Remote Handling Equipment at the Hanford Waste Treatment Plant

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ABSTRACT

Cold war plutonium production led to extensive amounts of radioactive waste stored in tanks at the Department of Energy’s Hanford Waste Treatment Plant. The storage tanks could potentially leak into the ground water and into the Columbia River. The solution for this risk of the leaking waste is vitrification. Vitrification is a process of mixing molten glass with radioactive waste to form a stable condition for storage. The Department of Energy has contracted Bechtel National, Inc. to build facilities at the Hanford site to process the waste. The waste will be separated into high and low level waste. Four major systems will process the waste, two pretreatment and two high level. Due to the high radiation levels, high integrity custom cranes have been designed to remotely maintain the hot cells. Several critical design parameters were implemented into the remote machinery design, including radiation limitations, remote operations, Important to Safety features, overall equipment effectiveness, minimum wall approaches, seismic constraints, and recovery requirements. Several key pieces of equipment were designed to meet these design requirements – high integrity crane bridges, trolleys, main hoists, mast hoists, slewing hoists, a monorail hoist, and telescoping mast deployed telerobotic manipulator arms. There were unique and challenging design features and equipment needed to provide the remotely operated high integrity crane/manipulator systems for the Hanford Waste Treatment Plant. The cranes consist of a double girder bridge with various main hoist capacities ranging from one to thirty ton and are used for performing routine maintenance. A telescoping mast mounted telerobotic manipulator arm with a one-ton hook is deployed from the trolley to perform miscellaneous operations in-cell. A dual two-ton slewing jib hoist is mounted to the bottom of the trolley and rotates 360 degrees around the mast allowing the closest hook wall approaches. Each of the two hoists on this slewer is mounted 180 degrees opposite each other. Another system utilizes a single one-ton slewing jib hoist that can extend and retract as well as rotate 270 degrees around the mast. Yet, another system utilizes an underhung monorail trolley with one-ton hoist capacity mounted to the bottom of the bridge girder. The main, slewer and monorail hoists each have power-rotating hooks for installing and removing equipment in the hot cell.

INTRODUCTION

The 50-mile stretch of the Columbia River known as the Hanford Reach is the last free-flowing section of the river in the U.S. This natural wonder is now a National Monument. A few miles west of the river, there remains a deadly legacy of the Cold War - 53 million gallons of radioactive and chemical wastes stored in 177 underground tanks. This radioactive waste has the potentioal of leaking and contaminating the groundwater, threatening the Columbia River and millions of people downstream. The Hanford Tank Waste Treatment and Immobilization Plant is located in the 200 East area of the Hanford Site, near Richland, Washington.

HANDFORD TANK WASTE TREATMENT AND IMMOBILIZATION PLANT

To meet the challenge of safely removing the millions of gallons of waste, the Department of Energy awarded Bechtel National, Inc. a contract in December of 2000 to design and construct the world's largest radioactive waste treatment plant. Bechtel National, Inc. is designing and building the waste treatment plant to vitrify Hanford's nuclear waste. Vitrification is a process of mixing molten glass with radioactive waste to form a stable condition for storage, which will be impervious to the environment. Silica and other glass-making materials are added to the waste, which is then heated to nearly 2,000 degrees Fahrenheit in an electric melter. The molten glass is poured into large stainless steel canisters, which are cooled for a few days before being welded shut and decontaminated.

As the waste is pumped out of the existing 177 tanks, it will be analyzed in a Pretreatment facility. Figure 1 shows how it will then be separated into High Level Waste or Low Activity

