self-regulatory process (Gupta and Lad, 1983), and can often yield better acceptance of technologies in certain industries, particularly if those standards are further referenced in government directives and regulations.

Despite significant funding by DOE EM for technology R&D, end users have been notoriously slow to accept the outputs for a variety of reasons, several of which center on uncertainty in the very risk-averse domain of nuclear site deactivation and decommissioning (D&D) activities. As highlighted by past U.S. Government Accountability Office (GAO) reports, site officials may not be familiar with innovative technologies and fear their use would present an unacceptable risk or be unacceptable to regulators, or could result in missing milestones if the technology fails to perform as expected. A lack of reliable information could contribute to this problem (GAO, 1997).

FIU ARC hypothesized that developing and promulgating consensus-based standards specifically tailored for fixative technologies could address some of the obstacles highlighted by contractors in the GAO reports and improve return on investments for development programs related to this type of technology. As highlighted by Mr. Andrew Szilagyi, Director for DOE EM's Office of

Infrastructure and D&D, "There is an intuitive sense by the community on the utility of fixatives to immobilize residual contamination and mitigate risk during D&D activities, but a more formal process needs to be available for site personnel and regulators to confirm their capabilities. Uniform standards can play a significant role in this effort." Consequently, FIU and other stakeholders across the D&D community continued to expand their engagement with ASTM International's E10.03 Subcommittee to develop and promulgate uniform, consensus-based standards for the testing and evaluation of new D&D technologies. The intended end state for this initiative is to further instill confidence and facilitate acceptance of new technologies being developed, tested and evaluated, thereby improving the ROI on federally-funded R&D research programs in this area.

Subtask 2.1: Objectives

Under this task, FIU ARC 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, 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 incombustible fixatives research and development activity 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 holistic technology deployment approach was devised for the adoption of intumescent technologies as fire resistant fixatives. SRNL's close relationship with the SRS 235-F PuFF Facility Risk Reduction Team and FIU's involvement with the American Society for Testing and Materials (ASTM) International's E10.03 Subcommittee on Radiological Protection for D&D of Nuclear Facilities and Components provided an ideal vehicle to test the initiative. In the span of a 4-year period, five (5) new international standard specifications for fixative technologies have been formally published and promulgated by ASTM, and two additional protocols are currently in the final process. More importantly, this effort has been an important pillar for the test and evaluation of a fixative technology that has been successfully deployed in the entry hood and process cell #7 at the SRS 235-F PuFF Facility, and serves as the basis for promoting the planned deployment of the intumescent foam technology on site in FY'22.

Subtask 2.1: Results and Discussion

FIU ARC, in collaboration with SRNL, introduced a fixative technology that mitigates the potential release of radioactive contamination under thermal and seismic stressors, and during the test and evaluation component of the activity it became readily apparent that the end-users at the site desired a more formal process that would assist in mitigating their risk exposure. In discussions with DOE EM, as well as commercial entities conducting the environmental restoration of various nuclear sites, it was determined many of these human factor concerns could be alleviated by:

1. Leveraging an international, consensus-based organization that develops and promulgates international standards and testing protocols for fixative technologies used in D&D, and
2. Referencing these new standards to update dated regulations and directives guiding the environmental restoration of nuclear sites.

Immediately addressing these concerns would provide tremendous credibility to the R&D effort and yield a significant return on investment as the fixative technology would be tested, evaluated, and compared to a set of uniformly accepted standards and metrics that ensure it satisfactorily addresses the three pillars of test and evaluation – quality, productivity, and safety. This requirement becomes even more pressing and prominent when technologies are on the higher end of the technology readiness level (e.g., 7-9) and are ready for acquisition and deployment.

There are several documents and guiding policies that emphasize and are intended to institutionalize this requirement, particularly when federal agencies are involved. For example, Section 12(d) of the National Technology Transfer and Advancement Act (Public Law 104-113), directs federal departments to achieve a greater reliance on voluntary consensus standards, and this mantra is also required by the Office of Management and Budget's Circular A-119,"Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities."

The ASTM International E10.03 Subcommittee on Radiological Protection during Decontamination and Decommissioning of Nuclear Facilities and Components is answering this challenge. It boasts a robust international membership that spans the entire spectrum of stakeholders and is perfectly postured to lead a collaborative process that bridges the organizational boundaries and cultures to achieve consensus on industry standards to facilitate uniform testing and evaluation of technologies and processes.

The E10.03 Subcommittee formed a D&D Fixatives Working Group that subsequently developed and published two new international standard specifications for fixative technologies that aim to immobilize radioactive contamination, minimize worker exposure, and protect uncontaminated areas against the spread of radioactive contamination during the decommissioning of nuclear facilities. The first specification, Specification for Strippable & Removable Coatings to Mitigate Spread of Radioactive Contamination (E 3104-17), establishes performance specifications for a coating that is intended to be removable during subsequent decontamination operations (ASTM, 2017). The second specification, Specification for Permanent Coatings Used to Mitigate Spread of Radioactive Contamination (E 3105-17), is for coatings that are intended to be permanent, non-removable, long-term material for fixing contamination in place during decommissioning (ASTM, 2017). The standards were formally approved and published by ASTM International in July 2017. These successes have ignited increased interest in the effort, and over the course of this Performance Year alone, two (2) additional standards have been developed, balloted, and formally promulgated.

This drive towards incorporating universally-recognized standards into the technology test and evaluation process for the fixative activity served as a critical enabler to the successful deployment of the technology into Process Cell #7 at the SRS 235-F PuFF Facility. It mitigated the risk to the end user by improving information symmetry on the technology for all the respective stakeholders

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

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Subtask 2.2: Applications of Intumescent Foams to D&D Problem Sets

Subtask 2.2: Introduction

In support of the DOE-FIU Cooperative Agreement under Project 3 (Waste and D&D Engineering and Technology Development), Task 2 (D&D Support for Technology Innovation, Development, Evaluation and Deployment), the FIU Applied Research Center (ARC) focused its research activities on identifying, testing and evaluating commercial-off-the-shelf (COTS) intumescent material technologies as fire resistant fixative solutions that have a high potential to: 1) successfully address postulated contingency scenarios outlined in Basis for Interim Operations (BIO) / Safety Basis documents across the complex; and, 2) demonstrate a high probability of transitioning to an operational test and evaluation in a radioactive environment on site. This approach resulted in one intumescent coating technology being deployed in the Entry Hood to Process Cell 1 and Process Cell 7 at the SRS 235-F PUFF Facility in September / October of 2018. It has also led to the identification of another COTS intumescent foam technology that has demonstrated initial promise during proof-of-concept experiments this year in addressing an operational requirement for a rigid, fire resistant fixative technology to immobilize and/or isolate residual contamination within a 3-dimensional void space of various volumes at sites across the complex.

An operational concept has been developed and proposed using the intumescent foam technology as an internal barrier, or "plug", prior to cutting contaminated pipework during dismantling and demolition operations on nuclear sites. Phase I of this research activity involved down selecting a potential intumescent foam against some initial operational parameters outlined in ASTM E3191-18, Standard Specification for Permanent Foam Fixatives, specifically developed by the ASTM International E10.03 Subcommittee to support this broader activity. These included: 1) the ability to immobilize contamination and fill 3D spaces; 2) fire resistance to extreme temperatures and thermal stressors; 3) ability to withstand certain environmental factors such as water; 4) mechanical properties such as rigidity and adhesion to ensure the material can act as a "plug" in piping and not be adversely affected when exposed to expected impact stressors; and, 5) confirmation of temperature profiles related to curing and uniform application of the material. Based on the initial findings and through extensive discussions with SRNL and other stakeholders across DOE EM, a COTS intumescent polyurethane foam (naming convention "I-H") has been identified and down-selected as a technology that warrants further investigation. The research plan for the next phase is to develop, in close collaboration with SRNL and site personnel, an operationally–focused test plan designed to directly evaluate the technology in terms of immediate, high priority requirements from safety basis personnel in order to conduct an operational test and evaluation on a DOE EM site by 2021. This approach mirrors the highly successful phased test and evaluation model employed by ARC and SRNL for the intumescent coating technology deployed in support of the SRS 235-F PUFF Facility as highlighted in the December 2018 Defense Nuclear Facility Safety Board (DNFSB) report and SRNL promotional video on the activity.

An added benefit produced during the test and evaluation related to this research activity was the discovery of a novel nondestructive evaluation technique to confirm or deny the uniform application of the intumescent foam technology in 304 stainless steel pipes of various thicknesses and dimensions. By coupling the foam's temperature profile during curing with a highly sensitive thermal imaging camera, ARC researchers have had initial success in correlating "cold spots" in temperature of the external skin of the pipe to irregularities in internal application of the foam technology. ARC researchers postulate this technique has the potential to significantly assist in guiding site personnel with nuclear pipe dismantling operations by verifying the plug's integrity. This technique will be further explored by ARC researchers as an added feature to the intumescent foam plugging concept and should mitigate risks associated with the anticipated operational test and evaluation in 2021.

Subtask 2.2: Objectives

This research activity involved down-selecting a potential commercial-off-the-shelf (COTS) intumescent foam against some initial operational parameters outlined in ASTM E3191-18, Standard Specification for Permanent Foam Fixatives.

1. Determine the uniformity of curing in various dimensions after application; which includes an initial assessment on the possibility of using temperature profile to predict inconsistencies in the application and curing process.
2. Determine designated mechanical properties of the cured intumescent foam to ensure quality performance.

Subtask 2.2: Methodology

The COTS intumescent foam selected for evaluation is the I-H foam. This product is a two-component polyurethane foam that expands up to six times in volume upon application and cures in approximately one minute. The volume of foam produced per cartridge is up to 110 in^3. Per the application instructions, the first five pumps of the dispenser (or until the foam in the mixer nozzle has a consistent red color) will be discarded because this initial portion is unevenly mixed.

The FLIR E53 thermal imaging camera was leveraged to assist in a non-destructive evaluation (NDE) method for using the foam's curing temperature profile to determine anomalies in application and/or curing of the intumescent foam. The FLIR E53 has the capacity to measure object temperatures up to 1,200°F and has a thermal sensitivity of < 0.07°F (40 mK). The measurement accuracy is ± 2% of reading. The supplemental FLIR software provides vast insight in terms of temperature data analysis. 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.

Mechanical properties tested include: Plug Strength, baseline and when exposed to stressors. Plug strength is defined as, in a push-out test with a specific test specimen geometry and size, the force level at which failure occurs in which fixative no longer acts as a plug, in units of pounds force (lbf). The stressors will involve drop test, water submersion and extreme heat conditions. Drop testing will be performed at heights of 4, 8, and 12 ft. Water submersion will be accomplished at a water depth of 3 ft. and submerged for 8, 12, and 24 hrs. Extreme heat conditions will be evaluated by placing the samples in a muffle furnace at a temperature of 1,475°F for 30 minutes. These testing protocols comply with Normal Conditions of Transport and Hypothetical accident conditions described in the United States Nuclear Regulatory Commission (NRC). All mechanical properties tests were conducted using the MTS Criterion Series 43 Tensile Tester, which has a 40kN rated force capacity.

Figure 9 shows a cross-sectional view of how the permanent foaming fixative will be evaluated for plug strength in 304-stainless steel pipes. An MTS 43 Criterion tensile tester will be used with compression plates.

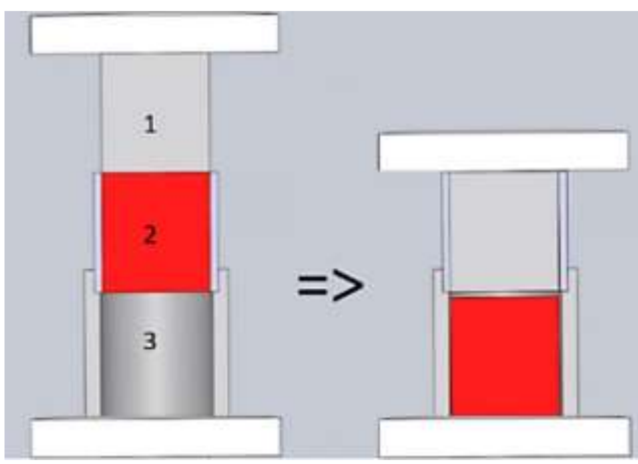

Figure 9. Plug strength test schematic.

Subtask 2.2: Results and Discussion

Uniformity of Foam Application/Curing

A novel idea emerged to use the foam's curing temperature profile as an indicator of uniform application and/or curing within pipes. If proved successful, this technique will assist site personnel in the decision making process for determining areas where it is safe to cut pipework while mitigating the potential for a release and enhancing the safety of site operators, by using this non-destructive evaluation (NDE) method. The initial proof-of-concept experiment was designed to determine if there is a correlation between curing temperature profile and anomalies in application and/or curing. Therefore, thermocouples were placed at varying heights along the pipe. Voids and artificialities were purposely created in order to evaluate the hypothesis.

The average rate of heating is combined with results from the previous NDE experiment, shown in Table 2. When these values are plotted, the resulting graph (Figure 10) is a logarithmic function. This indicates as the volume of an anomaly gets smaller, the ability to detect it, with the NDE method, rapidly becomes smaller. These results suggest that the current NDE methodology can detect anomalies with volumes greater than 0.110 in^3 through 0.125-inch thick, 304-stainless steel substrates.

Table 2. Average Rate of Heating Difference for each Anomaly Size

Anomaly Diameter (in)	Anomaly Volume (in^3)	Rate of Heating Difference (°F/s)
0.5	0.033	-0.0007
0.75	0.110	0.0006
1.0	0.262	0.0167
1.5	0.884	0.0239*
2.0	2.093	0.0319

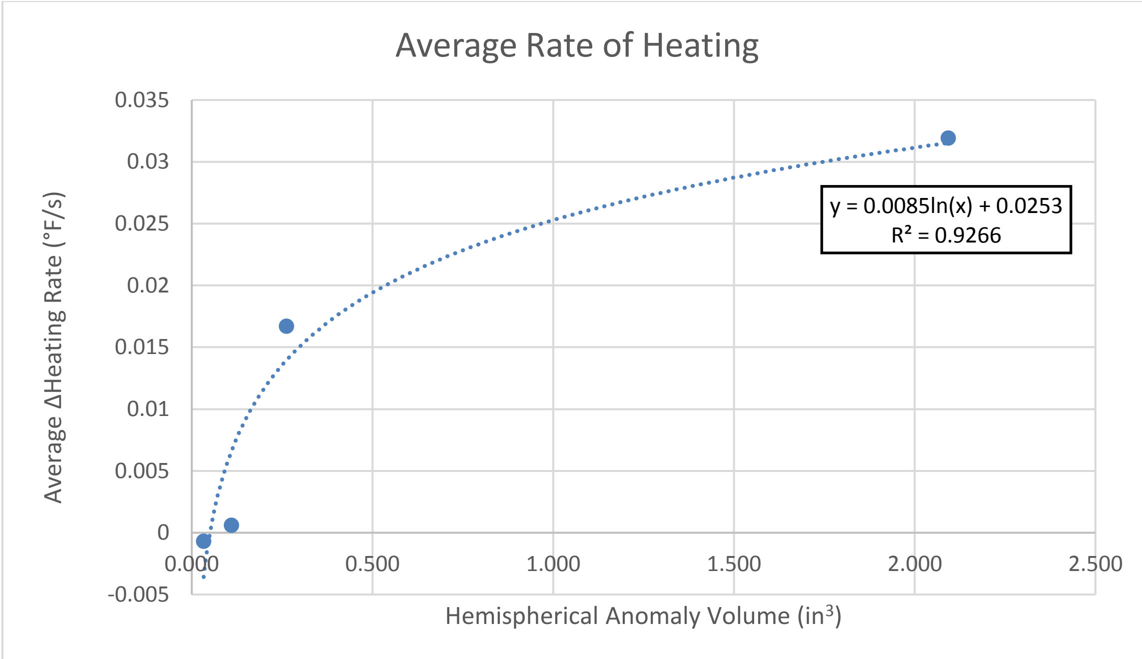

Figure 10. Average change in heating rate per anomaly volume.

Overall, using a non-destructive evaluation technique to detect anomalies or inconsistencies in application and/or curing when using intumescent foams as "plugs" for decommissioning of nuclear pipework seems extremely promising. Leveraging a highly sensitive thermal imaging camera is imperative for immediate visual detection of an anomaly in the first several minutes. Even more important is utilizing the temperature data analyzed with the FLIR Tools software for further detection and confirmation of anomalies even after there is no longer a visual cue. The temperatures produced in the area of an anomaly are significantly lower than the rest of the pipe. These "cold spots" correlate to areas that an operator should not perform any pipe cutting, because any cutting in that pipe section could result in potential release of residual contamination. Continued collaboration with SRNL and other site personnel will be critical in defining additional operational requirements for this technique.

Plug Strength Testing

Figure 11 shows the proposed experimental design. The machine shop at SRNL machined the components to the dimensions. A rate of 0.4 inches per minute was used since this is 10% of the pipe's height. This procedure is not standardized, but followed some protocols described in ASTM D1621: *Standard Test Method for Compressive Properties of Rigid Cellular Plastics* (Methods). The protocols follow guidelines to the rate of compression (10% of sample height).

Figure 10. Plug strength testing for 4" diameter pipe samples using the "plunger – bucket" method on an MTS testing device.

Plug strength testing was performed on various pipes sizes to determine a relationship of sample volume and failure loads. The 4-inch diameter, 8-inch long samples' volume was computed to be 100.54 in^3 and surface area was 100.56 in^2. The average failure loading for these samples were 5,305.53 ± 421.27 lbf compared to the 3,024.75 ± 469.39 lbf for the 4-inch diameter, 4-inch long samples. The 2-inch diameter, 4-inch long samples' volume was computed to be 12.56 in^3 and surface area was 25.13 in^2. The average loading for the 4-inch-tall, 2-inch diameter samples were 1,406.79 ± 281.32 lbf compared to the 1,302.24 ± 9.32 lbf for the 2-inch-long, 2-inch diameter samples. The computed stresses of the four volumes are shown in Figure 12. Three of the volumes' stresses were similar and averaged 56.25 psi. The 2-inch long, 2-inch diameter pipe had the smallest volume and largest stress of 103.68 psi. This high stress can be due to compressive stress occurring towards the center of the foam during the curing process since the curing space is smaller compared to the other volumes.

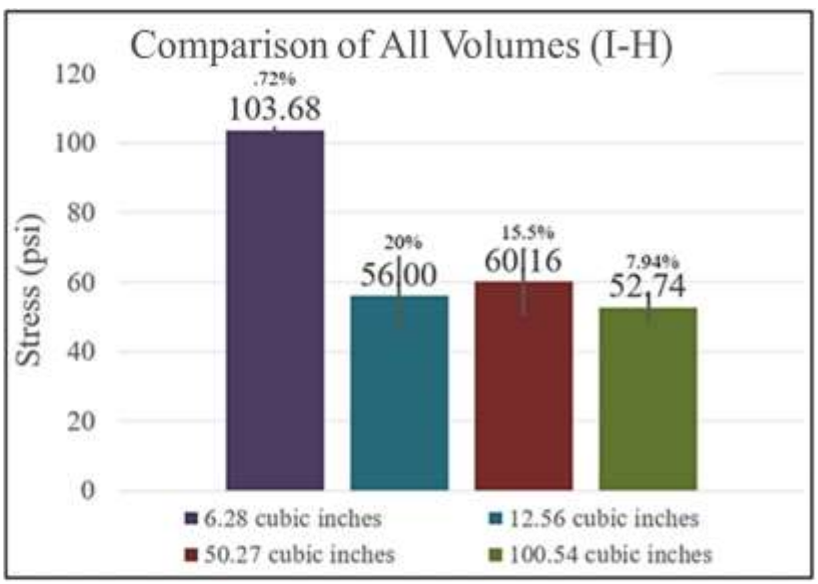

Figure 11. Maximum stress compared to the volume of samples.

All the four volumes equated to four different surface areas. Adhesion is ultimately a function of inner surface area of the pipe, since this is where all the shear stresses are located. One foam cartridge of I-H yields about 100 in^3 of foam material. Dispensing this amount in a 4-inch inner diameter pipe will fill up to 8 inches of height, while filling a 2-inch diameter pipe will fill up 31 inches worth. The surface area for the 4-inch inner diameter pipe is 100 in^2 while the 2-inch pipe creates 200 in^2. Different volumes will yield different surface areas. Plotting the surface areas of all the volumes tested and the breaking loads yielded Figure 12. The graph appears nearly linear and a linear trend line was added to develop a relationship of surface area and failure loads. This can be helpful in predicting failure loads in PFFs. The slope of the linear trend line is 50.79 psi, which represents the minimum stress the PFF shall withstand.

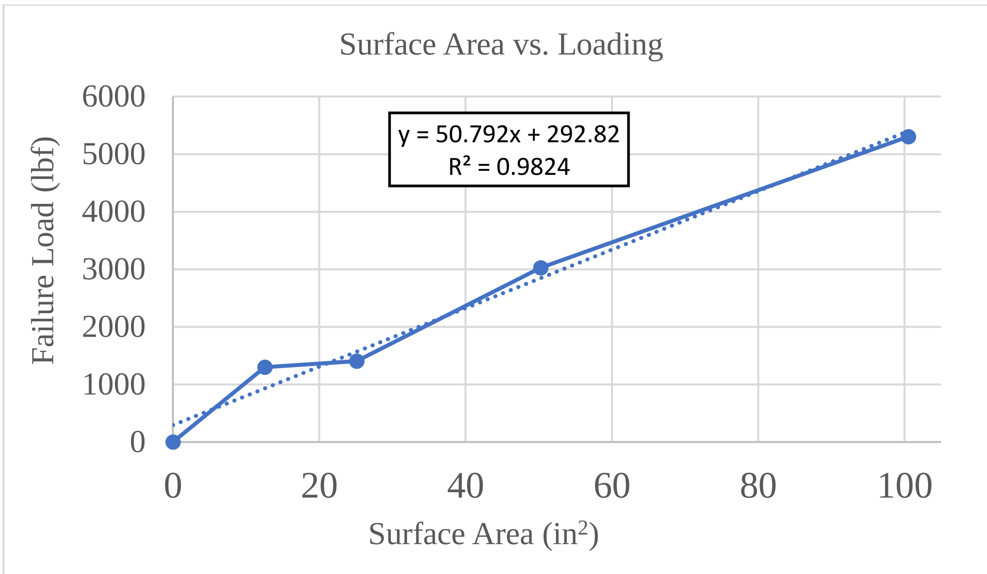

Figure 12. I-H foam plug strength failure load vs. pipe contact surface area relationship.

Evaluating the effects of physical stressors on plug strength was lastly executed. Figure 14 highlights the process of executing the three events that SBIO documents postulate. Figure 14a shows the water submersion testing that was done at a depth of 3 ft. at 8, 12 and 24 hours. Figure 14b shows how the samples were dropped at heights of 4, 8, and 12 ft. onto a steel plate. Figure 14c demonstrates the foam being placed in a muffle furnace at 1,400 °F (initially).

Figure 13. Experimental designs for relevant conditions testing. a) water testing b) drop/impact testing c) heat testing.

The findings are displayed in Figure 14. The water submersion samples' stresses ranged from 1,144.17 to 1,335.25 lbf. This was computed by dividing the failure loads by the surface areas. The samples that had longer exposure to water failed worse and one of the samples of the 24-hr. collection had water inside of it. These foams are closed celled foams so they should block the transport of water, but water still permeated the sample. The fire testing proved to be the worst due to the I-H completely intumescing and delaminating off the substrate. The muffle furnace's temperature did not reach 1,400 °F because of limitations with the equipment, but instead achieved 1,000 °F for 30 minutes. This presents an issue if a fire ever occurs for a long period and in this test, smoke was observed to be coming out of the muffle furnace. This smoke can be another hazard due to contamination being transported by the smoke. The drop test values ranged from 999.83 to 1,418.76 lbf. A few of the sample sets experienced adhesive failure for the 8 and 12 ft. drop. The collision impact may have negatively affected the adhesion interface. A few other samples were tested from the bottom and none of them failed in an adhesive manner. The sample failed at 1281.49 lbf compared to the default value of 1,302.24 lbf. This implies that adhesive failure could potentially occur if tested from the bottom surface.

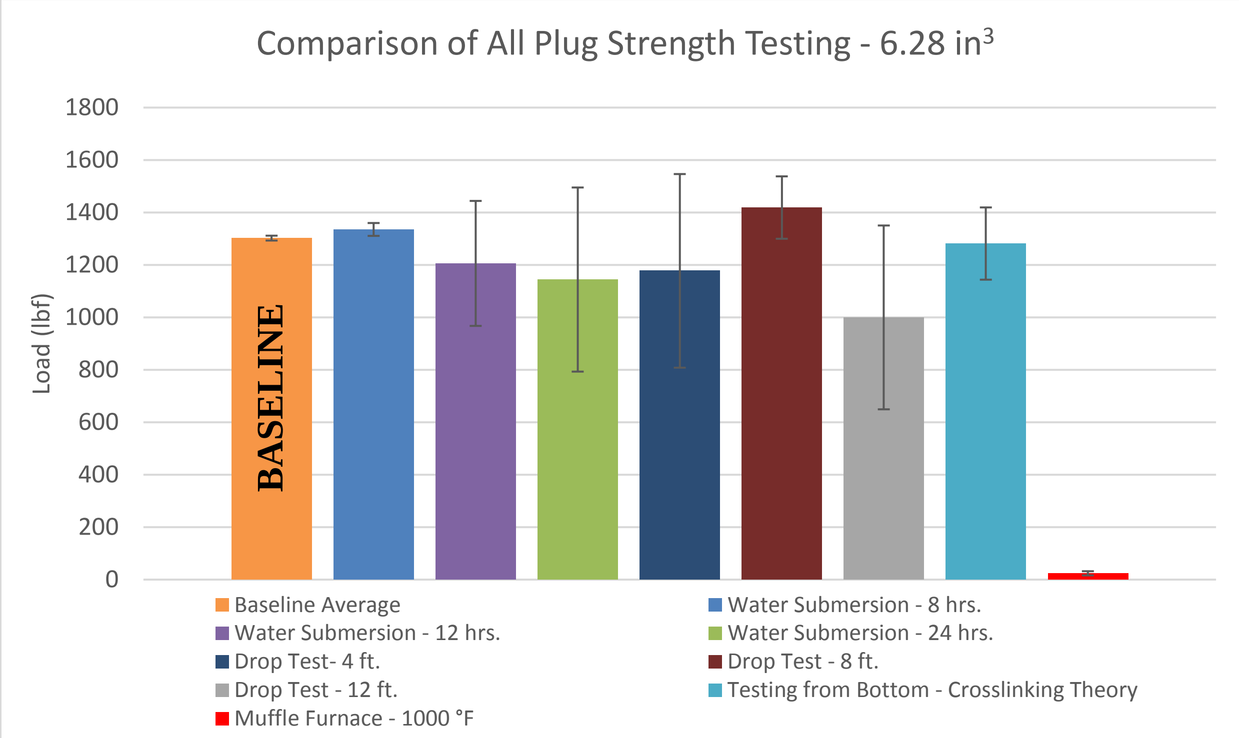

Figure 14. I-H maximum average failure load for all 2" inner diameter x 2" length samples.

