Archimedes Filter Plant Remote Maintenance System Design

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Abstract – *The legacy of plutonium production at the Hanford Site is millions of gallons of radioactive waste. The Department of Energy is planning to vitrify the waste for permanent disposal. The Archimedes Technology Group is developing a means of electromagnetically segregating this waste based on plasma mass separation, and Remote Systems Group at Oak Ridge National Laboratory is providing engineering assistance. A concept has been developed for remote maintenance featuring remotely operated overhead cranes and bridge-mounted servomanipulators.*

I. INTRODUCTION

The legacy of plutonium production at the Hanford Site is millions of gallons of radioactive waste. The Department of Energy is planning to vitrify the waste for permanent disposal. The Archimedes Technology Group is developing a means to electromagnetically segregate this waste based on plasma mass separation. The separation technique takes advantage of the fact that up to 90% of the atomic species are light-mass, non-radioactive elements. The radioactive waste material that accumulates on the mass separator collectors is periodically recovered, with the material on the “light” collectors treated as low-level waste, and the material on the “heavy” collector treated as high-level waste. This results in a 75 to 85% reduction in the mass of high-level waste to be vitrified. A schematic of the Archimedes filter is shown in Figure 1.[1]

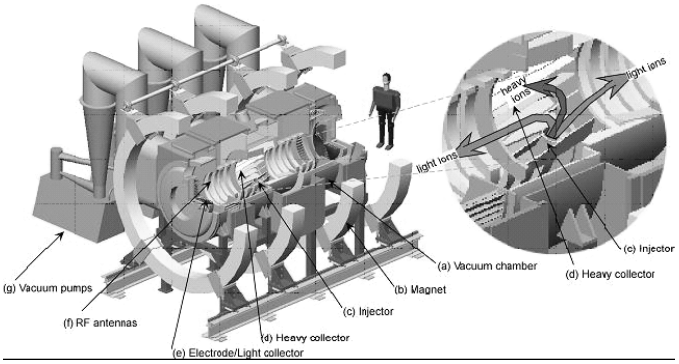

Fig. 1. Schematic of Archimedes filter.

Because of the highly radioactive waste stream being processed, maintenance and operational support require remote handling (RH) equipment. The peak in-cell dose rate is 10^5 R/h and the average dose rate is 10^3 R/h. Equipment will be specified to survive an integrated dose of 1×10^8 rad.

The plasma mass separators, also called Archimedes Filters, will be located in a large hot cell, and maintenance on the separators will be performed remotely. The collectors within the filters must be periodically removed for cleaning and refurbishment using RH equipment.

The Remote Systems Group at Oak Ridge National Laboratory (ORNL) is under contract to provide engineering assistance to the Archimedes Technology Group, in preparing the conceptual design of the remote maintenance system for the Archimedes Filter Plant (AFP).

II. AFP REMOTE MAINTENANCE CONCEPT DEVELOPMENT AND SELECTION

A trade-off study was performed to compare various RH alternatives prior to finalizing a concept for remote maintenance for the Archimedes facility. Alternative concepts were evaluated against RH system objectives.

II.A. RH System Objectives

The objectives considered in the trade-off study are outlined below.

1) The RH system and the AFP design should enable the AFP to achieve its design requirement of 65% plant availability over the first 10 years of operation.
2) The RH system should enable the AFP to be operational at high throughput for extended periods of time.
3) The RH system should minimize the number of personnel required and minimize their exposure to radiation and other industrial hazards.
4) The RH system should minimize the amount of radioactive waste produced during maintenance and remove that which is produced from the hot cells.
5) The RH system should minimize the total AFP project cost consistent with achieving the other objectives.
6) The RH system should be very reliable and capable of prompt recovery from RH equipment failures.
7) The RH system should be configured to optimize the hot cell design and the general arrangement of equipment inside and outside the hot cells.
8) The RH system should be compatible with methods for automation of repetitive maintenance sequences to reduce dependence on human operators and decrease the time required to perform the maintenance.
9) The RH system should be operational after (but not during) a design-basis earthquake, assuming electrical power and other required services are available.
10) The RH system should be designed to perform final decommissioning, decontamination, and dismantling of equipment within the hot cells.

II.B. RH Concepts Evaluated

Four options were considered for evaluation against the objectives listed. These options are described below.

