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SNS REMOTE HANDLING AND THE TARGET TEST FACILITY

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ABSTRACT

Design of the Spallation Neutron Source Target System Facility is well underway. The facility has provisions for remotely handling and maintaining target system components, and waste handling and disposal. In order to verify critical design concepts and demonstrate remote handling operations, the Target Test Facility was constructed. It is a full-scale prototype of the mercury-target flow loop for the SNS. It will be used to study thermal/hydraulic characteristics of the mercury flow loop, gain experience operating the mercury system, and develop remote handling operations for replacing various target system components. This paper describes remote handling for the SNS target system and the Target Test Facility.

INTRODUCTION

The Spallation Neutron Source (SNS) target system will become radioactive due to the interaction of 1 GeV protons and flowing mercury in the target. Therefore, maintaining and handling target system components will require the use of remote handling equipment and tools. The approach under development is based on the use of through-the-wall mechanical master-slave manipulators and a bridge-mounted, mobile manipulator. The wall manipulators are located along the target cell where side access is required to reach various components such as process piping connectors. These manipulators are stationary. The overhead manipulator moves along a crane bridge and provides the top access necessary for maintaining many of the components. In order to develop equipment arrangements that are remotely maintainable and to demonstrate efficient remote handling, a full-size mock-up of the target cell and the mercury process loop was constructed.

SNS TARGET CELL REMOTE HANDLING

The SNS target maintenance hot cells shown in Figure 1 are designed to shield personnel from radiation and contamination resulting from the operation and maintenance of the target system mercury process and related systems. All operations in the cells will be fully remote with operator viewing and control located in an operating gallery on one side of the cell, with service feedthroughs on the other. There will be two maintenance cells separated by a vertically actuated shield door that will allow an overhead bridge crane and gantry robot to pass with new components or packaged waste.

The process cell is divided into three working bays; the largest contains the mercury process equipment, the next bay will have a waste handling workstation, and the bay closest to the transfer cell will be used for storage. The single bay transfer cell will primarily be used to package and move new and used equipment in and out of the cell. It will also be used to decontaminate and maintain the through-the-wall manipulators, bridge crane and gantry robot. The transfer enclosure located above the transfer cell will serve as an airlock between the building environment and the cell.

Specific, planned maintenance functions identified for the maintenance cells have been used to develop the basic cell configuration and tooling. The most important function is the replacement of a target module several times a year. This includes handling and storage of the target module container and packaging of modules for shipping, since in-cell storage of waste will be limited to three spent modules. Handling and packaging of proton beam window modules, vessel inserts, and spent mercury processing components will be performed using the same basic equipment. Replacement of in-cell ventilation filters and other cell infrastructure tasks will also be performed remotely.

