Decontamination Using Remote-Deployed Nitrocision® Technology – 11221

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ABSTRACT

The Main Plant Process Building (MPPB), used during commercial spent nuclear fuel reprocessing between 1966 and 1972, is comprised of approximately 55 rooms (cells) with concrete walls varying in depths up to 1.5 meters (five feet). Two of the cells in the MPPB – the Process Mechanical Cell (PMC) and the General Purpose Cell (GPC) – were extensively contaminated with spent fuel during reprocessing operations with radiation dose levels measuring from 1-105 R/hour at the beginning of the Interim End State contract.

Due to the high levels of radiation in the cells, WVES would have to perform cell decontamination using remotely-deployed technology to protect its workers. Nitrocision® technology was selected for its historical performance in decontaminating surfaces, but the remote application was new technology and would require the combined engineering talents of both WVES and Nitrocision® to develop and operate the system effectively in-cell.

The system, provided by Nitrocision LLC, possesses several advantages including removal efficiency, waste minimization and versatility over other traditional decontamination methods including water, carbon dioxide and decontamination gels. WVES and Nitrocision have partnered to develop the remote application methods, evaluate performance and enhance system availability, develop lessons learned, test and deploy prototype equipment, and apply the technology to high-hazard, remotely-conducted decontamination work. This effort may lead to other remote applications at DOE cleanup sites, as well as nonradioactive industrial applications.

HISTORY

The West Valley Demonstration Project (WVDP) located in West Valley, New York, is a high-level waste (HLW) solidification and radiological cleanup project. The MPPB in West Valley was the location of the only commercially-operated spent nuclear fuel (SNF) reprocessing facility to have operated in the United States (1966-1972).

The primary mission of the WVDP is to complete actions articulated in the West Valley Demonstration Project Act (WVDP Act, Public Law 96-368). These actions include HLW solidification and transport; decontamination and decommissioning of facilities, materials, and hardware used to complete the HLW solidification; and disposal of low-level waste (LLW) and transuranic (TRU) wastes generated from the HLW solidification process. Activities related to HLW solidification were completed in September 2002; facility decontamination and waste processing activities are ongoing. Recently, these activities have focused on decontaminating highly radioactive and highly contaminated process cells in the MPPB where SNF reprocessing operations were conducted.

Constructed more than 40 years ago, the MPPB housed a system to prepare SNF assemblies for chemical processing to recover uranium (U) and plutonium (Pu) from SNF rods. Dismantlement of component and initial surface decontamination of two heavily-shielded, highly-contaminated Head End Cells (HECs) where SNF was mechanically prepared during commercial operations - the PMC and the GPC – were completed in 2004. That initial cleanup effort was concluded with the application of a fixative, Polymeric Barrier System (PBS), to the cell walls and floors to seal remaining contamination.

The U.S. Department of Energy (DOE) is currently preparing the MPPB for demolition under the Record of Decision issued in 2010. West Valley Environmental Services (WVES) has been contracted to further decontaminate the Head End Cells. WVES has evaluated several technologies and selected the remote application of high-pressure liquid nitrogen.

BACKGROUND

The GPC and PMC were coated with PBS fixative in 2004 to lock down remaining contamination after the removal of significant processing debris and cell waste. This resulted in significant improvement in airborne radiological conditions; however dose rates in the cell remained too high to permit human access. A survey performed in December 2009, before beginning further decontamination of the PMC, showed gamma dose rates in the range of 0.7 R/hr to 37 R/hr at a distance of three feet from the floor. GPC values (obtained in October 2010) are slightly higher with a range of 0.51 R/hr to 105 R/hr at the same three foot distance. As a result of the measured dose rates, further decontamination of the cells would require remote deployment of any selected cleaning technology.