Option 1

RH is by mechanical master-slave manipulators (MSMs) supplemented by a 10-ton overhead bridge-mounted crane. Viewing is performed through lead-glass shielding windows and supplemented by closed-circuit television (CCTV).

Option 2

RH is by one or more servomanipulators mounted on vertical masts supported from monorails. Lifting capacity of 10 tons is provided by combining hoists from multiple masts. In-cell CCTV viewing is supplemented by a limited number of shielded viewing windows.

Option 3

RH is by servomanipulators mounted on floor-supported masts. In-cell CCTV viewing is supplemented by a limited number of shielded viewing windows. Lifting capacity of 10 tons is provided by combining hoists from multiple masts.

Option 4

RH is by servomanipulators mounted on overhead bridge transporters. In-cell viewing is by CCTV. Lifting is by 10-ton gantry cranes.

Option 5

RH is by free-roaming robotics with a precision guidance system. The free-roaming robot is equipped with an integrated lifting capability of 10 tons. In-cell viewing is by CCTV.

All of the concepts also include a common maintenance area with MSMs for in-cell repair and refurbishment of equipment.

II.C. Concept selection

In order to objectively evaluate these options against one another, a decision analysis process was used. This process consists of four steps: (1) clarify the purpose of the decision, (2) identify objectives that are to be met through this decision, (3) weigh the objectives according to their relative importance, and (4) evaluate the options against the objectives and assign a numerical score for each option.

The evaluation process revealed the following risks for the various options.

Option 1: MSMs, windows, and 10-ton bridge crane

MSMs may not be able to reach the center of the filter machine. or areas on the side of the vacuum pumps. The filter machine may need to be redesigned to accommodate the reach limitations of the MSMs. The capability of the MSMs may be restricted for tasks at the limits of their reach.

Option 2: Monorail masts servo-manipulators and 10-ton combined lift

Servomanipulators may not be able to reach the center of the filter machine. And their capability may be limited for tasks at the limits of their reach. The filter machine may need to be redesigned to accommodate the reach limitations of the servomanipulators.

Option 3: Floor masts with servo-manipulators and 10-ton combined lift

Servomanipulators may not be able to reach the center of the filter machine and their capability may be restricted for tasks at the limits of their reach. The filter machine may need to be redesigned to accommodate the reach limitations of the servomanipulators. Floor masts block access to walls for penetrations and may impact filter design.

Option 4: Overhead bridge servomanipulator and 10-ton bridge crane

This concept might require two servomanipulator systems on each filter machine to meet the availability goal.

Option 5: Free-roaming robotics and 10-ton bridge crane

Free-roaming robotic technology is not well developed. Schedule and cost for development are significant unknowns and may not be feasible with the AFP schedule.

Option 4 was the concept finally selected because of the flexibility of the servomanipulator working envelope. The overhead bridge crane and servomanipulator are shown in Figure 2. The plan view of the cell is shown in Figure 3.

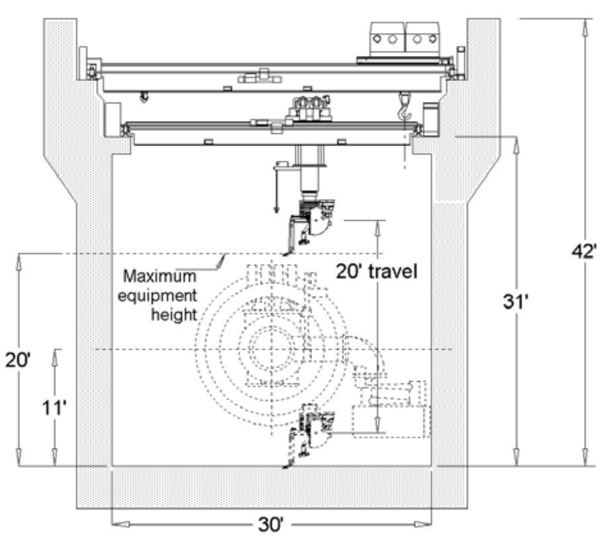

Fig. 2. Cross section of AFP filter cell.

