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Protecting Worker Health and Safety Using Remote Handling Systems

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DISCLAIMER

PROTECTING WORKER HEALTH AND SAFETY USING REMOTE HANDLING SYSTEMS

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INTRODUCTION

Lawrence Livermore National Laboratory (LLNL) is currently developing and installing two large-scale, remotely controlled systems for use in improving worker health and safety by minimizing exposure to hazardous and radioactive materials. The first system is a full-scale liquid feed system for use in delivering chemical reagents to LLNL's existing aqueous low-level radioactive and mixed waste treatment facility (Tank Farm). The Tank Farm facility is used to remove radioactive and toxic materials in aqueous wastes prior to discharge to the City of Livermore Water Reclamation Plant (LWRP), in accordance with established discharge limits. Installation of this new reagent feed system improves operational safety and process efficiency by eliminating the need to manually handle reagents used in the treatment processes. This was done by installing a system that can inject precisely metered amounts of various reagents into the treatment tanks and can be controlled either remotely or locally via a programmable logic controller (PLC).

The second system uses a robotic manipulator to remotely handle, characterize, process, sort, and repackage hazardous wastes containing tritium. This system usess an IBM-developed gantry robot mounted within a special glove box enclosure designed to isolate tritiated wastes from system operators and minimize the potential for release of tritium to the atmosphere. Tritiated waste handling is performed remotely, using the robot in a teleoperational mode for one-of-a-kind functions and in an autonomous mode for repetitive operations. The system is compatible with an existing portable gas cleanup unit designed to capture any gas-phase tritium inadvertently released into the glove box during waste handling.

This paper discusses the purpose of these remotely operated systems, provides background related to LLNL's low-level/mixed waste treatment processes, describes the major system components, outlines system operations, and discusses current status and plans.

BACKGROUND AND PURPOSE

Remote Reagent Handling System

The LLNL Tank Farm is used to treat aqueous hazardous and mixed wastes prior to discharge to the LWRP via the sanitary sewer, in accordance with established discharge limits. The facility consists of six open-top, conical-bottom tanks, each with a 6,800-L (1,800-gal) capacity. The aqueous wastes are batched together following specific procedures and then pumped to one of the treatment tanks. In the tank, the wastes are treated by adding various reagents to perform neutralization, oxidation, pH control, chelation/ flocculation, adsorption, and other chemical processes. These processes are performed to facilitate subsequent filtration of the wastewater in LLNL's wastewater vacuum filtration unit. More detail regarding aqueous waste treatment processes performed at the LLNL Tank Farm is provided in Bowers et al. (1). The Tank Farm is regulated under Title 40 of the Code of Federal Regulations (CFR) Section 264, Subpart J, "Tank Systems," and Title 22, Section 66264.190, of the California Code of Regulations (CCR).

Before this semiautomated feed system was completed, reagents used during the Tank Farm treatment processes were added to the tanks manually. An operator pumped a reagent from a storage drum into a wide-mouth, 19-L (5-gal) carboy; physically carried the partially filled carboy to the edge of the selected treatment tank; and poured the contents into the tank. When adding reagents such as ferric sulfate or hydrogen peroxide, only one trip between the pump and the tank was needed because of the small amount of reagent required. However, when large amounts of acids or bases were required, several trips to and from the tank were needed to add these reagents. As a result, this method, although performed under the strictest of safety procedures, had the potential for compromising the safety and efficiency of the facility. For example:

- A carboy of reagent, weighing up to 16 kg (35 lb), could be dropped or spilled onto an operator.
- A carboy (although labeled well) could be accidentally used for a different reagent which, if residue were present, might react with the reagent being added.
- The quantity of reagent added could be inaccurate because of the lack of control during the addition (volumes are estimated by the operator and overshooting of the pH endpoint is common).

The purpose for designing and installing the remote reagent handling system was to eliminate the need for this contact handling of the reagents and thereby improve operational safety and process efficiency.