Radiological contamination in the Head End Cells is a result of processing spent nuclear fuel and is primarily beta-gamma emitters with an alpha component. At deployment, the PBS, a very hydropholitic material, was applied with the viscosity of a thick paint and, even when cured, retains a very flexible, rubbery consistency. The material coats the walls and floors of the cells in varying thicknesses based on volume applied and the effect of a varying floor slope – experienced in both cells. Both cells also have complicated surfaces from a decontamination perspective, penetrating pipe, structures with rails and deep wells, and limited ability to access wall surfaces above the physical range of in-cell equipment.

As a result of the contamination and radiation levels associated with the Head End Cells, all equipment installation interfaces had to be done through prepared ports with hands-on work performed by robotic arms mounted to the inside cell walls or by an in-cell bridge crane equipped with a chain hoist and bridge mounted remotely operated arm (PaR arm). When selecting a decontamination technology, top priority was assigned to maintaining worker dose As Low As Reasonably Achievable (ALARA) and the capability of the technology to be applied remotely.

DECONTAMINATION TECHNOLOGIES EVALUATED

WVES evaluated several decontamination technologies – steam, carbon dioxide, sand/grit blasting, and liquid nitrogen for remote application in the HECs – before selecting Nitrocision® technology. Each of the other technologies had significant deployment disadvantages such as:

- Potential facility ventilation filtration integrity compromise;
- Questionable effectiveness;
- Inability to troubleshoot or verify performance at a distance;
- Significant secondary waste stream production and associated handling and disposal costs.

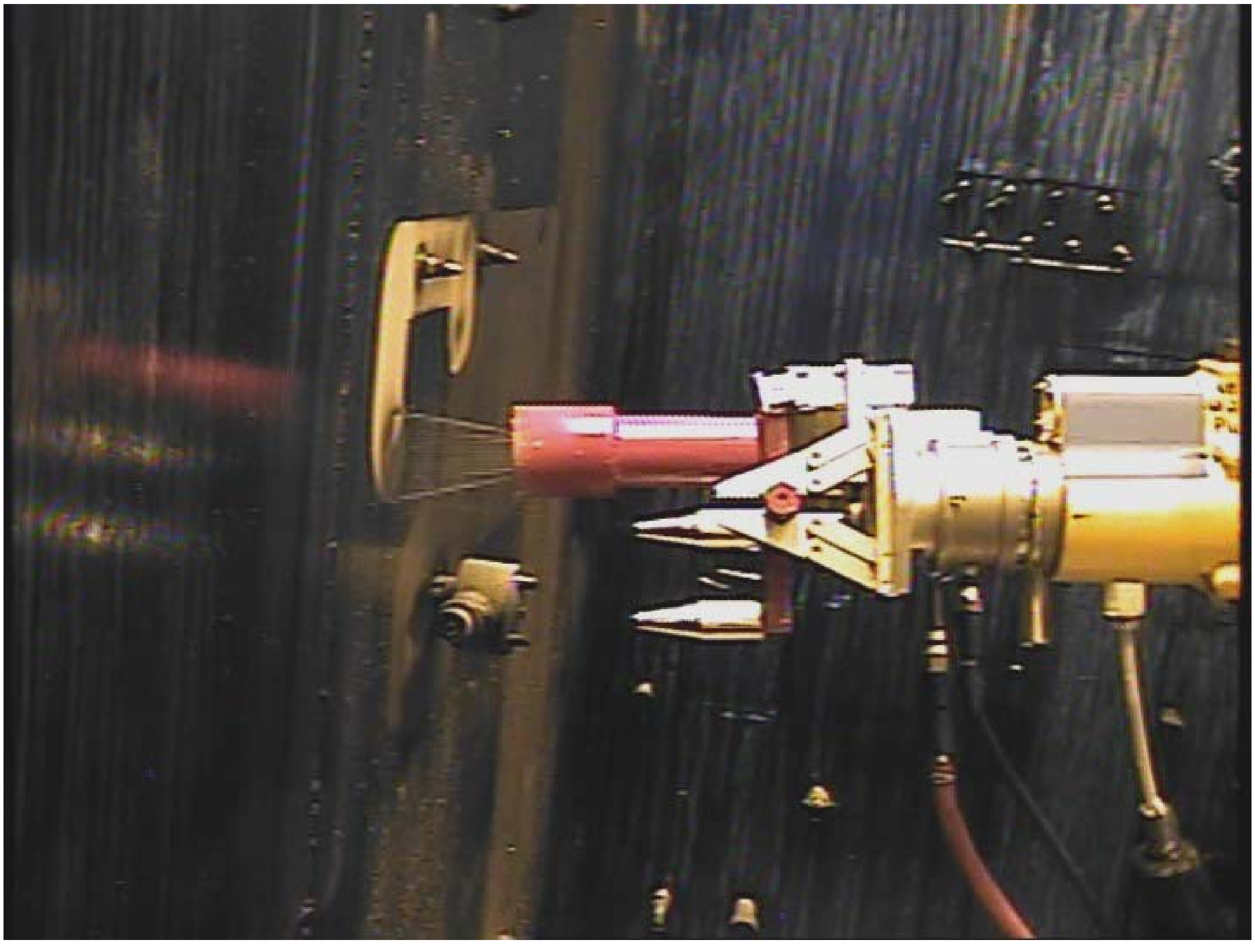
Cost-benefit analysis drove the selection of Nitrocision® technology to remove the PBS from the cell walls.