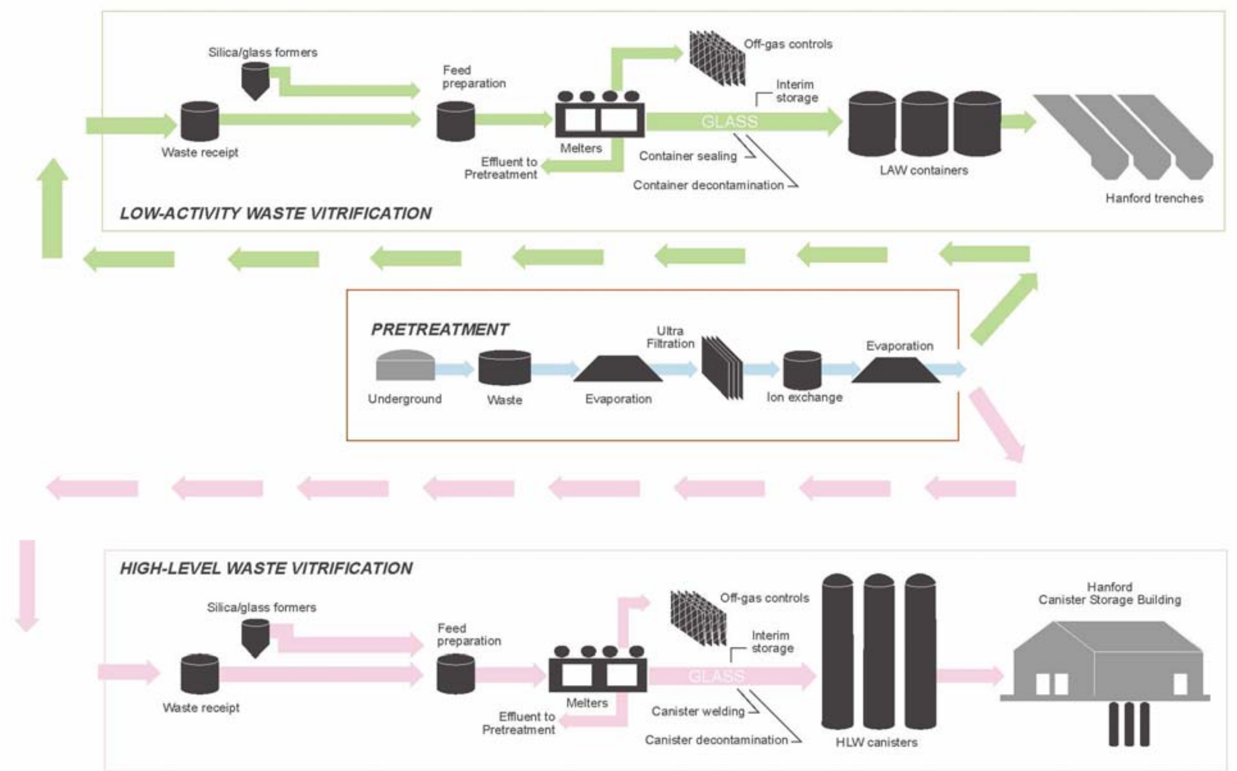

Fig. 1. Process Flow Diagram

Waste depending on the radiation levels of the waste.

The Pretreatment facility will be the largest at the Waste Treatment Plant site, measuring 215 feet wide by 540 feet long by 120 feet tall, or approximately 13,900,000 cubic feet. The radioactive waste will be pumped from the tanks to the Pretreatment facility interior waste feed receipt vessels. During the first stage of pretreatment, the waste is concentrated by removing water in an evaporation process. Solids are filtered out and the remaining soluble, highly radioactive isotopes will be removed by an ion exchange process. The facility main elevation houses a 406-foot long hot cell. This hot cell contains cesium ion exchange columns, ultra filtration equipment, evaporator reboilers, evaporator recirculation pumps and various mechanical process pumps for transferring process fluids to other tanks for processing. The tanks and other equipment are connected to the hot cell process equipment through a series of "jumpers" - remotely removable items for fluids, gasses and electricity. The solids are then sent to the High Level Waste facility, while the remaining liquids are sent to the Low Activity Waste facility.

The High Level Waste facility will contain the most radioactive and dangerous waste making it the most complex facility. This facility will measure 275 feet wide by 440 feet long by 95 feet tall, or approximately 8,600,000 cubic feet and will immobilize high-level radioactive waste in a glass matrix for long-term storage. When the waste and the glass-forming materials are mixed, they will be vitrified in two melters inside the facility. The vitrified waste will be poured into stainless-steel canisters that are two feet in diameter, and stand 14.5 feet tall. Each canister will weigh more than four tons and be temporarily stored at Hanford's 200 Area canister storage building. Eventually, the canisters will be shipped to an approved federal geological repository for permanent disposal.