SEM was performed on the I-H foam to determine the effects on the adhesion interface between the foam and the 304-stainless steel pipe wall. One sample set consisted of the stainless-steel pipe (0.625-inch ID, 0.75-inch OD) that was pre-cut to the specified height of 1-inch before the foam was applied. The other sample set included a longer pipe (6-inch height), with the same dimensions, that was cut into 1-inch samples (at 1420-2840 rpm) after the foam was applied.

The SEM analysis for the pipe samples that were cut before application of the I-H foam is shown in Figure 15. There were small voids on the adhesion interface and small cell collapse due to shaving off the excess foam.

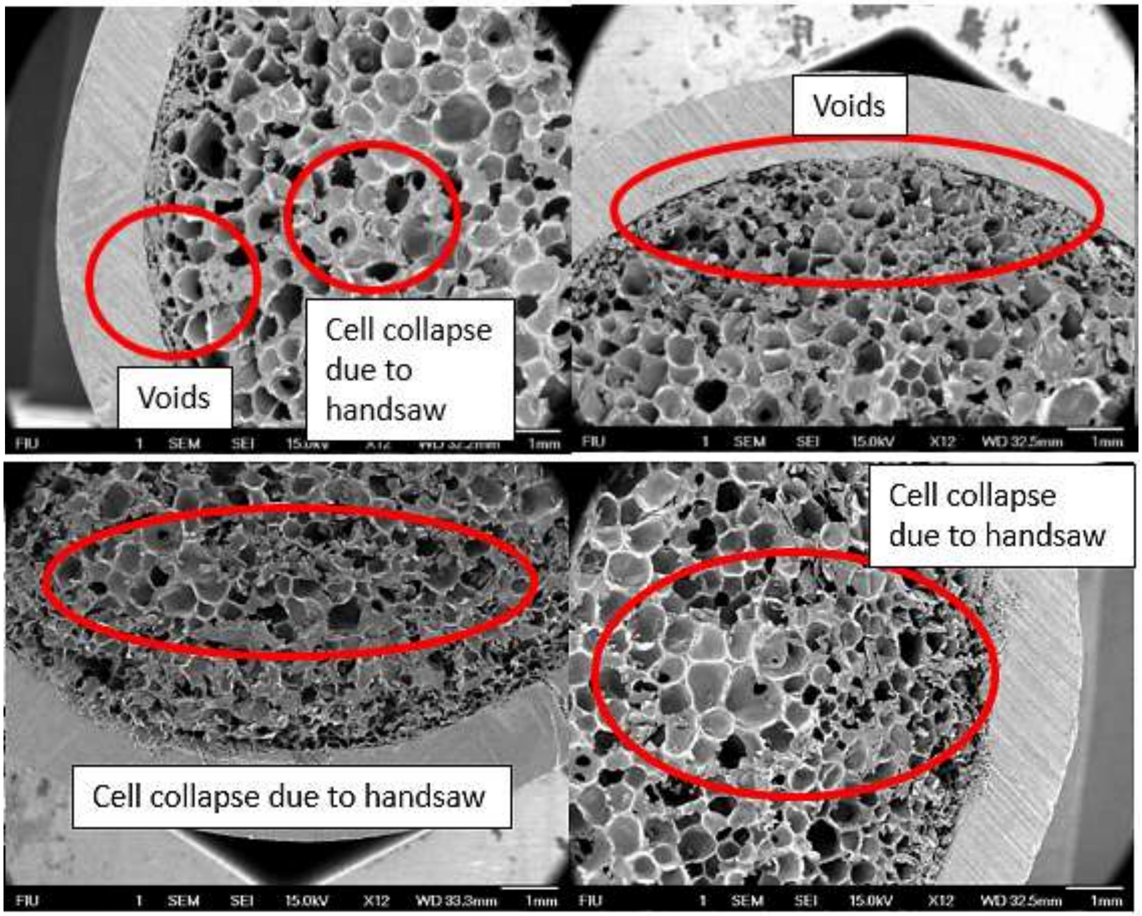

Figure 15. Pipe cut BEFORE foam application.

The SEM analysis for the pipe samples that were cut after application of the I-H foam is shown in Figure 16. There were larger cell collapses that occurred due to the high-speed pipe cutting mechanism. However, in these samples the foam showed excellent adhesion to the pipe wall, with little to no voids detected.

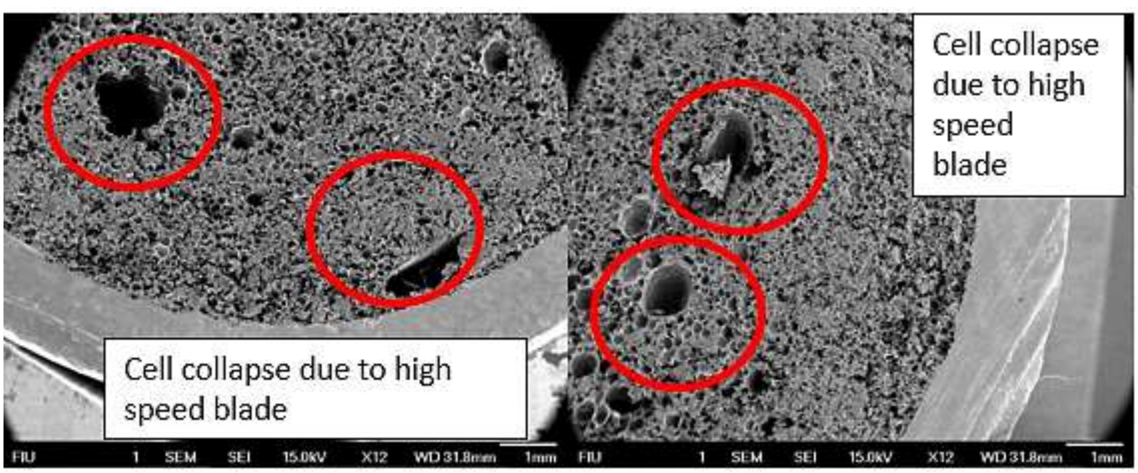

Figure 16. Pipe cut AFTER foam application.

Overall, these voids and cell collapse areas are relatively small regions as the scale on the SEM images are 1mm. However, these features indicate areas of vulnerability where there could be a release of contamination in operational scenarios and it could potentially affect the plug strength mechanical property testing. The voids at the interface in the SEM pipe samples are likely the result of the fast curing of the foam (about 1 min), which is attributed to curing agents like polyamide amine. Most cells in the I-H sample did not collapse to shear stress around the interface. This was due to its stronger mechanical properties that the consistent cell sizes induced.

Subtask 2.2: Conclusions

FIU will continue collaboration with SRNL and leverage ASTM practices and principals to further define operational parameters and additional testing required to take this technology to a hot (radioactive) operational test and evaluation at a site designated by DOE in 2022. Mechanical testing will include overall “Plug Strength” to determine the force required to cause the foam and other specialized concretes/mortars to fail (delaminate or a combination of failures) when inside 304-stainless steel pipes. Future trials will focus on the system as a whole and evaluating its performance under relevant site conditions and some worst-case conditions.

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Subtask 2.3: Support to SRNL and SRS 235-F for Onsite Hot Demonstration

Subtask 2.3: Introduction

FIU has supported SRNL with follow up activities for the intumescent coating fixative hot test and evaluation at SRS. The hot field test, conducted in September 2018, involved the use of a selected intumescent coating within Process Cell 7 and a contaminated entry hood to Process Cell 1 of the Plutonium Fuel Form Facility (PuFF) at SRS Building 235-F. The objective of this research was to select and validate the operational performance of fire resilient fixative coating material(s) for residual surface contamination after gross decontamination is completed in a hot, radioactive environment in support of the 235-F Risk Reduction Project.

One control coupon is being maintained in ARC's indoor laboratory under ideal conditions at ~72ºF and 30% humidity. The second is being maintained outside in ARC's hot cell testbed at Miami's ambient high temperatures and humidity. Weather conditions were also being monitored and a monthly average temperature and humidity will be documented.

Monitoring data collected by FIU is being evaluated for changes to the baseline data collected in December 2018. If a monthly measurement falls within the min-max range established, then that provides evidence that there has been no significant degradation of the coating or change in thickness. If a monthly reading falls outside of the min-max range, some amount of degradation or change in thickness has occurred.

Subtask 2.3: Objectives

FIU continued to monitor a set of control coupons developed at FIU for comparison to the results from the SRS hot demonstration. These control coupons were coated with the same selected intumescent coating being used at SRS and are being aged at FIU under cold (non-radioactive) conditions similar to the environmental conditions at SRS. Comparison of the control coupon results will support the hot demonstration objective to determine the mechanisms of failure that the material may experience due to long-term alpha/gamma radiation exposure.

Subtask 2.3: Methodology

A step-by-step process was conducted with the manufacturer of the DeFelsko Positector 6000 FNTS probe, so there is a high level of confidence in the initial data points using the instrumentation. The procedure is as follows:

1. The instrument was calibrated per the manufacturer's instructions and confirmed its accuracy on the DeFelsko 208.1 mils / 5.285 mm thickness standard coupon that came with the kit. Per the Certificate of Calibration (blue paper), FIU used the >2.5mm +/- (0.01 + 3% of reading) formula, which means for the known thickness coupon our tolerance was +/- 0.169 (5.285*.03 + .01 = 0.169), so our range was between 5.116 (min) to 5.454 (max). Then ten (10) measurements were conducted and all fell within the range, confirming accuracy of the instrument within the tolerance levels.

2. At each of the thirteen (13) designated points on the 12" x 12" 304 stainless steel control coupons, three (3) measurements were taken and then the average calculated, thereby establishing the anchor reading (column 5). The tolerance (column 6) was calculated and then the ranges (columns 7 and 8) were determined.

Table 3. Example of Establishing Baseline Measurements

Point	Trial #1 (mm)	Trial #2 (mm)	Trial #3 (mm)	Average (mm)	Average Tolerance (+/-) (mm)	Min Average Tolerance Range (mm)	Max Average Tolerance Range (mm)
1	4.32	4.28	4.29	4.30	0.14	4.16	4.44
2	4.95	4.99	4.95	4.96	0.16	4.80	5.12

**Note: Tolerance ranges are only calculated for the baseline measurements. All subsequent monthly measurements are an average of three measurements and are compared to this established range.*

3. Before each monthly measurement, the calibration of the instrument will be confirmed as outlined in #1 above, and then the procedure followed as outlined in #2 and added to the matrix / record.

4. If the monthly reading falls within the min-max range established in the baseline, then it will be assumed that no significant degradation / changes in thickness has occurred. If the monthly readings fall outside of the min-max range, then it will be assumed that degradation / changes in thickness has occurred.

Subtask 2.3: Results and Discussion

The coating was applied to the minimum required thickness to the manufacturer's recommendation using the sprayer method. Point 3 on Coupon 1 was omitted from the monthly measurements because of the uneven topography, which caused inaccurate readings. Initial testing indicated that the intumescent coating, which fully cures about 24 hours, takes more time to completely stabilize, ~2-3 months. There was up to a 5% difference (about 0.2 mm) at varying points in coating thickness readings in the first two months after the coating was initially applied. Once the measurements had stabilized, that became the baseline readings for the duration of the testing. The following tables provide the thickness measurements to date for the two 304-stainless steel control coupons coated in intumescent fixative.

Table 4. Monthly Measurements of Control Coupon 1 (indoors) at FIU

Control Coupon 1 - Indoors															
	Baseline		Monthly Measurements - 2019											2020	
Point	Minimum Average Tolerance Range (mm)	Maximum Average Tolerance Range (mm)	January	February	March	April	May	June	July	August	September	October	November	December	July	Standard Deviation
1	4.16	4.44	4.26	4.28	4.28	4.23	4.25	4.27	4.26	4.26	4.24	4.24	4.25	4.24	4.33	0.026
2	4.80	5.12	4.95	4.88	4.88	4.91	4.90	4.90	4.89	4.95	4.88	4.89	4.90	4.89	4.85	0.027
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	4.29	4.57	4.39	4.49	4.47	4.41	4.43	4.43	4.45	4.42	4.37	4.46	4.46	4.44	4.44	0.032
5	3.92	4.19	4.03	4.04	4.02	4.00	4.02	4.04	4.02	4.03	4.06	4.03	4.00	4.01	4.03	0.016
6	4.19	4.47	4.37	4.35	4.35	4.30	4.38	4.38	4.34	4.38	4.40	4.36	4.32	4.32	4.42	0.035
7	4.12	4.69	4.24	4.31	4.33	4.23	4.29	4.25	4.22	4.21	4.25	4.24	4.26	4.21	4.34	0.045
8	3.79	4.04	3.90	3.92	3.91	3.88	3.91	3.91	3.91	3.90	3.89	3.92	3.92	3.91	3.97	0.021
9	4.20	4.48	4.33	4.32	4.31	4.35	4.33	4.33	4.31	4.36	4.28	4.39	4.35	4.38	4.33	0.030
10	3.89	4.15	4.02	4.02	4.02	4.02	4.04	4.04	4.01	4.01	3.98	4.04	4.01	4.01	4.02	0.014
11	3.28	3.51	3.44	3.41	3.44	3.43	3.43	3.42	3.41	3.44	3.46	3.41	3.40	3.43	3.41	0.017
12	4.05	4.32	4.16	4.20	4.21	4.20	4.18	4.18	4.16	4.18	4.16	4.20	4.17	4.17	4.17	0.017
13	3.55	3.79	3.64	3.67	3.65	3.63	3.67	3.68	3.64	3.66	3.63	3.66	3.65	3.67	3.68	0.017

Table 5. Monthly Measurements of Control Coupon 2 (outdoors) at FIU

Control Coupon 2 - Outdoors															
	Baseline		Monthly Measurements - 2019											2020	
Point	Minimum Average Tolerance Range (mm)	Maximum Average Tolerance Range (mm)	January	February	March	April	May	June	July	August	September	October	November	December	July	Standard Deviation
1	3.23	3.45	3.40	3.42	3.39	3.34	3.37	3.37	3.39	3.38	3.38	3.37	3.38	3.37	3.38	0.019
2	3.39	3.62	3.53	3.57	3.52	3.46	3.53	3.52	3.52	3.51	3.49	3.51	3.52	3.51	3.53	0.025
3	3.03	3.24	3.15	3.13	3.12	3.10	3.11	3.10	3.12	3.12	3.10	3.10	3.13	3.11	3.10	0.015
4	3.92	4.19	4.10	4.15	4.12	4.01	4.05	4.07	4.09	4.07	4.06	4.08	4.10	4.08	4.09	0.033
5	3.75	4.00	3.87	3.94	3.91	3.84	3.87	3.87	3.89	3.87	3.85	3.89	3.90	3.89	3.90	0.026
6	4.39	4.68	4.56	4.58	4.59	4.49	4.55	4.54	4.54	4.52	4.54	4.54	4.57	4.52	4.60	0.031
7	4.19	4.47	4.33	4.36	4.34	4.26	4.29	4.32	4.33	4.33	4.30	4.31	4.33	4.30	4.37	0.029
8	3.67	3.92	3.80	3.79	3.78	3.75	3.74	3.75	3.79	3.76	3.77	3.75	3.76	3.74	3.76	0.019
9	3.59	3.83	3.75	3.74	3.71	3.65	3.68	3.69	3.70	3.72	3.67	3.69	3.72	3.70	3.69	0.027
10	3.33	3.55	3.48	3.43	3.44	3.39	3.40	3.42	3.42	3.43	3.44	3.41	3.42	3.41	3.40	0.023
11	3.25	3.47	3.38	3.39	3.37	3.34	3.36	3.36	3.37	3.37	3.32	3.36	3.38	3.38	3.34	0.020
12	3.32	3.55	3.46	3.43	3.42	3.42	3.41	3.42	3.41	3.41	3.41	3.43	3.42	3.44	3.43	0.015
13	3.01	3.22	3.15	3.10	3.09	3.10	3.08	3.07	3.11	3.12	3.11	3.12	3.12	3.15	3.06	0.027
Average Temperature (High/Low)			76°F / 64°F	76°F / 60°F	81°F / 68°F	84°F / 77°F	85°F / 71°F	88°F / 76°F	91°F / 77°F	92°F / 78°F	92°F / 78°F	91°F / 79°F	89°F / 78°F	83°F / 69°F	93°F / 79°F	
Average Daily Humidity			73%	75%	75%	74%	71%	68%	71%	69%	74%	67%	72%	67%	72%	

Subtask 2.3: Conclusions

All the thickness measurements across all points on the 12”x12” coupons remained within tolerances of the established baseline range, indicating that there has been no significant degradation in coating thickness.

In collaboration with SRNL, FIU will continue to assist with additional data analysis, reporting, and documentation for the SRNL Close Out report of the hot demonstration. The following 235F Deactivation Outline has been developed and approved:

Chronological Overview of What, Why, How, Results, and What’s Next

- I. Introduction
- II. Background
    - a. D & D Overview
        - i. Risk Reduction
            - 1. Regulations
        - ii. Traditional Approaches
            - 1. Mechanical
            - 2. Chemical
            - 3. Energy
    - b. Challenges
        - i. Technical Challenges
            - 1. Residual hold up after gross decontamination efforts
            - 2. Ensuring hold up isn’t released before final end state
        - ii. Institutional Challenges
            - 1. Institutional Barriers (e.g.: outdated DOE-HDBK-3010)
            - 2. Lack of standardized certification protocols
    - c. History of 235F
        - i. Description of building
            - 1. Construction materials
            - 2. Dimensions
            - 3. Attached facilities
            - 4. Current condition
            - 5. Final end state TBD?
        - ii. Uses over lifetime
            - 1. Constructed 1950s – original mission canceled
            - 2. ABL (Np-237)
            - 3. PEF and PuFF including OML (Pu-238)
            - 4. Processes ended by 1990
            - 5. De-Inventory and move to S&M in 2006
            - 6. Remove/immobilize MAR 2012
    - a. Use of Fixatives, Coatings, and Gels to address residual hold up
        - a. Only listed for “ideal” conditions
        - b. Failure due to fire or seismic
    - b. Special Challenges for PuFF
        - iii. Few penetrations into and/or between cells
        - iv. Difficult to manipulate components within cells
        - v. Maintaining confinement during setup and maintenance
            - 1. Pu-238 very “mobile”

vi. Hot and humid environment inside cells

III. Experiment

- a. Purpose
    - i. Investigate and "enhance operational performance" of fixatives, coatings, and gels for use in D&D (in 235F) [1]
- b. Scope
    - i. Collaboration across SRNL and FIU to develop and characterize a fire-resistant radiological contamination fixating platform deployable in non-standard environments [2]
- c. Identify Candidates
    - i. Basis for inclusion [1]
        - 1. Records search
    - ii. Commercial Fixatives, Coatings, and Gels (FCGs)
        - 1. List of materials considered
            - a. Manufacturer and Use info by category and material [3]
- d. Proof of Concept
    - i. FIU Partnership
        - 1. Design [1] [3] [4]
            - a. Preparation of Clean Test Coupons
            - b. No industry standards – FIU used references for construction materials to build internal standard used for this experiment [4]
                - i. Standards for Fire Resiliency (ASTM E84/D3806) [3]
                - ii. Standards for Fire Retardency (ASTM D1360) [3]
            - c. Use of "GloGerm" to replicate contamination on test coupons
            - d. Use of Muffle Furnace
            - e. Use of Propane Flame
        - 2. Results
            - a. External Lab Reports on "clean" coupon performance
            - b. FIU Lab Reports on "contaminated" coupon performance
- e. Down Selection
    - i. Incorporate prior FIU results with SRNL requirements and additional testing
    - ii. Design
        - 1. Environmental – Temp and Humidity
        - 2. Radiological – gamma irradiation 5M Rad
        - 3. Adhesion – fixative remains adhered to substrate
        - 4. Fire – direct flame performance
        - 5. Mass Loss – performance at discrete temps increasing to 800F
    - iii. Results
        - 1. Iterative Elimination
        - 2. Chart with combined results
        - 3. FireDam selection
- f. Cold Test
    - i. FIU Process [5]
        - 1. ID Technology and Tools

a. Addition of sprayer
b. Elimination of epoxy

2. Mock Up Construction
3. Application of IC inside Mock Up [6]
    a. Extension Pole and Roller Brush
    b. Slow pour and spreader
    c. Vertical or Ceiling Drip Testing
    d. Handheld Sprayer
4. Results [6] [7]
    a. Curing Confirmation
        i. Blot test
    b. Thickness Confirmation
        i. Defelsko PosiTector-6000 FNTS
    c. Basic Impact and Adhesion Testing
5. Lessons Learned [6] [7]
    a. Ability to pass and use tools inside the Demo Hot Cell
    b. Ability to achieve requisite thickness for FD
        i. Multiple Coats required
    c. Challenges with visibility and application
6. Calculations for volume to coat desired cell surfaces

ii. SRNL Process [2]
1. Identification of "Best in Class" application methods from FIU cold test
    a. Horizontal slow pour
    b. Vertical sprayer
2. Initial familiarization with application outside Mock Up
3. Trial inside mock up
    a. Use of paper/cardboard rather than SS
    b. Thickness measurements
    c. Tooling use through gloveports
    d. Identify obstacles

g. Hot Test [2]

i. SRNL Process
1. Design
    a. Use learnings from FIU and SRNL Cold Test
    b. Identify locations for application
2. Process
    a. Prepare Cells
        i. Install flex wall
        ii. Protect doors, windows, and pass through locations identified by facility personnel
    b. Prepare Tools
    c. Apply FireDam
        i. Entry Hood
            1. Spray back wall-3 applications
            2. Pour and spread floor-single application "overpour" to compensate for losses to

container walls and incomplete empty of host container

ii. Cell 7

1. Spray applied in 2 coats
   a. Difficulty with taped electrical passthrough and metal post with valves and hoses
2. Overpour on floor
   a. Cold joint was unable to be removed

3. Results
   a. Application thickness
   b. Cure time
   c. Estimated immobilization
   d. Estimated residual “free” contamination
   e. Somewhere in here we need to capture the estimated impacts of material degradation as a result of radiation – this will require baselining the thickness measurements from the floor of the entry hood (once taken) with our control coupons - Sinicrope

IV. Lessons Learned

a. Value in learning from each stage before hot test

b. Tools

i. Tape and plastic were difficult to place over electrical pass through
   1. Difficulty staying in place with application
   2. Consider alternative (suction cup)

ii. ACE
   1. ACE needs better marking to indicate proper placement
   2. ACE power cable too weak and repeatedly came unplugged
   3. Handling ACE cartridge inside cell was and measuring plates in waste cut easier than removing plates and passing them out

iii. Spreader
   1. Smaller and finer spreader to address details
   2. Shorter spreader handle for confined space

iv. Sprayer
   1. Full assembly except cartridge before passing into cell

c. Method

i. Spray distance given cell constraints
   1. Entry hood too close
   2. Cell 7 too far

ii. “Gut feeling” led to 2 applications of material on vertical surface instead of 1
   1. Consider a way to measure before curing

iii. “Overpour” to achieve required thickness on horizontal surface

iv. Coating most contaminated surface (floor) first is most beneficial

v. Curing was slower due to inhibited air flow

d. Safety

i. FireDam did not compromise gloves by adhering

ii. Flex wall was effective in containing contamination

iii. Tape and plastic were difficult to place over electrical pass through
1. Difficulty staying in place with application
2. Consider alternative (suction cup)

e. Personnel
i. "Spotter" may be necessary due to obscured visibility

f. Importance of addressing institutional barriers and non-technical challenges to facilitate acceptance of technical solutions

V. Next Steps [7]
a. Provide empirical data to support update DOE Handbook 3010 and demonstrate the positive impacts of fixative technologies in producing a new category (change of state) when calculating ARF / RF coefficients in the Source Term
b. Develop uniform testing protocols and performance metrics for Fixative technologies to improve technology certification, acceptance, and diffusion

VI. Conclusions

Subtask 2.3: References

Lagos, L., Sinicrope, J., Shoffner, P., Awwad, A., & Rivera, J. (2015). *Enhancing Operational Performance of Fixatives and Coatings for D&D Activities: Phase I - Baselining and Proof of Concept - Test Plan.* Miami: Applied Research Center - Florida International University.

Lagos, L., Sinicrope, J., Shoffner, P., Viera, J., Simoes-Ponce, T., & Nuñez, J. (2018). *Potential Applications of Intumescent Coatings to Address Safety Basis Requirement - Technical Progress Report.* Miami: Applied Research Center - Florida International University.

Nicholson, J., Siegfried, M., *Incombustible Fixative and ACE 2.0 Test Plan: Radiological Hot Field Test of Intumescent Coatings and Electrostatic Precipitators*, Savannah River National Laboratory, July 2018.

Sinicrope, J., Shoffner, P., Washington, A., Lagos, L. A Novel Approach to Enhancing Fire Resiliency in D&D: Adapting Intumescent Coatings as Fixatives for D&D Activities to Mitigate the Release of Radioisotopes in Fire and Extreme Heat Conditions, Waste Management Symposia, Phoenix, AZ, March 5-9, 2016.

Subtask 2.4: Support for Open Air Demolition Activities (NEW)

Subtask 2.4: Introduction

Under this subtask, FIU is initiating an evaluation of open-air demolition solutions including contamination control products (e.g., fixatives) under impact stressors in response to a high operational priority requirement 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. Specific emphasis will be placed on empirically quantifying contaminant release, and the results will be formally published in a Technical Progress Report. Furthermore, the results from this initiative will be shared with the ASTM International E10.03 Subcommittee to begin formalizing the development and promulgation of a new series of testing standards for the DOE EM and international D&D communities.

FIU has also developed an approved experimental design to quantitatively ascertain the effects of fixative technologies in immobilizing residual contamination under ideal conditions, as well as exposure to certain impact and environmental stressors. The experimental design was published and uploaded as a Technical Progress Report on OSTI and KMIT. The data obtained during the experimental phase of this activity will be used to support the update of the DOE-HDBK-3010.

Subtask 2.4: Objectives

The objective of this subtask is to develop testing protocols and a viable experimental design to meet the scientific rigor of end user requirements to quantitatively determine the selected technology's ability to fix and immobilize contaminants on a variety of surfaces under ideal conditions, as well as when exposed to impact stressors.

Subtask 2.4: Methodology

These initial experiments will only consider non-porous substrates (stainless steel coupons). All testing will be performed on coupons without a fixative (Control) to create a baseline of release quantities and with fixatives (FD and PBS). There are four main aspects to this experimental methodology: surrogate contaminant, impact test chamber, collection of released particulates, and analysis.