In this option, the servomanipulators and cranes are mounted on independent bridges. While multiple trolleys can be mounted on a single bridge, they could not pass one another, thereby preventing both the manipulator and the crane from covering both sides of the cell. By using two bridges, completely independent motion of the servomanipulator and crane is provided, and the two could be operated on opposite ends of the cell if necessary. The crane is mounted on the upper gantry to minimize the required clearance between the gantries when they cross over one another. Furthemore, the additional cost for increased crane lift is less than that for a longer tubeset.

To maximize cell coverage for both the servomanipulator and the crane, double steps are required in the cell walls, as shown in Figure 2. Because of its complexity this wall section, will be more expensive to construct. However, it increases operational efficiency by providing independent operation of the manipulator and the crane. Having two gantries also increases the cell height, so this option would be expected to have the highest ceiling height of any reviewed.

It should be noted that this general maintenance approach was chosen for the Spallation Neutron Source (SNS) Target Facility. For process cells like the SNS and AFP, which are wider than can be completely covered using MSMs, a manipulator mounted on an overhead bridge is usually the most straightforward method of providing coverage for the entire cell.

III. DETAILED DESCRIPTION OF FINAL CONCEPT

After RH concept selection, the cell layout and RH concept were further refined.

III.A. Cell and Process Equipment Description

The main filter components in the hot cell are the vacuum vessel, magnets surrounding the vacuum vessel, heavy collector, light collectors located at each end of the filter, radio-frequency (RF) heating units, injector torches, vacuum ducts, and vacuum pumps. The magnets and vacuum vessel are designed to be lifetime components. Although the magnets are intended to be lifetime components, their electrical and coolant connectors will be designed to be remotely maintainable, as will the RF module connectors. The light and heavy collectors will be routinely removed and replaced to recover “separated” product and for refurbishment. The injector torches require regular maintenance. The other filter components will be maintained on an as-needed basis.

The hot cell has internal dimensions of 30 ft wide, 240 ft long, and 42 ft high. The cell height was established by the requirement for the bridge-mounted servomanipulator to clear the RF coaxial transmission lines above the filter. This can be seen in the cell cross-section view shown in Figure 2.

The hot cell length includes a "hands-on" crane maintenance area (CMA) at each end of the cell. The CMAs are separated from the main process cell by a shield wall and a movable shield door. Two filter systems will be located in the hot cell, separated by a shared maintenance area (SMA) 60 ft long.

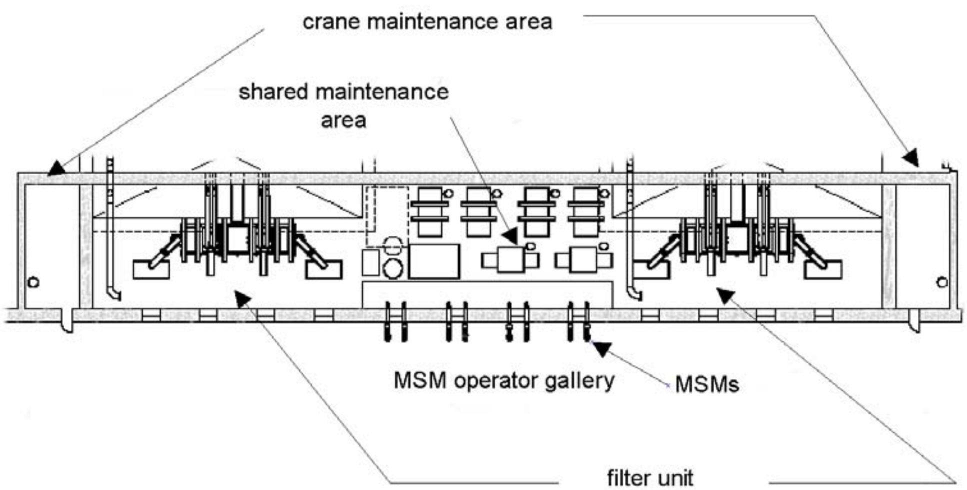

Fig. 3. AFP filter cell concept plan view.

Maintenance of the overhead bridge crane, the servomanipulator bridge, and the servomanipulator will be performed hands-on in the CMA. The equipment will be decontaminated as needed to allow hands-on maintenance by personnel wearing appropriate personal protective equipment. Decontamination equipment in each CMA includes a chamber for wash-down of the crane hook and servomanipulator prior to maintenance.