NITROCISION TECHNOLOGY

Nitrocision® employs liquid nitrogen at variable temperature and pressure to provide an aggressive, yet safe, cleaning application. The system is designed to support operating temperatures down to -160 degrees Celsius (-260 degrees Fahrenheit) and up to 4,200 kg/cm (60,000 psi) where the liquid nitrogen quickly converts to a gas.

Nitrocision® decontamination is accomplished by moving liquid nitrogen from a supply source through vacuum jacketed piping to maintain the temperature of the liquid and avoid direct conversion to gas before it is pressurized and cooled. The liquid is then introduced into the Nitrojet 6000 skid where it passes through a series of intensifiers and is pressurized up to 4,200 kg/cm (60,000 psi) where it is pushed from the skid through high pressure tubing to a chiller. The chiller is where the temperature of the liquid nitrogen is brought back down to approximately -160 degrees Celsius (-260 degrees Fahrenheit) and it is pushed through a flexible “whip tube” to the working tool (Fig. 1). The tools in use in the HEC include a 5 centimeter or 10 centimeter (two-inch or four-inch) head and can rotate or be used stationary depending on the application. The liquid nitrogen exits the tool through orifices sized in the thousandths of inches to direct the flow to the surface being cleaned. Air is used to rotate the working end of the tool and a nitrogen purge gas is used to keep the rotational bearings dry.

Fig. 1. Nitrocision® technology was deployed remotely in the Process Mechanical Cell (PMC).



In the conversion from a liquid to a gas, the gas expands nearly 700 times. Because the nitrogen dissipates into the environment almost immediately, all secondary waste streams are eliminated; all that remains for disposal is the material that was removed. Additionally, the almost immediate dissipation of the nitrogen gas by-product results in no impact to facility filtration systems. Nitrocision® does offer a grit entrainment system that can be added to the nitrogen stream at the tool end for cutting and scabbling applications. This provided WVES with additional options once the decontamination began if nitrogen alone was ineffective at removing thicker sections of PBS.

Remote deployment of the working tool and facility ventilation configurations caused the usage of nitrogen to be less of a safety concern than initially thought. Nitrocision® technology can be integrated with a vacuum capture system (Fig. 2) allowing for the simultaneous removal and collection of the PBS removed from the walls; thereby further limiting the impact to facility ventilation. Another advantage of using liquid nitrogen is that it freezes the PBS material as it is removed making it much easier to vacuum and collect. At performance testing it was found that when super-cooled by the liquid nitrogen, the fixative does not get sticky or liquefy. Instead it becomes brittle at removal and over time achieves the consistency of Play Doh®. Further benefits of using

Fig. 2. Nitrocision® technology is being used to vacuum the debris that was removed from the walls of the Process Mechanical Cell.