<u>Surrogate Contaminant and Controlled Contamination of Test Coupons</u>

Cesium Chloride (CsCl) is the surrogate contaminant being 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 in order 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 E3190-19 "Standard Practice for Preparation of Fixed Radiological/Surrogate Contamination on Porous Test Coupon Surfaces for Evaluation of Decontamination Techniques", are being leveraged for this design.

<u>Delivery of Stressor</u>

A given stressor (i.e. impact, heat, etc.) will function as the independent variable for any given trial. It is therefore imperative that this is an easily measurable and controllable parameter. Initial trials will focus on impact stressors, which are delivered by means of a certified impact tester.

BYK-Gardner PF-5546 Extra Heavy-Duty Impact Tester 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. Additionally, an acrylic housing assembly will be placed around the device, which will allow for artificially contaminated coupons to be tested for release fractions.

Figure 17. BYK-Gardner PF-5546 Extra Heavy-Duty Impact Tester.

<u>Contamination Release Collection</u>

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. MCE (mixed cellulose ester) filter cassettes and an air sampling pump will be used to collect any suspended airborne particulates. It might be necessary to use the air outlet as a means of creating a recirculating air flow. This would create a closed flow system that ensures that no particulate matter can escape. Any contamination that has settled on the walls of the test chamber or stress apparatus can be collected using sampling wipes. The filters and wipes will be dissolved in an acidic medium for the analysis process.

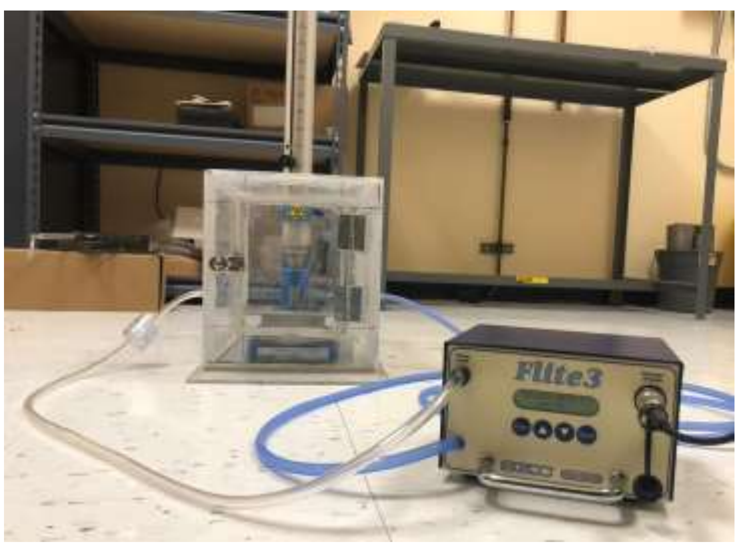

Figure 18. Impact tester with acrylic impact housing and Flite 3 901-3011 air sampler setup.

<u>Processing and Analysis</u>

After collection of the released contaminant, it can be analyzed using mass spectrometry. 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 in order 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.

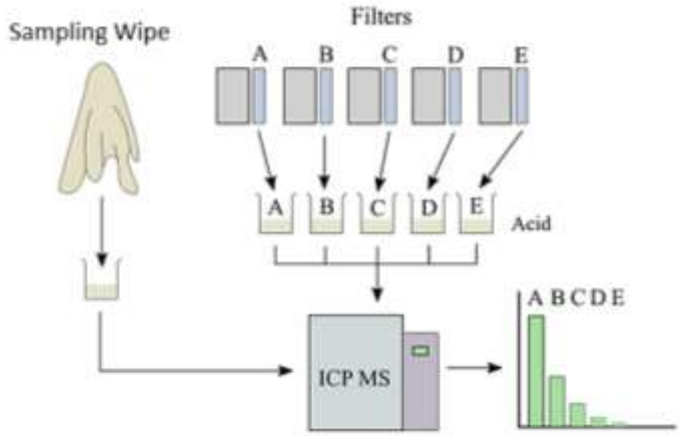

Figure 19. Collection and analysis techniques.

Subtask 2.4: Results and Discussion

Preliminary ICP-MS analysis was conducted to determine a calibration curve of cesium (Cs), determine any potential analysis interferences, and to begin using the cesium chloride (CsCl) surrogate contaminant. The lower limit of detection for this specific element is 0.1 ppb when using the ICP-MS. It is important to note that any dilutions were carefully tracked.

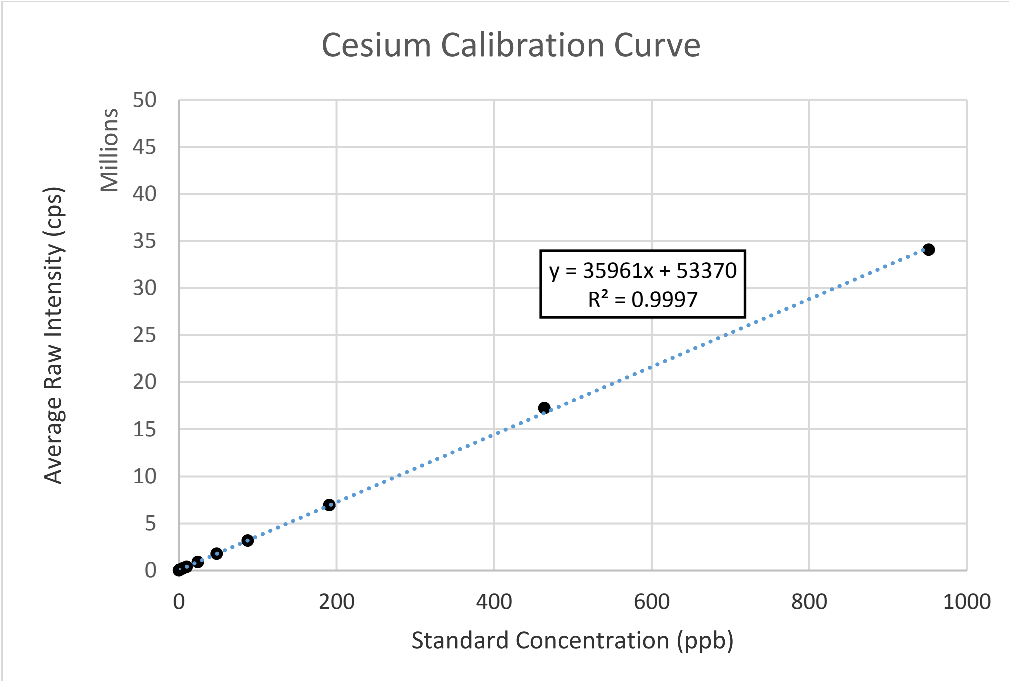

Figure 20. ICP-MS Cesium calibration curve.

A blank sample, 2% nitric acid only, was left open to the environment for a few days and it was determined that there is no interference with naturally occurring Cs. Two samples of the surrogate contaminant with a known amount were incorporated. One CsCl sample, denoted as CsCl-1000SS, was being used to test if the components in the 304-stainless steel coupon would affect the results. Table 6 shows these results and it seems like there is also no interference with the stainless steel. CsCl samples – 6-8% difference with calculated concentration of known contamination.

Table 6. Initial Trial with Surrogate Contaminant

<table>
<tr><th>Sample</th><th>Calculated Concentration (ppb)</th><th>ICP Concentration (ppb)</th><th>ICP Standard Deviation</th></tr>
<tr><td>CsCl-1000</td><td rowspan="2">1272.89</td><td>1166.58</td><td>42.80</td></tr>
<tr><td>CsCl-1000SS</td><td>1195.30</td><td>22.54</td></tr>
</table>

<u>ASTM Impact - Baseline</u> (NO Contamination)

The test method described in ASTM D2794 covers a procedure for rapid deformation by impact of a coating and its substrate and for evaluating the effect of such deformation. The test coupon can be placed in the apparatus with the coated side either up or down.

For initial impact testing, coupons were tested both coated sides up and down. Both fixative coatings were able to withstand the maximum amount of impact, at 320 in-lb., when the coated side was faced down. The impact also caused major deformation in the 304-stainless steel substrate, as shown in the figures below.

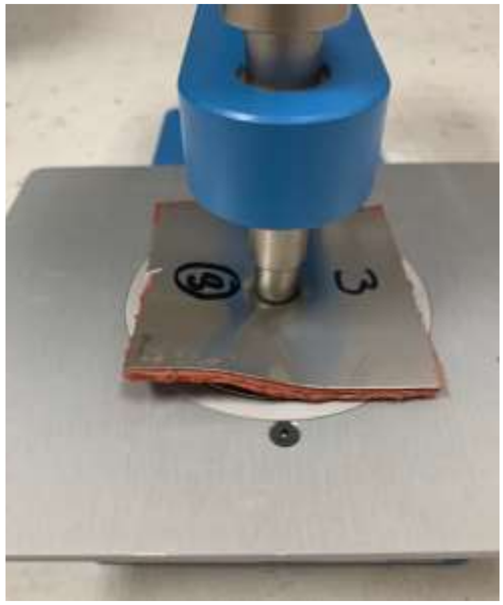

Figure 21. FD coupon (coated side down) directly after 320 in.-lb. impact which caused major deformation in the substrate.

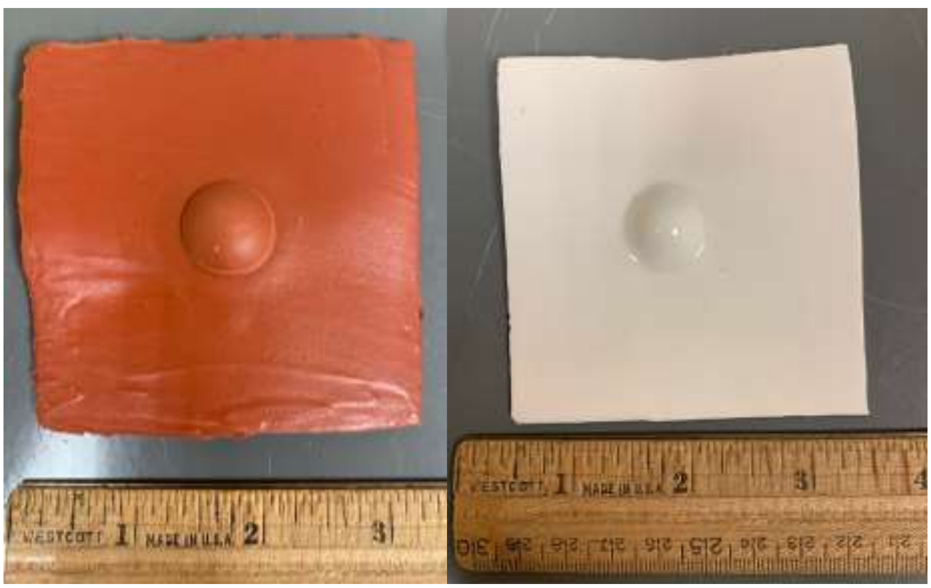

Figure 22. FD (left) and PBS (right) after impact at 320 in.-lb. coated side down.

For the remainder of the baseline testing, the coupons were only tested coated side up. For D&D purposes, the most likely scenario to occur is impact on the coated side facing up (i.e. an object falling in a hot cell onto the fixative). The results are displayed in Table 7, where only the FD coating was able to withstand the more intense levels of impacts.

Figure 23. Illustration of coupon, coated side up, in test apparatus before impact.

Table 7. Baseline Impact Results

Impact (inch-pounds)	FD	PBS
320	✓*	✗
160	✓	✗
80	✓	✗
56	-	1/3 passed
48	-	✗
32	-	✗
24	-	1/3 passed
16	-	✓

*Minor tears in some samples most likely occurred from removing the impact indenter.

Subtask 2.4: Conclusions

Preliminary tests have been conducted to assess the viability of certain aspects of the experimental design (i.e. uniform contamination procedures, accurate impact force measurements, etc.). FIU will continue with conducting thorough experiments using the surrogate contaminant, cesium chloride, for evaluating fixatives under impact stressors.

Subtask 2.4: References

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Subtask 2.5: Investigate the Potential for Multi-Functional Fixatives Intended for Mercury Abatement during D&D Activities (NEW)

Subtask 2.5: Introduction

FIU is collaborating with Idaho National Laboratory (INL) and investigating the potential for developing multi-functional fixatives intended for mercury abatement during D&D activities. Building upon past collaboration efforts between INL and FIU, INL enhanced the FX2 Advanced Fogging agent to target the reduction of mercury vapor generation rates. The fixative showed promising results at the bench scale level with up to 40x reductions. A field scale demonstration was conducted at the Y-12 facility in March 2019, and although some positive results were obtained, certain issues were identified that require remediation. INL has reached out to FIU and highlighted some of the operational issues encountered, to include:

- Identifying a compound that can combine with mercury while being chemically soluble and compatible with the FX2 Hg Advanced Fogging matrix
- Determining the viscosity threshold for fogging applications
- Exploring advanced methods and formulations for application
- Exploring alternative delivery mechanisms for the fogging fixative

Subtask 2.5: Objectives

FIU is exploring the feasibility of using L-Cysteine as the primary mercury abatement compound due to its anticipated ability to bond with Hg, as well as its projected solubility qualities in water and latex-based materials. The lack of solubility in the FX2 Hg Advanced Fogging Agent of the main active ingredient for mercury abatement - elemental Sulphur - was one of the primary deficiencies identified during the hot demo at Y-12 in March 2019

Subtask 2.5: Methodology

Solubility trials were conducted by first preparing a saturated solution of L-Cysteine HCl in deionized water. A known mass of this saturated solution was transferred into a pre-weighed, clean vial. The vial was gently heated and left to evaporate and dry for over 50 hours. The dry crystals were weighed to determine what the ratio of cysteine to water was.

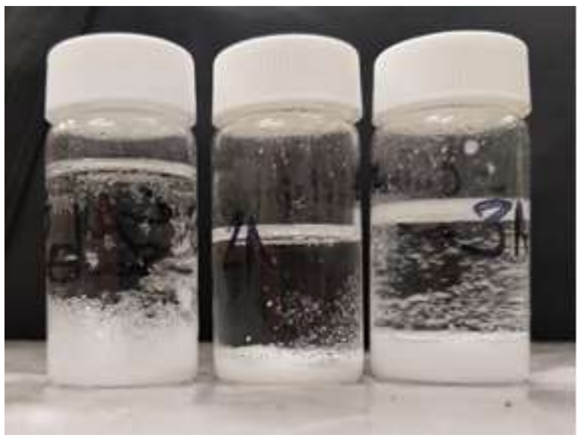

Figure 24. L-Cysteine saturated solutions with crystal sediment.

These trials were continued into a series of compatibility trials with the FX material. Freshly prepared and provided by INL, the new material was designated as FX3. The testing and development of fogging agents that contain L-Cysteine can help to progress the Hg abatement technology, however this does not address some of the other issues highlighted during the original demonstration. If a newly developed version of the FX3 product can be developed at FIU, further trials can be designed to investigate different application methods and define the limitations of the current application methods.

Subtask 2.5: Results and Discussion

To investigate the compatibility and solubility of L-Cysteine in FX3, a series of samples were prepared, each containing 25 g of FX3. Initially, 1.5 g of L-Cysteine HCl was added to the first sample and an immediate incompatibility was observed. Following this, the remaining samples were prepared with L-Cysteine freebase, rather than the HCl salt form. The freebase form showed to be compatible with the FX3 and the following sample matrix was produced in

Table 8.

Table 8. FX3 Samples for the Determination OF L-Cysteine Solubility

Sample ID	FX3 Mass (g)	L-Cysteine Mass (g)
1B	25.0054	0 (Control)
2B	25.085	1.5014 (HCl Salt)
3B	25.0586	1.5019 (Freebase)
4B	25.0124	3.0071 (Freebase)
5B	25.0105	4.5042 (Freebase)
6B	25.0525	6.0187 (Freebase)
7B	25.0082	7.5070 (Freebase)
8B	25.0095	9.0179 (Freebase)

The addition of L-Cysteine HCl to the FX3 caused precipitation of the acrylic micelles that are normally stabilized by sodium lauryl sulfate. This led to the FX3 thickening rapidly and producing a mildly sulfurous smelling gas, ultimately rendering the FX3 unfit for application. It is suspected that the acidic HCl group interferes with the alkali sodium lauryl sulfate. L-Cysteine free base does not contain the HCl counter ion and as such is compatible with the alkali nature of the FX3, however the solubility was lower than expected based on the tests conducted with L-Cysteine HCl in water.

After more than 50 hours of gentle mixing, 1 mL of each sample was pipetted onto a glass substrate and left to dry overnight. Once dry, the samples were inspected using a light source placed underneath the glass substrates to highlight any crystal formation, either from undissolved L-Cysteine or by dimerization to the cysteine form.

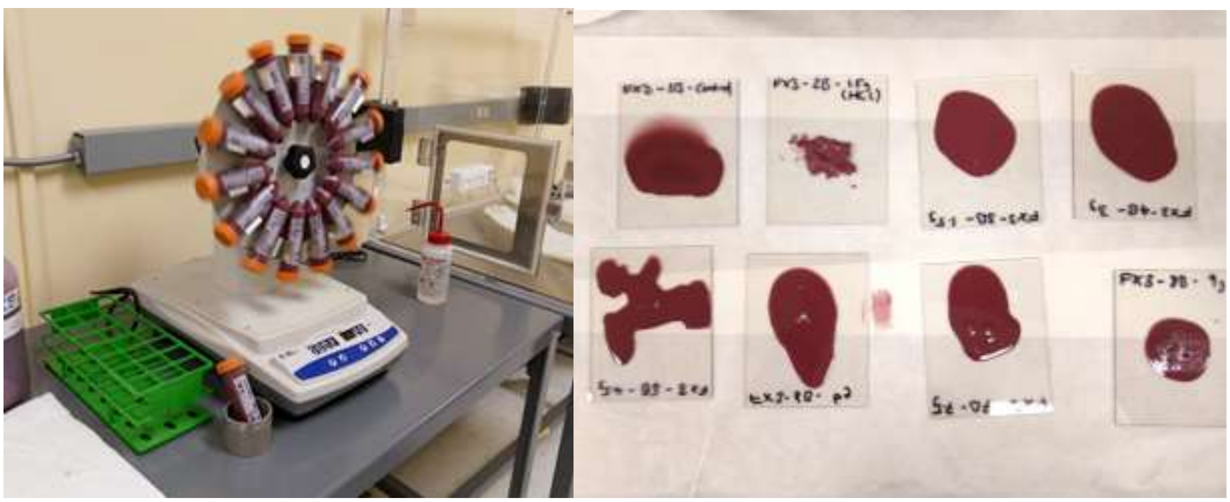

Figure 25. FX3 sample mixing (left) and sample slides (right).

From the dried sample, only 1B and 3B showed no signs of crystallization when examined visually while sample 4B and onwards all showed crystallization. Averaging the available data on the solubility of L-Cysteine HCl in water to 286.6 mg/g, and approximating the average water content for the FX3 to be 70% H_2O, the maximum L-Cysteine loading was expected to be 5.02g in the 25g samples. The observation of crystals in sample 4B suggests that the maximum loading for the free base is much lower than expected.

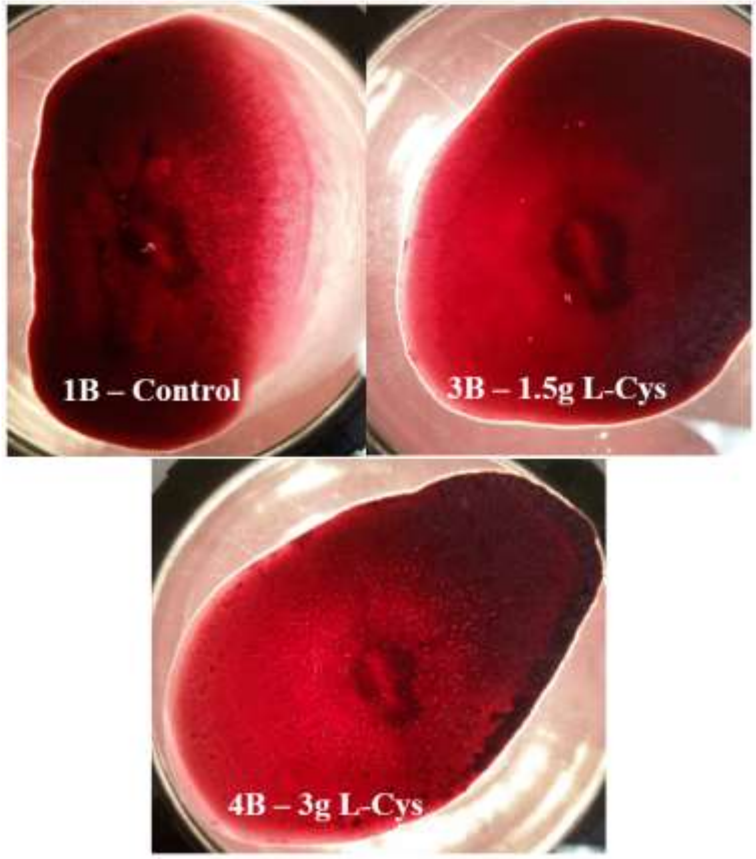

Figure 26. Control sample shown (1B) and sample containing L-Cysteine with no precipitation or crystallization (3B). Sample 4B shows needle shaped crystals of undissolved L-Cysteine.

These results place the solubility of L-Cysteine free base in FX3 in the range >60 $mg/g_{(FX3)}$ and <120 $mg/g_{(FX3)}$. Further refinement can reduce this range to a more accurate result.

Subtask 2.5: Conclusions

Given the initial success in the solubility trials, the next series of testing should confirm that the L-cysteine free base compound binds with mercury. In addition, the following proposed work has been identified by INL collaborators:

Fogger Clogging

The primary operational difficulty encountered during the March demonstration was clogging of the feed line and/or nozzle of the commercial fogging unit used. These issues were not experienced in the lab due to the shorter durations of fogging tests. It is presumed that the source of the clogging issue is the sulfur particulate suspended in the FX matrix solution. To address this issue, it is proposed that commercial off-the-shelf (COTS) foggers with a larger orifice size be identified and tested, if they exist. If one or more companies make fogger models that may be more tolerant of fine particulates, testing would be conducted on those foggers to determine if they can reliably dispense the FX Hg mixture.

Fixative Coating Thickness

A second operational difficulty with the FX formulation is the high water content required to atomize it into a fog for application. The resultant fixative coating is quite thin and takes a relatively long time to dry. A series of test fogs with lower water content recipes need to be conducted to determine the viscosity threshold that can be effectively fogged with whichever model fogger is selected.

Alternative/Enhanced Application Methods

In addition to dewatering the mixture to achieve a thicker fixative coating, the relative merits of spraying with a paint sprayer versus a traditional fogged application should be revisited. For specific application environments, spraying may be more effective, or a combination of spraying and fogging may be best. Generally, spraying will apply a thicker coat and one that adheres much more readily to vertical surfaces. Fogging, on the other hand, will infiltrate non-line-of-sight areas that spraying will miss.

Subtask 2.5: References

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TASK 3: D&D KNOWLEDGE MANAGEMENT INFORMATION TOOL

Task 3: Executive Summary

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 (FIU-ARC) with the support of the D&D community, including DOE EM, the former ALARA centers at Hanford and Savannah River, 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 EM workforce across the DOE Complex.

During this year of performance, FIU focused efforts on outreach and marketing of KM-IT. Additional content was also included in the recently developed research module. Efforts also included cyber security and administration of the D&D KM-IT infrastructure, content management addition and data analytics, and finally, updates to the KM-IT application and database hardware.

Subtask 3.1: Outreach and Marketing (EM Community Support)

Subtask 3.1: Introduction

FIU's activities for outreach and marketing of KM-IT included the following:

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

Conferences and Workshops**:** Participation and presentations of KM-IT at industry conferences boosts awareness of the website and its capabilities to the target users. FIU 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.

User Support and Ad Hoc Specialized Reports: 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 3.1: 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.

Outreach and marketing is a critical element towards the long-term sustainability of knowledge and is essential for the long-term strategic vision of D&D KM-IT. This task will allow D&D KM-

IT to continue to grow and mature into a self-sustaining system through the active participation of the D&D community it was designed to serve.

Subtask 3.1: 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 1,067 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.

Subtask 3.1: Results and Discussion

FIU submitted a full paper to the 2020 Waste Management Symposia on November 15, 2019 capturing the research and efforts on D&D KM-IT during 2019. The abstract was submitted on August 30, 2019 and was titled "*D&D Research on KM-IT Platform*". The abstract was accepted to be presented in a poster session at the conference, which was held in Phoenix, Arizona. FIU submitted the full paper and below are the details of the abstract presentation (session, date and time):

Abstract: 20494 D&D Research on KM-IT Platform
Session: D&D Technology Application - Posters (6.1b)
Date: Wednesday
Time: 8:00 AM - 11:35 AM

The following figure shows the poster prepared and presented at the conference on March 12, 2020 in Phoenix, AZ.

Figure 27. D&D Research on KM-IT platform poster presented at WM2020.

In addition, FIU had a booth at WM2020 where the team was able to showcase D&D KM-IT and interact with conference attendees about the system capabilities and features.

Figure 28. Dr. Himanshu Upadhyay and Walter Quintero presenting D&D Research on KM-IT platform poster at WM2020.

This subtask also included developing newsletters for mass communication via email to keep users informed of new system features and other related activities. FIU sent a newsletter to the participants of the Waste Management Symposia announcing the FIU booth, with information about the D&D KM-IT presentation times and locations. Other newsletters included topics such as: New technologies added to KM-IT, DOE Fellow WM2020 conference experience, etc.

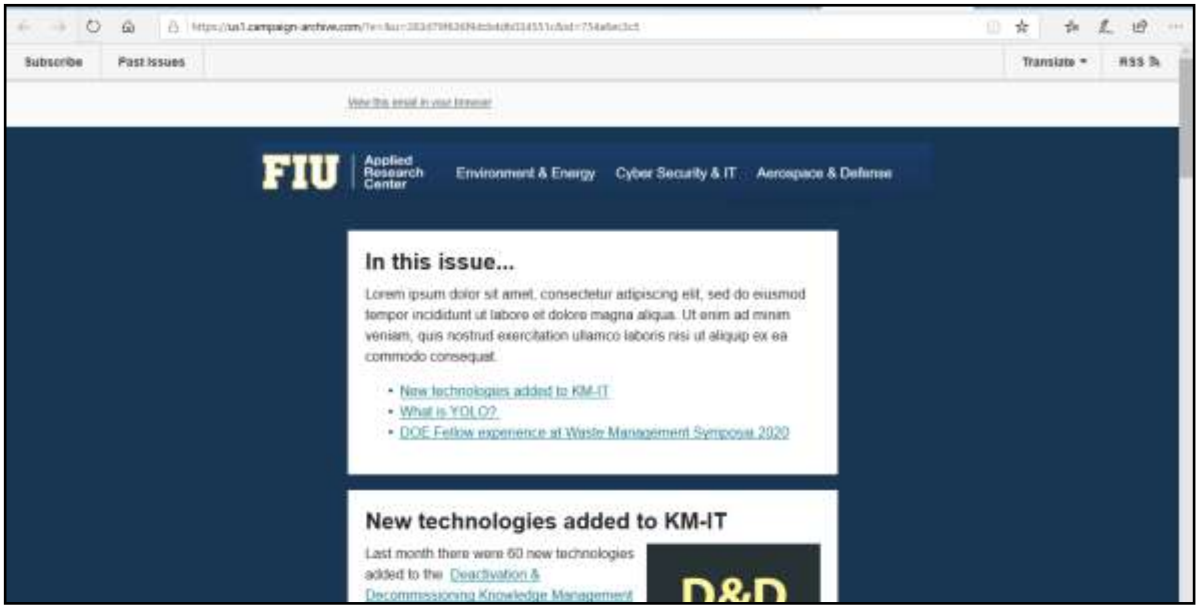


Figure 29. D&D KM-IT Draft Newsletter on KM-IT platform.