The Low Activity Waste facility will be the smallest of the three, measuring 240 feet wide by 330 feet long by 90 feet tall, or approximately 6,500,000 cubic feet. The Pretreatment facility sends liquid waste to the Low Activity Waste facility through underground pipes. The facility has two melters that will be responsible for vitrifying the waste. The product is then poured into the stainless-steel containers. These containers are four feet in diameter and seven feet tall and will weigh more than seven tons. The containers will be stored at Hanford in trenches covered with soil, far away from the Columbia River.

Amongst the many cells at the Waste Treatment Plant site, five key cells at the Hanford site require remote maintenance and manipulation. The Pretreatment facility consists of two of these cells, Pretreatment In-Cell Handling System (PIH) and Pretreatment Filter Cave Handling System (PFH). The High Level Waste facility consists of three other cells, High Level Waste Filter Cave Handling System (HFH) and High Level Waste Melter Cave Support Handling Systems (HSH 1 and HSH 2). Bechtel National, Inc. awarded PaR Systems, Inc. a contract in May 2003 to design and build high integrity cranes with power manipulators to remotely maintain each of these cells. The PIH cell sorts the waste and distributes it to the High Level Waste or Low Activity Waste facility. Air flow through all facilities moves from the least contaminated to the most contaminated areas prior to entering the filter caves. The PFH and HFH cells filter the air for the entire Pretreatment and High Level Waste facilities, respectively. Each HSH cell contains a melter where vitrification of the high level waste will occur.

HIGH INTEGRITY CRANES

The PIH crane is the largest of the four high integrity cranes and consists of a double girder bridge and a trolley main hoist with a thirty-ton capacity, see Figure 2 and 3. A telescoping mast mounted telerobotic manipulator arm with six degrees of freedom and a one-ton hook is deployed from the trolley to perform miscellaneous operations in-cell. A dual two-ton slewing

