Electro-Mechanical Manipulator for Use in the Remote Equipment Decontamination Cell at the Defense Waste Processing Facility, Savannah River Site - 12454

Bill Lambrecht*, Joe Dixon*, John R. Neuville**
*Par Systems, Shoreview, Minnesota, 55126
** Savannah River Remediation, Savannah River Site, Aiken, South Carolina, 29808

Abstract

One of the legacies of the cold war is millions of liters of radioactive waste. One of the locations where this waste is stored is at the Savannah River Site (SRS) in South Carolina. A major effort to clean up this waste is on-going at the defense waste processing facility (DWPF) at SRS. A piece of this effort is decontamination of the equipment used in the DWPF to process the waste. The remote equipment decontamination cell (REDC) in the DWPF uses electro-mechanical manipulators (EMM) arms manufactured and supplied by PaR Systems to decontaminate DWPF process equipment. The decontamination fluid creates a highly corrosive environment. After 25 years of operational use the original EMM arms are aging and need replacement. To support continued operation of the DWPF, two direct replacement EMM arms were delivered to the REDC in the summer of 2011.

Introduction

The defense waste processing facility (DWPF) is located at Savannah River Site (SRS) in South Carolina. The DWPF processes radioactive waste from underground storage tanks and produces a stable borosilicate glass product for long term storage. Equipment used by the process can become contaminated with highly radioactive waste.

Equipment failures occur during operation of the DWPF process. Equipment in the facility is moved by remote control cranes. Failed equipment is brought into the contact decontamination maintenance cell (CDMC) for hands on maintenance repair. Prior to being placed in the CDMC, equipment is cleaned and decontaminated in the remote equipment decontamination cell (REDC). The cleaning operations are performed to reduce radiation exposure to personnel working on contaminated equipment in the CDMC.

The REDC contains two electro-mechanical assemblies. The electro-mechanical manipulator (EMM) arms are a subassembly of an electro-mechanical assembly that contains two booms that extend the reach of the EMM. There are three different spray wands used to decontaminate equipment in the REDC; A wand that delivers a high pressure water jet, a wand that delivers decontamination fluid and a wand that delivers CO_2 pellets. Each EMM arm located in the REDC is used to mount two of the three spray wands. The original EMM assemblies were delivered to the DWPF in 1986. Due to regular use the original EMM arms are aging and require replacement. In the summer of 2011, two direct replacement EMM arms were delivered to the DWPF.

Discussion

The original EMM arms were delivered as part of several larger systems. Each larger system consisted of: controls, a vertical bridge, a vertical travel trolley, and an EMM arm with wrist. There are two systems in the REDC and a third system in the CDMC. The electro-mechanical assembly located in the CDMC is a spare unit that is used to swap out with a failed unit in the REDC. Only the electromechanical assemblies in the REDC are considered operational. In the latest procurement two EMM arms without wrists were provided to replace the original EMM arms. The original vertical bridges, vertical travel trolleys, and controls were not replaced.

The vertical bridges, trolleys, and EMM arms are primarily constructed of 304L stainless steel. The original wrists were also stainless steel, but several spare aluminum wrists have been previously procured by SRS.

Each EMM arm is a stainless steel version of PaR's standard M3000 manipulator, mounted horizontally on the end of a custom 2-axis horizontal rotating, folding arm to extend the reach of the M3000. (See Figure 1) While the new EMM arms were provided without wrists, they are designed to use PaR 3000 wrists and hands. Without the wrists installed an EMM arm has 6 axes of motion; upper boom, lower boom, M3000 shoulder rotate, shoulder pivot, elbow pivot, and wrist pivot. An M3000 wrist adds three more axes of motion; wrist rotate, wrist-extend, and hand open/close. The upper boom has +/- 90 degrees of rotation and the lower boom has +/- 180 degrees of rotation. The M3000 shoulder rotate has slip rings and is capable of continuous rotation in either the plus or minus direction. The shoulder pivot has +/- 125 degrees of rotation, the elbow pivot has +/- 135 degrees of rotation, and the wrist pivot has +/- 155 degrees of rotation. Each axis in the EMM arm has a slip clutch to protect the axis gears and axis drive motor from overload. In addition, the M3000 shoulder rotate has a safety lock brake to hold the load and protect the axis motor during load holding. A safety lock brake is a mechanical brake between the motor and the load. The wrist housing also has a custom utility outlet to run a 120 VAC tool. With the EMM arm fully extended, the length of the EMM arm from a mounting feature called the dovetail to the wrist rotation center is 4.44m (14.5 ft). With the wrist installed, the load capacity of the EMM arm is 45kg (100 lb) at full extension. An EMM arm weighs about 907 kg (2000 lbs).