Nitrocision® are that nitrogen is a comparatively inexpensive decontamination cleaning agent, non-hazardous, and a readily renewable resource.

SYSTEM INSTALLATION AND TESTING

Installation

Once the technology was selected, WVES Engineering worked with Nitrocision LLC personnel to further hone design work they had done on the remote tooling and guide selection of in-cell equipment to meet size constraints for moving equipment (e.g., vacuum system) through hatches among the HECs. Because the technology was being installed in an existing facility, there was significant retro-fitting and piping design work that had to be adapted to as-built components. Additionally, any area over seven feet in the MPPB is radiologically contaminated so care had to be exercised when installing piping in the overheads to avoid spreading contamination to the facility surfaces below.

Significant infrastructure upgrades and maintenance had to be performed specifically addressing functionality of the in-cell robotic arms, PaR bridge and hoist for both of the cells and associated aisles. This equipment was idle since the last decontamination effort in the HECs. Maintenance on that equipment is time-consuming and physically challenging due to high contamination levels and dose rates.

The layout of the MPPB was designed for SNF reprocessing, not facility decontamination. Mobility within the MPPB and access to areas that required retrofitting, equipment installation and/or maintenance was labor-intensive. The Nitrojet 6000 skid (the skid, Fig. 3) had to be located in an area large enough to support it and a hydraulic oil containment system (should there be a leak from the hydraulically powered intensifier supply) with adequate room to perform routine and emergent maintenance. A tool room was established and equipped with specialized equipment and tooling fabricated for sealed change outs both on the skid and the in-cell working tool. Electricians established additional power supplies from the HEC motor control center to support the power needs of the skid and vacuum system. Instrument and Controls staff installed the control panels, oxygen deficient monitors and various other communication lines needed to run and monitor the system.

Fig. 3. Nitrocision® 6000 skid.

Nitrocision® LLC, together with WVES and Cryotech International, designed the run of vacuum-jacketed piping that would convey the liquid nitrogen from the 49,000 liter (13,000 gallon) supply tank (outside of the MPPB) to the Nitrojet 6000 skid and chiller inside the MPPB. Additionally, the system relies on a clean, regulated 7.0 kg/cm (100 psi) of air to turn rotating motors on the in-cell working tool. The system was originally connected to the Plant air supply that later turned out to be problematic from both a supply and quality perspective. The existing MPPB air supply was moist and not clean, and fluctuated in its delivery volume based on demand in the rest of the building. Supply air issues caused operational down time that was not initially recognized by the team as being air supply related.

Testing

The system was performance tested at Nitrocision's facility and demonstrated that the equipment could decontaminate stainless steel coated with PBS at a rate of 1.2 linear meters (4 linear feet) per minute with at least 80 percent removal efficiency. Removal capabilities were also demonstrated on carbon steel and concrete with the same success rate. The vacuum system captured approximately 90 percent of the material removed from the surface at that rate of cleaning. System availability at performance testing was 100 percent with some slight delays getting started.

SYSTEM OPERATION AND AVAILABILITY IMPROVEMENTS

Since declared operational, the system's performance has varied from 18 percent in May 2010 to 67 percent in June, peaking in August 2010 at 80 percent. Figure 4 illustrates the failure type by frequency.