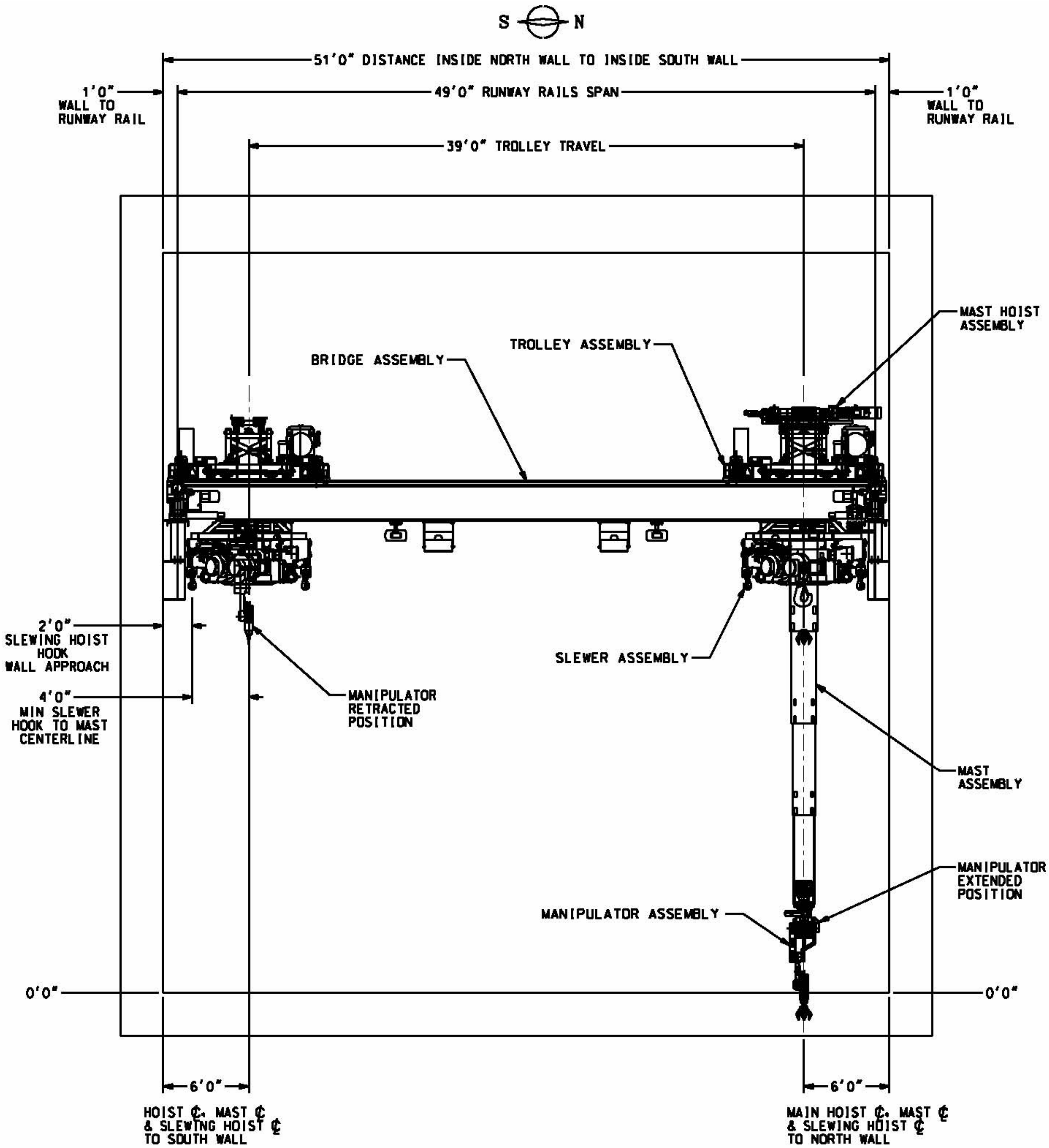

Fig. 2. Wall Approaches

jib hoist is mounted to the bottom of the trolley and rotates 360 degrees around the mast centerline allowing the closest hook wall approaches. Each of the two hoists on this slewer is mounted 180 degrees opposite each other. Both the trolley main hoist and slewer load blocks have power-rotating hooks for orienting equipment in the hot cell. The manipulator has both a parallel jaw hand as well as a hook hand that can be remotely exchanged in cell. PIH is the only system where cameras and lights on the crane are the only source of sight or light in the cell.

Due to the long length of the PIH cell, two slewer hooks, the manipulator hook, and the thirty-ton hook can be used to hold multiple tools and retrieve multiple items from the far end of the cell. The PIH slewing hoist will hold a nut runner that will remove the mounting hardware of the cesium ion exchange vessel should it need to be removed. The PIH thirty-ton main crane hoist will then pick the vessel and deposit it in the decontamination cell where it will be decontaminated and downsized and taken out of the cell. The PIH manipulator will be used to remove and replace the slave arms of the master slave manipulators. The slewer or manipulator can be used to remove wall mounted jumpers. The PIH cell will be operational 24 hours a day, 7 days a week.