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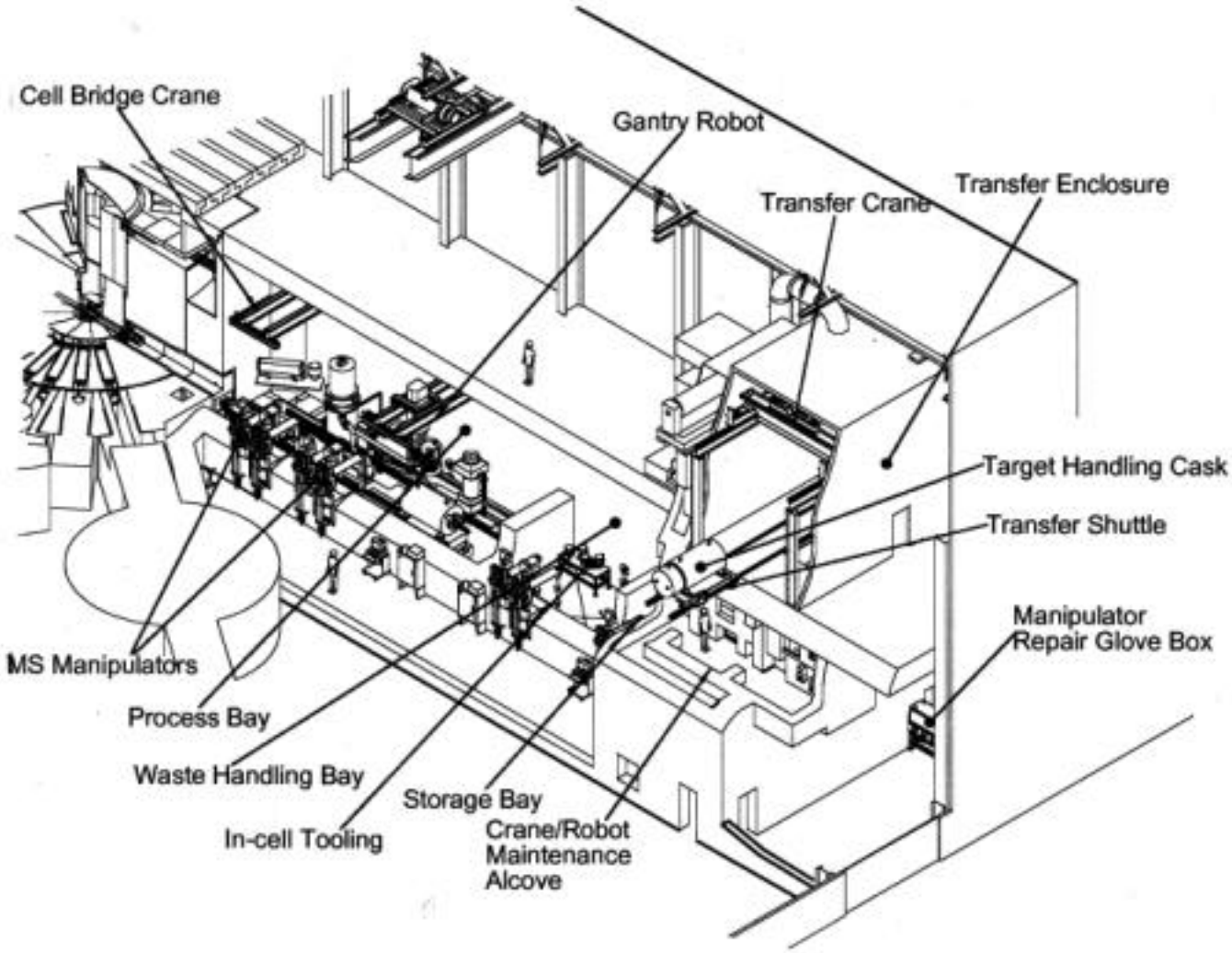

Figure 1. Cutaway view of the SNS Target Cell remote handling system.

It has been a design objective to use proven hot cell design techniques and equipment for the SNS maintenance cells. Thus the three most common hot cell tools are employed: a bridge crane will be the primary in-cell transport tool; a gantry robot will provide cell coverage for areas outside the reach of the through-the-wall manipulators; and special purpose window viewing stations with through-the-wall manipulators will be provided for detailed maintenance tasks such as the target removal and handling operations.

All the in-cell components are being designed for handling and manipulation with the three primary cell tools. For example, components will include lifting features specifically adapted to the in-cell crane. A gantry robot will be expected to perform numerous "standard" in-cell functions such as tool handling, component lifting, crane handling assist, connector mating, and CCTV inspection. Both systems must cover as much of the cell as possible, therefore, the cell is tiered to increase the wall-approach travel of the systems. The through-the-wall manipulators will be standard 3-piece units, thus the inner section of the manipulators will be maintained inside a special purpose glove box located in the transfer cell.

A GE-2000 shipping cask has been selected as the primary waste-handling container. Consequently, in-cell components, packaging equipment, and handling tools are based on processing used equipment for this cask. The cask will be loaded in/out of the cells via a ceiling port in the transfer cell.

The SNS proton beam will be on approximately 5500 hours per year; hence, the cell dose rate background will range from 250 rads/hr near the mercury process to less than 20 rads/hr in some locally shielded areas. When the beam is off; the background radiation field drops quickly to a range of 10-50 rads/hr. The radiation level in the transfer cell will be less than 10 rads/hr with the beam on and less than 0.5 rads/hr with the beam off.