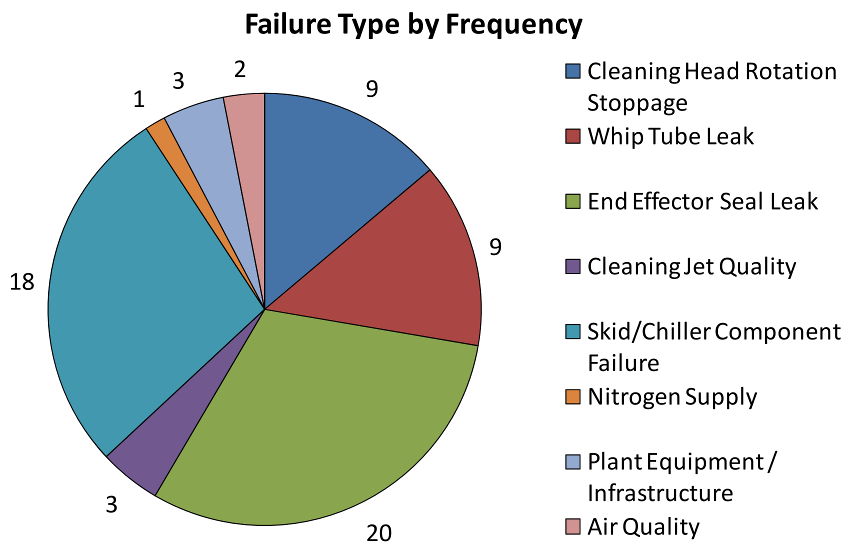


Fig. 4. Failure Type by Frequency.

The Team analyzed the initial operational challenges and grouped them into three general categories including in-cell components, ex-cell components, and plant equipment/infrastructure. In-cell failures were related to loss of rotation of the cleaning head, connection failures between whip tubes and between the tool and the tube, seal leaks on the end effectors (tool), plugged end effector jets. Ex-cell equipment challenges affecting operability of the equipment included chiller and skid operational issues, nitrogen tank and piping related supply inadequacies. The plant infrastructure and major in-cell equipment failures brought about operational down time as well. Equipment challenges related to the successful utilization of Nitrocision decontamination technology are described below.

Cleaning Head Rotation Stoppage and Air Quality: Loss of rotation of the decontamination head had been a result of plant air supply issues (inadequacy of volume/cleanliness of supply). Loss of rotation had resulted in approximately 12 percent of unplanned equipment shutdowns. When rotation is lost at the decontamination head, cleaning effectiveness is impacted immediately and typically results in the decontamination head freezing up. Rotational failure causes cleaning to stop immediately and results in tool swap out and lost time due to the need for remote tool change out. Initially, air supply quality was addressed by the installation of a desiccant drying system and an automatic blow down on the air supply, plumbing from another facility at the site, and removing excess hose and quick connections from the line to improve delivery quality and pressure, however; the ultimate solution became renting an air compressor that could provide high quality, dry, consistent air supply with a capability slightly beyond what is needed to compensate for line loss over distance. At the same time the team continues to monitor rotation issues and has procured a higher torque motor that can be tested and put into service on the tooling should this become necessary.

Whip Tube Leak: Whip tube connections between the sections of whip tube have come apart resulting in down time to reconnect remotely. Challenges at the whip tube connection had resulted in approximately 12 percent of unplanned equipment shutdowns. The connection between the whip tube and the end effector is coned and threaded 1.43 centimeter (0.5625 inch) high-pressure tubing that is susceptible to shouldering. Connection quality degrades over time with the frequent end effector change out and maintenance that is required to keep the tool viable. Down time is associated with tightening the whip tube connection at the end effector which can be exacerbated by the in-cell location of decontamination. Utilizing the remote equipment to bring the tool to the maintenance station is time consuming in itself and then there is the time to tighten the connection and test. A loose connection between whip tubes can result in a greater amount of down time because of the need to bring the connection to a work surface in cell and then perform the tightening. Because of the rigidity of the tube this can be very time consuming. Replacement of whip tube sections as the connection end becomes un-sealable has resulted in the replacement of whip tube sections. Operators have been trained on the correct procedure and sensitized to the importance of not over-tightening the connection. A new style torque wrench was modified for remote operations and installed in cell for this application to ensure over-tightening does not occur. Initial performance testing identified the whip tube to whip tube connection as a possible challenge as the fitting tends to come unscrewed as the tube is moved around during decontamination. Recognizing this problem, Nitrocision LLC worked with an outside vendor to produce 12 meter (40 feet) tube lengths rather than the 6 meter (20 feet) lengths they were working with to minimize the number of connections. Nitrocision LLC worked with an outside vendor to design/develop/test a new quick disconnect style connector for the end effector/whip tube location. This style connector has alleviated the problems associated with hard plumbed connections and has greatly reduced end effector change out time. Additionally, anti-vibration tubing connectors have been functionally tested and adopted to successfully address the whip tube to whip tube connection challenges.

