D&D Toolbox Project – Florida International University Technology Demonstration of a Whirling Nozzle for Fixatives Application in Hot Cell Interiors – 10430

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ABSTRACT

The objective of the Decontamination and Decommissioning (D&D) Toolbox Project is to use an integrated systems approach to develop a suite of D&D technologies, a D&D toolbox, that can be readily used across the Department of Energy (DOE) complex to improve safety, reduce technical risks, and limit uncertainty within D&D operations. Florida International University (FIU) is supporting this initiative by identifying technologies suitable to meet specific facility D&D requirements, assessing the readiness of those technologies for field deployment, and conducting technology demonstrations of selected technologies at FIU facilities. To meet the technology gap challenge for a technology to remotely apply fixative coatings, FIU is currently working on the demonstration of a whirling nozzle to apply fixatives to hot cell interiors. These whirling nozzles have been used at the Hanford Tank Farms with great success to apply fixatives to valve pits. FIU conferred with Hanford to select fixatives and dilution ratios that have been successfully used at the Tank Farms with the whirling nozzles. FIU completed the construction of a hot cell mockup facility at the FIU technology demonstration/evaluation site in Miami in 2008 and completed preliminary testing of the whirling nozzle in November 2009. The technology was deployed from outside the hot cell facility via a remote platform through an entry door and sprayed a fixative to immobilize loose/removable contamination on horizontal and vertical surfaces within the hot cell.

INTRODUCTION

Many facilities slated for decontamination and decommissioning (D&D) across the Department of Energy (DOE) complex pose hazards (radiological, chemical, and structural) which prevent the use of traditional manual techniques. Safe and efficient D&D of these facilities will require the use of remotely operated technologies. In addition, the D&D of a hot cell facility requires that each of the hot cells be decontaminated to a prescribed level and the remaining radiological contamination stabilized to allow demolition to occur while controlling worker radiation exposure to as-low-as-reasonably-achievable (ALARA) and without spreading any remaining radioactive contamination. One stabilization step typically relies on the application of a fixative coating (or similar material) to all hot cell surfaces to hold contamination in place during hot cell demolition. A study on available remote technologies for D&D activities, performed by Florida International University (FIU) and NuVision Engineering, indicated that there was no remotely operated technology available to meet the need for the remote application of fixative coatings [1]. This gap between the identified needs and the available technologies is especially critical for hot cell facilities, where access is typically very limited.

The objective of the D&D Toolbox Project is to use an integrated systems approach to develop a suite of D&D technologies (D&D toolbox) that can be readily used across the DOE complex to reduce technical risks, improve safety, and limit uncertainty within D&D operations. FIU is identifying technologies suitable to meet specific facility D&D requirements, assessing the readiness of those technologies for field deployment, and conducting technology demonstrations of selected technologies at FIU facilities.

To meet the technology gap challenge for a technology to remotely apply fixative coatings, FIU is currently working on the demonstration of a whirling nozzle to apply fixatives to hot cell interiors. These whirling nozzles have been used at the Hanford Tank Farms with great success to apply fixatives to valve pits. FIU conferred with Hanford to select fixatives and dilution ratios that have been successfully used at the Tank Farms with the whirling nozzles. FIU completed the construction of a hot cell mockup facility at the FIU technology demonstration/evaluation site in Miami in 2008. The hot cell mockup facility was then used in November of 2008 for the technology demonstration of an International Climbing Machine (ICM) robotic climber with a custom spray applicator for remotely spraying fixative on the hot cell facility surfaces [5].

Preliminary testing of the whirling nozzle was completed in November 2009 at the hot cell mockup facility in Miami. Additional testing was completed in December 2009. The selected technology was deployed from outside the hot cell facility via a remote platform through a man-entry door and sprayed a fixative to immobilize loose/removable contamination. The technology evaluation documents the ability of the remote system to spray fixative product(s) on all horizontal and vertical surfaces within the hot cell.

MATERIALS AND METHODS

Testing of the mobile platform and the whirling nozzle was conducted to demonstrate “proof-of concept” under conditions similar to those actually found in a DOE hot cell facility. This work constitutes an experimental, initial phase of method evaluation.