The SMA will be used for (waste) product recovery, remote component repairs, and waste volume reduction. Two heavy collector cleaning/product recovery stations, four light collector cleaning/product recovery stations, and a decontamination chamber are located int SMA.

Periodically the collectors will be removed from the filter unit and cleaned. The collector units will be disconnected from the filter unit using a servomanipulator. The collector unit will then be transported to its cleaning station via one of the cranes.

The SMA is shown in Figure 4. It is configured with four workstations located along one wall. Each workstation has a shielded window and a pair of through-the-wall manipulators.

Tasks to be performed at the window workstations include RF antenna maintenance, collector maintenance, waste reduction, decontamination, filter injector maintenance and small item repairs. The workbench area will have the tools required for the maintenance operations.

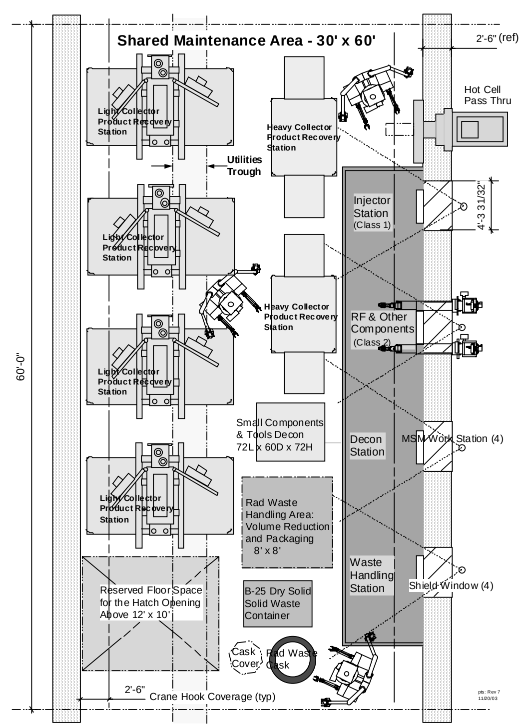

Fig. 4. Shared maintenance area layout.

III.B. RH equipment

The remote maintenance equipment will consist of two overhead cranes, two bridge-mounted servomanipulators, remote-viewing cameras, and four shield-window workstations with through-the-wall manipulators.

Each overhead bridge crane and servomanipulator will serve primarily one filter unit but will be able to traverse the full length of the cell. This provides redundancy in coverage area in the event of a failure of one of the cranes or servomanipulators. The controls of the cranes and servomanipulators are fully independent of one another. The servomanipulators will be mounted on the same lower rail, and the cranes will be mounted on a common upper rail. This provides independent operation of cranes and servomanipulators. A servomanipulator on its overhead transporter and a crane are shown in Figure 5.

Redundancy in coverage area is important. The RH system serves not only to perform maintenance but is also integral to the separation process. When the collectors in the filters are full, they must be replaced with clean collectors from the product recovery stations. Failure to change collector units in a filter due to a RH system failure will result in reduced plant availability.

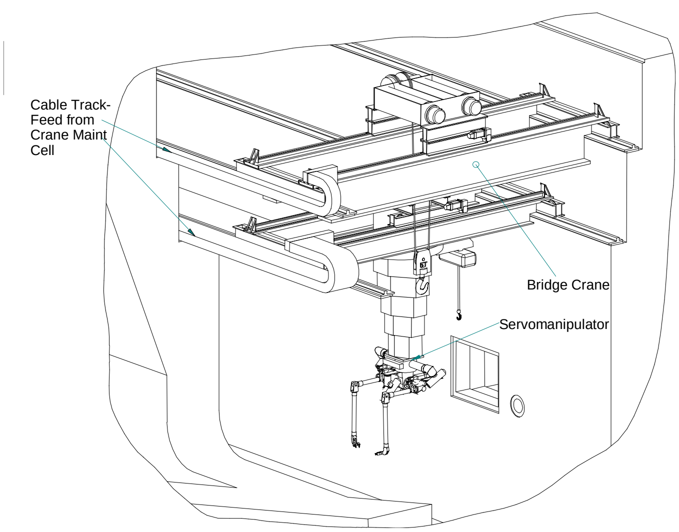

Fig. 5. Overhead remote handling system.