<u>End Effector Seal Leak</u>: Seal leaks at the end effector result in a visible cloud of nitrogen escaping before the true working end of the tool. Small leaks can be tolerated and do not impact decontamination efficiency but during operations the leak worsens and at some point takes up too much of the nitrogen being supplied to the cleaning head and decontamination effectiveness is impacted. At that point the tool is changed out. Rotary seal life expectation is currently 6 – 8 hours. Leaking end effector seals have resulted in approximately 25 percent of unplanned equipment shutdowns. Tooling repair is both time and labor intensive because of the remote nature of the work, however; the time involved has been decreased Significantly as a result of installing the quick disconnects on the tool and whip tube discussed above. Because of the nature of the seal, high pressure and extreme cold temperature, seal leaks are an understandable challenge, however; steps have been taken to alleviate the problem and to some extent lengthen the life of the seals. Cyclical cooling and warming of the seals tends to accelerate in seal failure. As a result the project has been staffed so that breaks and lunches are taken on a rotational basis and the equipment is not shut down. The original operations plan for the project included tool maintenance to be performed, in its entirety, remotely using manipulators and the PaR. As a result of in-cell environmental issues (cleanliness) and significant down time experienced during tooling maintenance, tooling maintenance is now performed hands-on rather than remotely and is a scheduled manned-entry into an ancillary cell on a weekly basis. Increasing the number of tools in the work area has allowed for ready tool change out and continued cleaning operations.

<u>Cleaning Jet Quality:</u> Plugged nozzles on the end effector can happen as the tooling is used for decontamination. It is not uncommon for one of four jets to plug while the others function well and decontamination efficiency is maintained. However, there is a point where either another jet plugs or material is clearly not being removed from the wall that the tooling is non-viable and must be changed out. Both the plugged jet and potential loss of cleaning efficiency are visible to the operator running the cleaning head. Plugged end effector jets have resulted in approximately 4 percent of unplanned equipment shutdowns. When the jet nozzles at the end of the cleaning head plug, cleaning stops, resulting in lost time due to remote tool change out. Tool disassembly location for change out has been changed to leave reduced chances of possible contamination of jets. When performing tool maintenance all orifices are replaced, not just the plugged one. Tool decontamination prior to teardown has been adopted to minimize the potential for loose particles to become trapped in the internals of the tool. This is performed with low-pressure nitrogen or air. Tooling maintenance entries are scheduled weekly and are performed using a Maintenance Mechanic and an operator so that both aspects of the maintenance activity are addressed: operability and tracking wear.