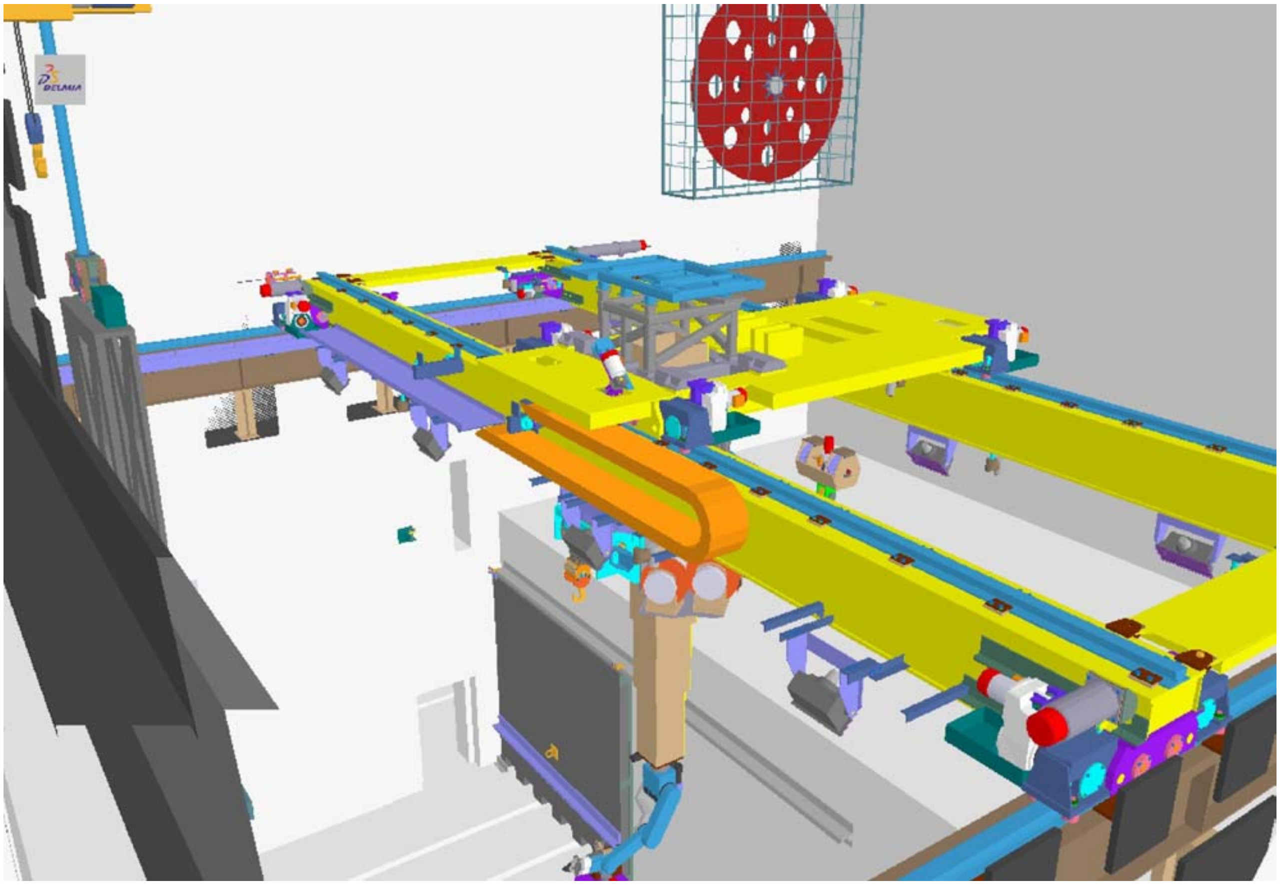

Fig. 3. PIH Crane with manipulator and slewer.

The PFH and HFH cranes are similar to each other and each of their trolley main hoists have a six-ton capacity. Neither of these systems has a slewer hoist, although both manipulators used in each of these systems are identical to PIH. The PFH crane is the only crane to utilize an underhung monorail trolley with a one-ton hoist capacity. This monorail is mounted on the bottom of the bridge girder and travels parallel to the trolley. The monorail load block is also equipped with a power rotating hook. The PFH and HFH filter cranes will use their six-ton hoists to remove the lids off the demisters and the high efficiency mist eliminators. The PFH one-ton monorail will then remove and replace the filters. The manipulator will be used to remove and replace wall mounted lights and cameras.

The HSH crane has a telescoping manipulator and a single one-ton slewing jib hoist that can extend and retract as well as rotate 270 degrees around the mast. The HSH manipulator has slightly shorter arm segments as well as a seventh degree of freedom with its wrist cross pivot. This crane does not have a trolley main hoist.