The above newsletter is a sample of the June newsletter sent to the users of D&D KM-IT with the following topics:

- 2019-2020 Waste Stream Forecast Data on WIMS
- New Technologies Added to KM-IT
- What is YOLO?
- DOE Fellow Experience at Waste Management Symposia 2020

A screenshot of the newsletter sent in June is shown below. In addition, the newsletter is archived on the web and can be read at this URL:
https://mailchi.mp/f1d1c22ea3d7/fiu-wms2019-4773270?e=094358cabe.

D&D KM-IT
Knowledge Management Information Tool

In this issue...

As we mark over 100 days since the enforcement of coronavirus academic and lockdown policies began in the US, FIU has remained busy at work. Here are just a few of the tasks that have kept us occupied during this time.

- 2019-2020 Waste Stream Forecast Data on WIMS
- New Technologies Added to KM-IT
- What is YOLO?
- DOE Fellow Experience at Waste Management Symposia 2020

2019-2020 Waste Stream Forecast Data on WIMS

In May, FIU collaborated closely with DOE HQ personnel to publish new forecast data on the Waste Information Management System (WIMS). WIMS tracks forecast data from 36 sites, 33 facilities, and 5 different waste types. The goal of WIMS is to provide a user-friendly online system to gather, organize, and present waste forecast data from DOE sites. The new data recently added contains data from 2020-2050. The new data can be accessed at https://emwims.org/

New Technologies Added to KM-IT

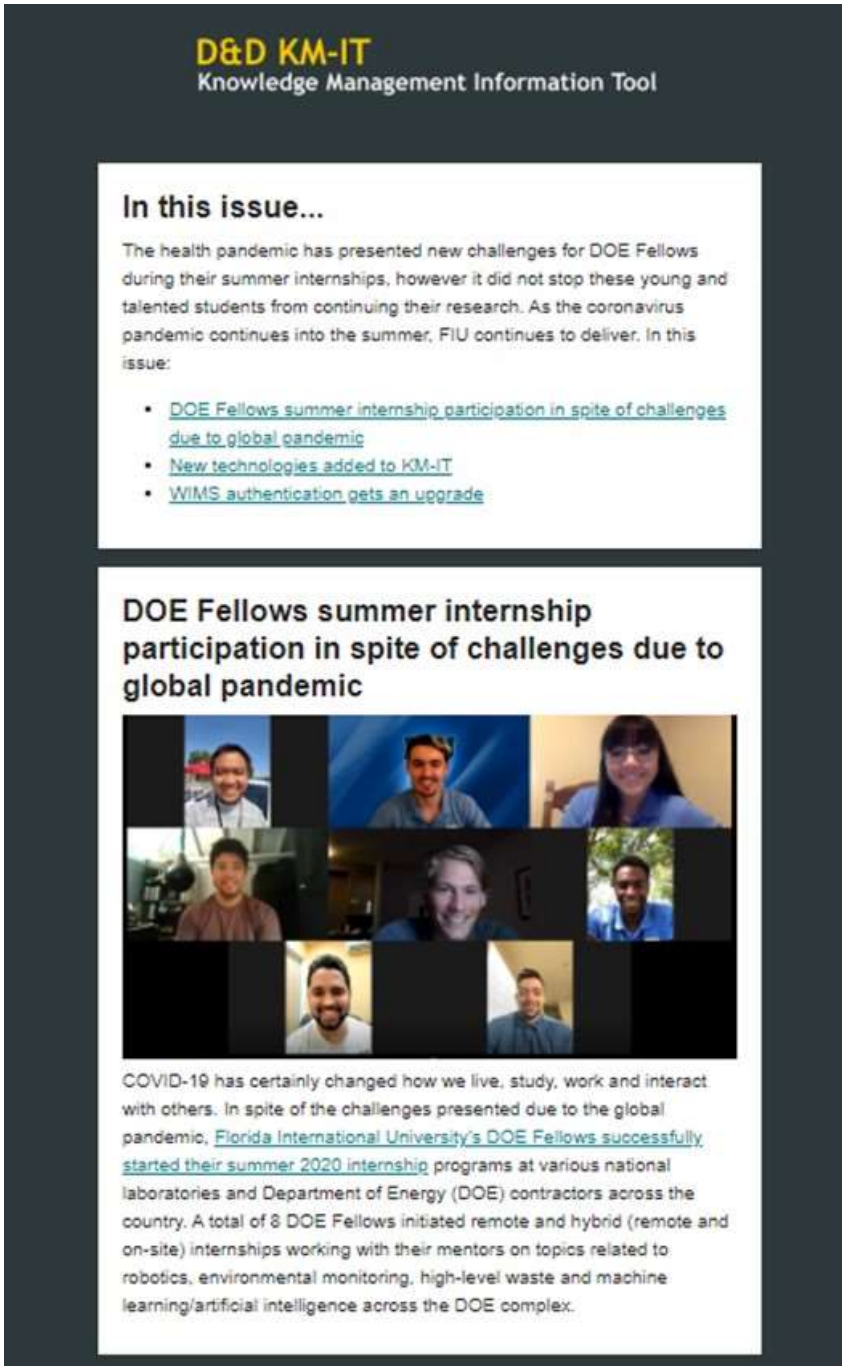
In May, 24 new technologies were added to the Deactivation & Decommissioning Knowledge Management Information Tool (D&D KM-IT) with an additional 40 published in April. Among these technologies were face masks, detection devices, sensors, and heavy machinery for demolition. These technologies were added by the DOE Fellows working on this project as well as various vendors supporting the D&D mission. Contact us if you are a D&D vendor and would like your technology listed/showcased in KM-IT. You can also browse our technology page to see if your technology is already featured.

D&D KM-IT

Figure 30. Screenshot of the D&D KM-IT June newsletter sent to D&D KM-IT users.

The following is another example of the newsletter sent in August 2020. The newsletter archive can be accessed at https://mailchi.mp/251adc5e4fe4/fiu-wms2019-4791118?e=094358cabe. Below is the newsletter sent that features the following topics:

- DOE Fellows summer internship participation in spite of challenges due to global pandemic
- New technologies added to KM-IT
- WIMS authentication gets an upgrade



D&D KM-IT
Knowledge Management Information Tool

In this issue...

The health pandemic has presented new challenges for DOE Fellows during their summer internships, however it did not stop these young and talented students from continuing their research. As the coronavirus pandemic continues into the summer, FIU continues to deliver. In this issue:

- DOE Fellows summer internship participation in spite of challenges due to global pandemic
- New technologies added to KM-IT
- WIMS authentication gets an upgrade

DOE Fellows summer internship participation in spite of challenges due to global pandemic

COVID-19 has certainly changed how we live, study, work and interact with others. In spite of the challenges presented due to the global pandemic, Florida International University's DOE Fellows successfully started their summer 2020 internship programs at various national laboratories and Department of Energy (DOE) contractors across the country. A total of 8 DOE Fellows initiated remote and hybrid (remote and on-site) internships working with their mentors on topics related to robotics, environmental monitoring, high-level waste and machine learning/artificial intelligence across the DOE complex.

Figure 31. D&D KM-IT newsletter sent for the month of August 2020.

User support, including ad hoc specialized reporting as requested, was also provided under this subtask.

In addition, under this subtask, content is continuously published into the various modules: Technologies, Vendors, Lessons Learned, Best Practices, Events/News and more. FIU focuses on collecting & publishing current research, lessons learned and technology information related to open air demolition while working with DOE sites, national labs, site contractors, universities, and international organizations.

DOE Fellows continue to support this task by performing data management activities in order to add current and relevant data to the KM-IT. Their efforts included identifying and adding additional D&D vendors and technologies from industry journals, conference publications, and news announcements as well as researching additional relevant D&D technologies offered by existing vendors.

Some of the maintenance and development tasks performed during this period included keeping up with Windows OS updates and patches provided from Microsoft and updating antivirus definitions and the software engine.

DOE Fellows and technical staff continue to add technologies and vendors to the D&D KM-IT. During this period, a total of 268 technologies were approved and are now live on the website. The names of each technology are listed below.

1. RCP Motor Lift Rig
2. M12 FUEL™ 1/2" Hammer Drill (Tool Only)
3. M18 FUEL™ SAWZALL® Reciprocating Saw (Tool Only)
4. M18 FUEL™ SAWZALL® Reciprocating Saw w/ ONE-KEY™ (Tool Only)
5. M18 FUEL™ Sewer Sectional Machine w/ CABLE DRIVE™
6. Contour Face Protection System
7. ELIPSE
8. High Visibility Performance Safety Vests
9. M12 FUEL™ 1/4" Right Angle Die Grinder
10. MAGNUM
11. Performance Safety Glasses with Gaskets
12. RCP Motor Alignment Tool
13. RCP Seal Maintenance Fixture
14. RCP Shaft FME Cover
15. Spectrum
16. Vision Plus
17. BARON
18. DESTRIER - LR
19. JAVELIN
20. SGLM 201K™
21. SGLM 202K™
22. RCP Motor Lift Rig
23. Leak Rate Monitor
24. Bio-Haz Vacuums
25. Mercury Recovery Vacuum System
26. Power-Propelled MORStak TM Drum Racker
27. Trentec Airlocks
28. Trentec Spent Fuel Pool Gates
29. High Temperature Solid State IR Camera
30. HYPERION™
31. INSTADOSE®+
32. ACCURAD™ PRD
33. ALLRad Mk2 Camera System
34. Compact Nuclear Zoom Camera
35. High Radiation Zoom Camera
36. Drum Dollies
37. Hydra-Lift Drum Rotators
38. A1000S

39. A100S
40. A200
41. CBS - Multi Tool Blast Recovery Vacuum
42. DenseCRETE®
43. Drum Manipulator
44. NFS-11 Floor Scabbler
45. Novair 700 / HEPA Filtered Air Purifier
46. Series II, X125 System
47. ShieldBLOCK®
48. ShieldGROUT®
49. Tank Waste Retrieval
50. EPOCH 650
51. EPOCH 1000 Series
52. OMNISCAN SX
53. SteerROVER
54. FlexoForm
55. IPLEX NX
56. Vanta
57. Vanta Element
58. Detective-100T
59. Detective-200 Ruggedized, Ultra-High Sensitivity, Transportable HPGe Radionuclide Identification System
60. GLIDER
61. Ion Specific Media (ISM)
62. IPLEX GX/GT
63. MapROVER
64. Micro-Detective Ultra light, Portable Hand Held Radioisotope Identifier
65. Micro-Detective-HX Advanced Hand-Held Radiation Detection and Identification RIID
66. Mobile Processing System (KMPS)
67. RADEAGLE
68. RADEAGLET
69. DeSCAL
70. Dri-Clean
71. Enzyte
72. Neutrad
73. SprayKlean
74. JT20 Directional Drill
75. JT20XP Drill Package
76. JT30 Directional Drill
77. FX20 Vacuum Excavator
78. 7A Type A IP-3 LiftPac
79. BermPac® Hurdle-Bracket Spill Containment Berms
80. HEPNAS High Efficiency Passive Neutron Assay System
81. LLMW Flexible Packaging
82. NucPac® LSA/SCO Wraps & Overpacks
83. RailPac Railcar Liners
84. SGEAS Single-shot Gamma Energy Analysis System
85. Spent Fuel Monitor

86. TechniCART™
87. TransPac Large Container Industrial Waste Bags
88. Type IP-1 LiftPac®
89. Type IP-2 LiftPac®
90. UN Certified IP-1 LiftPac®
91. Uranium Enrichment Monitors
92. FX30 Vacuum Excavator
93. FX65 Vacuum Excavator
94. Excel Modular Scaffold
95. FXT50 Truck Vacuum Excavator
96. FXT65 Truck Vacuum Excavator
97. Hanging Fume Arm
98. MV800 Vacuum Excavator
99. Premier Welding Booth
100. SPC-2000 Portable Fume Collector
101. SPC-230
102. SPC-5000 Portable Fume Collector
103. Standing Fume Arm
104. I-STIR CNC Series
105. ANAFI
106. ANAFI Thermal
107. Compact Series Laser
108. COMPACT-VAC
109. M3000
110. Laser Ultrasonic NDT System – LaserUT
111. M6000
112. VAC-PAC
113. Wet Separator / Waste Transfer Lid
114. I-STIR Plug Welding System
115. Enigma3hyQ
116. Enigma3m
117. Bags / Tunnel sleeves / Sheath
118. Half-suits
119. Intervention isolator / Bags and glove bags
120. Isolators
121. Phocus3
122. PrimeFlo-T
123. PrimeLog+
124. Sleeves
125. TALON
126. XiLog+
127. XiLog+ 1Fm
128. Xstream
129. Trentec containment hatches
130. EGS electrical penetration assemblies
131. EGS electrical seals
132. Leak rate monitor
133. Enertech snubbers

134. Hydranut
135. MaxiPass (MP) Maximum Passage Nozzles
136. TF Spiral Spray Nozzle
137. N Fire Protection Spray Nozzles
138. NC Full Cone Nozzles
139. NF - Flat Fan Spray Nozzle
140. Twist & Dry (TD) - Spray Drying Nozzle
141. EpeeCAM
142. Underground Marking & Warning Tape
143. Griffolyn® Type-90 Fr
144. Contaminated Equipment Covers
145. Custom Plant Dividers & Dust Partitions
146. Ptz Hd Color Camera
147. Ptz-R High-Rad Camera
148. Dual Hp-Led Droplight
149. Hps Nuclear Pool Light
150. Hps Nuclear Droplight
151. L100-Miniature Spotlight
152. 2F-85 Grippers
153. 2F-140 Grippers
154. 3-Finger Adaptive Robot Gripper
155. HP-LED Nuclear Pool Light
156. PT25 Pan and Tilt Positioner
157. PTZ Console
158. Anchor Trac Inspection System
159. Polyurethane Bags
160. PolyVinyl Chloride Bags
161. Radiological (Contamination Control) Tents
162. COVERALLS
163. Hitachi ZX300LC-6
164. Hitachi ZX30U-5
165. Hitachi ZX60USB-5
166. Hitachi ZX870LC-6
167. Horizon SM
168. NIOSH APPROVED AIR SUPPLIED BUBBLE HOOD
169. Titan SM
170. WELDER SERIES AIR SUPPLY SUITS
171. Wrist Camera
172. John Deer 17G
173. 50G
174. 260E
175. Counterbalance Drum Dumper
176. Counterbalance Drum Stacker
177. Counterbalance Manual Forklift
178. Counterbalance Walkie Lift Truck
179. Custom Drum Handling
180. Foldable Drum Dumper
181. John Deer 310L

182. John Deer 460E
183. Radiation Alert Ranger
184. Ranger EXP
185. Lexxi T1660
186. RD 5100H20+
187. Loki Pipe & Cable Locator
188. Rex LITE Pipe & Cable Locator
189. SenseFly Aeria X
190. SenseFly S.O.D.A 3D
191. John Deer 710L
192. John Deer 1050K
193. eBee Plus - A survey drone with a large-coverage photogrammetric mapping system.
194. eBee SQ
195. MicaSense RedEdge-MX
196. Parrot Sequoia+
197. senseFly Corridor
198. senseFly S.O.D.A
199. GilAir Plus Personal Air Sampling Pump
200. Gilian GilAir-3
201. Gilian GilAir-5
202. LMX100
203. LMX200
204. Model 7200 Gas Detection Controller
205. IceMap™
206. pulseEKKO®
207. SensAlarm Plus Point Gas Detection System
208. SensAlert ASI Point Gas Detector
209. SensAlert Four-Channel Gas Detection Controller
210. Sentry SAF-T-VISE Corrosion Monitoring Probes
211. Spidar
212. Multi-Jaw Demolition Tool (MRX)
213. Drop Hammers
214. Small Mounted Breakers
215. Large Mounted Breakers
216. Mobile Demolition Grapple (MDG)
217. Bucket Link Shears
218. Diamond Chain Saws
219. Hammer Drills
220. Handheld Breakers
221. HDR Grapple
222. Horizontal Grinder
223. Impact Wrenches
224. Mobile Hydraulic Pulverizer
225. Power Unit
226. Robotic Welders

227. Wood Shears
228. DeConTank
229. Artisan 100
230. Fukushima Drone
231. Compact Sodium
232. DS WS 15 WIRE SAW
233. Wire saw DSW 3018-E 3x480V PR
234. Hydrostress WCH14 & WCE14 Wire Saw
235. Mobile Track Wire Saw
236. WSE30-XLE Wire Saw
237. Wire Saw For Concrete
238. Series 1000 EG
239. S900T
240. Series 800 EG
241. S600 EGT
242. ALCOJET
243. LUMINOX
244. DETERGENT 8
245. M-7 Rad Wipes
246. ATILA 21-230
247. ATM 2 CBRN Decontamination Portable Unit
248. ATM 10
249. BX 24 CBRN
250. CAF Decon System
251. CeBeR™ Multi Purpose Wipes (CeBeR MPW)
252. Decocontain 3000 GDS HCC
253. DeconGel
254. LDV-X Large Volume Decon-X
255. DURAN® borosilicate glass 3.3
256. Durasoil
257. DURATAN® pre-stressed special glass tubing
258. GTAS® Battery Cell Lids
259. Radvision 3D Solutions
260. WCM-2000 Multi-Element Water Content System
261. WCM-3000 Robust Water Content System
262. AGILIOS Pan & Tilt Push Camera
263. Hi-Rad XS
264. iRis DVR Red Line Video Borescope
265. minCord Compact Push Camera
266. SM1B IS
267. SM1P02 IS
268. Wohler VIS 700 HD

Below is a sample technology DeConTank posted on the D&D KM-IT website in June. This technology belongs to the vendor ParkUSA. This technology page contains technology description, benefits, limitations, comments, pictures, and technology factsheet.

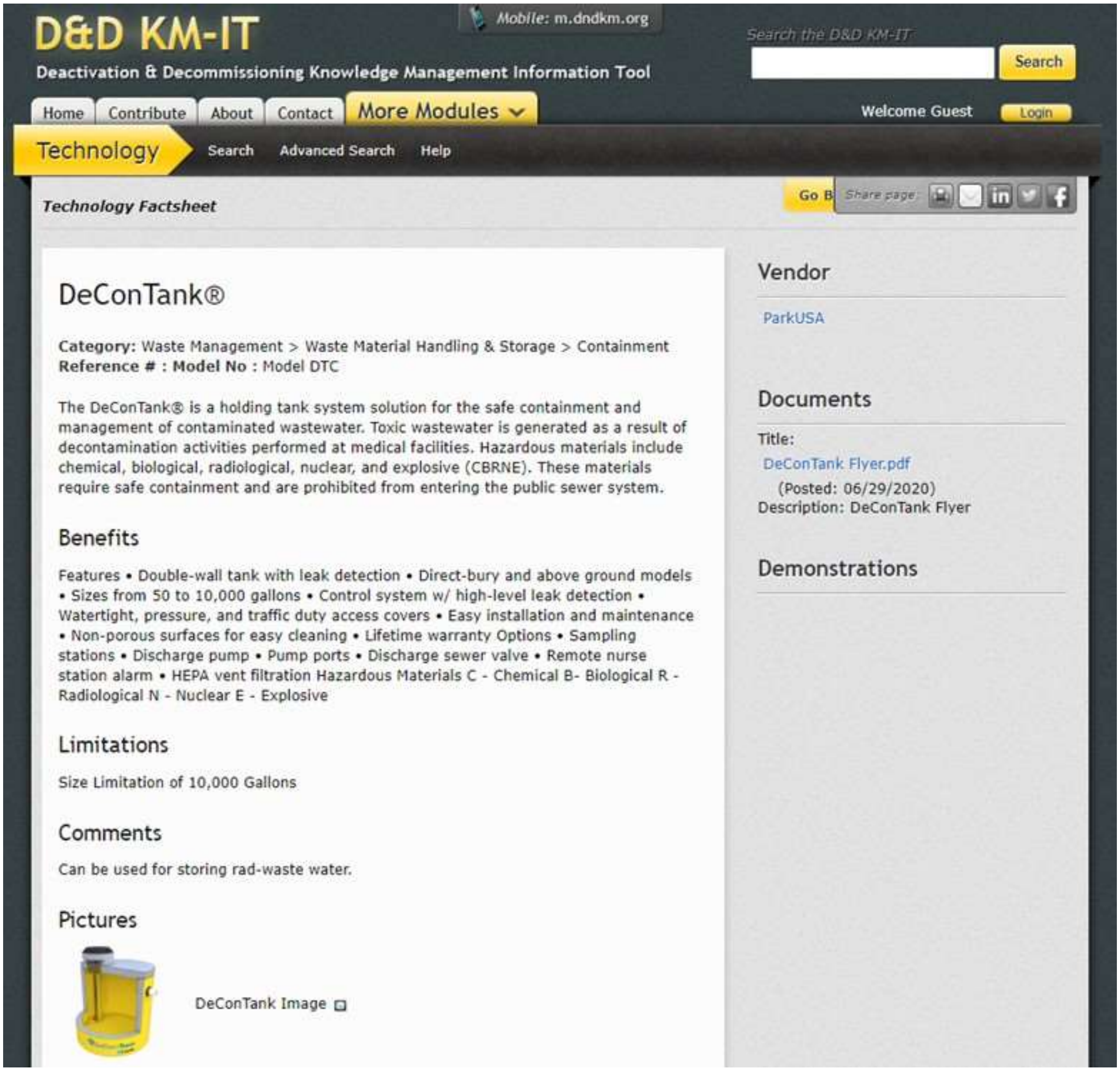


Figure 32. D&D Technology DeConTank on D&D KM-IT from vendor ParkUSA.

Some of the maintenance and development tasks performed during this period included keeping up with Windows OS updates and patches provided from Microsoft and updating antivirus definitions and the software engine.

The team presented the research performed on this task to DOE HQ officials and DOE Site POCs on August 25-26, 2020. This presentation consisted of accomplishments during this period of performance and plans for future work. The presentation shared with the team can be downloaded from the DOE Research website maintained by FIU at https://doeresearch.fiu.edu/.

The FIU team has submitted an abstract for the upcoming 2021 Waste Management Symposia conference titled *"D&D KM-IT Responsive Design"* that will focus on the task related to the responsive front-end redesign of the D&D KM-IT website.

On September 29, 2020, the team engaged in a demonstration of the D&D KM-IT application for DOE EM officials as a follow-up to the year-end presentations. In this meeting, a detailed presentation of each module was performed, and a discussion followed with the purpose of sharing ideas on how to increase participation by certain DOE sites and national labs. The team captured these ideas and will submit a plan on how each of them will contribute to this goal.

Subtask 3.1: Conclusions

As mentioned earlier, outreach and marketing is a critical element towards the long-term sustainability of knowledge and is 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. Finally, user support, including ad hoc specialized reporting as requested, will continue to be provided to the D&D user community under this task.

Subtask 3.1: References

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

Subtask 3.2: KM-IT Development and Enhancement

Subtask 3.2: Introduction

During the previous period of performance, FIU created a fixative sub-module on the KM-IT platform to capture and publish the research being conducted at ARC for the D&D community. The new D&D research published on KM-IT included the intumescent coating, fire resiliency and FX2 fogging research conducted under Task 2 of this project. During this period of performance, FIU worked on expanding this module to include the recent and current D&D research being performed across multiple DOE EM sites, national labs, other universities, and internationally. As a result, the user community will have a centralized location to review new D&D-related research within as well as outside the DOE EM complex.

Subtask 3.2: Objectives

This task expands the research module to include D&D research being performed across multiple DOE EM sites, national labs, other universities, and internationally. The objective is for the user community to have a centralized location to review new D&D related research in the community.

Subtask 3.2: Methodology

The FIU team will engaged multiple DOE EM sites, national labs, other universities to collaborate in sharing information to be published on the D&D KM-IT platform. This collaboration will be done by reaching out to existing contacts at conferences and attending other scheduled meetings to discuss the possibility of collaboration. Other methods will be emails, phone calls and presentations given at different events and seminars. When a research is agreed to be shared with FIU, the team will collect the information and categorize it so it can be added to the website. The information that is expected to be published includes research name, description, pictures, videos, factsheets and other research-relevant information.

Subtask 3.2: Results and Discussion

During WM2020 interacted with several contacts from the DOE sites and national laboratories. This engagement sparked a dialogue of collaboration which FIU will follow-up and pursue to establish a relationship in the near future. The objective is to reach an agreement where these sites and labs share their research on the Research Module of D&D KM-IT.

Several labs and universities were identified during this period based on the similarity of the work they do for DOE compared to FIU. Next, the team will follow up and make contact to see if there is a potential for collaboration. The most promising institutions are:

- ANL (Argonne National Laboratory)
- SRNL (Savannah River National Laboratory)
- ORNL (Oak Ridge National Laboratory
- South Carolina State University

The image below is a screenshot of the current research module to be expanded to include the additional research.