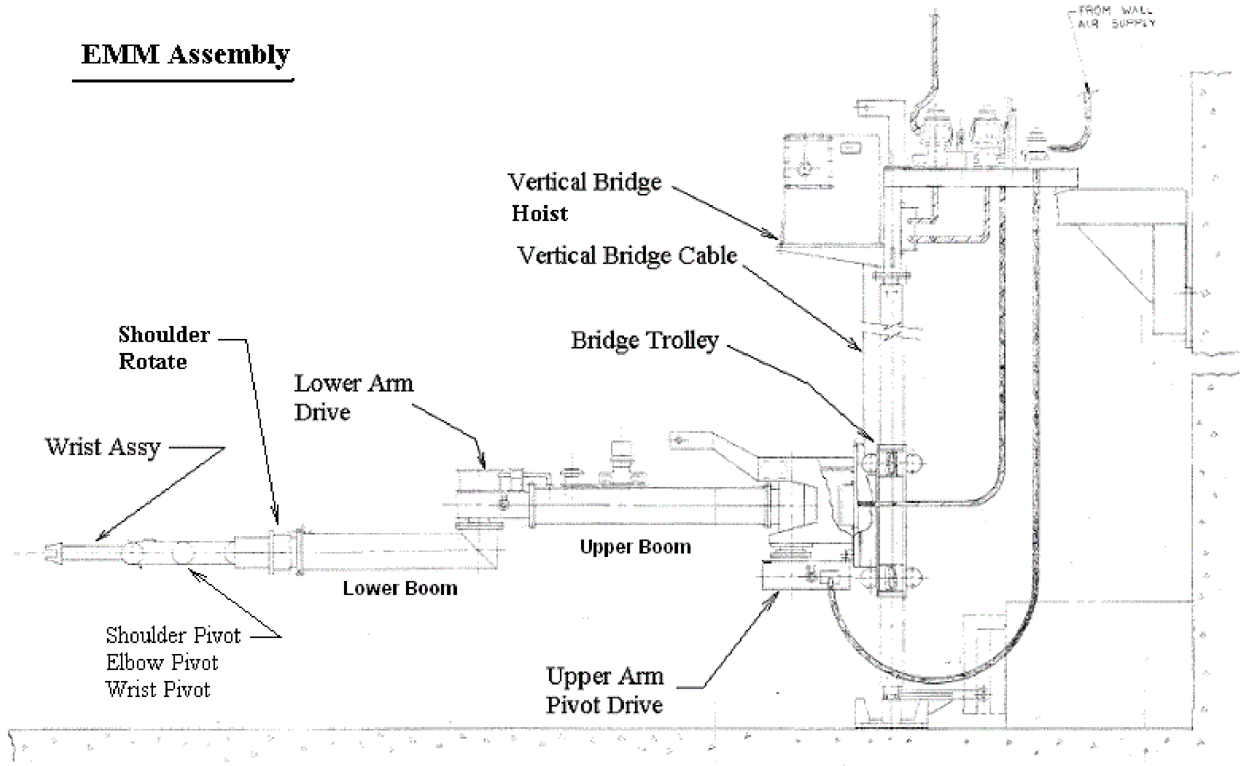

Fig 1. EMM Arm General Arrangement.

The vertical travel trolley has rollers that ride on the front and back of the vertical bridge. Vertical trolley travel is 5.44m (17 ft 10 in). A hoist raises and lowers the vertical travel trolley.

