Robotic Technologies for Nuclear Remediation, Test and Evaluation, Knowledge Management, and Student Training

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Abstract: For over 20 years, the Applied Research Center (ARC) at Florida International University (FIU) has conducted university based fundamental and applied research for the U.S. Department of Energy's Office of Environmental Management (DOE EM) in the area of deactivation and decommissioning (D&D), high level waste (HLW) processing, technology innovation, development, testing/evaluation, and deployment; knowledge management; and STEM student training. Recent research with innovative robotic/remote systems include the development of a mini rover system and a pneumatic pipe crawler developed for the inspection of double shell tanks (DST) at DOE's Hanford Site in east Washington State. Other innovative remote system developments have included the design and prototyping of a wall decontamination system and the test and evaluation of a wall climbing remote system patented by International Climbing Machines (ICM). In addition, FIU is currently working to identify cross-cutting robotic technologies being developed for other applications that could potentially be used in support of hot cell and glove box D&D activities. The test and evaluation of D&D technologies includes investigating the effectiveness of commercially available intumescent coatings to enhance the fire resiliency of fixatives and facilities in support of D&D projects facing potential fire and/or extreme heat conditions; developing a to-scale hot cell testbed for testing, evaluating, and demonstrating technologies; and evaluating an advanced fogging agent developed at Idaho National laboratory (INL) for fixing loose radioactive contamination as well as for knocking down airborne particulates. To collect, maintain, preserve and disseminate the D&D knowledge base from DOE and around the world, FIU developed an online web-based system, the D&D Knowledge Management Information Tool (D&D KM-IT), to capture the knowledge, experience, and lessons learned from past and present D&D projects. The D&D KM-IT currently hosts information on over 1,300 D&D technologies, including over 521 robotic and remote systems. Finally, the scientific research being performed at ARC provides real-world hands-on training for FIU STEM students through the DOE Fellows Program, preparing the workforce of tomorrow to meet the challenges of the nation's largest environmental cleanup mission.

Keyword: Nuclear Remediation, Robotic Platform, Knowledge Management (KM), STEM, Workforce Development and Training, DOE Fellows

1 Introduction

Florida International University's Applied Research Center (ARC) has been performing research and technology development for the environmental cleanup of the U.S. Department of Energy nuclear weapons complex sites since 1995. ARC engineers, scientists and students apply specialized knowledge and skills in state-of-the-art research facilities to understand the underlying science and develop and deploy technology solutions to complex environmental challenges while training the environmental workforce of tomorrow. Applied research areas at ARC include: 1) deactivation and decommissioning (D&D); 2) high level waste (HLW) processing; 3) technology innovation, development, testing/evaluation, and deployment; knowledge management; and 4) STEM student workforce development and training.

2 Robotic Technology Development

ARC's robotics research includes development of systems to facilitate the safe environmental remediation of the DOE EM contaminated facilities across the DOE complex. The research and development (R&D) activities concentrate on robotic inspection, surveying, as well as, D&D by implementing the latest technology.

A few of the robotic technologies being developed at ARC in support of the DOE EM mission are described in this section.

2.1 Pneumatic Pipe Crawler

The pneumatic pipe crawler is an inspection tool designed to inspect radioactive pipelines with sizes between 3- and 4-inches in diameter, while providing video, environmental and structural feedback. The device is currently being developed at ARC for the robotic inspection of the ventilation header of the AY-102 double-shell tank, storing radioactive waste at the Hanford Site. The worm-type robot has a modular design, composed of interchangeable modules connected with flexible links. The device can be customized for several specific tasks with the addition of extra modules, such as instrumentation, material sampling, and pipe repair. The design is an evolution of the pipe crawlers previously developed at ARC, and uses pneumatic actuators to emulate the contractions of the peristaltic movement (see Figure 1).

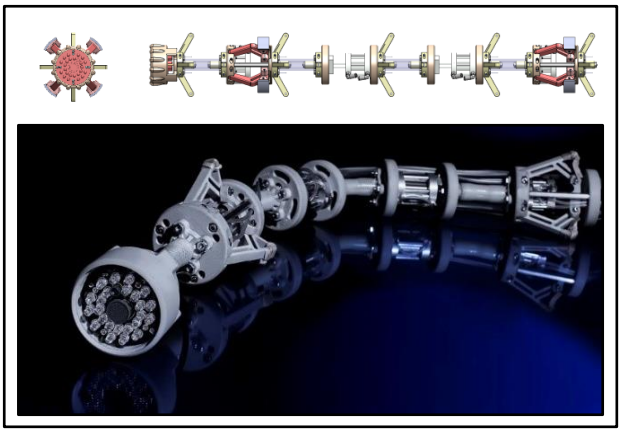

Fig.1 Pneumatic Pipe Crawler.