The HSH manipulator will be used for many tasks which include moving vacuum suction hoses for in cell cleanup, changing out vacuum filters and branched air lines in case they get plugged, and installing horizontal thermocouples into the thermal wells on the melters. Due to their zero wall approach abilities, the manipulator will be used to remove and replace wall mounted cameras and lights and make through wall penetration connections. There is also cross pivot on the manipulator that adds an additional level of dexterity to better make flexible jumper and connector connections. There are approximately 1700 remote interface points within the HSH cell and the manipulator will be used to access and service over half of them, see Figure 4. In

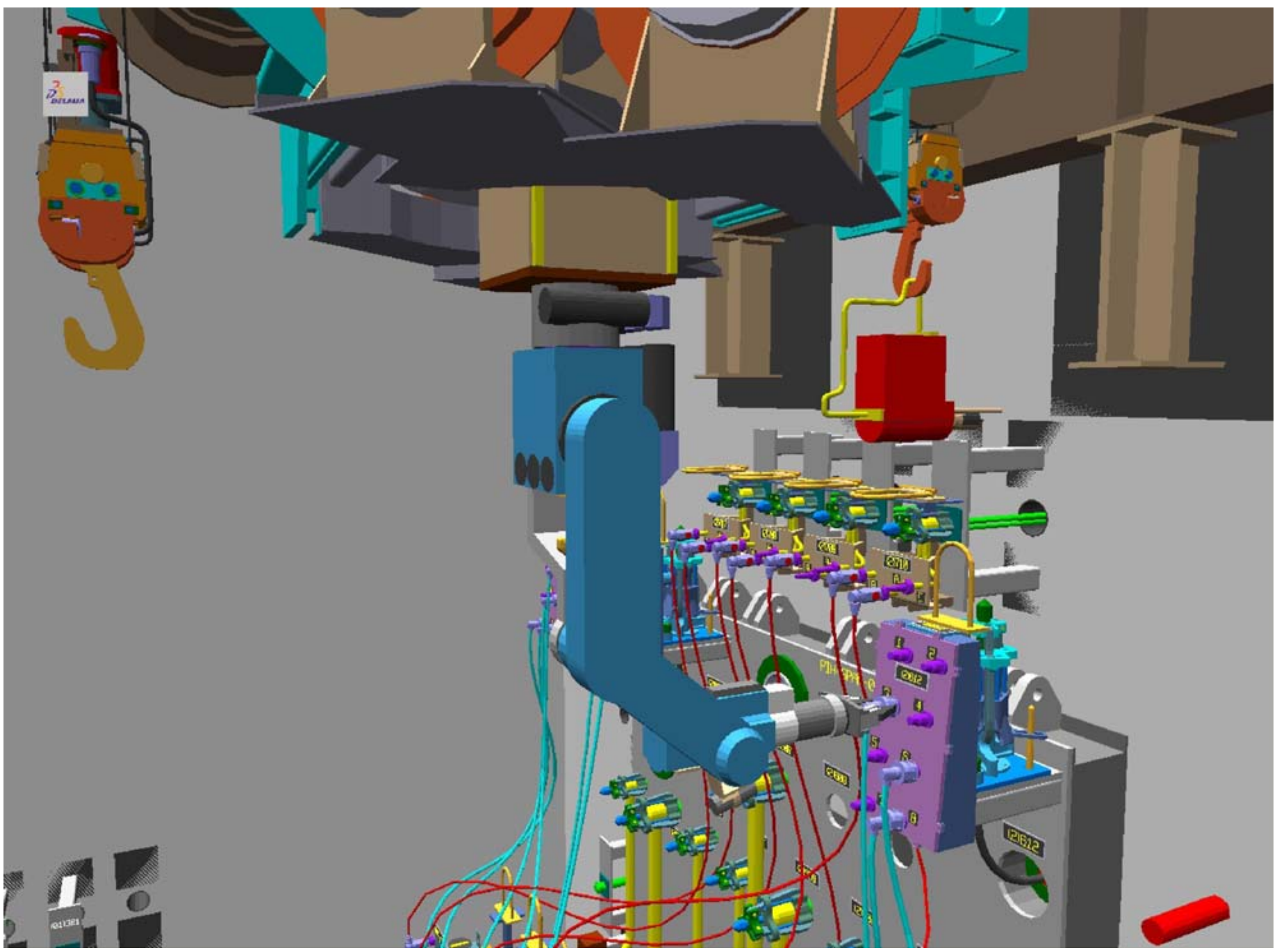

Fig. 4. Manipulator making a jumper connection.

one case the manipulator offers torque resistance for operating a nut runner used to install and remove a 6800 amp melter bus tray to the floor. The manipulator is extensively used to connect the melter to all other required process and electrical services.