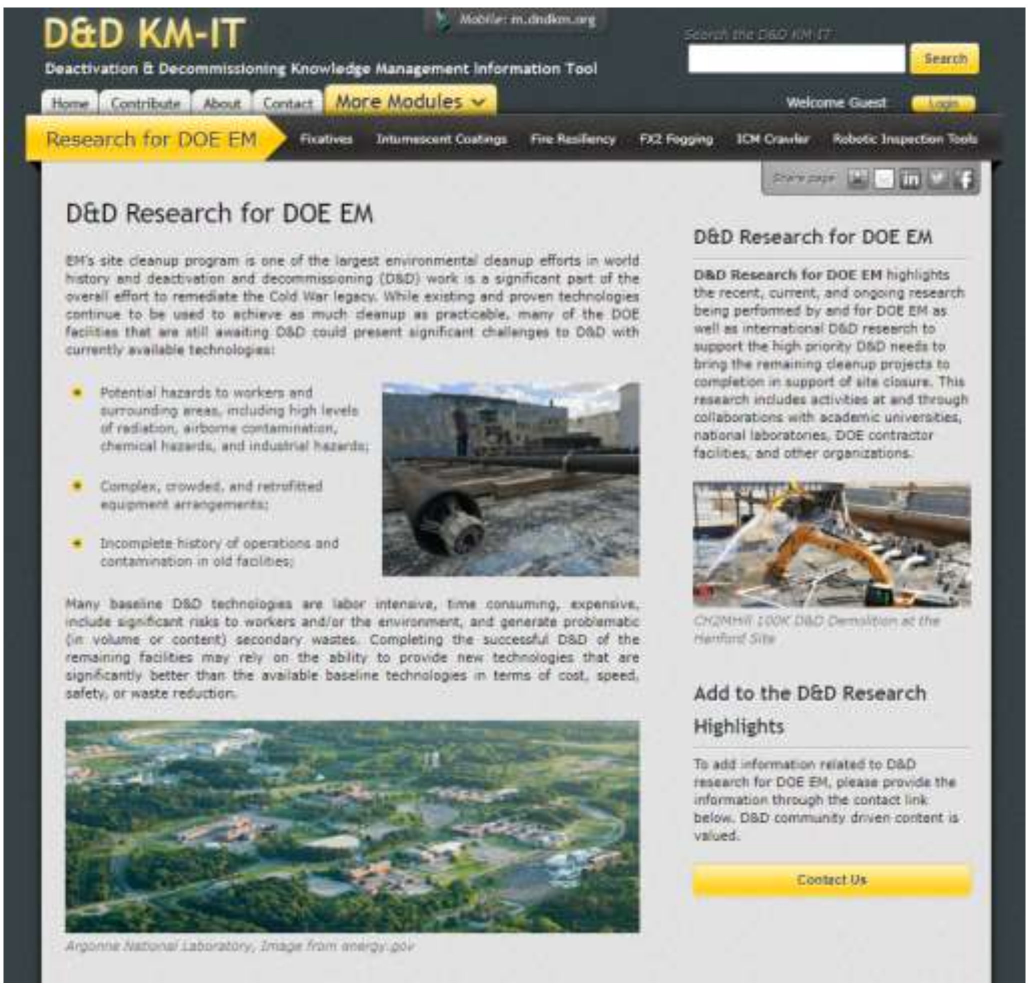


Figure 33. Screenshot of D&D KM-IT research module.

The team is working with potential collaborators for the D&D Research module from Idaho National Laboratory, Perdue University, Florida A&M University, Los Alamos National Laboratory as well as some international organizations. During this period, the FIU team reached out to these collaborators and is in the process of determining with them which of their research will be made available on D&D KM-IT. FIU is still awaiting feedback and has therefore extended this task into next year's scope.

Subtask 3.2: Conclusions

As of the end of this period, the team was working with potential collaborators but has not been able to receive research to publish on the research module yet. As a result, this task was extended into next year to allow the collaborators to provide research to publish on the D&D KM-IT. As the information continues to arrive at FIU, the team will categorize it and make it available on the D&D KM-IT Research module. The idea is for the user community to benefit from a centralized location to review new D&D-related research within, as well as outside the DOE EM complex.

Subtask 3.2: References

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

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

Subtask 3.3: KM-IT Maintenance & Administration

Subtask 3.3: Introduction

This task is broken down into three areas:

- Cybersecurity & Administration of KM-IT Infrastructure
- Content Management and Data Analytics
- KM-IT Application and Database Hardware Updates

Each of these areas is focused on keeping the D&D KM-IT application running at peak performance by providing infrastructure support, cybersecurity protection, and application and database upgrades.

Subtask 3.3: Objectives

Cybersecurity & Administration of KM-IT Infrastructure: The KM-IT infrastructure is deployed, secured and maintained in the FIU facility. The objective of this task is for researchers and DOE Fellows to continue to test, maintain, secure and administer the KM-IT system to keep it secured.

Content Management and Data Analytics: 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.

KM-IT Application and Database Hardware Updates (NEW): The current KM-IT application and database are running on old physical servers in a clustered environment. This effort's objective is for FIU to update this physical environment and move the KM-IT application and database to the virtualized environment. This will allow the staff to use the latest virtualization technologies to administer the application.

Subtask 3.3: Methodology

Cybersecurity & Administration of KM-IT Infrastructure: As mentioned above, researchers and DOE Fellows will continue to test, maintain, secure and administer the KM-IT system. This involves the administration and upkeep of the application server, windows server and database servers of D&D KM-IT system. Penetration testing tools, malware analysis and reverse malware engineering techniques are used in the DOE Cyber lab to test and secure the KM-IT infrastructure.

Content Management and Data Analytics: The FIU team will use factsheet, conference material (agenda, proceedings, brochures, etc), vendor website, publication, DOE newsletters and other sources to continue to publish additional technologies, vendors and lessons learned on the KM-IT platform. In addition, the team will use 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 will also monitor the website data analytics on the D&D KM-IT website and look for anomalies, spikes in traffics, 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 about features that should be enhanced and/or added to the website based on user behavior.

KM-IT Application and Database Hardware Updates (NEW): The objective of this task is to update the physical environment of the existing D&D KM-IT application and move the application and database to the virtualized environment. This will require the installation of the necessary servers and software, including IIS (application server), SQL Server (database server), and Microsoft Visual Studio (development tool), as well as migrating the application and database to these new servers and performing needed configuration in the virtual environment. This effort will result in enhanced system availability, security, maintenance, backup and disaster recovery, etc. It will also facilitate future migration/upgrade processes for KM-IT server's hardware and software and reduce overall maintenance costs.

Subtask 3.3: Results and Discussion

Cybersecurity & Administration of KM-IT Infrastructure: The KM-IT infrastructure is deployed, secured and maintained in the FIU facility. This is a repetitive task, as researchers and DOE Fellows continue to test, maintain, secure and administer the KM-IT system. This involves the administration and upkeep of the application server, windows server and database servers of D&D KM-IT system. Penetration testing tools, malware analysis and reverse malware engineering techniques are used in the DOE Cyber lab to test and secure the KM-IT infrastructure. To keep this infrastructure secure, the team performs various tasks. For instance, each month FIU IT security scans the D&D KM-IT website and provides a report to the team on security vulnerabilities. On a weekly basis, Symantec/Norton scans the D&D KM-IT website for vulnerabilities and malware and sends a report to the team, which is then reviewed and analyzed. If anything in the reports looks critical, the team implements counter measures to minimize the risk of the vulnerability.

In addition, other tasks are executed related to disaster recovery, such as performing backups of the D&D KM-IT and WIMS environment. These backups are incremental and full backup schemes are then moved to a separate NAS device outside the network. Finally, updates to the operating system are performed which include patches and other OS updates from the vendor. Typically, these updates are performed on the staging environment to make sure that they work properly before moving the changes to the production server. There are also other tasks that are performed to keep the application secured, but they are not necessarily done each month. These include:

- Update domain controllers and DOE environment domain
- Update all SSL encryption for DnDKM-IT and WIMS websites
- Follow the latest security policy recommendations from DOE
- Monitor local users on the DnDKM-IT and WIMS environment
- Update applications on the DnDKM-IT and WIMS environment (SQL servers, IIS servers, ASP.Net)
- Monitor network switches and logs for permissions and traffic
- Monitor users and bandwidth of the firewall
- Create and change NAT policies on the firewall
- Manage the firewall updates and policies

DOE Fellows assist with many of these tasks. This allows them to get real life experience on cybersecurity and network administration that is way beyond the material they learn in the classroom. For instance, DOE Fellow Alejandro Koszarycz learned about penetration and ethical hacking tools to test the KM-IT infrastructure. In June, Alejandro's emphasis was on learning ISO OSI seven-layer models. This model is extremely important because it defines all layers that are used in sending a message. Each of these layers has multiple protocols that can be used as attack vectors once there are established vulnerabilities in a system. It is important to clearly understand the flaws in the protocols of each layer to exploit. The seven layers are: Physical Layer (defines standards for transmission media, physical connection to the media, and how data should be sent over the network), Data Link Layer (provides error checking and transfer of message frames), Network Layer (performs packet routing across networks), Transport Layer (supports reliable end-to-end delivery of data), Session Layer (negotiates and establishes a connection with another computer), Presentation Layer (provides encryption, code conversion, and data formatting), and the Application Layer (provides services such as email, file transfers, and file servers).

To use these hacking tools, Alejandro learned about getting into the mind frame of an attacker to think of ways to exploit and attack a system. He set up a virtual machine and installed Kali Linux onto it. Kali Linux is an extremely powerful penetrating testing program that offers over 600 preinstalled tools. The tools range from information gathering and vulnerability analysis, to exploitation tools and forensics. Alejandro also began using network reconnaissance tools such as nMap to be able to find vulnerabilities pertaining to versions and operating systems being used by hosted websites. This helps attackers find a way to exploit any vulnerability of systems. Below is a screenshot of the nMap hacking tool being used by Alejandro.

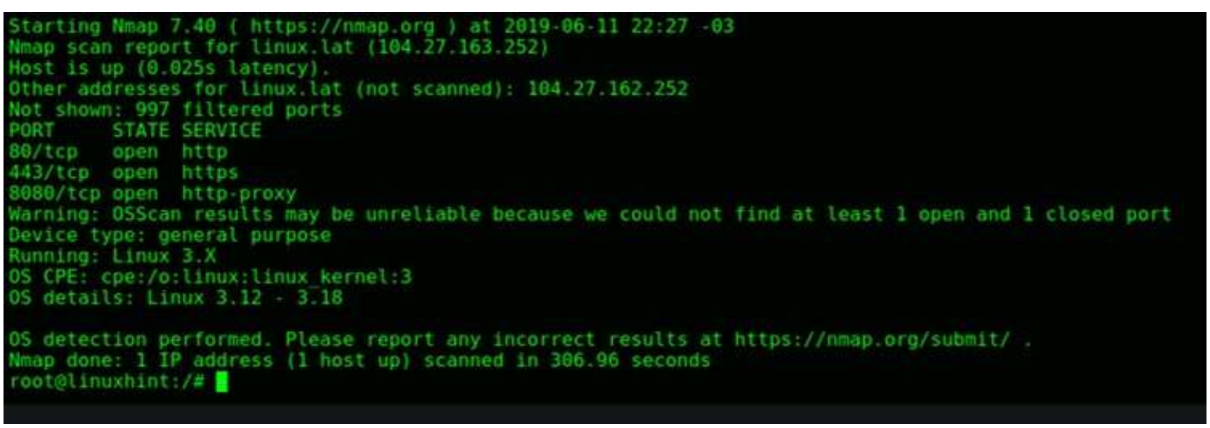


Figure 34. Screenshot of nMap console interface.

DOE Fellows have also learned certain tools that would enable a user to do password cracking: John the Ripper. It allows a user to create a wordlist that can be used to crack a password. They have also been learning in more detail about the 6 types of modules: Exploits, Payloads, Auxiliary, Post, Encoders, Nops, and Evasion. Exploits take advantage of system vulnerabilities; payloads give access to computers like rootkits within a system. Auxiliary scans target systems for DDOS attacks. Post is post exploitation after the system has already been compromised to allow for further attacks. Nops deals with null operators that can pause a system to do nothing for a clock cycle; this can allow exploitation of buffer overflows. Fellows then began to focus on Bluetooth surveillance/recon and continued learning additional built in tools: wireshark, hciconfig, hcitool, sdptool, l2ping, and btscanner. Hciconfig allows us to enable Bluetooth adapters via the Bluetooth interface. Wireshark is a network analyzer that when connected to the same Wi-Fi network as a user, can allow us to snoop on a particular user and see what applications are being used on their phone in real time, making it extremely invasive but powerful. Hcitool allows us to perform various tasks like scans and the pulling of names. It is very useful in learning about devices being used as well as getting MAC addresses to corresponding devices. With sdptool, we can learn more about what is potentially available to us on devices and it gives us the limitations of what can/cannot be performed. We can do queries on Bluetooth devices to understand the permissions. With l2ping, we can ping all nearby devices whether they are in discovery mode or not by their corresponding MAC addresses. Lastly, with btscanner, we have another scanning mechanism of Bluetooth devices; but this time, we have a graphic user interface that makes it much easier to navigate and see the addresses of certain devices. Many Bluetooth devices do not randomize their MAC address, which means that the address will be the same each time it is used. This makes it possible for Bluetooth tracking if the user does not disable corresponding devices.

During the next period of performance, DOE Fellows will learn the various tools provided via Kali Linux. In addition, they will follow the proper sequences in penetration testing in order to test the KM-IT infrastructure, determine any vulnerabilities and ultimately help to protect it from penetration and exploits.

Cybersecurity and administration of the D&D KM-IT application is an ongoing process to keep the application secure and reliable.

Content Management and Data Analytics: FIU continues 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 268 technologies published on the D&D KM-IT website. Below is the breakdown by quarter.

- First Quarter (Sep – Dec, 2019) – 49 technologies published
- First Quarter (Jan – Mar, 2020) – 102 technologies published
- First Quarter (Apr – Jun, 2020) – 77 technologies published
- First Quarter (Jul – Sep, 2020) – 40 technologies published

In addition to technologies and vendors added to the system, there was also training, and conference opportunities related to D&D added to the system.

Content management has allowed the D&D KM-IT to increase its content. The graph below summarizes the growth over the years. As of August 2020, the system has 1,259 D&D technologies, 1,064 registered users, 991 D&D vendors, and 103 subject matter specialists.

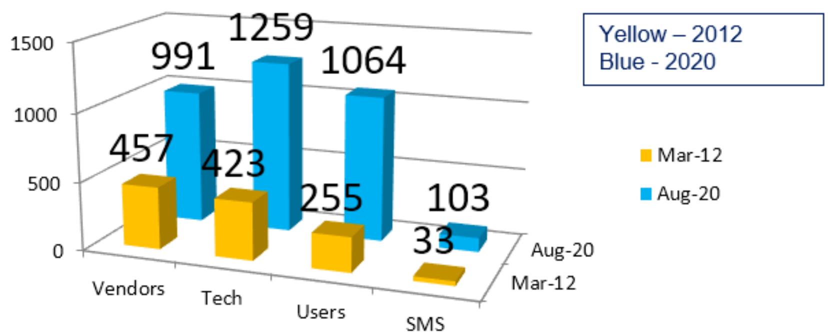


Figure 35. Number of vendors, technologies, users and SMS as August 2020.

The data analytics portion of this subtask also tracks web activity on the D&D KM-IT website. The following figure shows the most relevant key metrics from Google Analytics (GA). Notice that by comparing 2019 vs. 2020, the system has shown growth in multiple areas which include Number of Sessions per User, Pages/Sessions, Average Session Duration and Bounce Rate. Other areas showed a decline like users, new users, sessions and pageviews.

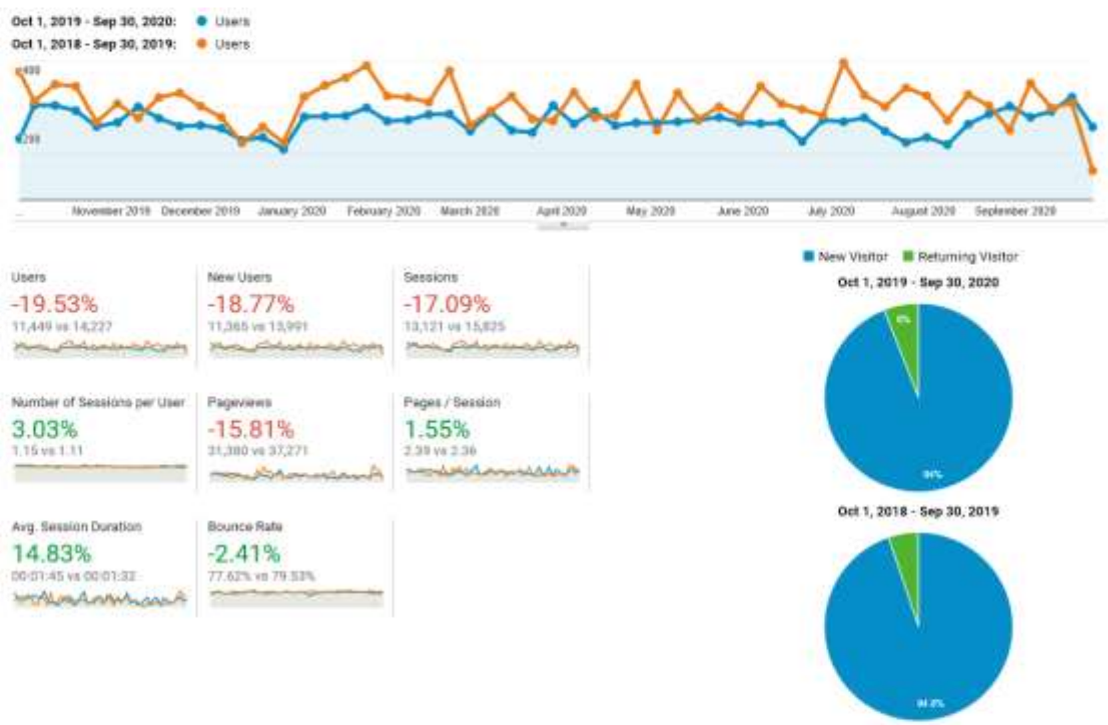


Figure 36. D&D KM-IT Google Analytic activity (2019 vs. 2020).

The GA data analytics captures some interesting information such as the location of a user visiting the website. For instance, the map below shows the changes in the amount of activity by state. Notice the shading of each of the states. The darker color shows more activity, so from this image it is clear that the top five states that visited the website were Illinois, Virginia, California, Florida and Texas.

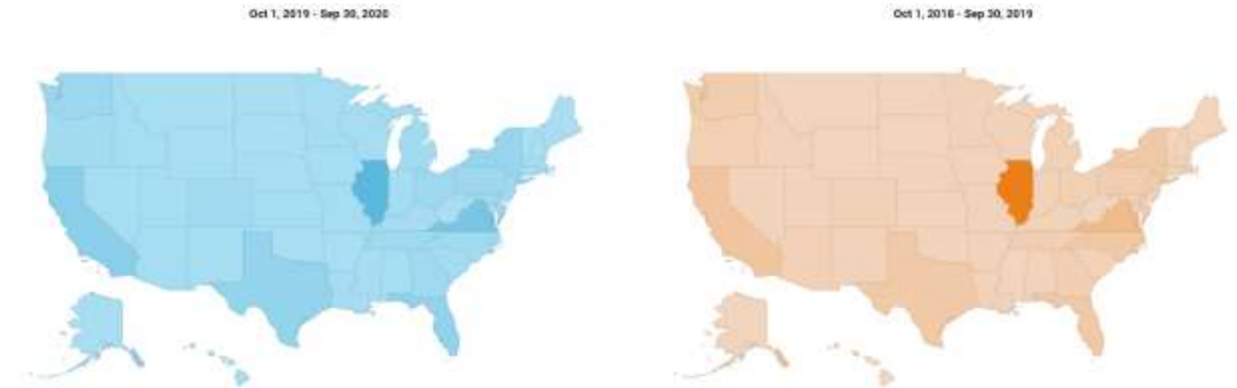
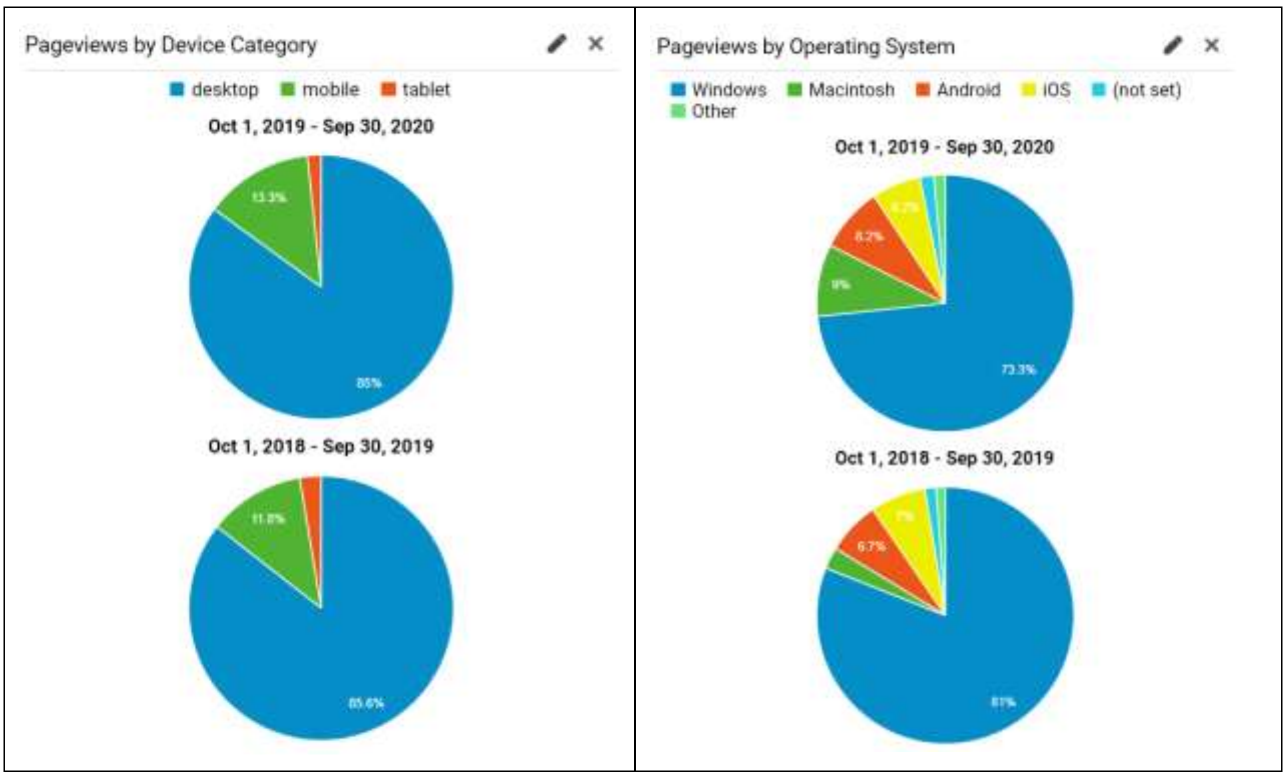
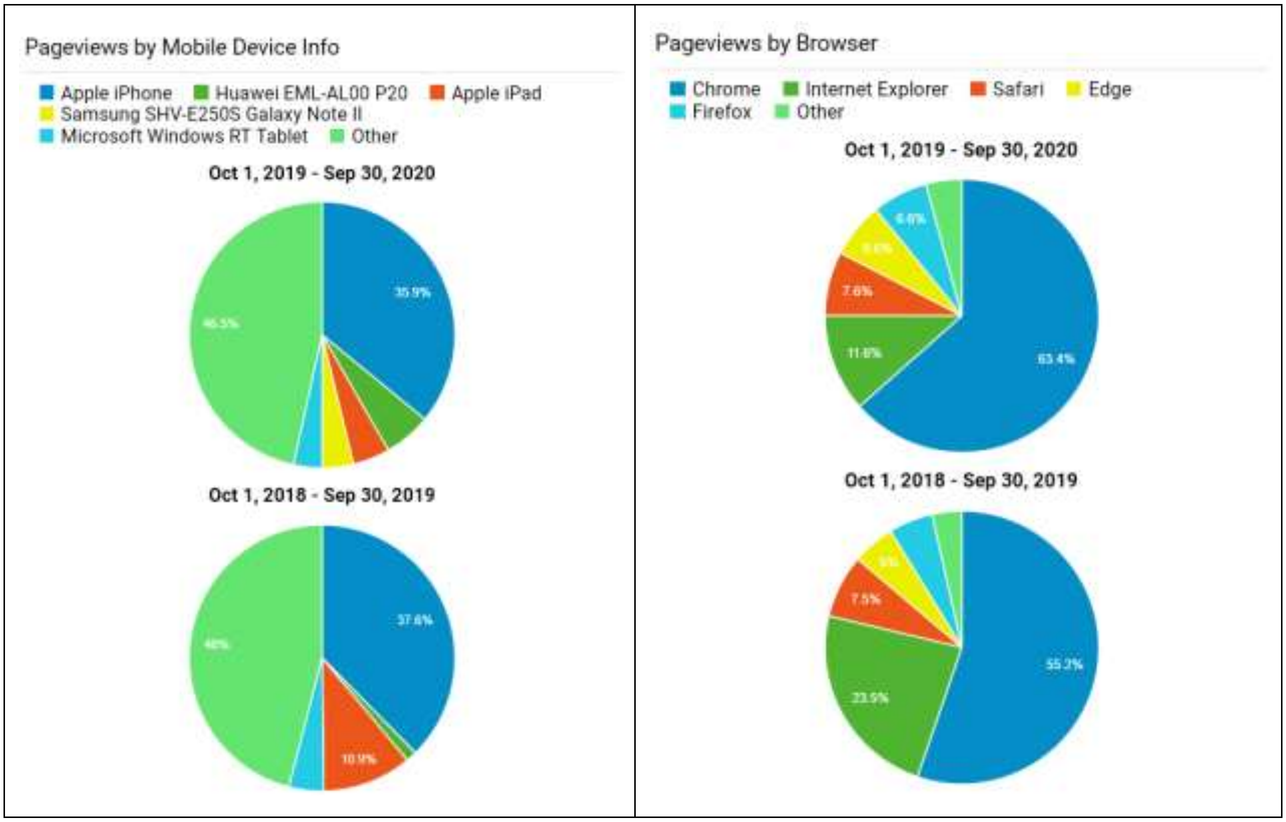


Figure 37. D&D KM-IT activity by state (2019 vs. 2020).

Other information captured by GA is the type of devices used by the visitors, operating system, mobile devices and even browsers. Below are some comparisons of each of these metrics to the previous period.

Table 9. Google Analytics Metrics for D&D KM-IT





KM-IT Application and Database Hardware Updates (NEW): The current KM-IT application and database are running on old physical servers in a clustered environment. In this subtask, the FIU team updated this physical environment and moved the KM-IT application and database to the virtualized environment. This required the installation of the necessary servers and software, including IIS (application server), SQL Server (database server), and Microsoft Visual Studio (development tool), as well as migration of the application and database to these new servers and performing needed configuration in the virtual environment.

The FIU team started by acquiring the server and software necessary for the application and hardware upgrade. The team then proceeded to create a development environment to run parallel to the existing production environment. Once all the migration was done, the team made the necessary network changes so the application did not have any downtime on moving from a physical server to a virtual server. The figure below shows a traditional server architecture vs. the new virtualized server architecture now supporting the D&D KM-IT application.

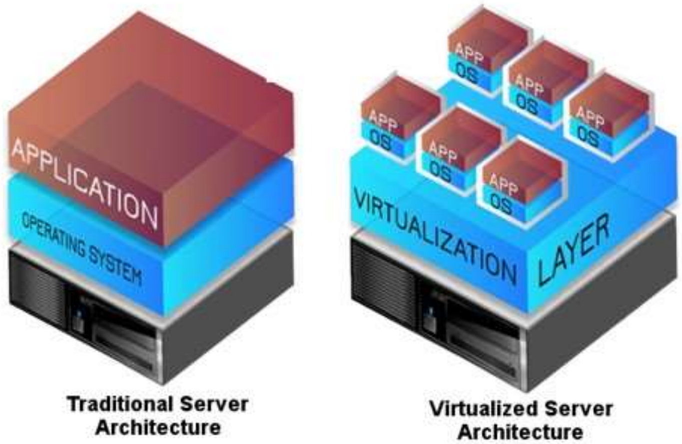


Figure 38. Traditional server architecture vs. virtualized server architecture.