2.2 Mini Rover

The mini rover is a miniature robotic system designed for the inspection of the primary tank floor through the refractories of the double-shell tanks at the Hanford Site. It is a remotely controlled device that can navigate through the air refractory slots to the central plenum of the tank by traveling upside down along the tank floor via magnets. Integrated inspection sensors facilitate measurements of temperature, humidity and radiation levels within the refractory channels. The mini rover is equipped with a camera for visual feedback, and can navigate semi-autonomously for the tank floor visual inspections. It is low cost, easily swappable and disposable. In addition, minimal modifications will allow the mini rover to navigate through the drain slots (see Figure 2).

Fig.2 Mini Rover.

2.3 Wall Climber Robot

The wall climber is a robotic vehicle that is able to climb a vertical flat surface for the purposes of monitoring and inspection. The unit is extremely light and utilizes a fan/motor to create a suction force that keeps the system attached to the wall. It is designed to be low-cost, easy to operate and remotely controlled with various sensor integrations (see Figure 3).

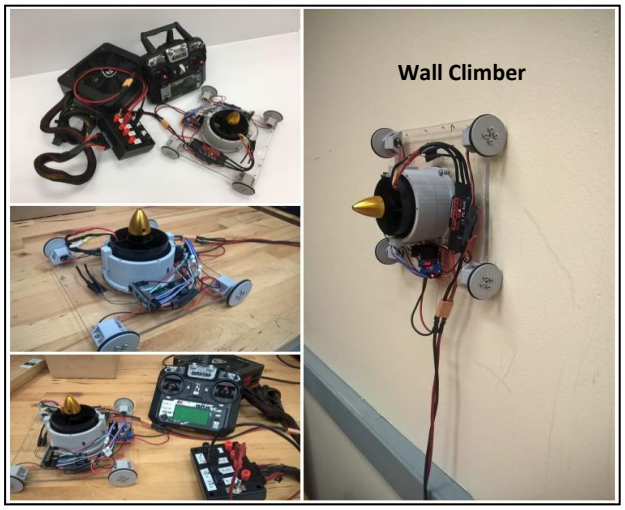

Fig. 3 Wall Climbing Robot.

2.4 Wall Climber for Hot Cell Inspections

Based on initial observations and findings from the test and evaluation of incombustible fixatives for hot cell application conducted under ARC's D&D Technology Test & Evaluation research area (see Section 3 below), a potential requirement for a remote dry film thickness gauge capability has been identified. Determining the precise thickness of fixatives applied

in restricted spaces (e.g., hot cells) and confirming they are within specified parameters throughout the area has proven exceptionally challenging. Based on this need, one of ARC's robotic platforms is being modified and paired with a dry film thickness gauge to validate the thickness of the fixative application throughout the radioactive space. The current research includes:

- developing a conceptual design for the inspection tool,
- evaluating deployable coating thickness sensors,
- investigating different communication methods between microcontrollers and sensors, and
- investigating a better tether construction alternative.

Also for this research, ARC is planning to use a controller area network (CAN bus) in the tether design. The conceptual design is based on the existing wall climbing platform currently being developed at ARC. The existing technology, shown in Figure 4, has the potential to be successfully deployed to measure thickness of fixative coatings. These types of coatings are commonly applied to stabilize radioactive contamination during D&D activities of hot cells.

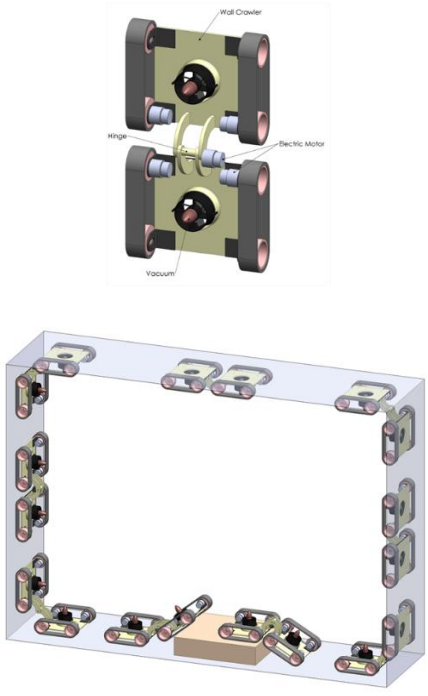

Fig.4 Wall Climber for Hot Cell Applications.