Applied Research Center (ARC) evaluators were present at all times for the duration of the testing to record performance data and take photographs and videos during the technology’s operation. A detailed technology demonstration test plan was developed for this technology evaluation [2]. During the demonstration, ARC evaluators gathered data concerning the technology’s operation, performance, maintenance, health and safety aspects, cost, benefits, and limitations, and the ability of the technology to be decontaminated.

FIU was responsible for providing operators for the technology equipment and the same operators were available throughout the duration of the demonstration to ensure continuity of operation and consistency of comments and feedback.

Testing included the following:

1. Trial-runs of the mobile platform and whirling nozzle were performed to determine the required fixative flow rate as a function of the applied pressure and the fixative’s ability to coat the hot cell surfaces. As the nozzle head revolves, it should cover the entire area with an effective amount of fixative. As pressure increases, relative droplet size decreases. If pressure is elevated too high, an ineffectual mist is created. The manufacturer recommended increasing flow rate rather than pressure as a more efficient method. Trial runs were also used to work out any logistical requirements of the technology. Initial trial runs were performed using only water and subsequent preliminary testing was performed using a basic flat latex paint as the fixative. The trial runs of the whirly nozzle were also used to determine the optimal fixative dilution ratio.

2. Testing of the whirling nozzle in the hot cell mock-up. This demonstration was performed from the side entry point and performance was evaluated as per FIU’s test plan [2]. The preliminary testing placed the whirling nozzle at 15 feet from the entry wall and equidistant from each side wall (Walls A and C). Further testing placed the whirling nozzle at two locations, each five feet from each side wall (Walls A and C), and at 5 feet and 15 feet from the entry wall. The surfaces

sprayed included 4 walls, the ceiling and the floor surface within the hot cell mockup. Table I describes the surfaces sprayed.

Table I. Hot Cell Mockup Surfaces Sprayed With Fixatives

Surface	Description	Dimensions	Notes
Wall A	Pre-existing long wall	10' x 20' 3 m x 6 m	
Wall B	Pre-existing short wall	10' x 10' 3 m x 3 m	
Wall C	Newly constructed long wall with window	10' x 20' 3 m x 6 m	Window and exhaust fan were covered prior to spraying.
Wall D	Newly constructed short wall with entry door	10' x 10' 3 m x 3 m	Entry door was covered with plastic during active spraying.
Floor	Pre-existing floor	10' x 20' 3 m x 6 m	1 coat
Ceiling	Pre-existing ceiling	10' x 20' 3 m x 6 m	Lighting fixture mounted to ceiling was disconnected and removed prior to spraying.

3. At the conclusion of each phase of the technology demonstration, the equipment was "decontaminated" with water, Simple Green (or equivalent) and disposable wipes. The need for equipment and personnel decontamination is highly field site –specific and requires consideration of the following factors:
    - types of onsite contaminants
    - levels of contamination
    - personal protection levels utilized
    - work activities performed
    - evaluation/testing parameters

    The test "decontamination" procedures were performed on all equipment and accessories that entered the hot cell mock-up. The decontamination station consisted of the following:
    - overall equipment clean up steps
    - equipment disassembly steps
    - equipment and accessories clean up
    - equipment's cable removal & clean up
    - collection/disposal of waste and consumables
    - PPE disposal/cleanup
    - clean up material collection/disposal

TEST SITE DESCRIPTION

The Applied Research Center at FIU uses its state-of-the-art facilities to conduct research and development, testing, evaluation, and validation for new and innovative technologies to support DOE and industry. ARC's headquarters, laboratories, and technology demonstration facilities are part of FIU's Engineering Center, a 243,000-square-foot (22,575 m2) building that occupies 38 acres (0.15 km2) in Miami, FL. ARC facilities include numerous specialized laboratories and facilities, including the outdoor Technology Assessment Facility that was the location of this technology demonstration. The technology demonstration was conducted under standard non-nuclear conditions.

A hot cell mock-up was built at the outdoor technology assessment facility for technology demonstrations. The hot cell design represents a typical DOE site facility hot cell in size, construction materials, and points of access. The hot cell mock-up is 3-m wide x 6-m long x 3-m high (10-ft wide x 20-ft long x 10-ft high) and has an entry point at one end as well as a window in the side. The construction of the wall is poured concrete and Plexiglas was installed over the window. Figure 1 shows the hot cell mockup facility from the outside.