Subtask 3.3: Conclusions

Cybersecurity & Administration of KM-IT Infrastructure: The FIU team has managed to maintain the KM-IT infrastructure secured as a result of continued cybersecurity and administration efforts on the KM-IT system. This is a necessary repetitive task as new threats are developed each day. DOE Fellows assist on this task by using penetration testing tools, malware analysis and reverse malware engineering techniques to test and secure the KM-IT infrastructure.

Content Management and Data Analytics: FIU published 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 268 technologies published on the D&D KM-IT website. 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.

KM-IT Application and Database Hardware Updates (NEW): In this subtask, the FIU team updated this physical environment and moved the KM-IT application and database to the virtualized environment. This effort resulted in enhanced system availability, security, maintenance, backup and disaster recovery, etc. Moving forward, the application will be easier to migrate/upgrade, reducing overall maintenance efforts. It also facilitated future migration/upgrade processes for KM-IT server's hardware and software and reduced overall maintenance costs. Below are the highlights of some of the benefits of this application and hardware upgrade.

This effort resulted in virtual KM-IT infrastructure that is:

- More reliable
- More secured
- Easier to maintain
- More efficient to backup and conduct disaster recovery
- Easier to migrate and upgrade

Subtask 3.3: References

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

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

TASK 6: ANALYSIS OF IMAGE DATA USING MACHINE LEARNING/DEEP LEARNING AND BIG DATA TECHNOLOGIES

Task 6: Executive Summary

Structural health monitoring is imperative to the ongoing surveillance and maintenance (S&M) across the DOE complex. Machine Learning and Deep Learning are state-of-start technologies capable of facilitating the assessment of structural integrity in aging nuclear facilities. Auto Encoders and Convolutional Neural Networks are used to implement the deep learning approach.

Task 6: Introduction

The nuclear industry is experiencing a steady increase in maintenance costs even though plants are maintained under high levels of safety, capability, and reliability. Surveillance and maintenance of nuclear-decommissioning infrastructure provide many challenges with respect to maintenance or decommissioning of the buildings. As these facilities await decommissioning, there is a need to understand the structural health of these structures. Many of these facilities were built over 50 years ago and in some cases, these facilities have gone beyond operational life expectancy. In other cases, the facilities have been placed in a state of "cold and dark" and they are sitting unused, awaiting decommissioning.

In any of these scenarios, the structural integrity of these facilities may be compromised, so it is imperative that adequate inspections and data collection/analysis be performed on a continuous and ongoing basis. There is a need for a framework to analyze the huge amount of data generated by the sensors on the nuclear reactor components as well as structures, to monitor the conditions of these buildings over a period.

Under this subtask, FIU investigated a specific LiDAR technology mounted on a robotic platform to be deployed at FIU mockup facilities to develop a pilot-scale infrastructure using machine learning/deep learning and big data technologies for structural health monitoring of facilities. FIU worked closely with SRNL to identify applications at SRS or other DOE facilities.

Task 6: Objectives

The overall objective of this new task is to investigate specific applications of machine learning and big data technologies to satisfy DOE-EM problem sets and challenge areas, including potential applications of existing state-of-the-art technologies (e.g., imaging, robotics, big data, and machine learning/deep learning) to assess the structural integrity of aging facilities in support of ongoing surveillance and maintenance (S&M) across the DOE complex.

Task 6: Methodology

To accomplish the objectives, the FIU team used a four-step implementation geared towards machine learning and deep learning. The first step was to collect all the data necessary to achieve the desired goal (data collection). The second step was to save/store the collected data in the local network storage for future processing (data storage). The third step was to build deep learning models using convolutional neural networks trained with the stored data (model building). The last step was to use the trained neural network models to infer and predict a never before seen data sample (inferencing). Each one of these steps was critical and involved multiple minor tasks that drive the enterprise artificial intelligence environment.

FIU continued the initial development of a pilot-scale infrastructure to implement structural health monitoring using scanning technologies, machine learning/deep learning and big data technologies. In addition to utilizing existing data sets, FIU investigated a light detecting and ranging (LiDAR) technology to be deployed in FIU testbed mockups to collect structural data. Resulting data will be processed and analyzed using machine learning/deep learning and big data technologies. The proposed pilot system is intended to serve as a starting point to engage the DOE field sites on related data sets and their decision making needs. It is anticipated that proposed machine learning/deep learning and big data technologies can be effectively employed using anomaly detection to solve EM challenges in surveillance and maintenance of the D&D facilities.

Task 6: Results and Discussion

During the first quarter of this period, the team performed the following tasks:

Data Storage:

The image dataset from the outdoor mockup testbed has been re-labeled to increase the accuracy of the ground truth information. Additional images have been collected at different times of the day to introduce more variety in the data. The new images were collected using high definition video recording devices and preprocessed for frame extraction. The entire image dataset resides in the storage network with redundancy measures.

The FIU team upgraded the infrastructure of the Big Data Cluster (BDC) from the CPU server to the GPU server. The goal was to distribute the imagery datasets in the HDFS where the server has a GPU resource. This setup allowed the Machine Learning/Deep Learning models to execute the training phase much faster compared to the CPU server. Multiple setup parameters were researched and explored to achieve a stable environment.

Architecture:

A new convolutional neural network architecture with fewer layers is trained on the image dataset. The architecture was made up of 8 layers which consisted of 1 input layer, 1 output layer, and 6 hidden layers. The breadth of the hidden layers was increased by a factor of 2 and the activation functions were left unchanged. The kernel size of the convolutions was increased by 1 and the stride was left unchanged. The increased complexity per layer in this architecture was mitigated by the reduction of 2 hidden layers as compared to the old 10-layer architecture.

Algorithm:

The algorithm was modified to have the ability to train with any image size. A 'training and testing' set was created to test the ability of the convolutional neural network to generalize with the higher pixel count in the images. The 8-layer CNN input layer was modified to accept the n-dimensional feature space for the dynamic image sizes. The subsequent hidden layers and output layer were left unchanged in order to benchmark the performance difference.

To increase the accuracy in the 8-layer convolutional neural network the learning rate and the decay factor of the Adadelta (adaptive learning rate method) optimizer were modified. Adadelta is a robust extension of Adagrad that adapts the current learning rate based on a moving window of gradient updates instead of accumulating all past gradients. Adadelta continues learning even after many updates have been done. The value for the initial learning rate was set to 0.95 and rho (decay factor) was set to 0.9. The loss function in the model is still set to categorical crossentropy and accuracy is being used as the appropriate metric.

Results:

The 8-layer convolutional neural network performs almost as well as the 10-layer but has an increased false positive/false negative rate. It achieved an accuracy of 97.7% in 6 epochs of training and converged rather quickly. This network seems to perform a little better with larger images and has the capacity to be extended. Additional convolution layers can be implemented if they are needed for more feature abstraction.

After additional testing, the 8-layer convolutional neural network showed an increase in the accuracy as compared to the previous month's results. The model is currently at 98.5% accuracy in the testing dataset, which means the higher pixel count is having an impact on the ability to infer. A reduction in the Type I and Type II errors was also observed. The accuracy increased to 99.3% in the testing dataset for the 8-layer convolutional neural network. The number of epochs (iterations) during the training phase was changed from 7 to 10. The model was learning more slowly but was able to generalize with better precision. This version of the model had less Type I and Type II errors than the previous one. Performance per epoch did not change much as the data set was not changed in any way.

During the second quarter, the FIU team worked with a new algorithm to perform object detection and localization. Object detection is a computer vision and image processing technique that deals with detecting instances of semantic objects of a certain class in digital images and videos. Object localization is the task of predicting the boundaries (location) of an object. The main goal for the algorithm is to find the desired object in an image and decide the bounding area.

There are multiple techniques and algorithms to perform object detection available and each have advantages and disadvantages. The classical approach is to use a Sliding Window technique, which slides systematically across an image extracting subsamples and passing them through a neural network classifier. The classifier will then determine what the class is for the subsample. If the classifier predicts the class of the target object, the size of the sliding window and the location of the subsample become the bounding box for the object found. This method has the highest accuracy overall but it is the slowest. The other algorithms offer faster processing time with the tradeoff being accuracy.

The current task is to find a wooden block in an image. To achieve this task with the sliding window technique, a custom dataset of wooden block images was used to create a neural network classifier. Since the task is to find a single class of object (wooden block), a One-Class Classifier (OCC) is implemented. A Convolutional Neural Network (CNN) was selected to do the classifying since they are exceptionally good with image datasets.

There is one main difficulty with OOC when implemented as a CNN. In general, neural networks are discriminative in nature and that means it has to be trained with two classes. For this task, the object of interest is a wooden block, which means that the compliment class (not wooden block) is everything else and that is infinite. To solve this issue, a state of the art approach using an Autoencoder coupled with a CNN was trained in a Generative Adversarial Network (GAN) approach. One part of the overall network is in charge of creating images (generator) and the other side of the network is in charge of classifying (discriminator).

The Autoencoder works as the generator by learning how to reconstruct the wooden blocks from the custom image dataset. This process highlights inliers (wooden blocks) while destroying outliers (not wooden blocks). Highlighting means that the reconstruction error from the Autoencoder is marginal. Destroying means that the reconstruction error from the Autoencoder is high and above a threshold. The AutoEncoder is trained with a mean squared error (MSE) loss function that compares the input image to the reconstructed error. Training is continued until the MSE is very low which means the reconstructed images are as close to the original as possible.

The CNN was trained with the original images of the wooden blocks as well as the reconstructed images from the AutoEncoder. Since the CNN is trained with both sets of images, it learns very well the features from the original data set and discriminates the rest. This approach is an end-to-end unsupervised learning method for OCC that has dynamic threshold included.

Data Collection:

The FIU team has collected 1,000 images from 9 wooden blocks. The images were collected with a green screen and then cropped to the size of the wooden block. A regular RGB camera was used to collect images. The dataset contains images of the wooden blocks in different orientations and angles.

Figure 39. Sample image of wooden blocks used to create the custom dataset.

Results:

The AutoEncoder achieved an RMS of 0.02 when trained by itself. The CNN achieved an accuracy of 98.7% when trained by itself. Once both networks were trained together using a GAN style, the network was not able to learn correctly. The implementation needs hyper-parameter tuning and more training. It was also compared to the results from the published research paper.

Algorithm:

The FIU team made some improvements on the One-Class Classifier (OCC). Additional convolution layers have been added to extract more features in the deep learning approach. Batch normalization was also added between convolution layers and max pooling layers to increase stability in the Autoencoder side. The Autoencoder starts the encoding side with two convolutional layers of 32 filters each, a 3x3 kernel, and batch normalization. After the second convolutional layer there is another batch normalization followed by the max pooling with a 2x2 kernel to reduce the spatial dimension. The composition of these layers constitutes a block in the encoder. Subsequent blocks are similar except for the number of filters, which doubles in each block.

The latent space is the compressed representation of the image data and is formed with 256 filters. The encoding side begins immediately after the latent space and is exactly the same as the encoding side but in reverse. The discriminator side was modified to include more convolutional layers as well. Each block here has 3 convolutional layers followed by a max pooling layer and then a drop out of 25% to prevent overfitting and memorization. The discriminator currently has three of these blocks with 16 filters at the beginning and ending with 64 filters. Each one of the blocks has the same amount of filters. The activation function being researched for the GAN is the sigmoid function.

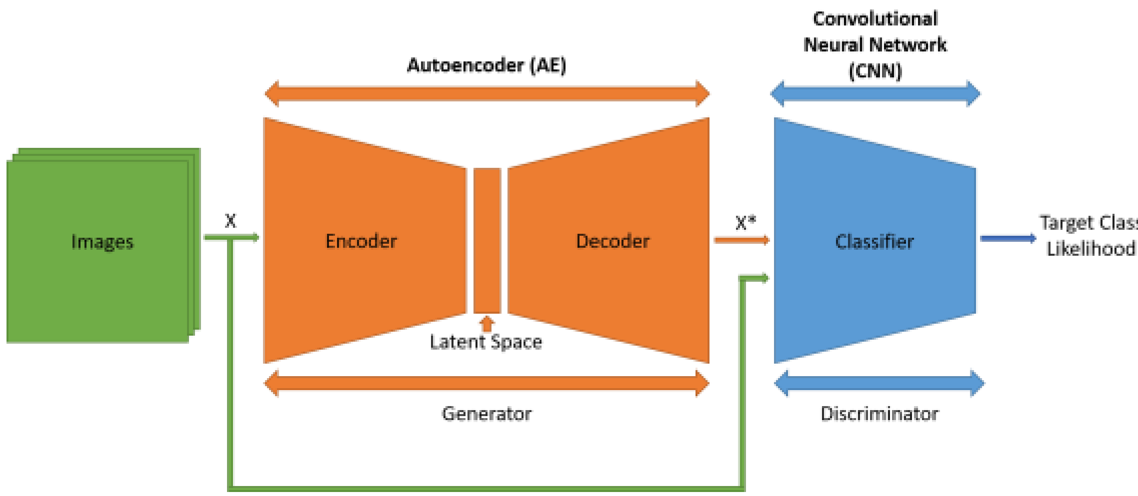


Figure 40. One-Class Classifier (OCC) architecture overview.

Data Collection:

Two additional image datasets for the blocks were collected by the FIU team. Each dataset was collected by a different team member to introduce random observations such as backgrounds and ambient lighting. The first dataset is composed of 65 images containing the wooden blocks and was collected from an environment outside of the FIU facility. The second dataset is composed of 50 images and was collected around the cubicles in the Applied Research Center. The purpose of these datasets is to augment the original green screen images to increase the accuracy of the network.

Figure 41. From left to right – Wooden block with transparent background (green screened), wooden block in ARC research lab, wooden block outside of FIU facilities.

Results:

The Autoencoder is achieving a Mean Squared Error (MSE) of 0.0015 after 4k iterations with images in gray scale and an MSE of 0.003 after 10k iterations for RGB images. The Convolutional Neural Network (CNN) classifier is achieving an accuracy of 98.9%. When both networks, the Autoencoder and CNN are combined and trained as a GAN, the accuracy falls to the low 70%.

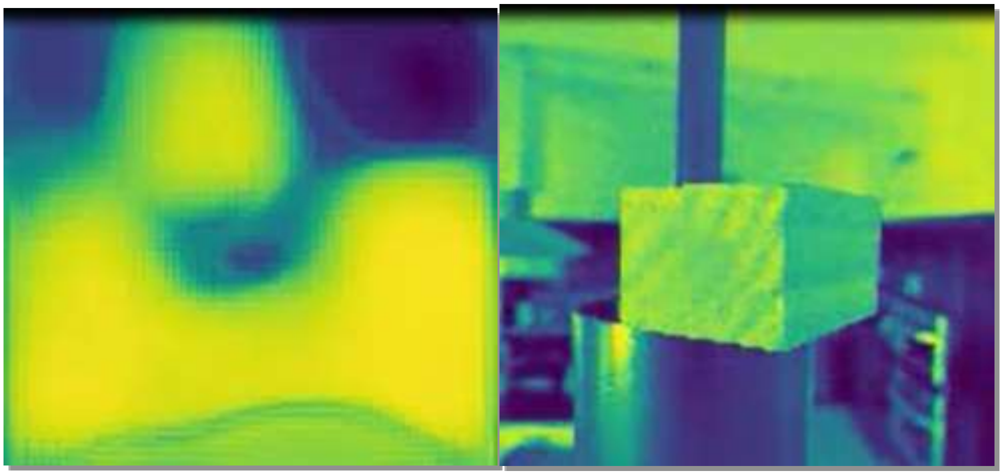


Figure 42. Left image – Output of Autoencoder after 10 iterations. Right image – Output of Autoencoder after 4k iterations. Images are in grayscale with a viridis color map.

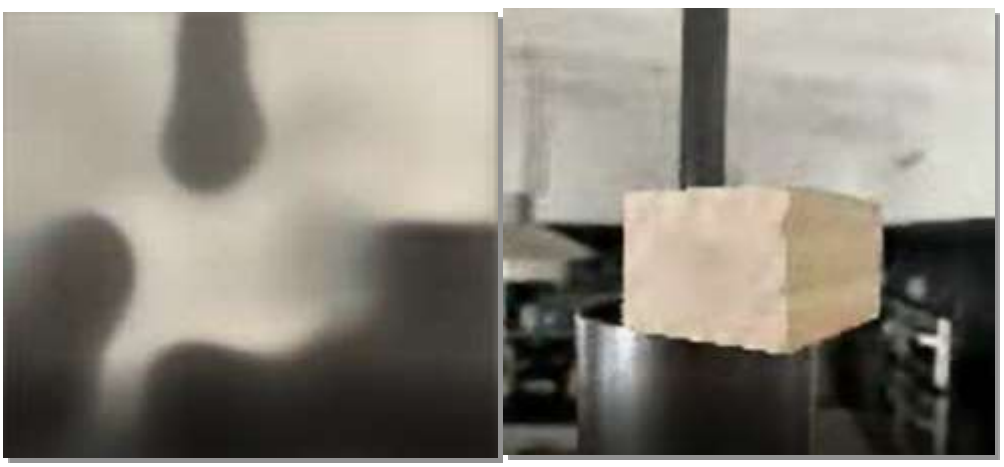


Figure 43. Left image – Output of Autoencoder after 1k iterations. Right image – Output of Autoencoder after 10k iterations. Images are RGB color mode.

Algorithm:

The FIU team modified the AutoEncoder module in the OCC to save an image of the output layer per iteration. The images are saved sequentially and serve as a visual representation of how the network is learning over time. The sequence of images can be "stitched" together at any desired FPS to construct a video. The video is used to analyze and diagnose the Autoencoder network. This approach allowed the team to see when the algorithm was stuck in a local minimum and how the optimizers helped jump out of them in search for the global minimum.

Further training was performed with the wooden block image dataset in both RGB and grayscale formats. The RGB dataset is more taxing on the input/output operations (I/O) since it contains two additional dimensions (color) of information, but seems to be outperforming the grayscale dataset now. The Mean Square Error (MSE) for the RGB dataset is currently 0.001 and further hyper parameter tuning is still possible.

With the viable AutoEncoder, the next step for object detection was started. The AutoEncoder was connected to the Convolutional Neural Network (CNN). This coupled network was trained as a Generative Adversarial Network (GAN) to teach the generator side how to properly reconstruct the images that have wooden blocks in them, and to teach the discriminator side which images have wooden blocks in them. While training the network using the GAN approach there was an issue with the Keras library. The training progression was showing inconsistencies between the outputs of the CNN alone when compared to the coupled network.

To fix the network inconsistency in the Keras library the FIU team manually coded the GAN approach. This was done by using the model.train_on_batch() function in the library instead of the model.fit() function with does the training under the hood. By using the model.train_on_batch () the team was able to code exactly what happens at each iteration of the training on the batch. Inferencing was done on every batch per iteration. If an inference was wrong then backpropagation was done on the AutoEncoder to train it.

Results:

The AutoEncoder module is getting stuck in local minimums but stabilizes at around 1k epochs and settles on a minimum. With an MSE of 0.001 the RGB wooden block dataset is being reconstructed almost perfectly. The CNN classifier maintains the 98.9% accuracy as before. The new training implementation of the GAN approach is showing accuracies in the mid 70’s but is not conclusive yet. More training and testing is required.

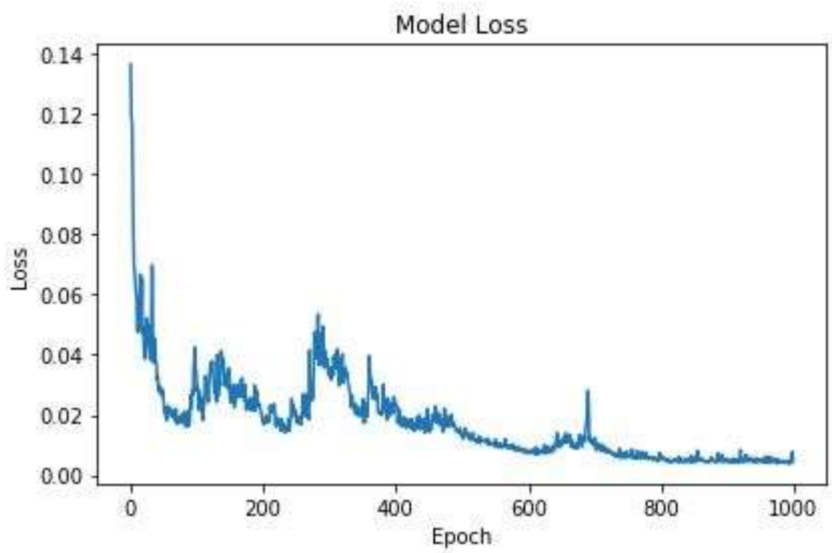


Figure 44. Autoencoder model loss per epoch for the RGB wooden block dataset.

The FIU team implemented the You Only Look Once version 3 (YOLOv3) object detection architecture. YOLOv3 is a deep learning approach that allows for real time inferencing with highest accuracy. The main benefit is that an image only passes once through the network for the objects to be found. The speed of the network makes YOLOv3 suitable for objection detection in streaming videos, static videos, and images. Having an end-to-end architecture, YOLOv3 is the current state-of-the-art technology for detection speed.

YOLOv3 uses the Darknet structure, which has 53 convolutional layers. In order to perform object detection, an additional 53 layers are stacked on top of Darknet. The entire network is composed of 106 layers. This new architecture uses residual skip connections and up-sampling techniques. The residual skip connections are used to tackle the issue deep learning networks have trying to converge. The connections work by connecting the output on one layer with the input of an earlier layer.

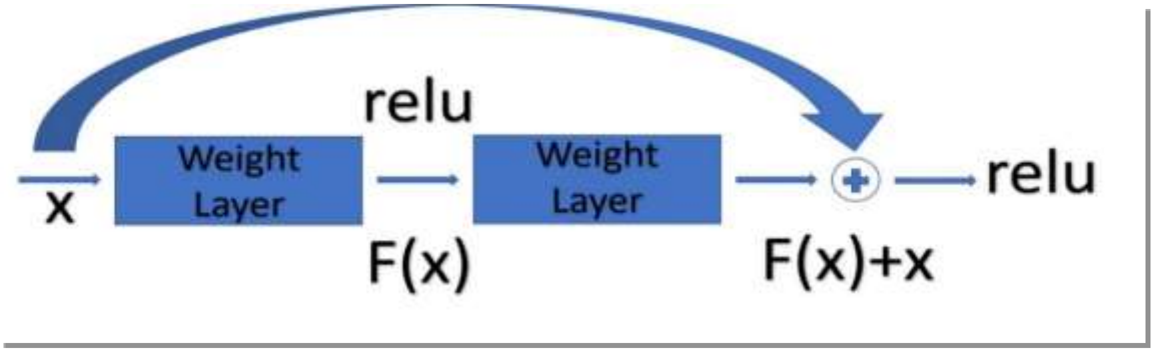


Figure 45. Skip connection implementation.

Usually a deep learning model learns the mapping, M, from an input x to an output y. This relationship is expressed as follows.

$$M(x) = y$$

Instead of learning a direct mapping, the residual function leverages the difference between the original input x and a mapping applied to x.

$$f(x) = M(x) - x$$

Using the skip connection, we get:

$$M(x) = f(x) + x$$

In this case, it is much easier to optimize the residual function, f(x), than the original mapping.

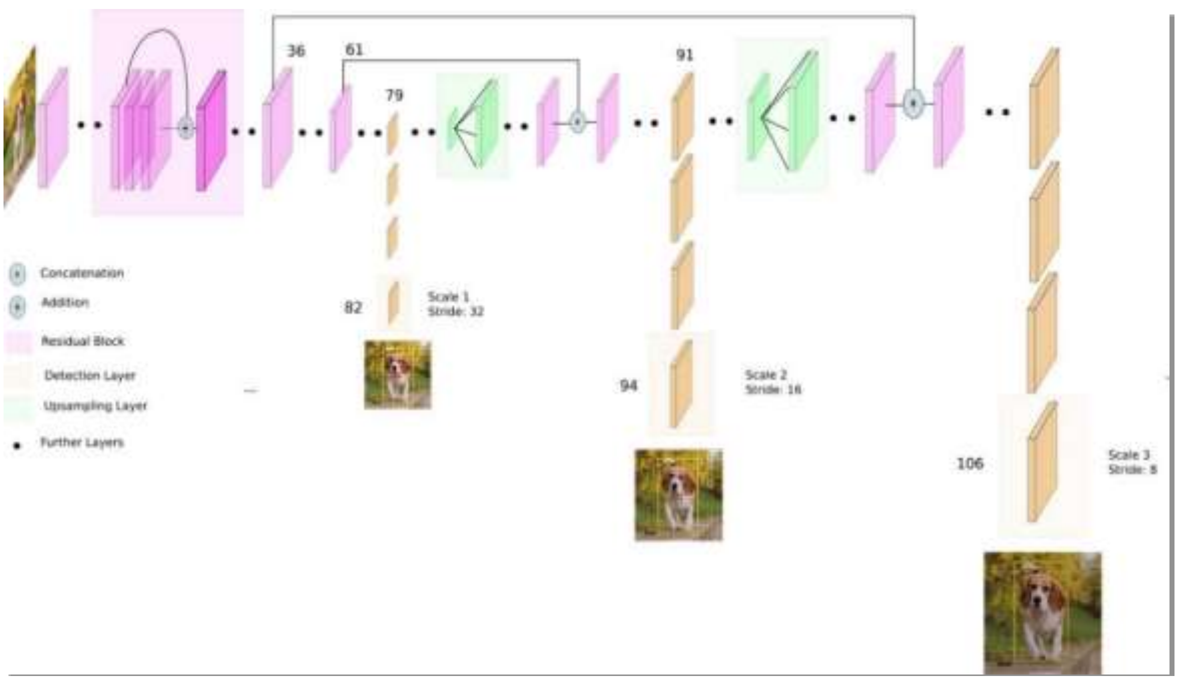


Figure 46. You Only Look Once version 3 (YOLOv3) architecture.

Source: https://towardsdatascience.com/yolo-v3-object-detection-53fb7d3bfe6b

Results:

The YOLOv3 Network was able to learn the wooden block image dataset. The loss function converged at a value of 14.25 and the training lasted 200 iterations. GPU processing is required for training these models since CPU is not powerful enough to train in a tractable timeframe. The depth of the YOLOv3 architecture makes it very demanding on memory resources during the training process. The FIU team was able to perform inferencing and object detection at roughly 22 frames per second. Currently the model is not fully optimized, and team is working on hyper parameter tuning.