3 D&D Technology Test & Evaluation

ARC has over 20 years of experience in performing research in the area of the D&D of nuclear facilities, having participated in over 300 projects since 1995 in support of the DOE's Office of Environmental Management. As part of this support, ARC has evaluated baseline and innovative technologies for D&D applications; to date, over 150 technologies have been assessed at ARC's facilities in Miami, at DOE sites, and at technology vendors' facilities. Specific current areas of research include:

- D&D technology innovation, development, demonstration, evaluation, and deployment;
- Adaptation of intumescent coatings to enhance fire resiliency and protection for fixatives and facilities in support of D&D activities at SRS 235-F and across the DOE EM complex;
- Implementation of a phased approach for the standards development, testing, evaluation, and deployment of D&D technologies, with an initial emphasis on intumescent coatings and fixatives; and
- Cross-cutting applications of robotic technologies from ARC's high-level waste research area in support of D&D activities.

The primary objective of this task is to standardize and implement proven processes to refine and better synchronize DOE-EM technology needs, requirements, testing, evaluation, and acquisition by implementing a three-phased technology test and evaluation model. The development of uniformly accepted testing protocols and performance metrics is an essential component for testing and evaluating D&D technologies. Current research in this area includes the following efforts:

3.1 Uniform Testing Protocols and Performance Metrics for D&D

ARC is continuing to work with the ASTM International E10.03 Subcommittee on Radiological Protection for Decontamination and Decommissioning of Nuclear Facilities and Components to move forward with creating consensus-based, international standards for D&D technologies. In discussions with federal and

international regulators, as well as commercial entities conducting the environmental restoration of various nuclear sites, many of the social and human factors associated with technology deployment (e.g., providing a regulatory umbrella to mitigate legal risk and exposure, stakeholder contribution and ownership, incentivizing adoption of the new over the existing baseline technology, etc.) can be alleviated by: 1) leveraging international organizations that employ adaptive management principles through consensus-based, whole-of-society stakeholder involvement to develop and promulgate scientifically grounded international standards and testing protocols for fixative technologies used in D&D, and; 2) referencing these new standards to update decades old regulation and directives guiding the environmental restoration of nuclear sites. This approach addresses challenges encountered by science and technology solutions intended to operate in highly regulated industries characterized by risk adverse business practices, unfavorable public perception, outdated directives, and a host of other social dimensions.

The next bi-annual meeting is scheduled for January 21-23, 2018, in New Orleans, LA. The focus of this meeting will be on initiating the development of standardized testing protocols for: 1) determining a fixative's ability to immobilize radioactive contamination and measuring its impacts on airborne release fractions (ARF) and respirable fractions (RF) in the source term formula when exposed to thermal and seismic stressors, and; 2) determining the decontamination factor (DF) of strippable coatings on various substrates. Both of these objectives are directly aligned with and in support of DOE EM's incombustible fixatives research need, and based on significant feedback received from the DOE sites and national labs, have been integral in facilitating the introduction of a designated intumescent coating technology into a contaminated environment. They also provide empirical data that could be used to address other DOE EM initiatives such as updating DOE handbooks, capturing and archiving lessons learned and best practices in a systematic manner, etc. Over the past year, this effort has resulted in the publication of two new ASTM international standard specifications for fixative technologies (July 24, 2017).

3.2 Technology Demonstration under Nonradioactive Conditions at FIU

FIU ARC, in close collaboration with Savannah River National Laboratory (SRNL), led the development and implementation of a phased approach to improve the operational effectiveness of fixative technologies in the critical area of fire resistance to better address the unique D&D challenges being faced by the Savannah River Site (SRS) 235-F Project and other high priority D&D projects across the DOE complex. Leveraging firsthand knowledge and experience of ARC research scientists in the use of intumescent coatings to harden facilities and improve fire protection in support of the U.S. military, it was hypothesized that commercial-off-the-shelf (COTS) intumescent materials could be adapted to enhance fire resiliency in fixatives and potentially mitigate the release of radioisotopes when exposed to thermal stressors. Over the past 2 years, ARC and SRNL have successfully navigated the safety basis issues for introduction of this technology at the site, and the research has progressed to the point where a designated intumescent coating technology will be tested and evaluated in a contaminated facility this fiscal year. Figure 5 shows the outdoors hot cell mockup at ARC. Figure 6 shows a duplicate hot cell typically found at a DOE facility as well as handheld sprayer tool used during the application of fixatives and intumescent coatings.