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Perhaps the most difficult maintenance function will be the inspection and maintenance of the overhead systems. Thus, manned access will be provided in the transfer cell from an alcove located above the operator gallery for maintaining these systems when the proton beam is not in operation. An independent method of pulling each system into the transfer cell will be provided to rescue the overhead systems in the event of failures while they are in the process cell.

The cells will use a combination of conventional high power lighting for window viewing and local closed circuit television cameras for both general cell viewing and local detail viewing. Cameras will be mounted on the cell walls for overall viewing and portable cameras will be positioned for close up viewing as required.

Target Test Facility

The Target Test Facility (TTF) is a full-scale replica of the mercury-target flow loop for the SNS. It is installed in a high bay facility at Oak Ridge National Laboratory (ORNL) and is a multi-purpose facility used to study thermal/hydraulic characteristics of the Hg flow loop, gain experience operating the mercury system, and develop remote handling operations on various target system components. Figure 2 is an overall view of the TTF enclosure.

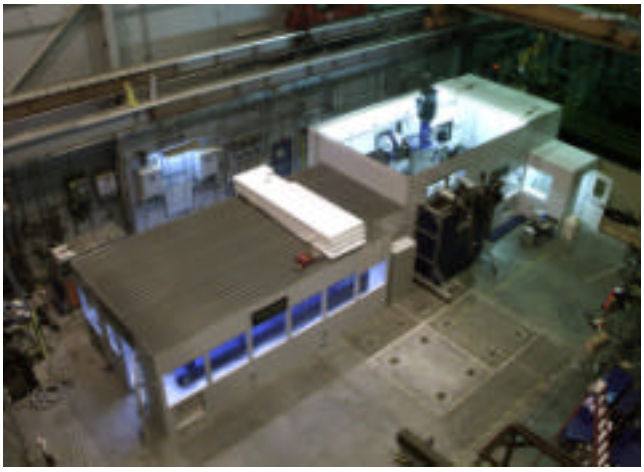

Figure 2. Overall view of the TTF enclosure.

The mercury target flow loop includes a 75 hp centrifugal pump, a mock heat exchanger, storage tank, simulated target module, numerous pipes up to 8 inches in diameter, pipe couplings, valves, and various diagnostics and sensors. The facility contains 1.4 cubic meters of mercury for the thermal/hydraulic flow tests. The presence of mercury in the system requires that the test loop must be operated in an enclosure that provides secondary containment for mercury. The enclosure was constructed as two separate cells with a common wall. One cell houses the process equipment, the other houses a replica of the target module and interconnecting pipes between the cells.

The enclosure also includes a ventilation system designed for five air changes per hour, special ventilation-duct carbon filters, mercury monitors, and clean up/spill equipment. During remote handling operations, when mercury is not present in the flow loop, the roof of the process equipment cell can be removed to allow use of the bridge-mounted manipulator for overhead remote handling operations. Other remote operations on the process equipment will be performed using the through-the-wall manipulators.

The remote handling operations will focus on demonstrating that key components in the target cell can be replaced within acceptable time limits. Wherever possible, commercially available tools and equipment are being used. End-effector tools will consist of power driven torque wrenches, modified “hand” tools, and various lifting fixtures. Remote viewing equipment will also be used in the TTF to optimize placement of cameras and lighting in the SNS target cell. Since the flow loop equipment in the target cell is designed to be modular, the mode of maintenance operation will be to replace failed or worn components as modules. Repair and/or disposal of components will be accomplished off-line. This approach has minimal impact on the operating availability of the target system.

A new, multisystem mock-up that encompasses remote handling operations for replacing the proton beam window, moderators, shutters, cooling water connections, and other related components will be constructed in late FY00 and operated in FY01.

The overall remote handling test program has five major goals through FY2002:

- verify the replacement of all subsystems and components,
- feed back information on design improvements to the target system engineers,
- develop and demonstrate appropriate remote handling tools and procedures,
- assess downtime, and
- provide operator training for the mercury flow loop.