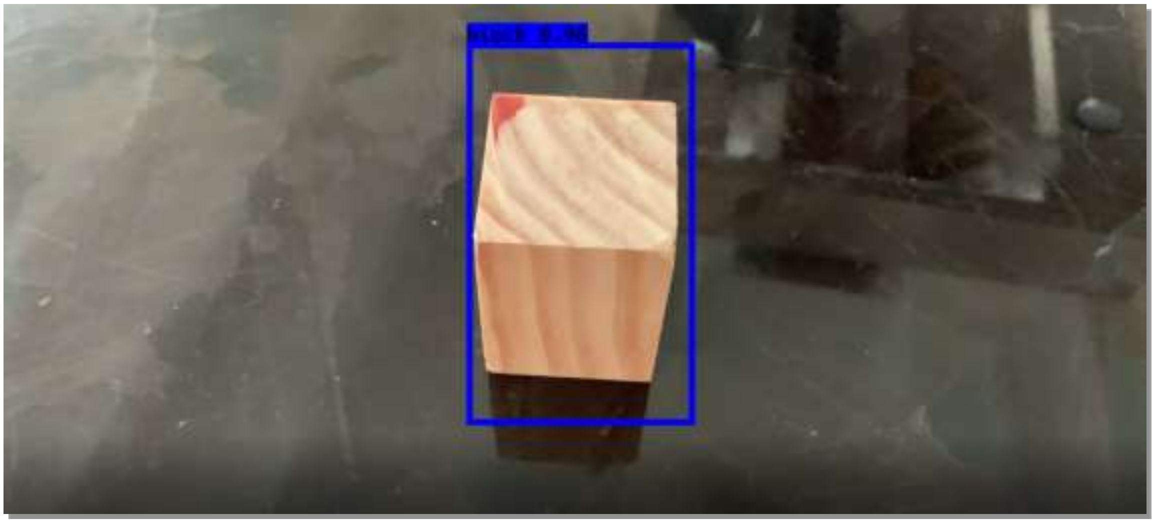


Figure 47. YOLOv3 model detecting wooden block on a countertop surface with 0.96 confidence score.

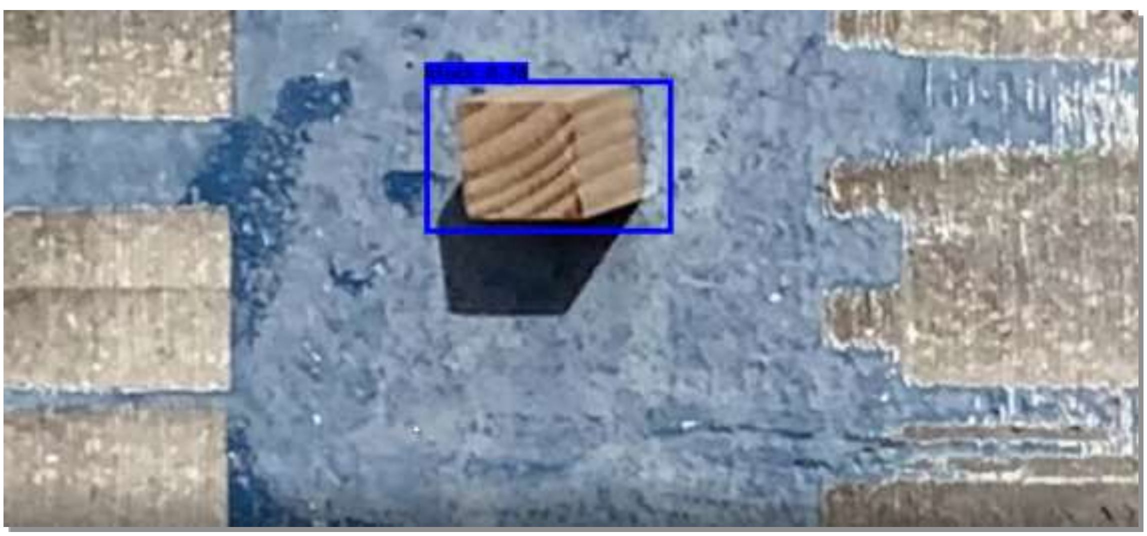


Figure 48. YOLOv3 model detecting wooden block on outdoor test facility mock-up wall with 0.78 confidence score.

In May 2020, the team began transitioning its research to focus on object detection using Light Detection and Ranging (LIDAR) data.

Current Approach & Algorithm:

Data Collection: The LiDAR point cloud data was collected from the test facility at FIU. The set of four blocks are stacked on the wall as an object. LiDAR scans are collected to see and identify the four wooden blocks along the side of the wall. The data collection using the LiDAR device included using a semi-autonomous platform that can obtain colored point clouds in ideal environments using LiDAR. The map was generated by the platform, by driving it around the environment and then saving using map_server node. The team used a loop closing SLAM program, such as Google cartographer, to generate maps for the best results, by running a command to let the robot autonomously navigate to the set goals while building a colored point cloud of the environment. This point cloud contains data comprised of X, Y, Z coordinates as well as R, G, B values. The collected data is saved into a specified folder as a text file.

Data Preprocessing: The FIU team worked on data preprocessing of LiDAR point cloud data by initially removing unnecessary data points such as points belonging to people and the floor using the open source software, CloudCompare. Consequently, only the wall data was left. The wooden blocks located on the wall as well as subsets of the wall were isolated and saved to text files.

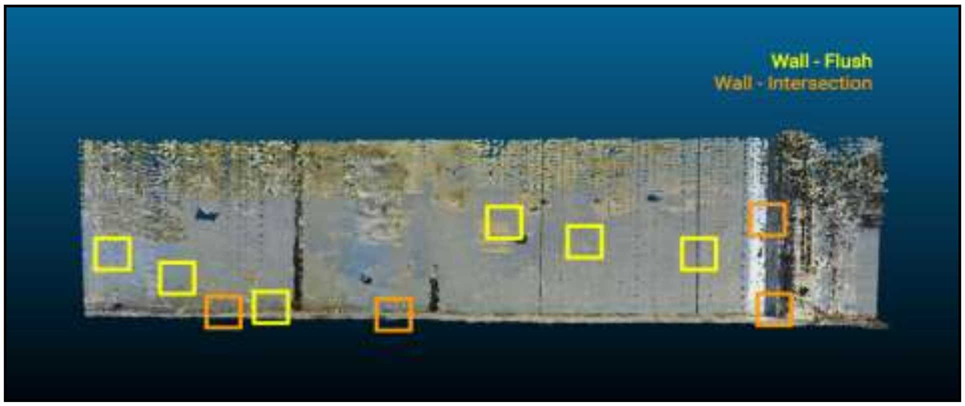


Figure 49. Isolated portions of the wall.

Figure 50. Isolated blocks.

Now that that these two groups of items (block and wall data) have been saved separately, the preprocessing was started. To normalize the data, the origin of each object was reset by subtracting each axis by the respective minimum of that object. In other words, it was ensured that each object's range starts at zero. For example, if for a given object the X axis' range is (4.18, 5.6) then after the transformation, the range will be (0, 1.42). In order to convert the data to a quantifiable unit, all the data is multiplied by a calculated factor leaving the data in terms of centimeters.

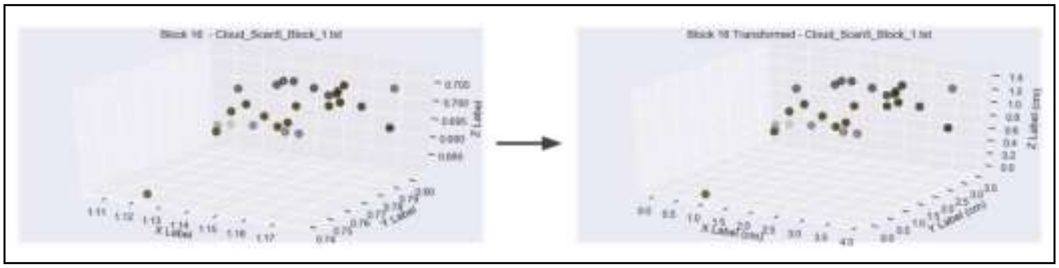


Figure 51. Plots of a block before and after transformation, left and right respectively.

Lattice grid structure: A lattice structure is simply a mathematical ordering where numbers fall within integer intervals. This structure does not allow any decimal values except for integers. With this type of structure, it could allow floating point values to be approximated to a fixed sized lattice.

Even though the data is now in an understandable unit, there is still a problem if this data is fed to a neural network. Now, each data entry varies in the number of points it contains. Some blocks/walls contain 20 points while others contain 200. This variability is not good for a neural network which expects a fixed sized input. To combat this issue, a solution was devised to approximate each object to a lattice grid.

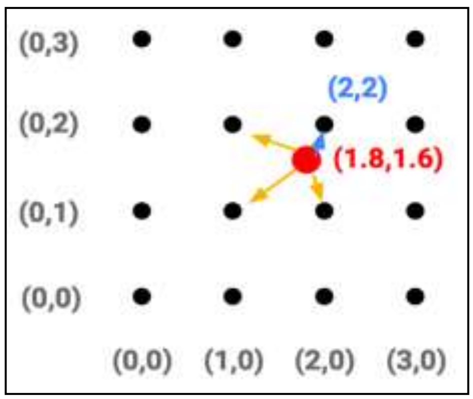


Figure 52. Point approximation onto a 2D lattice.

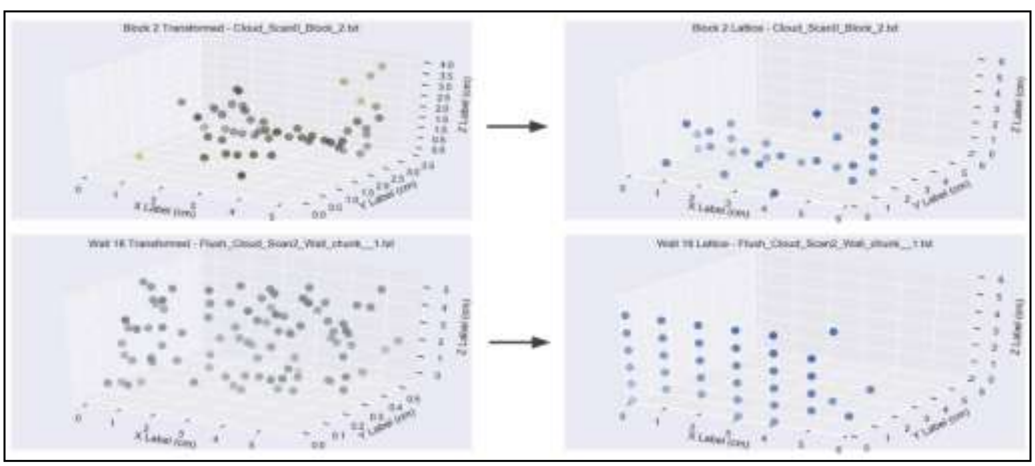


Figure 53. Plots of objects before and after lattice transformation, left and right respectively.

The point approximation technique seen in Figure 53 was applied to all the data, leaving a three-dimensional array of zeros where there is no point and ones where a point exists. This set of 3D arrays can be labeled appropriately and fed to a neural network.

Neural network design: Since there is no longer an enormous amount of data samples to work with, many neural network architecture variations seem to perform very well. The following design is an example of an architecture that gives good results:

Input → Dense (8) → Dense (8) → Dense (16) → Flatten → Dense (2)

As mentioned previously, the input of the network is a 3D array of 0s and 1s. The last layer of the network is a dense layer of 2 neurons since it is preferable that the probabilities of the input belong to either Class 0 (wall) or Class 1 (block).

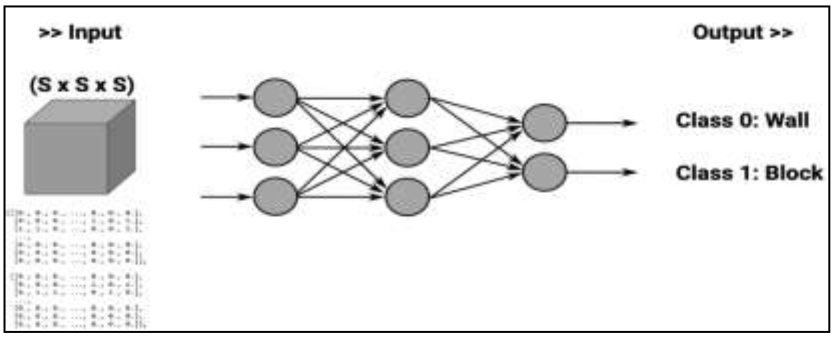


Figure 54. Simplified network architecture showing the input and output.

Results:

The current approach of converting the raw data into a three-dimensional lattice structure has been producing great results so far. Even though with the data highly polished, the results prove that there is potential for future work. Below is a graph showing the accuracy and loss metrics over training iterations. With the current data, an accuracy of 93 percent can be achieved on the selected test data.

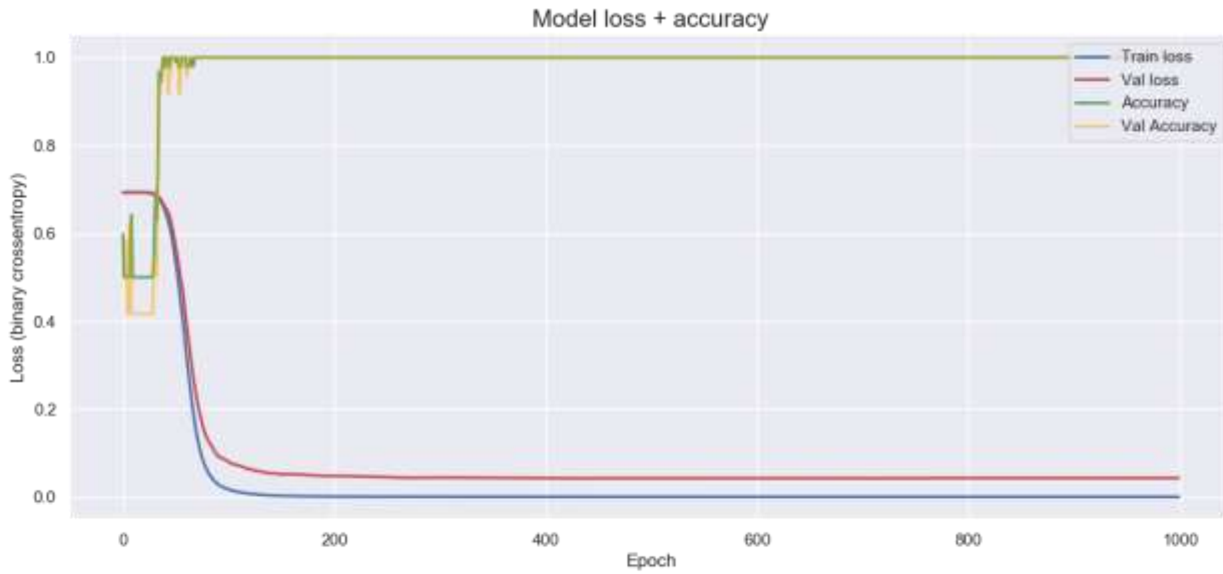


Figure 55. Graph of model accuracy and loss using the network architecture mentioned previously.

In June, it was determined that additional 3D images were needed to continue to develop the models. As such, 3D Rotations were created using quaternions to generate multiple 3D images of blocks. These new images are being used to mature the LiDAR deep learning models. Below is the specific process followed to successfully execute the generation of 3D images using quaternions.

1. Introduction

Due to limited block information in the LiDAR scans, the FIU team needed to find a data augmentation technique to increase the training data for the network; since the work is being done with 3-dimensional data, it makes sense to generate new data via rotations.

2. 3D Rotations using quaternions

The incentive for using quaternions to perform rotations instead of rotation matrices is its efficiency, compactness and speed.

Simplified idea of quaternions:

- Quaternions was invented by William Hamilton with the goal of trying to generalize complex numbers to 3 dimensions.
- Quaternions usually take on the form:
  - $q = a + bi + cj + dk$
- Quaternion conjugates takes the form:
  - $q^* = a - bi - cj - dk$
- The fundamental formula for quaternion multiplication:
  - $\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = \mathbf{ijk} = -1$
- Given 2 quaternions:
  - $q_1 = a_1 + b_1 i + c_1 j + d_1 k$
  - $q_2 = a_2 + b_2 i + c_2 j + d_2 k$

- $q_1 * q_2 =$
  $$a_1a_2 - b_1b_2 - c_1c_2 - d_1d_2 + (a_1b_2 + b_1a_2 + c_1d_2 - d_1c_2)i + (a_1c_2 - b_1d_2 + c_1a_2 + d_1b_2)j + (a_1d_2 + b_1c_2 - c_1b_2 + d_1a_2)k$$

- The magnitude of a vector v (x,y,z) is represented as:
  - $\| v \| = \sqrt{x^2 + y^2 + z^2} \| v \| = \sqrt{x^2 + y^2 + z^2}$
- The unit vector of vector v (x,y,z) is represented as:
  - $\acute{v} = \left(\frac{x}{\|v\|}, \frac{y}{\|v\|}, \frac{z}{\|v\|}\right) \acute{v} = \left(\frac{x}{\|v\|}, \frac{y}{\|v\|}, \frac{z}{\|v\|}\right)$
- The quaternion result of rotating a vector vv by $\alpha\alpha$(in radians) on the vector xx is:
  - $rot = q_{rotation} * v * q_{rotation} rot = q_{rotation} * v * q_{rotation}$
  - where $q_{rotation} = cos\left(\frac{\alpha}{2}\right) + sin\left(\frac{\alpha}{2}\right) * \acute{x}\, q_{rotation} = cos\left(\frac{\alpha}{2}\right) + sin\left(\frac{\alpha}{2}\right) * \acute{x}$

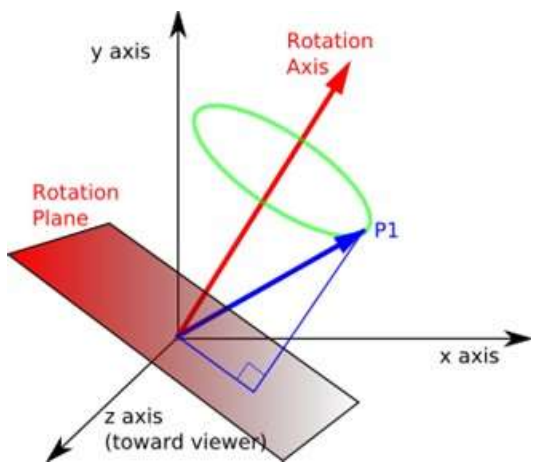


Figure 56. Quaternion (source).

Using these quaternion rules, rotations can be performed for each block in our dataset.

In the python implementation, each block is rotated:

- **on an axis of (x, y, z)** where x, y, and z are integers randomly selected between 1 and 10 inclusive.
- **by deg degrees** where deg is an integer randomly selected between 1 and 359 inclusive. (the code converts the degree into radians.)

3. Python code for the quaternion implementation

The following code shows the Python code implementation to generate multiple images with different angles to help build LiDAR models.

```
In [2]: # CODE FOR ROTATIONS USING QUATERNIONS

        # Rounds number n by decimal d
        def round_up(n, d=0):
            multiplier = 10 ** d
            return np.ceil(n * multiplier) / multiplier

        def truncate(n, d=0):
            multiplier = 10 ** d
            return int(n * multiplier) / multiplier

        def trunc_round(n, d=0):
            trunc = truncate(n, d+1)
            round_ = round_up(trunc, d)
            return round_

        # Multiplies 2 quaternions
        def multiply_q(q1, q2):
            w1, x1, y1, z1 = q1
            w2, x2, y2, z2 = q2
            w = w1 * w2 - x1 * x2 - y1 * y2 - z1 * z2
            x = w1 * x2 + x1 * w2 + y1 * z2 - z1 * y2
            y = w1 * y2 - x1 * z2 + y1 * w2 + z1 * x2
            z = w1 * z2 + x1 * y2 - y1 * x2 + z1 * w2
            return w, x, y, z

        # Get conjugate of q
        def conjugate_q(q):
            w, x, y, z = q
            return (w, -x, -y, -z)

        # Convert vector to quaternion
        def v_to_q(v):
            x, y, z = v
            return (0, x, y, z)

        # Convert quaternion to vector
        def q_to_v(q):
            w, x, y, z = q
            return (x, y, z)

        # Gets unit vector for a vector
        def getUnitVector(v):
            x, y, z = v
            magnitude = np.sqrt(x**2 + y**2 + z**2)
            return (x/magnitude, y/magnitude, z/magnitude)

        # Convert degree to radians
        def deg_to_Radians(deg):
            return np.radians(deg)

        # Gets the quaternion axis for rotation
        def axisAngle_to_q(v, deg):
            v = getUnitVector(v)
            x, y, z = v
            half_angle = deg_to_Radians(deg)/2
            w = np.cos(half_angle)
```

Figure 57. Python code used to general multiple block images based from the original.

```
    x = x * np.sin(half_angle)
    y = y * np.sin(half_angle)
    z = z * np.sin(half_angle)
    return w, x, y, z

# Rotates vector v on axis ax by deg degrees
def rotate_vector(v, ax, deg):
    q_rotation = axisAngle_to_q(ax, deg)
    q_rotation_conj = conjugate_q(q_rotation)
    v = v_to_q(v)
    rotation = multiply_q(q_rotation, v)
    rotation = multiply_q(rotation, q_rotation_conj)
    result = q_to_v(rotation)
    x, y, z = result
    x = trunc_round(x, 8)
    y = trunc_round(y, 8)
    z = trunc_round(z, 8)
    return (x, y, z)

# Generates random vector and degree
def generate_rand_rotation():
    x = randint(1,11)
    y = randint(0,11)
    z = randint(0,11)
    deg = randint(1,360)
    return (x, y, z, deg)
```

Figure 58. Continuation of Python code used to general multiple block images based from the original.

LiDAR scan data (Wall images)

Data Collection:

The team has uploaded six new scans of the wall to the model-building algorithm in an effort to continue to mature the LiDAR models. This ongoing process helps models to be more efficient and precise.

The FIU team experimented with CloudCompare. It is a 3D point cloud processing software. It can also handle triangular meshes and calibrated images. It is now an independent open source project and a free software.

Pre-processing the LiDAR scan data using CloudCompare:

The “CloudCompare” tool was used to pre-process and visualize the latest wall images generated using LiDAR device. The LiDAR files can be dragged and dropped into the CloudCompare software as shown in Figure 59.

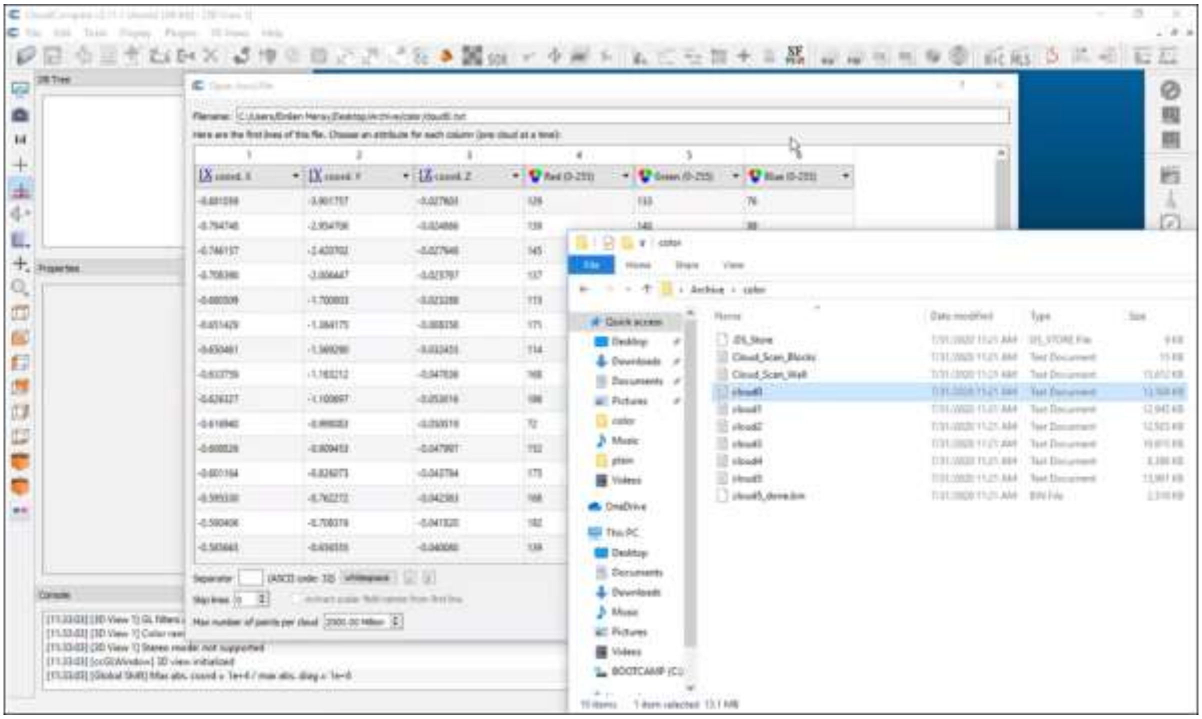


Figure 59. Importing the image files into the software.

Once the file is imported into the software, it can be viewed using the specific tools and methods, as shown Figure 60. This tool is used to pre-process and filter the required portion from the image (blocks and walls in this case). Various configurations can be changed to get a better understanding of the image. One of these features is the point size (which is quite small by default), that can be changed to get a more wholesome representation of the data.