Fig.5 Hot Cell Mockup Facility.

Fig.6 Hot Cell Structure & Handheld Sprayer.

4 D&D Knowledge Management & Cyber Security

ARC performs applied and advanced research in the areas of enterprise systems, cyber security and data science. The solutions are tailored to deliver critical information to federal, state, local governments and the private sector clients, keeping them well informed, connected and secure. ARC has built enterprise solutions using multi-tiered / service oriented architecture on the Microsoft platform. Specific research areas that support the DOE-EM mission include: database management, machine learning, data mining, mobile applications, cyber security, cyber analytics and visualization, and knowledge management (KM).

4.1 D&D Knowledge Management

To help prevent the loss of the collective knowledge from EM's aging workforce, the need to collect, retain and disseminate knowledge in an organized and structured way through the development and maintenance of a universally available and usable knowledge management system was identified by DOE-EM, resulting in the design and development of the Knowledge Management Information Tool (KM-IT) at ARC. The system was developed to help capture and maintain the experience-base of EM's knowledge across the DOE complex. The long-term active use, operation, development and continued growth of the knowledge base within the KM-IT system will result in enhanced worker safety, improved operational efficiencies, and enable the cross-generational transfer of knowledge to the future workforce.

The system includes 12 modules and it can be accessed at www.dndkm.org. D&D KM-IT currently hosts information on over 1,337 D&D technologies, including over 521 robotic and remote systems technologies. The system has over 988 registered users from around the world, 103 subject matter specialists, and over 954 D&D vendors. In addition, the system contains 169 reports from the Hanford and Savannah River ALARA Centers as well as 231 Innovative Technology Summary Reports (Green Books). Figure 8 shows a sample of data analytics.

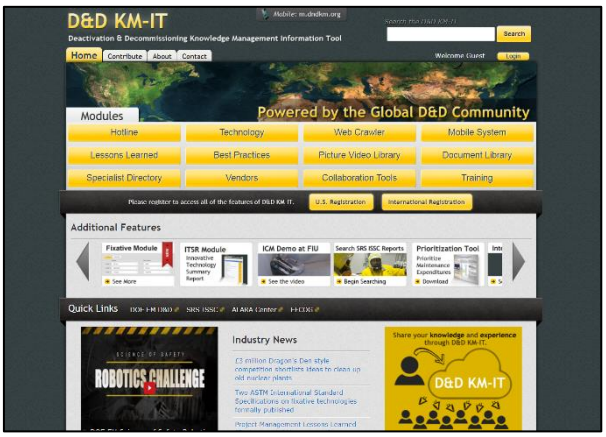

Fig. 7 Web-based KM-IT System.

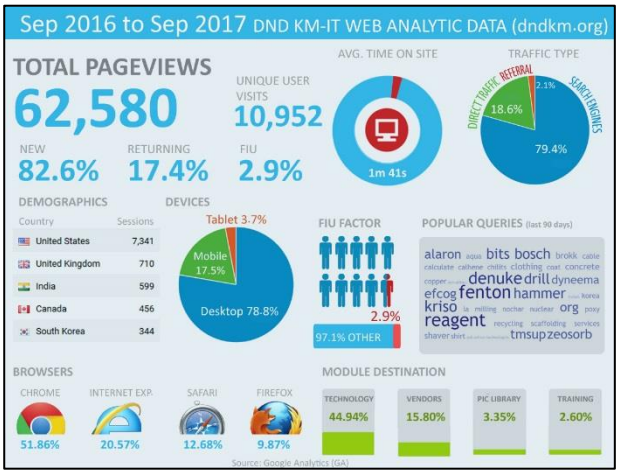

Fig. 8 KM-IT Web Analytic Data 2017.