Each overhead crane will have a 20-ton capacity for handling filter unit components. The heaviest components are the magnets which weigh 16 tons. During conceptual design the filter unit design evolved and the 10-ton crane capacity previously considered was not sufficient. The crane bridge will be equipped with two cameras for remote viewing, and the crane hoist and bridge will have redundant drives to ensure that, in the event of a failure, the crane can be returned to the CMA.

The servomanipulator will have dual arms, six degrees of freedom, and force reflection. Each servomanipulator will be equipped with three cameras for remote viewing. The tasks that will be performed with the servomanipulator include the following:

- visual inspection of all interior hot cell surfaces and structures,
- insertion and removal of fasteners,
- tool handling and operation,
- lift fixture positioning and placement,
- small parts placement and positioning,
- electrical connector make/break,
- tubing connector make/break,
- decontamination of interior cell surfaces and structures,
- size reduction of existing contaminated target process equipment, and
- debris collection and packaging.

As with the cranes, the servomanipulator bridges and tubeset hoists will have redundant drives for failure recovery. The servomanipulator will be equipped with a 1000-lb auxiliary hoist for handling tools and small components.

The cranes and servomanipulators will include load and position sensors to provide feedback to the operators in the control room. The control system will include the following functions:

- programmable travel exclusion zones for the bridge crane and servomanipulator bridge, including all bridge, tubeset, auxiliary hoist and interface package axis drives, and
- automatic replay of learned trajectories for the bridge crane and servomanipulator bridge.

These automated functions will be particularly important in operation support (collector replacement).

As was noted in the description of the cell layout, four MSM workstations are available for decontamination, small equipment repair, and waste volume reduction.

III.C. Viewing Equipment

Through-the-wall manipulator operations require direct viewing of the work in order to maximize operator effectiveness. Viewing windows are required to provide this direct in-cell view while still providing radiation shielding for personnel outside the cell. A dry viewing window is located at each remote maintenance station in the SMA.

These windows are an assembly of glass slabs surrounded by a frame. The process for forming the glass includes ingredients that provide its radiation-shielding properties and minimize radiation-induced browning. Two types of shielded windows are currently available — wet and dry. These terms refer to the voids between and around the glass slabs. In wet windows, these voids are filled with a mineral oil, while nitrogen is used in dry windows. Wet windows have been available for many years and are installed in the vast majority of hot cells in the United States. Dry windows are relatively new and are more common in Europe and Japan. The primary advantage of the dry windows is their low maintenance requirements. The SNS facility under construction at ORNL will contain some of the first dry windows installed in this country. The expense of the windows usually limits their size to a critical viewing area, but a "typical" cold-side glass area might be 24 by 36 in.

Remote viewing is required, because direct viewing available through the shielded windows is limited. In-cell viewing is provided with radiation-tolerant cameras that can be functionally categorized as general-cell-viewing, task-viewing, or portable viewing systems.

General-cell viewing-cameras are mounted in strategic locations throughout the cell to provide the maximum amount of viewing coverage. Four wall-mounted cameras will be placed around the perimeter of each filter unit and 4 cameras around the perimeter of the SMA for a total of 12 cameras. To further maximize coverage, the general-cell-viewing cameras are mounted on remotely controlled pan-and-tilt mechanisms and will have zooming capabilities.

The wall-mounted cameras will provide overall views for positioning the bridge cranes and servomanipulator transporter bridges. These cameras will be mounted at a high location on the wall but be accessible for remote maintenance by the servomanipulators.

Eight bridge-mounted cameras will be located in the hot cell. The camera locations are as follows: one camera on each side of the crane bridges (total of four), and one camera on each side of the servomanipulator bridges (total of four). The cameras will provide overall views for positioning of the crane hooks and servomanipulator transporters as well as provide auxiliary views for the servomanipulator operators. These cameras will be mounted near the ends of the bridges, above the inside surface of the cell wall.

Servomanipulator task viewing is provided by servomanipulator-mounted cameras. There are three cameras on each pair of servomanipulator arms (two upper cameras on positioning arms, and one lower camera between the servomanipulator arms). Each servomanipulator camera will have two 75-W halogen lights. The cameras will provide the primary views for the servomanipulator operators. Cabling and connectors will be provided for another portable camera, which may be used as a manipulator-held inspection camera. The connector for this camera will be capable of remote connection and disconnection by the servomanipulator arms. Camera locations are shown in Figure 6.