System controls consists of a cabinet with a power supply, transformer, and SCR drives to drive the system motors; and an operator console. The operator console uses finger switches to control motor direction and speed. Finger switches are rotator switches. Axis direction is determined by which way the switch is rotated and axis speed is determined by how far the switch is rotated. Release the switch and the switch will snap back to the zero position, there will be no power to the motor for that axis, and motion for that axis will stop. Multiple axes may move at one time and the number of axes moving is constrained by how many finger switches the operator can manipulate simultaneously. The control signals as well as service air are connected to the vertical bridge through Hanford connectors. Service air is used to purge the hoist box and the inside of the EMM arm. Hanford connectors are also used to connect the control signals and service air from the vertical bridge to the EMM arm. A cable from the electrical Hanford connector, connects to a junction box on the side of the upper pivot arm. From the upper pivot arm one cable connects to the drive for the upper boom and another cable enters the upper boom drive. Power for all axes and uses below the upper boom is run internal to the EMM arm. If power to the EMM arm is lost, the upper and lower booms both have external recovery drive nuts. To move the upper and lower booms during a loss of power event a powered nut driver is suspended from the facility overhead crane. Guide features on the upper and lower boom axes help the crane operator position the nut driver and torque reacting features on the EMM arm prevent the nut driver from self-rotating.

If SRR had upgraded the EMM arm controls, joysticks or a space mouse to control the EMM arm could have been procured. (See Figure 2) Two, replacement through wall manipulators (TRM) used to service the DWPF glass melter have also been provided. (See Figure 3) The TRMs are all stainless steel PaR 6350 tele-robotic manipulators with 1.27m arms (50 in) and a payload of 68 kg (150 lbs). The TRMs can utilize a programmed movement path or can be manually operated using a space mouse. The TRMs also have pneumatic tool changers and can change between several end effectors. One tool used to clean solidified glass out of the melter nozzle is a 50mm diameter burr (2 in) on the end of a 457mm (18 in) shaft that is spinning at 500 rpm. Another tool is used to replace sacrificial inserts in the melter nozzle and inspect melter cave equipment. The final tool is a pneumatically operated gripper. The PaR 6350 manipulator can be moved in and out of the melter cave with the DWPF overhead crane. Support for the manipulator is provided by a tube inserted through a wall penetration. Electric power, and pneumatic and hydraulic supply lines are also routed through the penetration tube.

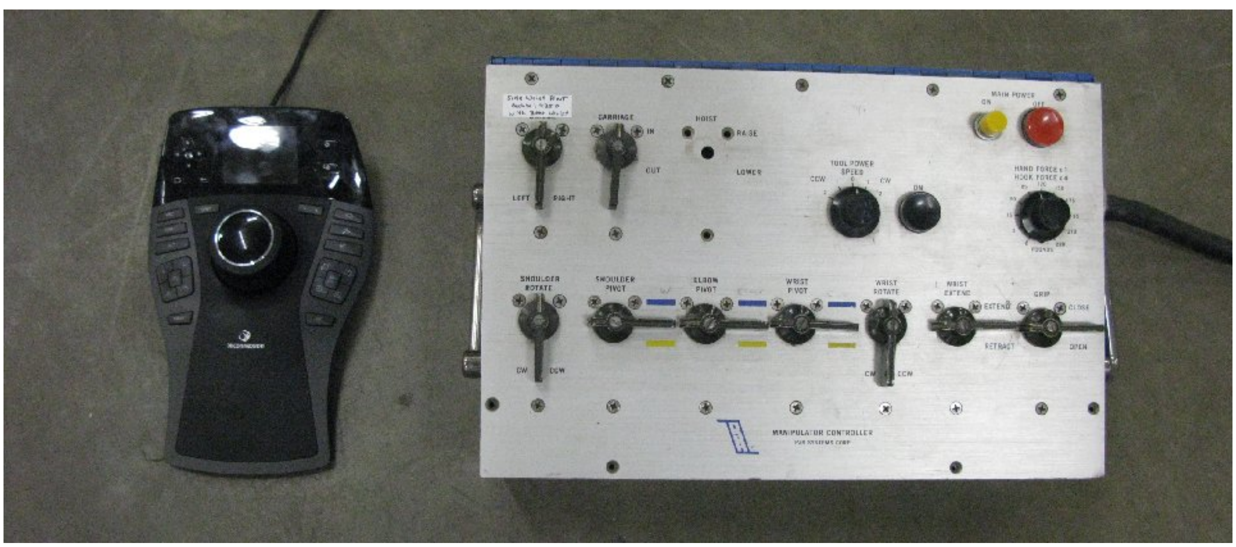

Fig 2. Space Mouse to be Used With Replacement TRM and Typical Finger Switch Console