4.2 Native Mobile Application

ARC is developing a pilot native mobile application for the D&D Fixatives Module to be deployed on the Android platform. This module can assist in the selection of commercially available fixatives, strippable coatings, and decontamination gels for application during D&D activities. A native application is an app that is developed for use on a specific platform and which is downloaded onto a

mobile device in order to be accessed. As such, the native app does not need an internet connection to be used. Figure 9 shows a screen shot of the pilot app.

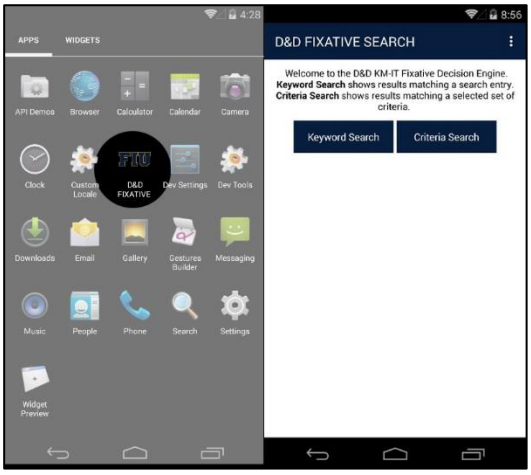

Fig. 9 Native App for Fixatives.

4.3 Cyber Security

FIU ARC is conducting hypervisor research with the purpose to of improving cyberspace monitoring and analysis. This research is being conducted using virtualization technologies to deliver automated and real-time analysis of cyberspace attacks on distributed systems. This approach enables quick deployment and fine-grained monitoring of malware including analysis of their effects on live systems as well as their propagation patterns within the compromised network.

As cyber threats keep evolving, it is very important to develop new custom sensors and custom data analysis tools to understand the new threats, and to disseminate the new knowledge to cyber defenders. The Kernel Q Agent Testbed will provide custom sensors and data analysis tools for Kernel Q injection threats, a novel malware attack technique.

5 STEM Workforce Development & Training

The DOE-FIU Science and Engineering Workforce Development Program is designed to build upon the existing DOE/FIU relationship by creating a "pipeline" of minority scientists and engineers specifically trained and mentored to enter the U.S. Department of Energy's workforce in technical areas of need. The main objective of the program is to provide interested students with a unique opportunity to integrate course work, DOE field work, and FIU applied research into a well-structured academic program, providing the successful graduate with the ability to leverage their education, skills, knowledge, and distinctive work experiences to the pursuit of careers in DOE, DOE national labs, DOE contractors, other federal agencies, or STEM related industry.

The mission of this program is to build upon FIU's long research relationship with DOE to create a "pipeline" of minority environmental engineers and scientists. The vision to meet this mission includes:

- Provide top quality minority students with a unique opportunity for hands-on research and a potential career with the DOE;
- Enhance the quality of student, faculty & staff R&D through close collaborations with scientists from national labs; and
- Stimulate greater numbers of minority students to enter STEM disciplines at graduate and undergraduate levels.

Since the program inception in 2007, a total of 131 FIU STEM minority students have been inducted as DOE Fellows. A total of 120 internships have been completed at DOE facilities across the US and over 172 poster/paper presentations have been completed by our students at national and international conferences such as the Waste Management Symposia (Phoenix, AZ), American Nuclear Society and American Chemical Society meetings. Figure 10 shows our DOE Fellows participating at the 2017 Waste Management Symposia. The DOE Class of 2016 is shown in Figure 11.

Fig.10 DOE Fellows at WM17, Phoenix, AZ.

Fig. 11 DOE Fellows Induction Ceremony 2016

6 Conclusions

The environmental restoration and cleanup of the U.S. Nuclear Weapons Complex is being managed by the U.S. Department of Energy's Office of Environmental Management. During the last 20 years, DOE EM has successfully completed significant accomplishments in its mission. Nevertheless, the mission still has approximately another 50 years before completion. To complete this mission, new technologies and a skilled future workforce will be needed to complete one of the most challenging nuclear cleanup projects in the world. FIU ARC has supported DOE EM during the last 20 years and provided technology development, test and evaluation, as well as knowledge management expertise to aid DOE in its mission. Finally, the scientific research being performed at ARC not only provides solutions to DOE EM technical challenges but also provides real-world hands-on training for FIU STEM students through the DOE Fellows Program, preparing the workforce of tomorrow to meet the challenges of the nation's largest environmental cleanup mission.

Nomenclature

None.

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