The HSH slewer hoist will be used to remove and install bubblers. These bubble air into the molten glass to help agitate and increase the heat transfer rate. The bubblers are in direct contact with the glass and get contaminated and degraded. They will be replaced every few months. The slewing hoist will also be used to cap spare unused Purex nozzles that protrude straight off the wall. These Purex nozzles are used to transfer processed fluid in and out of cell. The slewing hoist has a triangular shaped booming frame used to deploy the load block allowing access into corners to reach three-way valves for a slurry feed. Real estate in a hotcell is extremely valuable and typically limited. With the ability for the slewing hoist to reach into the corners, more real estate is available for cell layout and process design.

Large cable reels (up to 12 feet in diameter) will supply power, signal, and control to the cranes through two segregated cables. Each cable is approximately 2.5 inches in diameter. One cable is for power and the other is for signal and control to reduce signal interferences. Each cable contains its designated conductors as well as steel cords. These cords strengthen the cable to the extent that should the crane ever fail in cell, the cable reel will be able to retrieve the crane by pulling it back into the crane maintenance area.

CRITICAL DESIGN FEATURES

Due to the high radiation levels, the hot cells are closed off to direct human intervention. Each high integrity custom crane has been designed to remotely maintain equipment in the hot cells. Several critical design parameters were implemented into the remote machinery design, including radiation limitations, remote maintenance, Important to Safety features, Overall Equipment Effectiveness, minimum wall approaches, seismic constraints, and recovery requirements. Several key pieces of equipment designed to meet these requirements were high integrity crane bridges, trolleys, main hoists, slewing hoists, a monorail hoist, and telescoping mast deployed telerobotic manipulator arms.

The total integrated radiation dose over 40 years within the various hot cells ranges from 1.0E+07 Rad (100 Rads per hour) at the bridge elevation to 3.5E+08 (500 Rads per hour) at the manipulator arm. To help put this in perspective, the National Regulatory Commission recommends an annual dosage limit of 5 Rad above and beyond what one would be exposed to from natural background radiation on Earth. Due to the high level of radiation, the hot cells are closed off to human intervention. All access to the cells is handled remotely through viewing windows or cameras mounted in cell or on the cranes. Special consideration must also be taken in choosing organic materials. All gaskets, o-rings, insulation, and cable jacketing must be chosen to withstand these high levels of radiation. Bechtel National, Inc. has also taken precautions in the design of the shield doors that separate the hot cell from the decontamination areas and the decontamination area to the crane maintenance areas to eliminate or reduce radiation shine paths.

All components within the cell must be remotely maintained. These include lightweight components such as nuts, bolts, pins and other equipment weighing up to thirty tons. All items in the hot cells have lifting points that are accessible by various hooks or the manipulator arm. Any fastened component in cell can be remotely removed with impact wrenches or nut runners.

Historically, Important to Safety functions came from the nuclear field to ensure no radioactive materials escape a plant or that the plant can safely shut down in an emergency situation. Important to Safety components have a higher degree of quality documentation, verification, and more extensive witnessing. These cranes were designed to several Bechtel National, Inc specifications as well as CMAA (Crane Manufactures Association of America) and ASME NOG requirements. In addition to these requirements, Bechtel National, Inc dictated specific Important to Safety mandates such as material certifications for all load path items, hoist high and high-high limit switches, overload protection, wire rope misreeving protection, redundant and independent hoist braking systems, drum overspeed detection system, and mast tilt indication switches. These various Important to Safety functions were designed into the equipment to further ensure in cell safety.