Fig. 1. Hot cell mockup facility at FIU-ARC's outdoor Technology Assessment Facility.

TECHNOLOGY DESCRIPTION

Potential vendors and technologies were researched via: (1) FIU D&D technology databases, (2) internet search, and (3) Hanford ALARA Center. The Lechler whirling nozzles were selected for the initial technology demonstration based on the experiences at the Hanford Tank Farms. Figure 2 shows the Lechler whirling nozzle (Series 569).

The Lechler whirling nozzle is from Lechler's line of tank cleaning nozzle products. As such, it was originally designed to be used with water and cleaning fluid. However, the Hanford Tank Farms have successfully used the whirling nozzle to apply fixatives in valve pits. This device is a rotating nozzle that is lowered into a tank pit and applies fixative in all directions, coating pit walls, floor, and ceiling.

The following information and specifications for the whirling nozzle is from the Lechler tank cleaning nozzles product brochure [3]. The Series 569 whirling nozzle has the following features:

- Flat jet nozzles with improved vertical coverage
- Better balance for smoother operation
- Fits through small openings
- Slip-on or thread connection
- Free spinning, self-lubricating and self-flushing
- Maximum tank diameter: rinsing – 4.5 m (15 ft), cleaning – 3 m (10 ft)
- Operating pressure: 103-276 kPA (15-40 psi); max 552 kPA (80 psi)
- Maximum fluid temperature: 93 C (200 F)
- Weight: 0.45 kg (1 lb)
- Material: 316L stainless steel
- Bearing: Double row, angular contact ball bearing in 316L stainless steel with PEEK cage and Rulon bushing
- 360-degree spray angle

Fig. 2. Lechler whirling nozzle, series 569.

A prototype mobile fixative application platform was developed by FIU as an inexpensive alternative to deploying the whirling nozzle. The technology developed consisted of a mobile robotic platform controlled from a computer by a wired communication system.

A pump is needed to supply the fixative to the nozzle and flexible tubing was used as the connection between the pump and the robotic platform. The pump needs to provide the nozzle with 335-689 kPA (50-100 psi) of discharge pressure and capable of providing a flow of 82-250 liters per minute (18 – 55 gallons per minute).

The mobile platform was staged immediately outside the hot cell entrance. The mobile platform was then guided into the hot cell by the computer interface and the fixative was applied via the whirling nozzle. Meanwhile, the pump and the drum of fixative remained outside of the hot cell with the operator.

The whirling nozzles have a rinsing diameter of 4.5 meters (15 feet) and a cleaning diameter of 3 meters (10 feet). The hot cell mock-up has dimensions of 3 m width x 6 m length x 3 m height (10' width x 20' length x 10' height). The nozzle manufacturer, Lechler, Inc., suggested that two nozzles be used to apply fixative to the entire hot cell mock-up. Instead of using 2 nozzles, the mobile platform was used to place the whirling nozzle at the first of the proposed locations for the preliminary testing. Subsequent testing will use the mobile platform to place the whirling nozzle at the first, followed by the second, locations to provide fixative coverage to the entire hot cell interior.

In order to properly spray the hot cell mock-up, the nozzle needed to be placed 1.5 m (5') above the ground; this requirement was obtained from the nozzle manufacturer. As the mobile platform is 0.42 m (1'4.5'') in height, a pipe connection was used between the platform and the nozzle to raise the nozzle to the desired height. The Lechler whirling nozzle is meant to work in either the right side up vertical position or the upside down vertical position without experiencing any losses due to gravity. As it can be seen in Figure 3, the pipe was connected to the top of the platform with a flat plate that has an extruded hollow cylinder on it.