TTF ES&H Requirements

Because of the hazardous nature of liquid Hg, several features were incorporated into the facility to protect personnel from potential exposure and to comply with pertinent environmental safety and health (ES&H) regulations. The first of these features is the TTF enclosure shown in Figure 2. The enclosure is constructed of prefabricated panels of 3-inch thick polystyrene foam sandwiched between two sheets of 26-gauge steel. A U-shaped base channel fastened to the concrete floor of the high bay holds the panels. Numerous windows in the facility provide ample viewing of the equipment from outside the enclosure. The enclosure is divided into two distinct rooms designated the Target Room and the Pump Room, separated by a common wall. Both rooms occupy an area of 14 ft × 28 ft. The Target Room has a fixed ceiling height of 8 ft, while the Pump Room incorporates a removable roof with a height of 12 ft. The removable roof panels allow access to the Pump Room equipment by an existing ORNL overhead crane and a remotely-operated PaR Systems Inc. power arm. Figure 3 is a schematic plan view of the TTF.

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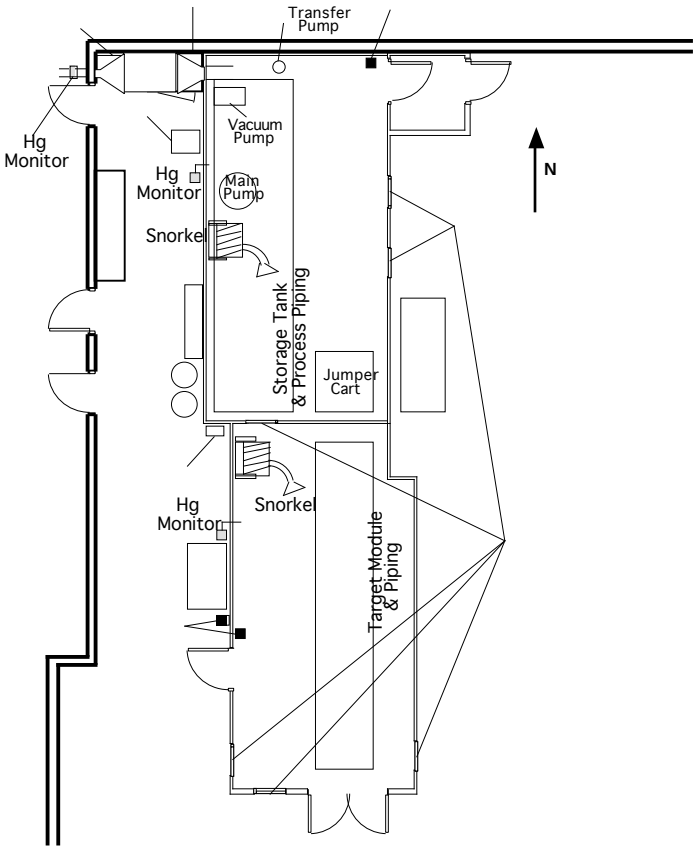

Figure 3. Schematic view of the TTF enclosure and equipment.

Within each room of the enclosure is a stainless-steel floor pan designed to contain any liquid Hg that may escape from the primary containment system of the process piping. It is constructed by welding 4 ft × 8 ft sheets of 0.125-inch thick 304L stainless sheets. The pans are sized to provide wall-to-wall coverage and have 3-inch edge flanges that are attached to the walls of the enclosure. Both pans were designed to contain the entire volume of Hg should a catastrophic failure of the primary containment occur. The capacity and leak-tightness of each pan were verified using water.

Ventilation in the enclosure is provided by the building off-gas system, which is connected to the enclosure through an 8-inch duct. A filter chamber is installed in-line with that duct containing sulphur-impregnated charcoal filters that capture Hg vapors before they enter the building ventilation exhaust system. The ventilation system draws five air changes per hour through each room of the enclosure from the high bay. Flexible hoses were installed in both rooms for localized ventilation when activities within the enclosure have the potential to expose personnel to Hg vapors, such as during pipe flange replacement. The local ventilation provides an air velocity of 100 ft per minute at the source of the vapors.