Bechtel National, Inc has also mandated that the cranes shall be designed with an overall equipment effectiveness greater than 90%. Overall equipment effectiveness is the product of the availability, performance efficiency, and quality rate for all items of equipment (Ireson and Combs, 1998).

Performance Efficiency = 1- (Σ Component MTTR / Available Production Time)

Quality Rate = 1- (Σ Failure Rates Of Components That Could Cause Damaged Product / Available Production Time)

Taken as a percentage, availability can be calculated by dividing a component's mean time between failures (MTBF) divided by the sum of MTBF and its mean time to repair (MTTR).

Availability = MTBF / (MTBF + MTTR)

The availability for these high integrity cranes had to be greater than 98%. Components were designed to maintain this high level of performance to minimize down time over the 40 year projected life of the plant. Load bearing parts, radiation sensitive components, mechanical components experiencing wear and tear, and any other component with a history of failure were included in this analysis. Mean time between failure values came from vendors and published reliability data. These values were compiled and calculated for the PIH and PFH cranes. The PIH crane overall equipment effectiveness and availability values resulted in 98.14%. The PFH crane overall equipment effectiveness and availability values resulted in 98.21%. These values were identical for each crane because the values of the performance efficiency and quality rate were so close to 1.

Making full use of the hot cell is critical to operations and plant designers. Wall approaches must be maintained to allow access to items placed close to or on the wall. The hot cells are filled to maximum capacity and space is limited, so the crane hook approaches are critical. Equipment was placed in cell according to these wall approach requirements. The PIH and PFH cranes both have the main hoist and mast hoist on the same centerline parallel to the length of the cell to allow both hooks the same sidewall approach. In order to package all the equipment in the HFH cell, the filters had to be placed along the end of the cell wall. The HFH crane has the main hoist and mast hoist on the same centerline parallel to the width of the cell to allow both hooks the same end of cell wall approach. The HSH crane wall approaches were based only on the mast hoist centerline.

The cranes for all of the hot cells have been designed to maintain their integrity under seismic conditions. Bridge and trolley restraints have been implemented as necessary to resist uplift and lateral forces. The cranes have been modeled and run through finite element analyses to simulate the design earthquake conditions and confirm member stresses are acceptable. All connection joints have also been analyzed and designed to withstand these associated forces. Although the crane does not have to function after a seismic event, no part of the crane may fall during or after the event.

Due to the high level of radiation and limited personnel accessibility, the cranes must be able to remotely recover from a single random or common mode of failure. All loads shall be removable and cranes shall be able to return to the crane maintenance area. To achieve this, all bridge, trolley, hoist, and slewing rotation, extension, and retraction drive trains must have recovery capability.

All bridge and trolley drive trains have remotely deployed jackdown wheels to allow recovery should one of the wheel assemblies fail. All four corners of the bridge and trolley have motor driven wheel mechanisms. In the event that a powered or idler wheel seizes or the drive train fails, the jackdown wheels will deploy at the failed corner as well as at the same corner on the opposite rail. The other two corners will drive the bridge or trolley to a recoverable position. The jackdown wheel is mounted to an eccentric bearing and is deployed as it rotates into position. With the exception of the slewing hoists, all other hoists on all four cranes have an independent recovery hoist that will allow its associated hook to set its load down and fully retract or extend as necessary. Because the slewer hoist does not have a recovery hoist, a set of cable cutters has been implemented to cut the wire rope and load block free should it be necessary. The slewing rotation, extension and retraction operations have slip clutches built into the drive train that will enable a failed operation to be back driven into a recoverable position.

CONCLUSION

The Department of Energy and Bechtel National, Inc. are committed to stabilizing any threat of leaking waste at the Hanford Waste Treatment Plant. PaR Systems, Inc. is committed to supporting this effort by providing these high integrity cranes and manipulator systems where human intervention is not possible. Although the hot cells and cranes are similar, each is unique to the process or function it supports. Through combined efforts between Bechtel National, Inc. and PaR Systems, Inc. the hot cells and cranes will remain functioning safely over the forty year life of the plant.

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