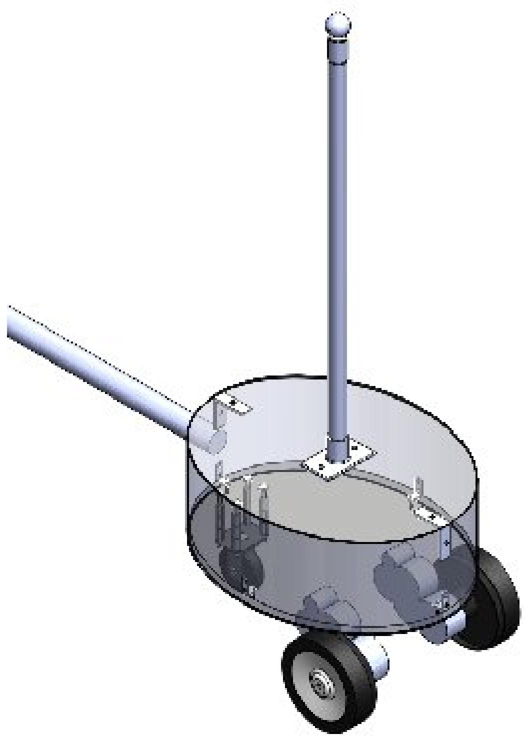

Fig. 3. Mobile platform with PVC pipe and nozzle attached.

The platform entered the hot cell through the existing door and was controlled by a operator via a wired connection from a computer. Trailing behind the unit was flexible tubing and the wired connection. The tubing provided a connection between the pump and the platform/nozzle for the fixative.

RESULTS AND DISCUSSION

The preliminary testing for the technology demonstration was performed from November 16 to November 22, 2009. Additional testing was performed from December 15 to December 17, 2009. The remote platform was expected to remotely enter the hot cell mockup facility and use the whirling nozzle to spray a fixative that would be capable of immobilizing loose/removable radioactive contamination.

Trial-runs of the remote platform into and through the hot cell mockup from the side entry point were first performed to gain familiarity with the mockup design, to ascertain that the technology can remotely gain entry into the hot cell mockup, and to determine how much of the hot cell interior is accessible to the technology. This trial run was also used to work out logistical requirements of the technology (e.g., how to handle trailing cords, etc.). The remote platform had no difficulties in entering the hot cell mockup remotely from the entry door and gaining the desired position of 5 feet from each side wall and 15 feet from the entry door wall.

Prior to performing tests with a fixative, the technology was tested with water. With the water running through the system, any leaks due to weak connections could be detected and repaired. During the testing phase with the water, flow rates were calculated based on how fast the motor was rotating the gear pump. The inverter controls the speed of the shaft and the display on the LED screen showed the current speed of the motor, in Hz. A tank was filled with 75.7 L (20 gallons) of water and used to determine the flow rate through the 30.5 m (100 ft) hose. With the information provided on the LED screen of the inverter, the data in Table II was collected and the flow rates calculated [4].

Table II. Flow Rate Values for Water - 30.5 m (100 ft) Hose

Tank Volume, L (gal)	**Speed Monitor, Hz**	**Time, s**	**Flow Rate, L/min**	**Flow Rate, gpm**
75.7 L (20 gal)	15.13	212	21.42	5.66
75.7 L (20 gal)	15.06	208	21.84	5.77
75.7 L (20 gal)	29.98	110	41.29	10.91
75.7 L (20 gal)	30.09	105	43.26	11.43
75.7 L (20 gal)	35.12	75	60.56	16.00
75.7 L (20 gal)	35.01	82	55.39	14.63
75.7 L (20 gal)	35.06	87	52.21	13.79

A 75.7 L (20 gallon) tank was filled with water and three different settings for the motor speed were used, 15, 30, and 35 Hz. After starting the pump at the selected motor speed, the time for the pump to use the 75.7 L (20 gallons) of water was recorded. As the speed of the motor increased, the flow rate of the water also increased. During testing with water, as the flow rate increased, the nozzle head would spin less and less. The operating pressure for the nozzle is between 103 - 276 kPA (15 - 40 psi) with a maximum of 552 kPa (80 psi). So as the flow rate increased the pressure decreased. The flow increased until at 50 Hz, there was no longer a stream of water exiting the nozzle. The droplet size significantly decreased until a mist was created and the nozzle head would not spin anymore [4].