Mercury vapor levels are continuously measured using Jerome 431-X vapor monitors produced by Arizona Instruments. Three stationary monitors are in continuous use; two units monitor air in each of the enclosure rooms, and one monitors the air in the ventilation duct downstream of the filters. These three monitors have interface boards linked to the TTF control and alarm system. A fourth monitor is used in a portable manner for monitoring personnel and equipment in and out of the enclosure.

In addition to these physical and engineering controls, there are administrative controls in place to minimize the potential for Hg exposure and contamination. Only authorized and trained personnel are allowed access into the facility, and the entrance doors remain locked until access is needed.

PREPARATIONS FOR TTF OPERATIONS

Several tests using water preceded loading Hg into the TTF to verify the leak integrity of the enclosure and the flow loop, and to accurately determine the fluid capacities within the flow loop.

Tests to Verify Enclosure Floor Pan Integrity Capacities

The purpose of this test was to verify the fluid capacity and leak tightness of the floor pans located in the enclosure that houses the Target Test Facility. Floor pans are provided to contain Hg in the event of a leak from the TTF system or the TTF storage tank.

The required capacity of each floor pan, based on the total Hg inventory of the TTF, is specified at 396 gallons (1500 liters). This volume equates to about a 1.6-inch depth of water in the floor pans, assuming the floor pans were level and void of the TTF support structure. However, the facility floor, and thus the floor pans, are not perfectly level and the base of the TTF support structure will displace some fluid. Therefore, the fluid depth will vary across the floor and exceed 1.6 inches in some locations. For this reason, each pan's capacity was verified based on filling to the specified volume and recording the fluid depth. In addition, the pans were filled beyond the 396 gallon capacity requirement to assure a margin of safety and to verify that the total capacity would allow the addition of a layer of water on top of a Hg spill should it be desired to minimize Hg evaporation. The leak tightness of the floor pans was verified.

Tests to Verify TTF System Integrity and Capacities

This test consisted of:

- a hydrostatic leak test of the TTF flow loop and storage tank at a pressure of 100 psig;
- measuring the level of fluid in the sump tank sight glass and the corresponding fluid volume when the loop is at the normal operating level; and
- separately measuring the total fluid volume of the system loop and the storage tank when filled with water.

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The hydrostatic test was performed with tap water pressurized with a hand-operated piston pump. The test rig included calibrated pressure gauges and over-pressure protection (relief valve). The leak test consisted of a visual inspection of TTF external surfaces and joints while at pressure. The loop and storage tank were interconnected when pressurized. Level and volume checks were completed during the system fill, starting with the loop. The TTF He gas, vacuum pumping, and off-gas vent lines were not included in the test.

Tests to Verify Operation of TTF Systems with H2O

This test consisted of:

- verifying proper operation of the TTF system prior to the loading of liquid Hg;
- verifying equipment operating procedures; and
- training division personnel in the operation of TTF.

The TTF system was operated with water in accordance with the associated sections of the Equipment Operating Procedure. For the purposes of this test, the storage tank was filled with 1400 liters of water which approximates the full Hg inventory of the system.

The main circulation pump curves were generated to compare pump performance to the curves specified by the manufacturer (Sterling Pumps). The pump curves consist of pump discharge pressure and flow for specified pump speeds ranging from 200 to 600 RPM, and flow throttle valve positions ranging from fully open to closed. Although the manufacturer's pump curves specify Hg, operation with water produces the same results in terms of discharge pressure in head (feet) and flow for a specific RPM.

All procedures were verified and the operation of all equipment was demonstrated. In addition, these tests also verified the operation of the instrumentation and control system.