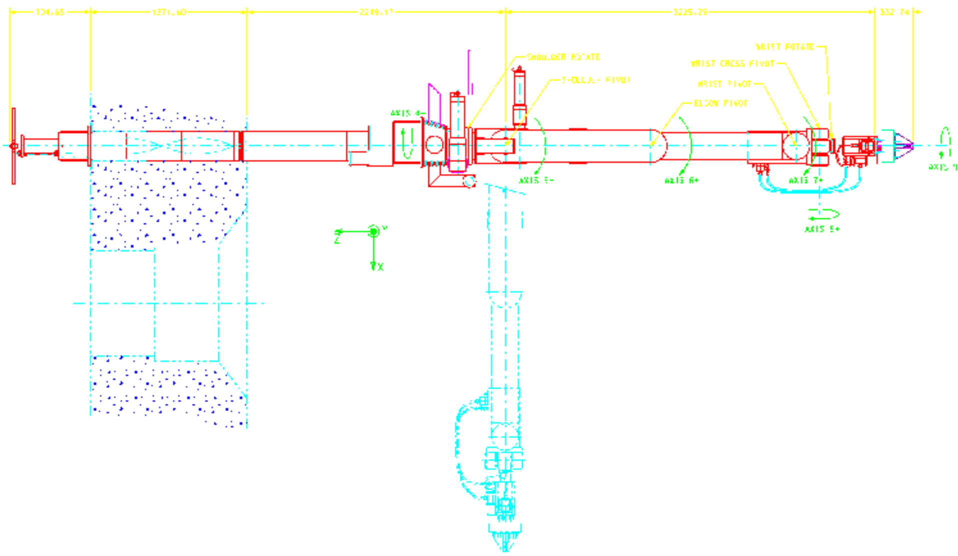

Fig 3. 6350 Tele-Robotic Thru Wall Manipulator.

The EMM arms can be moved within the DWPF canyon by remote control, overhead crane. On each vertical travel trolley there is a V shaped slot. The EMM arms have a V shaped plate referred to as the dovetail. The EMM dovetail fits in the slot on any vertical travel trolley. To prepare for a crane lift the EMM arm must be placed in the transport position. (See Figure 3) The EMM arm transport position is the upper boom arm positioned at its zero position; the lower boom arm is rotated to either the plus or minus 180 degree travel position and the M3000 is positioned so that the shoulder pivot, elbow pivot, and wrist pivot point straight down. A locking stop pin is dropped through a cylinder in the EMM arm lifting bail bracket and into a catch cup on the top of the upper boom arm. A pivoting stop bracket on the underside of the upper pivot arm catches a stop plate on the lower boom arm. The Hanford connectors are disconnected from the bridge and stored on dummy positions on top of the upper boom arm. The EMM arm transport position is balanced so that when the EMM arm is hanging by its bail from the overhead crane, the vertical angle of the dovetail plate is 0 +/- .1 degree. This level of balance simplifies the insertion and removal of the dovetail and eliminates binding in the V shaped slot on the vertical travel trolley. This is particularly important during removal of the dovetail from the V shaped slot.

Fig 4. Photo of EMM Arm Being Lifted During Preparation for Checkout.

The EMM arms are installed on a vertical bridge that allows the EMM arm to reach the top and bottom regions of tall canyon equipment. The vertical bridges are also installed and removed by remote control crane. Movement of a vertical bridge requires prior removal of the EMM arm and two jumpers that are used to power the bridge hoist and the EMM arm. The Hanford connectors used on the jumpers are disconnected from the hot cell and stored on dummy connectors on the top of the vertical bridge. Bridge mounting structure was installed in the REDC and CDMC before the facility went hot (January 1996).

The new EMM arms were to be delivered in a 13 month time period that ended at the end of September 2011. The original drawings were all paper drawings and the fabricated components of the original manipulators were built in PaR's own shop. The fabrication shop no longer exists. To minimize fabrication and assembly issues, the EMM arms were completely modeled in SolidWorks, detail drawings were updated and new assembly prints were generated. The two new EMM arms were delivered in July 2011, 11 months after order.