After the flow rate of the water was determined, plastic was wrapped around the platform to protect the electrical components from being exposed to water. Once the platform was properly sealed, the flexible hose was connected to the PVC pipe attached to the platform and a test with water at a flow rate of 53

L/min (14 gpm) was performed. The platform was set up 1.5 m (5 ft) from the inner most wall of the hot cell. The inverter was set to 35 Hz which corresponds to 53 L/min (14 gpm) of water flowing through the pump. The tank was filled with 113.6 L (30 gallons) of water. After the motor was turned on, the pump pumped 30.3 L (8 gallons) of water in 47 seconds. The 30.3 L (8 gallons) of water were enough to spray the three inner walls of the hot cell. The walls had enough water on them to show that, at that flow rate and pressure, more than half of the hot cell walls were coated. The floor was puddle with water as well. The section of ceiling right above the nozzle did not have a good layer of water on it. Due to the nozzles design, there was no water stream directly above the nozzle. The water did not seem to reach the ceiling as well as it did for the highest corners of the hot cell. Even though the corners of the hot cell did have water on them the sections of ceiling directly above the corners did not. The cause of the lack of water reaching the ceiling may be due to the design of the nozzle, the nozzles original tank cleaning purpose and the fact the water has to fight gravity in order to reach the ceiling. During the 47 seconds that the nozzle was spraying, the platform remained stationary. If the platform were to move closer to the corners of the hot cell as the nozzle sprayed, it is likely that the ceiling would receive better coverage [4].

After the water was tested, the hot cell mock-up facility was prepared for testing the whirling nozzle using fixative. The initial testing used 19 liters (5 gallons) of basic water-based latex paint diluted with enough water to aid the pump in the transfer of the liquid. The paint was diluted with about 7.6 liters (2 gallons) of water and 0.87 liters (29.5 fluid ounces) of “canary yellow” paint was mixed in to tint the paint for easier evaluation of the ultimate coverage in the hot cell. Prior to spraying in the hot cell, flow rate testing was performed with the fixative mixture (Table III) [4].

Table III. Flow Rate Values for Fixative – 9.1 m (30 ft) hose

Tank Volume, L (gal)	**Speed Monitor, Hz**	**Time, s**	**Flow Rate, L/min**	**Flow Rate, gpm**
30.3 L (8 gal)	20	60	30.3	8.0
30.3 L (8 gal)	30	44	41.3	10.9
30.3 L (8 gal)	35	39	46.6	12.3
30.3 L (8 gal)	40	40	45.5	12.0
30.3 L (8 gal)	50	41	44.3	11.7

For the fixative flow rate testing, the length of hose used was 9.1 m (30 ft). As seen in Table III, as the speed of the motor shaft increased, a point was reached where the flow rate no longer increased. As previously mentioned, the flow rate increases as the pressure decreases.

After testing the flow rates for the fixative, hot cell mock-up facility was prepared for the exposure to the fixative. The hot cell has one window covered by Plexiglass, two manipulator port holes, and one access hole for a ventilation fan. Each of these areas was covered with plastic to keep the fixative inside the hot cell and to protect the window and exhaust fan from the fixative. Plastic was also placed over the entrance of the hot cell to keep the cameras and equipment on the other side clean.

Video and pictures were taken during the fixative testing of the whirling nozzle. The first test consisted of running the motor at 35 Hz for 10 seconds. Because a flow meter cannot be used to determine the flow of the fixative, the same data that was collected for the flow rate test was used. For the flow rate test, it took 39 seconds to empty out the 30.3 L (8 gallons) of fixative at 35 Hz (Table III). However, the fixative coverage after 10 seconds was not adequate with the pump running at a frequency of 35 Hz (providing a flow rate of 46.6 L/min or 12.3 gpm). The hot cell surfaces were just modestly and somewhat randomly splattered with the fixative.

For the next test, the speed of the motor was increased to 45 Hz and allowed to run for about 30 seconds. With the new flow rate and pressure in the tubing, a better coverage area was obtained. The whirling nozzle covered most of the wall right in front of it (Wall B), except for some dry sections along the corners, and more than half of the walls to each side (Walls A and C). The floor of the hot cell was completely covered, including the area under the remote platform. As expected, the surfaces closer to the whirling nozzle received the most coverage with the amount of coverage decreasing with increasing distance from the nozzle.

The ceiling of the hot cell was the only surface that did not receive a good coverage. The nozzle design may be responsible for that. In addition, the fixative has to work against gravity to cover the ceiling. Similar to the testing with the water, the ceiling was only covered directly above the nozzle. The area of the ceiling that is farther away from the nozzle did not receive any coverage. In addition, the floor received more fixative than necessary for complete coverage. That is mainly due to the amount of excess fixative that dripped from the walls and the seconds before and after the nozzle head began to spin. For those few seconds that the nozzle head does not spin due to the lack of pressure, streams of fixative come out of it and run to the floor. Once the nozzle first starts to spin, the fixative breaks up as the droplet sizes start to decrease.