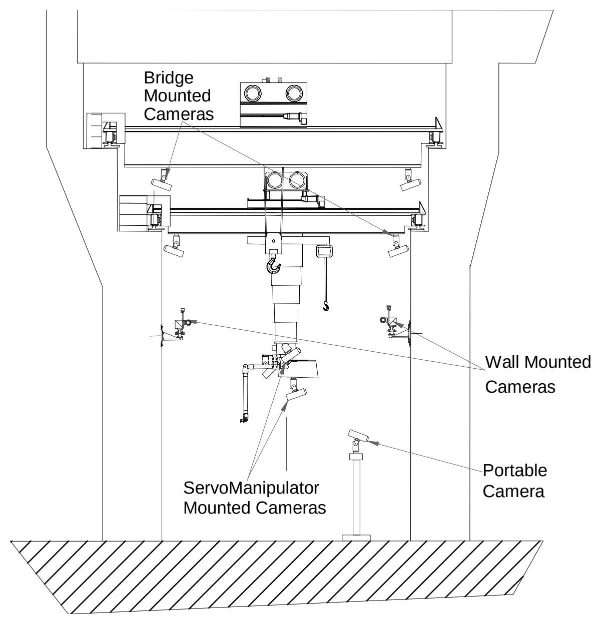

Fig. 6. Locations of in-cell viewing cameras.

General hot cell lighting will be designed to provide adequate illumination for remote operations in the hot cell using remote video viewing and shielded viewing windows. Each light fixture will be fabricated from stainless steel and radiation-resistant materials. Commercial fixtures with a combination of 2000-W and 1000-W lights are available for use in the hot cell to provide general cell lighting.

The number and location of light fixtures are based on lighting requirements for the various viewing methods (remote CCTV cameras and shield windows), and on the resultant heat load in the hot cell. General hot cell lighting must provide an average of approximately 300 foot-candles of illumination for the filter cells with CCTV viewing and approximately 500 foot-candles of illumination for the SMA for shield window viewing.

Fourteen complete 2000-W lighting fixtures will be needed for the SMA and 12 complete 1000W lighting fixtures will be required for each filter cell (24 total). Additionally lights are mounted on all the bridges.

The hot cell cameras and lighting will be operated from the hot cell video control system. Video control stations are located in the remote maintenance control room, and at portable video control consoles located at the MSM operator gallery, and the CMAs.

III.D. Control Room

Out-of-cell control equipment is located in the control room, and selected other locations. The equipment in the control room provides control for all of the remote maintenance equipment: (1) bridge cranes, (2) servomanipulators and bridge transporters, (3) hot cell audio and video, and (4) general hot cell lighting. The minimum space required for the remote maintenance control equipment in the control room is approximately 15 by 43 ft. The control room is shown in Figure 7.

Additional portable control stations will be provided in the CMA of the hot cell and the MSM operator gallery. These portable control stations will have the capability to control selected equipment: (1) the crane and servomanipulator bridges and (2) hot cell video. An intercom will also be provided for communication between the control room, and the portable control stations.

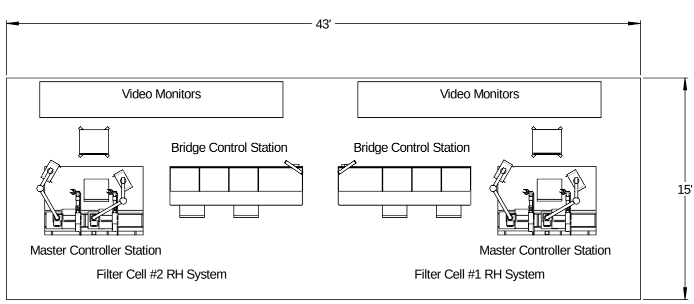

Fig. 7. AFP remote maintenance control room.

The bridge control stations provide for control of both overhead bridge systems: the crane bridges and servomanipulator bridges. There are two bridge control stations (one for each filter unit). The following capabilities are included in the bridge control stations:

- independent multi-axis controllers for all bridge drive axis,
- simultaneous, independent control of both bridge systems,
- independent, adjustable maximum speed control of each drive axis,
- individual and simultaneous drive axis lockout control,
- bridge drive axis position readout
- emergency stop button(s),
- bridge-mounted light control (on/off and intensity control), and
- crane hoist load readout.