REDC Decontamination Operations

The REDC is used to decontaminate canyon process equipment. The cell has a volume of 7.93 m (26 ft) X 9.14 m (30 ft) X 9.37 m (31 ft) high. Decontamination of equipment is performed in the REDC until sufficiently low levels of radioactivity remain on the equipment that allows for personnel access to the equipment for repair in the CDMC. Decontamination is also performed to clean equipment and improve its performance before return to service as shown in figure 5. General administrative objectives for radioactivity levels of equipment being repaired in the CDMC are as follows:

Dose Rates:	Contamination Levels:
<50,000 mrem/hr Extremity	<20,000 dpm/100 cm^2 alpha
<15,000 mrem/hr Skin	<250 mrad/hr beta-gamma
<100 mrem/hr Whole Body	

The majority of large process equipment that are decontaminated in the REDC are Process Coils, Agitators and Process Pumps. This equipment takes up a space about 4.57m (15 ft) high by 1.22m (4 ft) diameter and weighs 1814-4535 kg (2 – 5 tons). The equipment is brought into the REDC by remote control crane and placed on a support stand. The EMM is then moved around the piece of equipment to fully decontaminate all surfaces that are in contact with process fluid. The long reach as described above allows access all around most equipment with little movement of the equipment. EMM arm speeds are relatively slow and operation of the finger switches can be mastered quickly. This allows an operator looking thru a 1.37 m (54 in) thick Radiation Window Assembly (that is filled with oil and consists of multiple glass panes) to safely decontaminate equipment. In certain instances, the equipment to be decontaminated is suspended by the remote control crane to improve accessibility during decontamination activities.

The methods used to deliver decontamination fluid to clean canyon equipment have evolved over the years of DWPF operation. These methods have changed to accommodate less water usage and to clean the surface of equipment that has collected dried hard waste material. Chemicals and mechanical energy are used to remove build-up of bulk radioactive contamination from the surface of equipment. A nitric acid decontamination solution is used to dissolve radioactive sludge. The decontamination fluid consists of a mixture of 12%-20% nitric acid, 1% potassium permanganate and water. This fluid is delivered in a 25mm (1 in) diameter, 15.2 m (50 ft) long, EPDM hose rated at 1.72 MPa (250 psig) to a spray wand at .55 MPa (80 psig). The decontamination solution is sprayed from a nozzle attached to the wand onto equipment, in the form of steam at 149 deg C (300 deg F). The sealed and purged all-stainless steel construction EMM arm allows the EMM arm and vertical bridge to be wetted with the nitric acid solution and not corrode. A master-slave manipulator (MSM) is also used in the REDC to scrape dried hardened material off of the wall of equipment. The MSM is covered with a protective boot to keep acid solution and radioactive contamination off of internal components. A tear in the boot on the MSM results in unscheduled maintenance of the MSM. The MSM also does not have the capacity to handle the heavy spray wands. The construction of the EMM arm minimizes maintenance and improves availability for use.

Other decontamination methods that use the EMM include a pressure spray water jet and a CO_2 pellet delivery system. The water jet wand which delivers water at 20.7 MPa (3000 psi) and 13.2 liters/min (3.5 gpm), is used to remove bulk material from the outer surfaces of equipment by imposing an impact force on the solid waste material. The EMM also holds a wand used to deliver CO_2 pellets to equipment surfaces. The CO_2 system is used to remove fixed contamination from the surface of equipment by rapid volumetric expansion of a chemically inert CO_2 pellet. The pellet removes and disperses fixed contamination located on electrical components by a sublimation process that changes the phase of the pellet from solid to gas when it hits a solid surface. Decontamination of equipment is performed until the level of radioactivity remaining on the equipment is sufficiently low that personnel can be allowed access to the equipment for repair or allow the equipment to be returned to service. (See Figure 5)