HG STORAGE/LOADING

The Target Test Facility requires approximately 1500 liters of elemental mercury to fill the pump and sump tank to operating levels. This mercury was obtained from inventory at the Y-12 plant in Oak Ridge, Tennessee. The mercury is stored in flasks which contain approximately 76 lbs (34.5 kg) of mercury, corresponding to a volume of about 2.5 liters. Empty flasks weigh approximately 8 lbs. and have cylindrical shapes with a curved, tapering neck that has a threaded opening fitted with a steel plug. Flasks are stored in wooden pallets, 45 flasks per pallet, for a total pallet weight of approximately 4,000 lbs. The pallets have a 36 × 36 inch footprint and are nearly 26 inches in height as shown in Figure 4. A total of 12 pallets (540 flasks) were used for the TTF.

Each flask had its plug loosened with an impact wrench and then re-tightened using hand tools, to allow for easy removal during loading operations. Once the plugs were removed and the mercury transferred into the system, red plastic plugs were placed back into the flasks indicating that the flasks were empty.

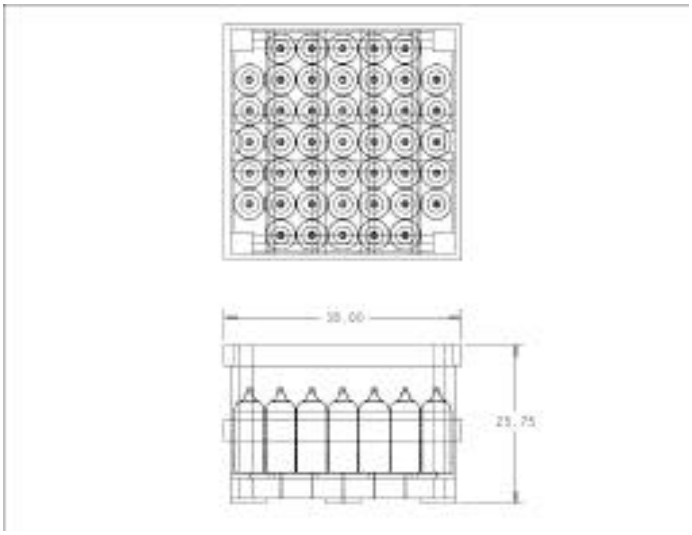

Figure 4. Mercury flask arrangement in a pallet.

An existing instrument drain line in the flow loop was used as the channel for mercury loading into the storage tank. This instrument drain was installed by the fabricator of the TTF equipment, and runs to the north end of the storage tank. A hand control valve and flange were added to the drain line to make it more conducive to transfer operations. Figure 5 shows a pallet mounted on a platform in the Target Room with tubing attached to the instrument drain line.

The storage tank was evacuated with the flow loop vacuum pump to approximately 2 psia. The dip tube assembly was then placed in a full flask and the instrument drain line hand valve was opened to allow the mercury to flow into the drain line. The vacuum in the storage tank was adequate to transfer mercury from the flask to the tank in less than 1 minute. In Figure 5, a peristaltic pump is also shown on the pallet platform; it was a backup if the vacuum was not adequate to siphon the mercury from of the flask. Its use was not required. Also shown in figure 5 is the Jerome monitor to detect any rise in mercury vapors which would be hazardous to workers' health. This monitoring occurred during the entire loading operation and detected only slightly elevated levels at the end of loading on the second day. All loading was completed in two and a half days without incident.

CONCLUSIONS

The design of the Spallation Neutron Source Target System Facility is well underway. The facility has provisions for remotely handling and maintaining target system components, including waste handling and disposal. In order to verify the critical design concepts and demonstrate remote handling operations, a full-scale prototype of the SNS target station was constructed. Its primary test objectives are to demonstrate remote handling operations on components that make up the mercury target flow loop system, and assess the thermal/hydraulic characteristics of the mercury flow loop. In addition to demonstrating the remote replacement of various

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TTF components, procedures and operations are being developed using this facility to ensure that SNS maintenance operations will be completed in their allotted time. The remote handling tests have five objectives: verify the replacement of all subsystems and components, provide feedback to the Target Station design engineers for design improvements, develop and demonstrate appropriate remote handling tools, assess downtime for replacing various components, and provide operator training for actual remote maintenance operations.

ACKNOWLEDGEMENTS

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Figure 5. Mercury loading operations.

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