Only the first section of the hot cell was tested during the preliminary testing due to the positioning of the video camera. During the additional testing performed December, the mobile platform sprayed again at the first location and then was driven to the second location. Both halves of the hot cell received similar fixative coverage: 100% floor coverage, 95% wall coverage, and 60% ceiling coverage.

Figure 4 shows the hot cell interior before and after the application of fixative with the whirling nozzle mounted to the remote platform.

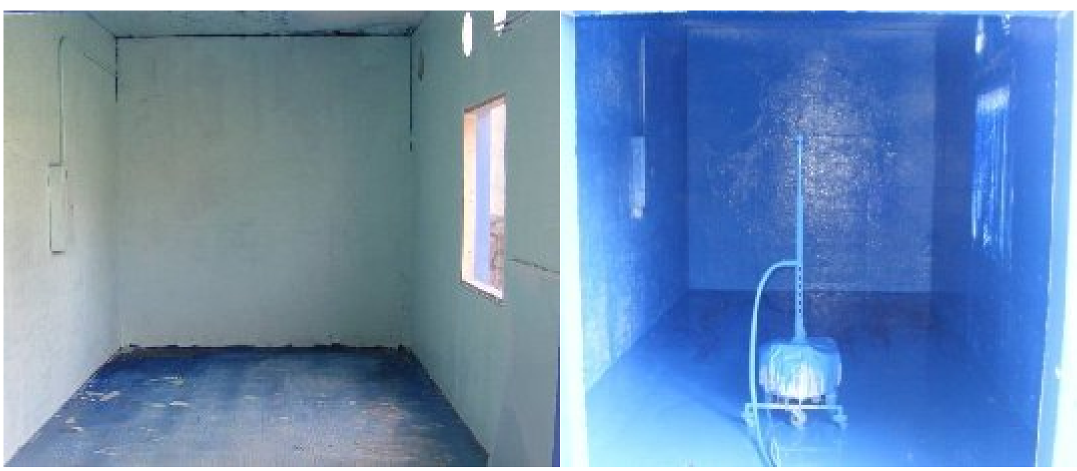

Figure 4. Hot cell mock-up interior before and after fixative spraying via whirling nozzle on remote platform.

At the conclusion of the testing, the equipment was flushed with water and cleaned. If used in a radioactively contaminated environment, the plastic over the body of the remote platform would be cut off and disposed since it is inexpensive and not conducive to decontamination. The cables and hoses in the tether (e.g., electronic input line and flexible hose for the fixative) could be wiped/ decontaminated as an alternative to disposing of the entire tether. The body of the remote platform could be wiped/ decontaminated but may be difficult to free-release due to the difficulty in confirming that the contamination did not enter through any openings.

CONCLUSIONS

Overall, the testing indicates that the technology is capable of successfully achieving the objectives of this demonstration. It was able to remotely enter the hot cell mockup from the side entry door, travel across the floor to the position desired for spraying while being controlled remotely by the operator, and spray a coating of fixative to the wall, floor, and ceiling surfaces. The floor surface received coverage of approximately 100%, the walls of approximately 95%, and the ceiling of approximately 60%.

After a period of 24 hours, the hot cell coverage was evaluated for a second time and much of the fixative had run off the walls and onto the floor, indicating that the 5 to 2 (fixative to water) dilution ratio used was too high.

The technology was also evaluated for health and safety risks. The biggest risk to the operators of the prototype is from the electrical power source. All the connections between the inverter and the motor were checked by an electrical engineer. The connections were inspected numerous times before the power cord was plugged in. Another risk factor has to do with the pump, if the hose were to come off the barbed fittings or if there were a leak somewhere in tubing there could be a risk of electrical shock as well as the risk of being struck by a higher pressure fluid. The robotic platform also poses a risk. The motors on the platform provide a high torque. If not properly controlled, the platform could run into something or someone.

The design and modification of the remote platform as well as the testing of the remote platform and whirling nozzle also served as the senior design project for a mechanical engineering student at FIU [4].

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