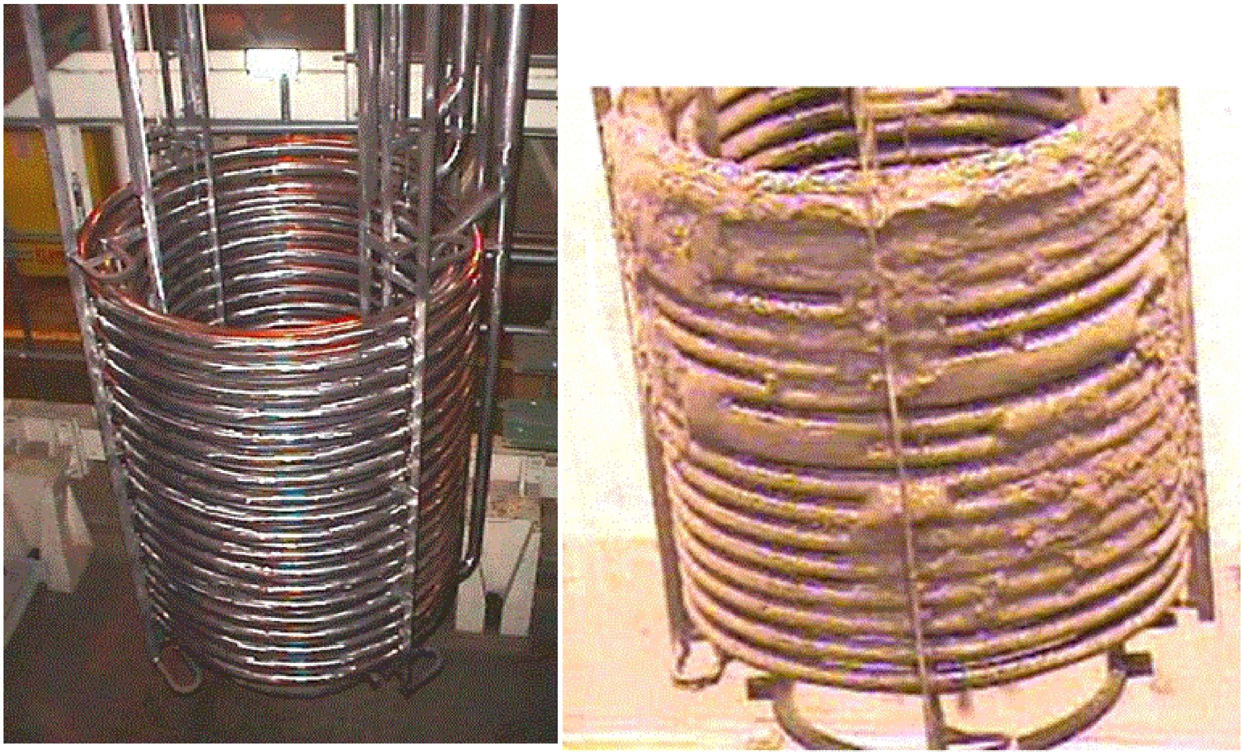

Fig 5. Clean process coil (left) and fouled process coil (right)

The original EMM Arm was designed to hold a single wand that sprays decontamination fluid onto the surface of contaminated equipment. A single spray wand was originally held by a PaR M3000 Parallel Jaw Gripper. As operating experience was gained, the wrist was removed and a cover plate was designed for the wrist housing to have one or two fixed mounting posts. Each post can hold a single wand. The second post was developed to hold a pressure washer wand or a CO2 wand.

The EMM arms have had several operational problems. The EMM wrist housing seals failed and allowed decontamination solution to corrode electrical slip rings. Replacement of the wrist assembly with wand posts solved the internal corrosion problem. This modification also made the EMM arm more versatile by allowing simultaneous carriage of two separate cleaning processes at one time. The design of the EMM arm, locates motors for all the other axes away from the business end of the EMM arm and they are less likely to come into direct contact with the nitric acid solution. The EMM supports a set of heavy hoses when the two wands are attached to the EMM wrist housing. The extra weight from the hoses applies a large side load on the EMM arm. The EMM arm now routinely carries its maximum payload all the time. This leads to more wear on the manipulator overload clutches. Over time the clutches slip and require frequent adjustment. In the new EMM arms the clutches are lapped in, to provide a more consistent friction surface and longer life.

SRS has successfully used the EMM arms for 25 years to clean equipment. The arms have withstood the severe corrosive environment with very few problems. The extended reach of the EMM arms allows more complete coverage of DWPF equipment during decontamination while the stainless steel construction allows the EMM arm to survive in the corrosive environment without using a fragile boot to protect it. The size of the EMM arm allows regular carriage of heavy hoses that carry decontamination fluid and the spray wands that minimizes the need to reconfigure the EMM arm for different cleaning methods. The design of the EMM arm and the vertical bridge allows the EMM system to be moved in and out of the REDC for maintenance. Future upgrades to the operation of the REDC are being considered to improve the availability of the DWPF canyon crane for other functions. One option being considered to upgrade the REDC is a dedicated crane to hold DWPF process equipment during the decontamination evolution.