Tritium Handling System

Approximately 2,000 mixed and low-level waste containers listed on the LLNL Hazardous Waste Management database contain quantities of tritium ranging from about 10^{-6} μCi to about 5,000 Ci. These items are stored in various containers such as DOT 7A boxes, 55-gallon drums, and carboys. In some cases the physical status of the stored waste is only partially known. Therefore, to properly characterize the waste for either treatment on site or shipment off site, LLNL has been developing various methods for examining the contents of the waste containers. Some of the non-obtrusive methods being developed are real-time radiography, digital radiography, and active and passive computed tomography. Also, head space gas sampling techniques are being developed to determine types and quantities of gases inside 55-gallon waste drums. But in addition to these methodologies, LLNL determined that a facility was needed that could provide a safe method for opening containers, in a sealed environment to minimize any chance for release of tritium gas to the environment. Opening containers is necessary to obtain quality assurance data in support of non-obtrusive methods, to separate and repackage mixed and hazardous wastes for shipment and disposal, and to examine the contents of those containers that cannot be identified by other means.

The purpose of this project is to provide a safe tritium legacy waste handling and characterization system incorporating existing LLNL-developed robotics and tritium processing technologies and to demonstrate a practical and efficient glove box/robotics system for use at U.S. Department of Energy (DOE) facilities.

SYSTEM DESCRIPTIONS

Remote Reagent Handling System

The overall remote reagent handling system is illustrated in Figure 1. It consists of a pumping station with four metering pumps, four sets of piping to each of the six Tank Farm tanks, actuated discharge valves at each tank, a pH/temperature probe at each tank, and a PLC system. Each reagent has one pump circuit associated with it (one circuit for each drum of reagent). All four pumping circuits are independent of each other and all can pump reagents to any one of the six treatment tanks. A schematic of the typical pumping circuit is shown in Figure 2.

Control of the pumping station and monitoring of the measured parameters in each treatment tank is performed using a PLC system. The system is designed to allow the operator, from a safe location, to control and monitor the flow rate of the liquids through all the reagent pumps and to monitor the pH, temperature, and level status in the treatment tanks. Pneumatically operated air-open/spring-return actuators are used to open and close all the reagent discharge valves on the system (shown in Figure 1). The air to these actuators is switched on and off using 24-V dc solenoids controlled from the PLC. In addition, position indicator signals from each of the valves are used to verify valve open-closed status at the PLC.

A permanently mounted, combined pH and temperature sensing probe is submersed into the fluid of each treatment tank during the entire batch process. The sensors are attached to the lower end of a 0.02-m (0.75-in.)-diameter stainless steel tube that is 1.5 m (5 ft) long. The tubes are mounted to the treatment tank lids using a compression-type fitting which allows the operator to withdraw the tube safely from the tank for calibration, storage and maintenance of the pH probe. The transmitters for the probes are housed adjacent to the tanks where the operators can safely perform calibration procedures and execute various maintenance functions on the pH system.

During operation, the PLC continuously monitors the pH and temperature readings from each of the treatment tanks. If, during the insertion of reagent into the treatment tanks the pH reading rises above or drops below operator-selected set points, the controller will automatically shut off the pump that is adding the reagent and alert the operator.

Ultrasonic level indicators are also mounted on each of the tank lids. If the tank is filled to the high-level point, an alarm will be enunciated by the PLC to alert the operator. If the tank filling continues to the high-high level, the PLC will automatically shut off the pump and all other fill paths to the tank to prevent overflow; it will alert the operator with an annunciation alarm.

Pressure switches are installed in each reagent line to prevent inadvertent overpressurization of the system. If any of these switches is activated, the corresponding pump is immediately shut down and the condition is annunciated to the operator. As an additional safety feature to prevent overpressurization, the hydraulic bypasses in the metering pumps are set to approximately 345 kPa (50 lb/in.^{2}).

The entire system is interlocked to prevent unintended operational modes. For example, only one reagent pump is allowed to operate at a time and only one discharge valve is allowed to open. All other reagent pumps remain off and all other valves remain shut to prevent inadvertent