Skid and Chiller Operational Issues: Skid and chiller operational issues combined have resulted in approximately 23 percent of unplanned equipment shutdowns. The bypass valves on the chiller both have failed resulting in shut down of operations. Three different failure types have been associated with the skid and chiller unit; a failure of the chiller valve result in an inability to divert or shut off the supply to the end effector or the bypass nozzle in a timely manner. The failure of the bypass valve on the chiller results in decreased cycling of the intensifiers on the skid and a subsequent rupture disk failure and skid shut down. Intensifier check valve assembly failures and static and dynamic seal failures result in poor system performance at the skid. WVES worked with Nitrocision to troubleshoot and repair the system, the vendor was called in to assist directly with this effort. Both valves were custom made during system construction by a secondary vendor to Nitrocision. The divert valve has since been replaced with a new custom valve and the bypass valve was replaced with an off the shelf model that performs the same function as the one that failed. Replacement of the valves has led to zero failures at that location on the equipment. Nitrocision's troubleshooting resulted in the recognition of the temperature-induced shrinking of the bushing (brass) resulting in the valve stem inability to shift/operate properly when brought down to operating temperature. The issue was diagnosed as material incompatibility (brass and stainless steel) due to different thermal expansion rates in the valves. As a result, updated versions of the equipment are outfitted with the new valves identified through the WVES problems. Mechanics continue to develop new techniques for seal replacements. System performance monitoring is the job assignment of an operator to catch issues before they become significant. It is critical to have the maintenance mechanic trained to a high level so they can troubleshoot and repair skid components when operational issues arise. Maintenance activities are scheduled to continue to avoid run to failure conditions.

Nitrogen Supply: To this point, issues with the nitrogen supply system have contributed 1% of unplanned equipment shutdowns. Failure of the nitrogen supply system has only impacted operations once, resulting in the inability to run the system, the cause was a failed solenoid on the main supply valve between the bulk tank and the skid. Troubleshooting of the failed solenoid resulted in the engineering determination that it was a non-predictable failure. Because the failure was unpredictable and the purchase of a spare solenoid was feasible the team decided to have a spare solenoid on the shelf in the event of another failure of this type. The voltage of the solenoid was not common to any similar valve on site so there is no common stock to draw from.

Plant Equipment/Infrastructure and Air Quality: Eight percent of the downtime has been attributed to plant equipment, infrastructure and air quality issues. Significant infrastructure upgrades and maintenance had to be performed specifically addressing functionality of the in-cell robotic arms, PaR bridge and hoist for both of the cells and associated aisles because this equipment was idle since 2004. Fabrication of tooling to perform sealed change outs and maintenance as well as adequate room to perform maintenance activities around the Nitrojet 6000 skid unit were critical factors in minimizing system downtime. The system relies on a clean, regulated 7.0 kg/cm (100 psi) of air to turn rotating motors on the in-cell working tool. The system was originally connected to the Plant air supply that later turned out to be problematic from both a supply and quality perspective. The existing MPPB air supply was moist and not clean, and fluctuated in its delivery volume based on demand in the rest of the building. Supply air issues caused operational down time that was not initially recognized by the team as being air supply related. WVES brought on-line a generator to produce sufficient, high quality air for this project.

LESSONS LEARNED FROM CELL WALL DECONTAMINATION OPERATIONS

Cell wall decontamination in the PMC offered learning opportunities for the team that were implemented in the decontamination of the GPC. Specifically, high pressure liquid nitrogen exiting the end effector must be kept away from cell penetrations. Enhanced radiological monitoring for the spread of contamination was performed after finding that radioactive contamination was pushed through cell penetrations to the operating aisle. An initial effort was made to seal cell penetrations however, some existed but were not obvious/identified on drawings and when the decon tool is passed over them, even those that were sealed had the potential to leak as a result of the high pressures involved. Subsequently, decontamination of the aisle wall shared with the cell was performed in respiratory protection with accompanying contamination monitoring to continuously look for changed conditions and protect the operator.