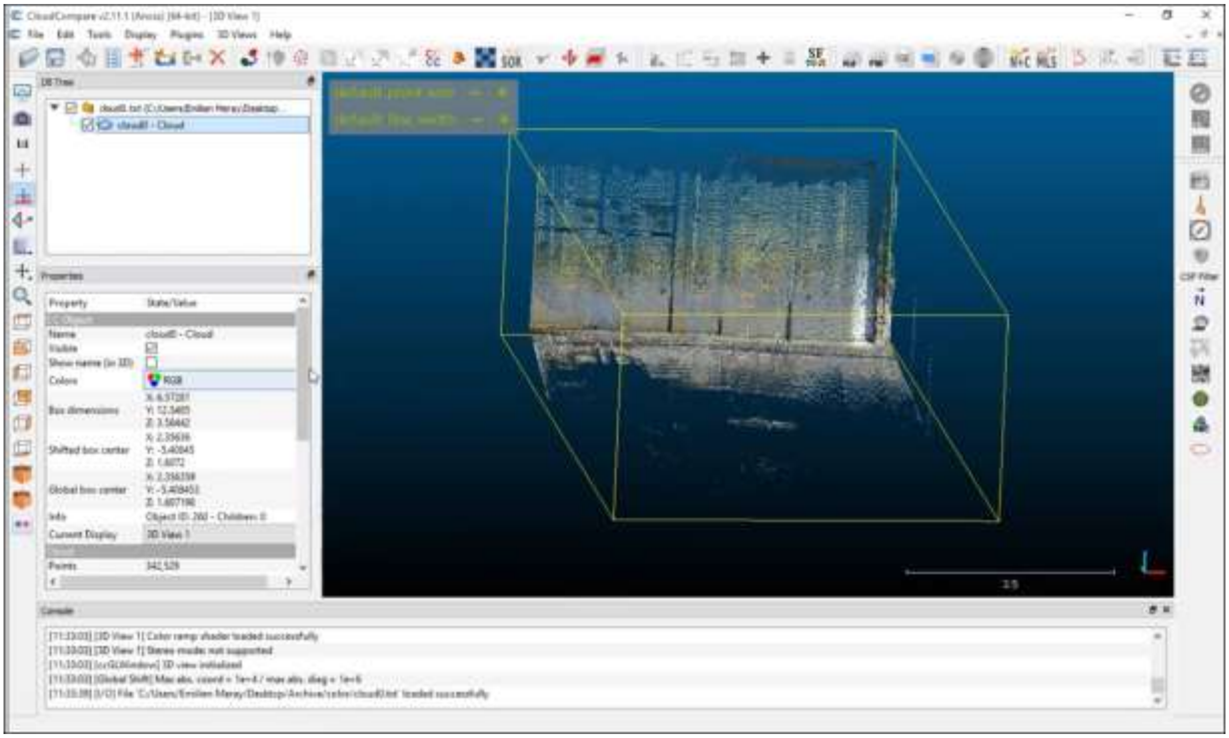


Figure 60. Visualizing the image files into the software.

The FIU team collected more LiDAR data for analysis. Unlike the initial time that data was collected, the scans were taken indoors, and four objects were placed on the wall as opposed to just one, the wooden block. The four unique objects are a curved PVC pipe, a plastic block, a helmet, and a small spherical ball. These objects can be seen in Figure 61.

Figure 61. Lidar scan setup.

Data Pre-processing:

The open sourced software CloudCompare was used to manually isolate each object and saved to separate files to be used for classification. We also isolated portions of the wall to be able to train the neural network. Figure 62 shows the LiDAR scans with the objects labeled.

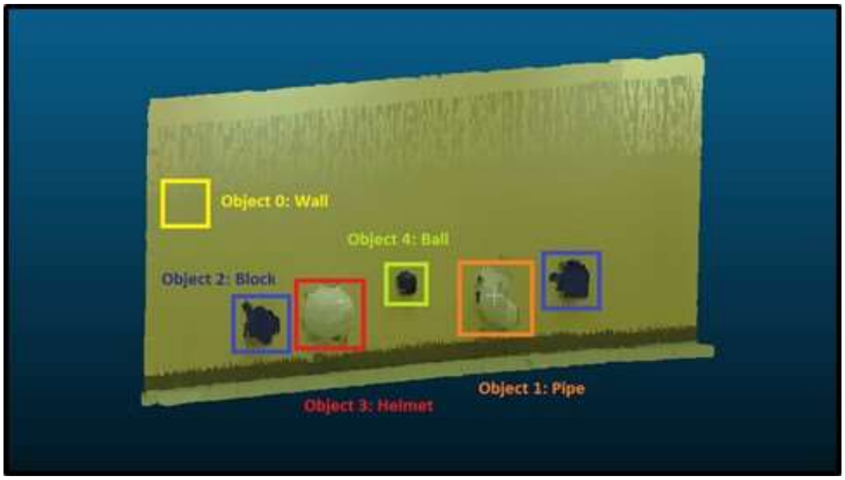


Figure 62. Sample LiDAR scan with all the objects labeled appropriately.

Data Augmentation:

A total of 71 files were generated to use for analysis. To increase the number of data points used for training and testing, data augmentation techniques were used. The team performed 3-dimensional scaling and rotations using quaternions resulting in a 500% increase of data points.

Data Transformation:

To standardize the data for training using a neural network, the origin of each object was reset by subtracting each axis by its respective minimum and converting the result to a lattice structure. As a reminder, the lattice structure is a fixed structure that does not allow any decimal values except for integers.

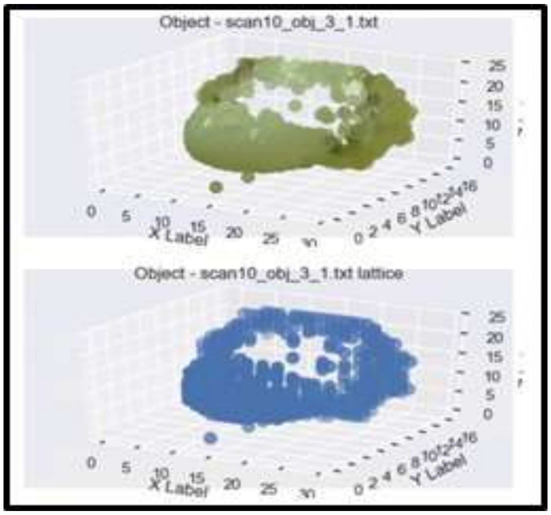


Figure 63. Plot of a helmet before and after the lattice transformation, top and bottom respectively.

Since we are working with larger objects than the first trial using the wooden blocks, the size of the lattice was increased from 7^3 to 50^3; this way, all the objects fit inside the same lattice structure. Figure 63 shows an example of one object (a helmet) before and after the lattice transformation.

Neural network design:
The following network architecture gave acceptable results:
Input → Dense (16) → Flatten → Dense (5)

The last layer of the network is a dense layer of 5 neurons since probabilities of the input belonging to all the 5 classes are desired:

- Class 0 (wall)
- Class 1 (pipe)
- Class 2 (block)
- Class 3 (helmet)
- Class 4 (ball)

Results:

Through experimentation, a very small network, described above, produced good results. An accuracy of about 94% on the training set and 75% on the testing set using a 70% / 30% split respectively was achieved. The model accuracy and loss can be seen in Figure 64 below.

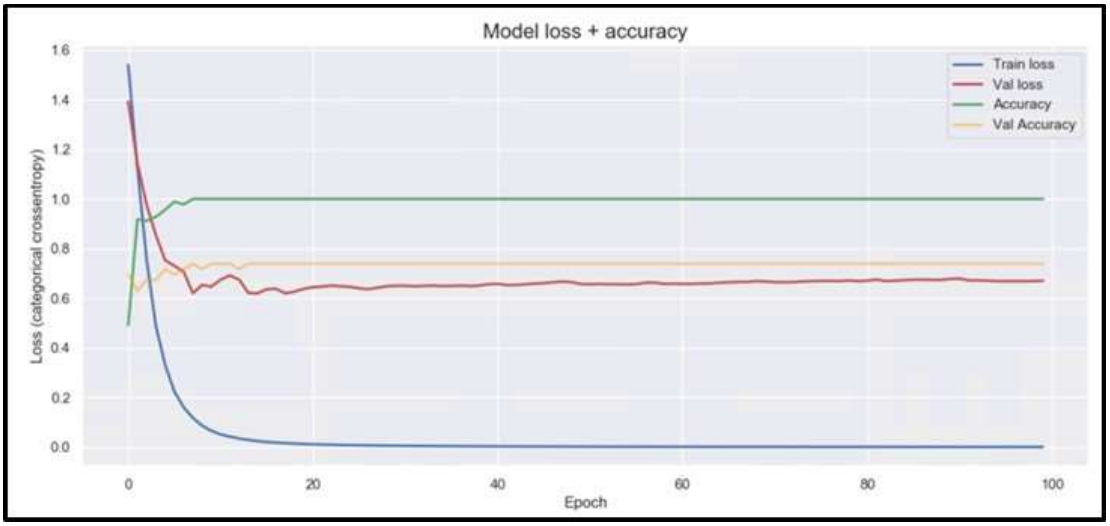


Figure 64. Graph of model accuracy and loss using the network architecture mentioned previously.

The model seemed to do very well on objects with distinct features. For example, the helmet received a high accuracy for correctly classifying the object (Figure 65). On the other hand, there was some difficulty classifying objects with similar characteristics. For example, the wall and the block; both objects have flat surfaces and thus the model is not as accurate in differentiation and classification of the objects.

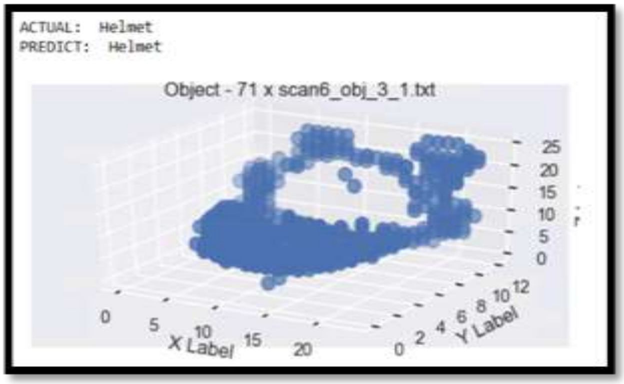


Figure 65. Sample test object that was correctly classified.

Next Steps:
From what was observed in the results, the team will experiment and find out why the neural network does not learn with more than 2 hidden layers. Determination of the cause will enable higher accuracy beyond 75%. In addition, adding more hidden layers will allow the model to extract more features from the input and be more accurate in classifying objects with similar features such as the wall and the block.

The FIU team presented the research performed on this task to DOE HQ officials and DOE Site POCs on August 25-26, 2020. This presentation consisted of accomplishments during this period of performance and plans for future work. The presentation shared with the team can be downloaded from the DOE Research website maintained by FIU at https://doeresearch.fiu.edu/.

In the month of September, the FIU team continued working on developing a neural network model using the data collected in the previous month.

Data Collection:
The 28k image dataset used in the previous task is used to train the Convolutional AutoEncoder (CAE) network. Small modifications are performed in order to make the dataset compatible with the current approach. The proposed network uses images that are 128, 256, and 512 pixels in width and height for input. An image preprocessing routine was created to scale images to the correct size.

Algorithm:
The FIU team implemented a new state of the art robust solution for anomaly detection. This new architecture uses a Convolutional AutoEncoder (CAE) followed by an image post processing routine to generate an anomaly heat map of the predicted defects in the input images. The approach was taken from the recent work published by Chow et al. (J.K. Chow, 2020), and the unsupervised learning method is being used in this research.

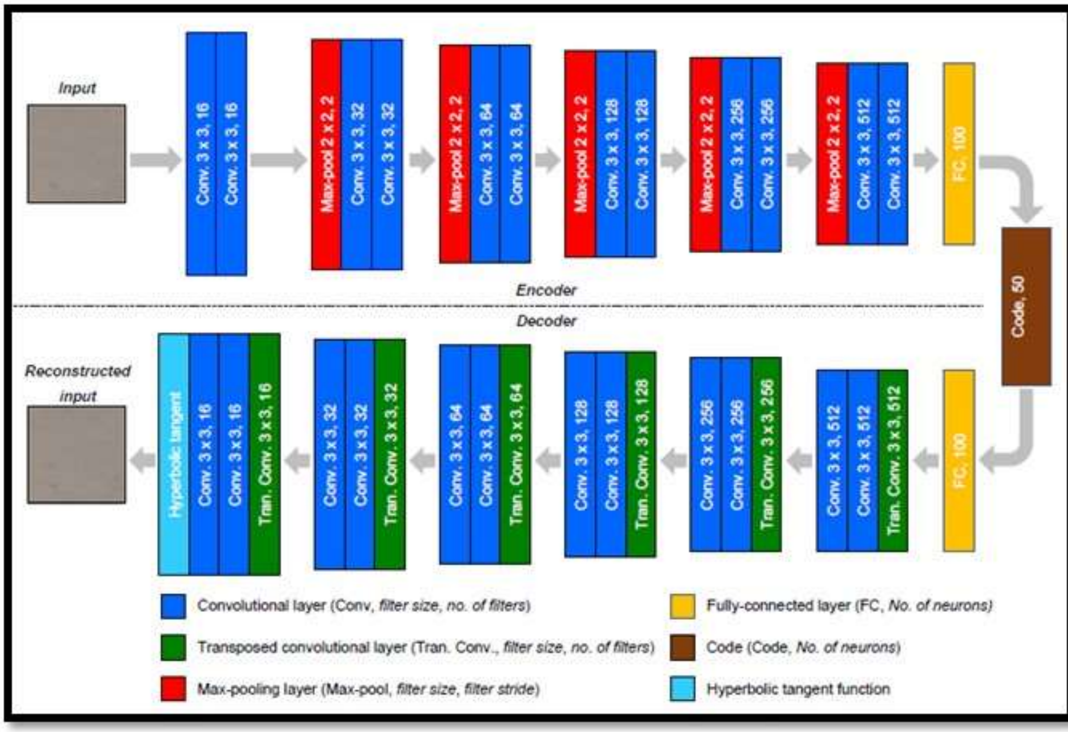


Figure 66. Convolutional Autoencoder network design. Source: (J.K. Chow, 2020).

The CAE network (Figure 66) works by training on defect-free images in an unsupervised manner. This is a huge advantage in the implementation, as the dataset does not have to be manually labeled or annotated. The model uses mean squared error (MSE) for the loss function and it is trained until the MSE value converges to a satisfactory value. The fully trained model can reconstruct images from its training dataset distribution with a low reconstruction error. In contrast, images that do not belong to the training dataset distribution will be reconstructed with a much higher reconstruction error.

The anomaly detection (Figure 67) is performed by comparing the input image given to the trained model and an output image generated. Comparison is performed by doing a pixel subtraction between the two images. The result is a new image with the reconstruction error, which is analyzed using image processing. Ideally, sections of the image that are recognizable by the trained model will have a low reconstruction error and the anomalous areas will have a high reconstruction error. This error is visualized by plotting a heat map from the pixel subtraction comparison. The heat map uses a threshold value so that the contrast between normal and anomalous sections is clearly distinguishable.

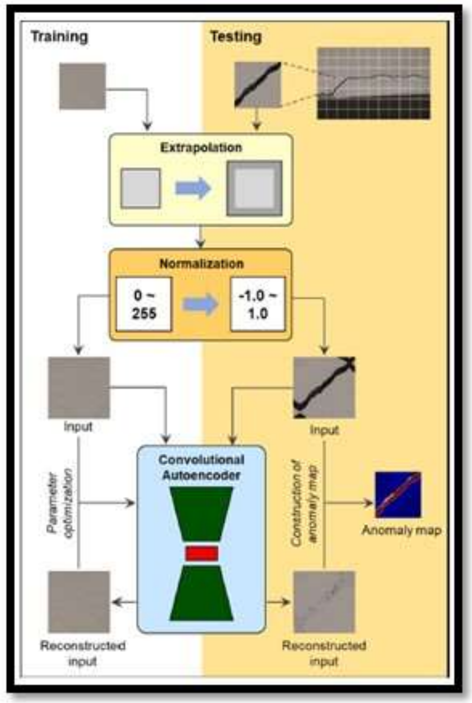


Figure 67. Processing pipeline for training and testing [1]. Source (J.K. Chow, 2020).

FIU submitted an abstract for the 2020 Waste Management Symposia capturing the research and efforts on D&D KM-IT during 2019. The abstract was submitted on August 30, 2019 and is titled "Artificial Intelligence Application to D&D". The abstract was accepted on October 1, 2019 and was delivered as an oral presentation at the conference, which was held in Phoenix, Arizona. FIU started to develop the full paper for WM2020 in October. Below are the session, data and time when the paper was presented:

Abstract: 20492 Artificial Intelligence Application to D&D
Session: 140 - Application of Innovative D&D Technologies Including Application of Virtual Reality (6.7b)
Date: Thursday March 12, 2020
Time: 1:00 PM - 4:35 PM

In November, FIU submitted the full paper to the 2020 Waste Management Symposia on November 15, 2019, capturing the research and efforts on D&D KM-IT during 2019.

FIU prepared a poster for WM2020 capturing the progress of this research during the past year. The poster contains background information and objective of the research. It highlights the tools used in this research (Artificial Intelligence, Machine Learning and Deep Learning). Finally, it summarized the used case that was applied (D&D Structure Health Monitoring) to validate the research effort. A picture of the poster is included below.

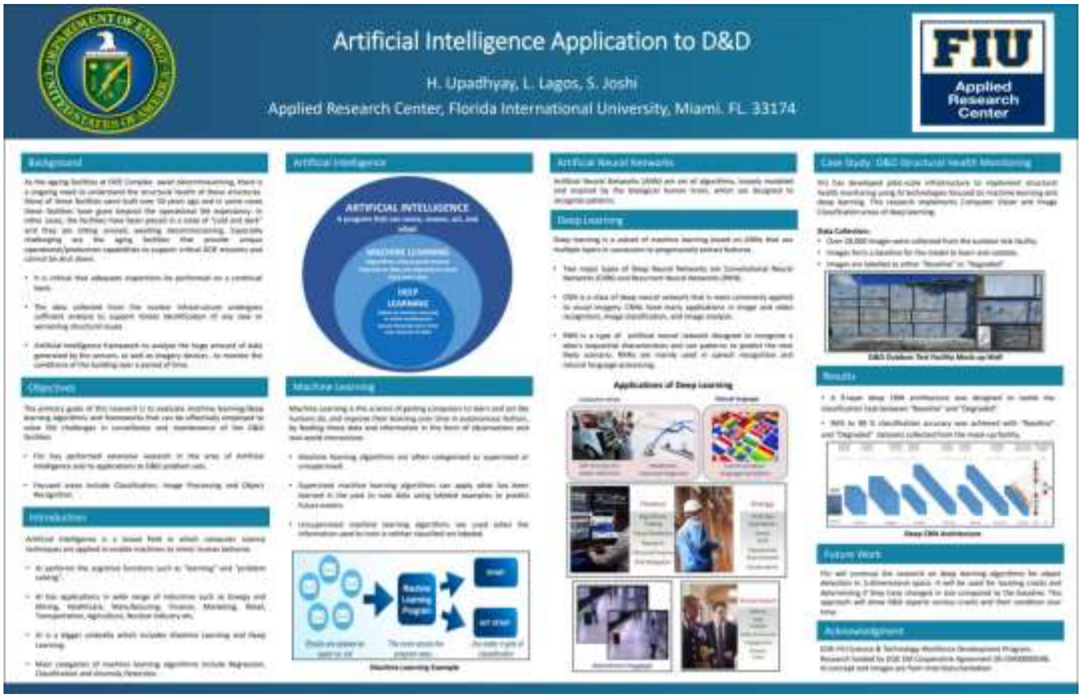


Figure 68. Artificial Intelligence Application to D&D poster presented at Waste Management 2020.

The poster above was presented at WM2020 in Phoenix, AZ on March 10, 2020. A picture of the poster presented by Dr. Himanshu Upadhyay and DOE Fellow Roger Boza is shown below.

Figure 69. Dr. Himanshu Upadhyay and DOE Fellow Roger Boza

Figure 70. From left to right: FIU's Ravi Gudavalli, Dr. Himanshu Upadhyay, and DOE Fellow Roger Boza.

Task 6: Conclusions

The team has successfully constructed the CAE network in python using TensorFlow as the backend and the Keras library for rapid prototyping. The code compiles without any errors and can run in both CPU and GPU hardware. The image pre-processing for creating a set of cropped images with a sliding window approach from a high-resolution image works as expected. The network is ready to begin the training phase.

The results of the research conclude that deep learning is a viable option for structural health monitoring. The high accuracy and low Type I/Type II errors are strong indicators that neural networks can learn from a baseline and thus infer the health condition of a structure. Further modifications and additional research are required to make the model more robust and adaptable to different environments. Using images for structural health monitoring is a stepping-stone in the advancement of monitoring systems but it has limitations. Images do not contain the full story of the environment it captures. 2D images represented by pixels using red, green, and blue (RGB) lack depth information. Depth is extremely important and necessary to accurately determine the health of a structure. Using light detection and ranging (LiDAR) scans is the next step in the data collection process to accurately capture the 3D space of a structure.

Task 6: References

Li Deng and Dong Yu (2014), "Deep Learning: Methods and Applications",
http://dx.doi.org/10.1561/2000000039

D. C. Dennett, "Introduction to deep neural networks",
https://deeplearning4j.org/documentation2015

TensorFlow - An open source software library for machine intelligence,

https://www.tensorflow.org/2015

Sabokrou, M., Khalooei, M., Fathy, M., & Adeli, E. (2018). Adversarially learned one-class classifier for novelty detection. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (pp. 3379-3388).

[1] J.K. Chow, Z. S. (2020). Anomaly detection of defects on concrete structures with the convolutional autoencoder. Advanced Engineering Informatics.

CONFERENCE PARTICIPATION, PUBLICATIONS & AWARDS

Professional Conference Presentations and Proceedings

Komninakis, M., J. Sinicrope, T. Donoclift, J. Nicholson. Certifying the Performance of Fixative Technologies under Open Air Demolition Activities for D&D, Waste Management 2020 Conference, Phoenix, AZ, March 2020.

Donoclift, T., J. Nicholson, B. Peters, L. Mathurin, M. Komninakis, T. Simoes-Ponce (DOE Fellow), J. Sinicrope. Advancement of Commercial Intumescent Expanding Foams for Deactivation and Decommissioning in the Nuclear Sector, Waste Management 2020 Conference, Phoenix, AZ, March 2020.

Himanshu Upadhyay, Walter Quintero, Leonel Lagos. Waste Information Management System with 2019-20 Waste Streams. Waste Management 2020 Conference, Phoenix, AZ, March 2020.

Walter Quintero, Himanshu Upadhyay, Leonel Lagos. Research on KM-IT Platform. Waste Management 2020 Conference, Phoenix, AZ, March 2020.

Himanshu Upadhyay, Leonel Lagos, Santosh Joshi. Artificial Intelligence Application to D&D. Waste Management 2020 Conference, Phoenix, AZ, March 2020.

Graduate Research Activity – Presentations and Proceedings

Simoes-Ponce, T. (2019). Adhesion Capabilities of Permanent Foaming Fixatives for D&D Activities. DOE Fellows Poster Exhibition 2019.

Simoes-Ponce, T. (DOE Fellow), J. Sinicrope, M. Komninakis, T. Donoclift, L. Lagos, J. Nicholson. Mechanical Properties of Polyurethane Foams for D&D Activities, Waste Management 2020 Conference, Phoenix, AZ, March 2020.

**Simoes-Ponce, T. (DOE Fellow), J. Sinicrope, L. Lagos, J. Nicholson. Adhesion Capabilities of Permanent Foaming Fixatives for D&D Activities, Waste Management 2020 Conference, Phoenix, AZ, March 2020.

**NOTE: WM Symposia awarded the rating of a "Superior Paper" for the "Adhesion Capabilities of Permanent Foaming Fixatives for D&D Activities" paper.

Student Awards

Tristan Simoes-Ponce – DOE Fellow of the Year; 2nd Place DOE Fellows Poster Exhibition 2019 (Graduate Competition)

ACKNOWLEDGEMENTS

Funding for this research was provided by U.S. DOE Cooperative Agreement #DE-EM0000598. FIU's Applied Research Center would like to acknowledge the commitment of DOE-EM to this specific workforce development project and to all the research being conducted as part of the Cooperative Agreement. The partnership between DOE EM and FIU has resulted in the development and training of outstanding minority STEM students that will benefit this country as a whole.

APPENDIX

The following documents are available at the DOE Research website for the Cooperative Agreement between the U.S. Department of Energy Office of Environmental Management and the Applied Research Center at Florida International University: https://doeresearch.fiu.edu

FIU Year 10 Annual Research Review Presentations:

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

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

Date Submitted to OSTI (mm/dd/yyyy)	OSTI ID	*STI PRODUCT TITLE:	Publication/ Issue Date
09/09/2020	1658912	PROJECT TECHNICAL PLAN - Project 1: Chemical Process Alternatives for Radioactive Waste	12/13/2019
09/09/2020	1658920	Literature Review of Adhesion Mechanisms For Mobile Platforms	4/10/2020
09/15/2020	1660375	Summary of Testing for the Miniature Rover with Integrated UT Sensor	7/24/2020
09/15/2020	1660379	Initial Testing for the H-Canyon Study	8/14/2020
09/15/2020	1660434	FIU PROJECT 1: Chemical Process Alternatives for Radioactive Waste	8/25/2020
09/15/2020	1660389	PROJECT TECHNICAL PLAN - Project 2: Environmental Remediation Science & Technology	12/13/2019
09/15/2020	1660396	FIU PROJECT 2: Environmental Remediation Science & Technology	8/25/2020

09/16/2020	1660534	PROJECT TECHNICAL PLAN - Project 3: Waste and D&D Engineering and Technology Development	12/13/2019
09/16/2020	1660535	EXPERIMENTAL DESIGN: Quantifying / Certifying the Effects of Radiological Fixating Materials & Technologies ISO Source Term Calculations and Open Air Demolition	1/31/2020
09/16/2020	1660536	FIU PROJECT 3: Waste and D&D Engineering and Technology Development	8/25/2020
09/16/2020	1660539	PROJECT TECHNICAL PLAN - Project 4: DOE-FIU Science and Technology Workforce Development Program	12/13/2019
09/16/2020	1660538	Subtle Process Anomalies Detection using Machine Learning Methods	12/20/2019
09/16/2020	1660543	Neptunium (IV) Diffusion through Bentonite Clay	12/20/2019
09/16/2020	1660544	Amplicon Sequencing Assessment to Measure Microbial Community Response from Heavy Metal Contaminated Soils in Savannah River Site, Tims Branch Watershed	12/20/2019
09/16/2020	1660714	An Assessment of Long-Term Monitoring Strategies and Developing Technologies	12/20/2019
09/16/2020	1660717	Mechanical Properties Permanent Foaming Fixatives for D&D Activities	12/20/2019
09/16/2020	1660721	Contributing to the DOE EM 4.1 and 4.12, Office of Groundwater and Subsurface Closure	12/20/2019
09/17/2020	1660918	Double Shelled Tank Visual Inspections	12/20/2019
09/17/2020	1660919	H-6bR Water density Stratification Investigation	12/20/2019
09/17/2020	1660921	2D Dam-Break Analysis of L Lake and PAR Pond Dams Using HEC-RAS	12/20/2019
09/17/2020	1660922	Plutonium Migration from Estuary Sediments (Ravenglass, UK)	12/20/2019
09/17/2020	1660923	FIU PROJECTS 4 & 5: DOE-FIU Science and Technology Workforce Development Program	8/25/2020
09/17/2020	1660925	PROJECT TECHNICAL PLAN - Project 5: DOE-FIU Science and Technology Workforce Development Initiative for Office of Legacy Management (NEW)	12/13/2019
09/17/2020	1660926	DOE-FIU Science and Technology Workforce Development Initiative for Office of Legacy Management	4/30/2020

09/18/2020	1661159	Biotic dissolution of autunite under anaerobic conditions: effect of bicarbonates and Shewanella oneidensis MR1 microbial activity.	Environmental Geochemistry and Health/12/19/2019. https://doi.org/10.1007/s10653-019-00480-7