The bridge system controls also include four portable pendant controllers for field/local control of either bridge system. Transfer of control to a pendant controller will be performed at the bridge control station. Two pendant controllers will be used at the MSM operators gallery and the other two will used in the CMAs of the hot cell. The pendant controllers will connect to the bridge control system via electrical connectors located at the respective windows or CMAs.

The servomanipulator control stations provide the control equipment for the dual-arm servomanipulators. There are two servomanipulator control stations, one for each filter unit, as shown in Figure 7. Each servomanipulator control station consists of the following components: servomanipulator master arms, servomanipulator control panel, bridge handheld controller, and video control station.

The servomanipulator slave arms will be a joint-to-joint position-controlled kinematic replica master control with a digital control system that allows

- variable force reflection ratios between the master and slave arms,
- gravity compensation of the object(tool) weight, and
- position off-set indexing between the master and slave.

Microswitches will be provided on each master arm for (1) position indexing, (2) slave-tong lock, (3) slave all joint lock, and (4) tool power on/off control.

III.E. Miscellaneous Tools

General-purpose remotely operated tools will be provided for use with the servomanipulators and MSM workstations to perform remote maintenance. Remotely operated tools will be used for tasks such as loosening and tightening bolts and fasteners and operating lifting fixtures. These tools will be stored at a location in the hot cell for accessibility by the remote maintenance system. Typical remote tools and equipment are shown in Figure 8.

General-purpose remote lift fixtures include slings, strong-backs, and lifting rings. Typical general-purpose lift fixtures, shown in Figure 9, include 5-ton strong-back with adjustable lift point, self-standing multi-leg chain sling, hook extension, and swivel-hoist lifting rings.

These will be commercially available lifting devices that have been modified for RH. Typical modifications include adding legs on lift fixtures so that they stand upright, adding retainers on the hooks for multi-leg slings, and modifying the threads of lifting rings for easier installation.

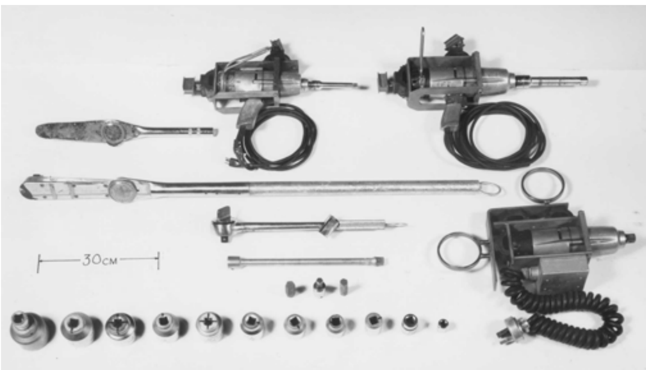

Fig. 8. General-purpose remote tools.

Fig. 9. General-purpose lift fixtures.

Some of the larger, more complex repairs such as those for the RF antenna module and the collector modules may require movable support stands. These work stands would permit easy rotation and repositioning of the item to allow the through-the-wall manipulator to have full access for maintenance. Also, heavily contaminated components of the RF antennas may be disassembled at a window workstation prior to transfer to a hands-on maintenance area in another part of the facility.

IV. SUMMARY

The Archimedes Technology Group is developing a means of electromagnetically segregating tank waste based on plasma mass separation. The Remote Systems Group at ORNL has developed a remote maintenance concept for the separation facility.

Because of the high radiation levels the separation units (filters) are located in a hot cell. At each end of the cell there will be a CMA for hands-on maintenance of the servomanipulators and cranes. Inside the main cell area are two filter units separated by an SMA which is used for product recovery and maintenance.

The SMA has wall-mounted MSMs for performing maintenance. Maintenance in the main cell area uses two sets of servomanipulators and cranes. Each set serves primarily one filter unit but is also available to serve the other unit, thereby providing redundancy in coverage area.

In-cell viewing is provided by shielded windows in the SMA and by wall, manipulator, and bridge mounted cameras.

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