The team had decided to move away from remote rebuild of equipment early in the process of PMC decon because of the dirty in-cell environment introducing particulate contaminates into the very small internals of the tools and causing subsequent failures requiring more maintenance. As a result, tool maintenance has been performed hands-on. Initially, hands-on work did not pose a problem from a contamination or radiation stand point on the tooling, however; as the project progressed, radiological hazards moved to the forefront and additional controls had to be put in place. The team was using low pressure (less destructive) to decontaminate/blow off the tools before transferring them to the hands-on work area. Eventually, tooling dose rates reached 120 Rad /hr (contact) with associated removable contamination levels 5.6 E6 dpm/100 cm^2 alpha and 2.8 E8 dpm/100 cm^2 beta/gamma. Utilization of high pressure liquid nitrogen decontamination on that tooling resulted in a 90 percent drop in levels and the ability for site workers to continue hands-on maintenance with the higher quality result. As a result of the success in cleaning the end effectors, the project team is working on developing ways to protect critical areas of the PaR and have performed initial decon to reduced levels on that equipment as well.

Remote Tooling

The first generation tooling and first-time deployment of this equipment in a fully-remote application has challenged WVES mechanics to use their ingenuity and on-site facilities to make modifications to tooling designed by Nitrocision LLC as well as design new tooling to meet operational challenges that were unforeseen in the development phase. Specific tooling challenges have included:

- The interface location between the robotic arm or PaR grip and the end effector tooling;
- Special “hand tools” to use with the robotic arm and PaR to perform remote disassembly of equipment (e.g., performing a modification of the torque wrench to make it more remote-able); and
- Fabrication of tooling extensions that allow for the stable passage of whip tube, utility lines, and vacuum hose and the associated end effector into difficult-to-access areas such as an in-cell passageway approximately 2.3 meters (7.5 feet deep) by 0.6 meters (2 feet) wide.

Additionally, WVES mechanics have designed and fabricated camera mounts to allow for visibility of the working surface and a table to perform in-cell tool maintenance for each cell that is used for disconnection of one tool and the replacement of another on the whip tube. The ability to design and build modifications to the tooling on site has resulted in less down time.

CHALLENGES AND SOLUTIONS

Though the system has had its share of operational issues which have been primarily with the end effectors, the system has had remarkable results cleaning the PBS coating off the walls and floor. Except for a few hard-to-reach areas, the walls of the three-story PMC have been cleaned using the Nitrocision tooling and efforts are now focused on cleaning and vacuuming the floor. As of November 2010 approximately 87 percent of the wall surfaces and 10 percent of the floor have had the PBS material removed and collected in TRU waste drums. GPC wall decontamination has begun with approximately 30 percent of the cell being complete to this point. Approximately 30 square meters (100 square feet) can be decontaminated in a ten-hour shift, achievable surface area varies with characteristics of the terrain. Penetrations and irregular surfaces add time as does the surrounding area because the whip tube and utility line bundle have to be watched at all times for snagging. Final cell radiation surveys will be conducted once decontamination of the cell floors is complete and containerized waste is removed from the cell. Additional decontamination efficiency data will be gained by performing identified “hot spot” decontamination and subsequent re-survey after the initial decontamination pass is complete.

As a result of the effectiveness of the technology to date WVES has opted to deploy the technology in other facilities. As a result, Nitrocision LLC has developed software and skid upgrades to allow one skid to facilitate decontamination operations in two different cells in adjoining facilities at the same time while maintaining cleaning efficiency.

PARTNERING

The combination of WVES' expertise on the conditions of the PMC and GPC and Nitrocision's technology, and the synergy gained by putting the two areas of expertise, has been a winning strategy.

Internal partnering among WVES operational, engineering and radiological disciplines further contributed to the success-to-date of the decontamination of the PMC and GPC using Nitrocision technology. Finding site-specific means of deploying the technology, using outside-the-box thinking to enhance system performance, and evaluation of lessons learned for future applications will be the legacy of this strong technical partnership.

CONCLUSION

The partnership between WVES and Nitrocision led to the evolution of an already-established technology into an enhanced technology with remote radioactive decontamination applications that can be used, not only in other areas of the WVDP, but in the larger DOE cleanup complex and in other industrial settings where remote applications are necessary or desired.

REFERENCES

www.nitrocison.com