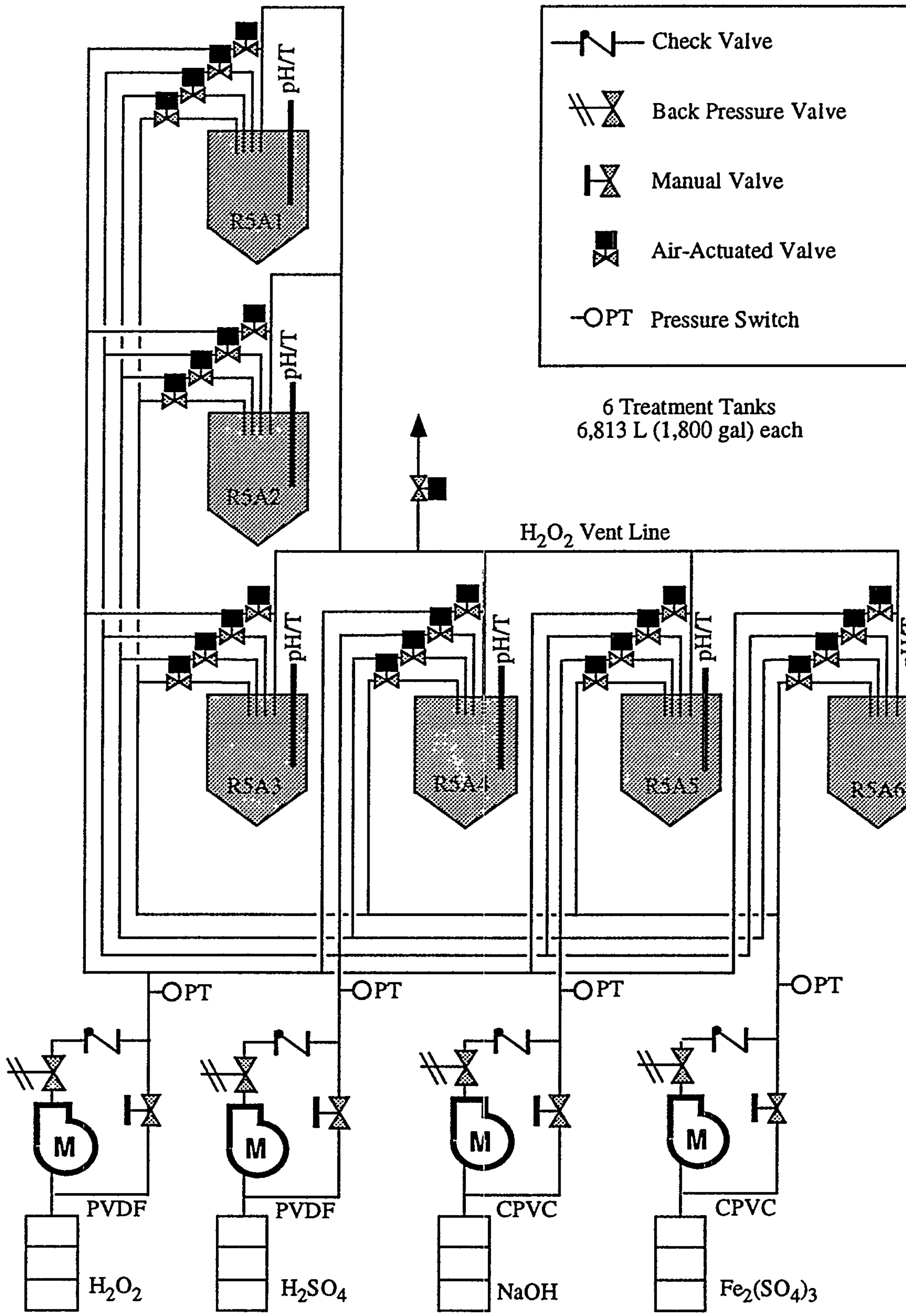

Figure 1. Remote Reagent Handling System Piping Schematic

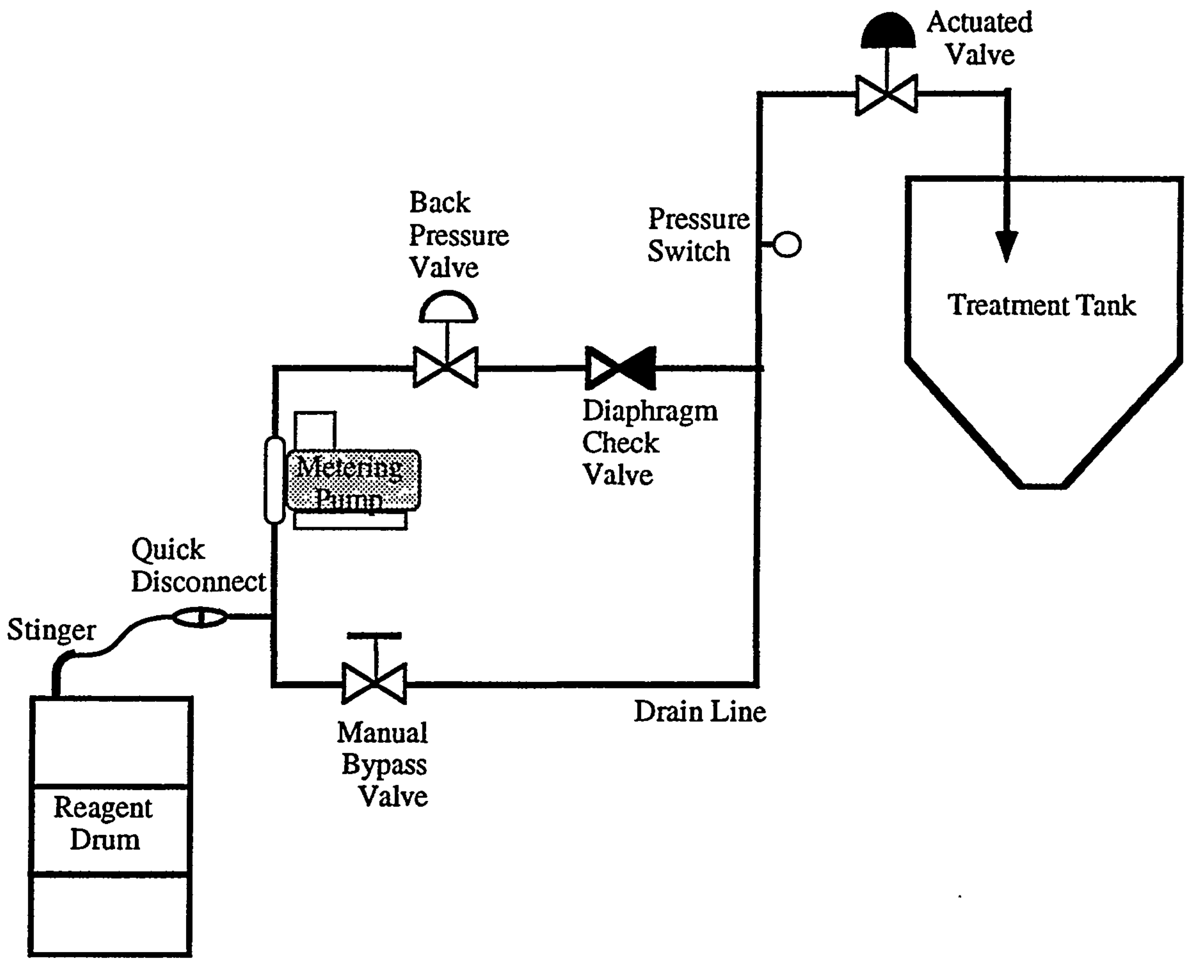

Figure 2. Typical Metering Pump Circuit Piping and Flow Diagram (One tank only is shown for clarity)

mixing and possible chemical reactions between the various reagents. In addition, easily accessible crash buttons are placed at various locations around the Tank Farm and near the control locations to allow for emergency shutdown. In addition, the PLC system controls and interlocks all of the other Tank Farm operations.

Tritium Handling System

The tritium handling system consists of four major components—a robot manipulator, a controller, an enclosure, and a tritium processing system. The robot manipulator is a gantry system that was originally designed by IBM for use in large-scale manufacturing operations at both IBM and Ford Motor Company assembly plants, where it has a proven record of reliability and performance. The manipulator is suspended from two rails that are mounted on each side of the system enclosure and extend along its entire length. For this application, modifications were made to the robot manipulator to maximize its vertical travel while minimizing required overhead space for the vertical mast (i.e., minimize required glove box height and volume) and to allow it to lift heavier loads. The robot manipulator has six degrees of freedom, three linear and three rotary. The robot is able to reach 1.1 m (42 in.) down into a DOT 7A storage box, grasp objects that weigh up to 27 kg (60 lb), and lift them out of the box and onto a working surface

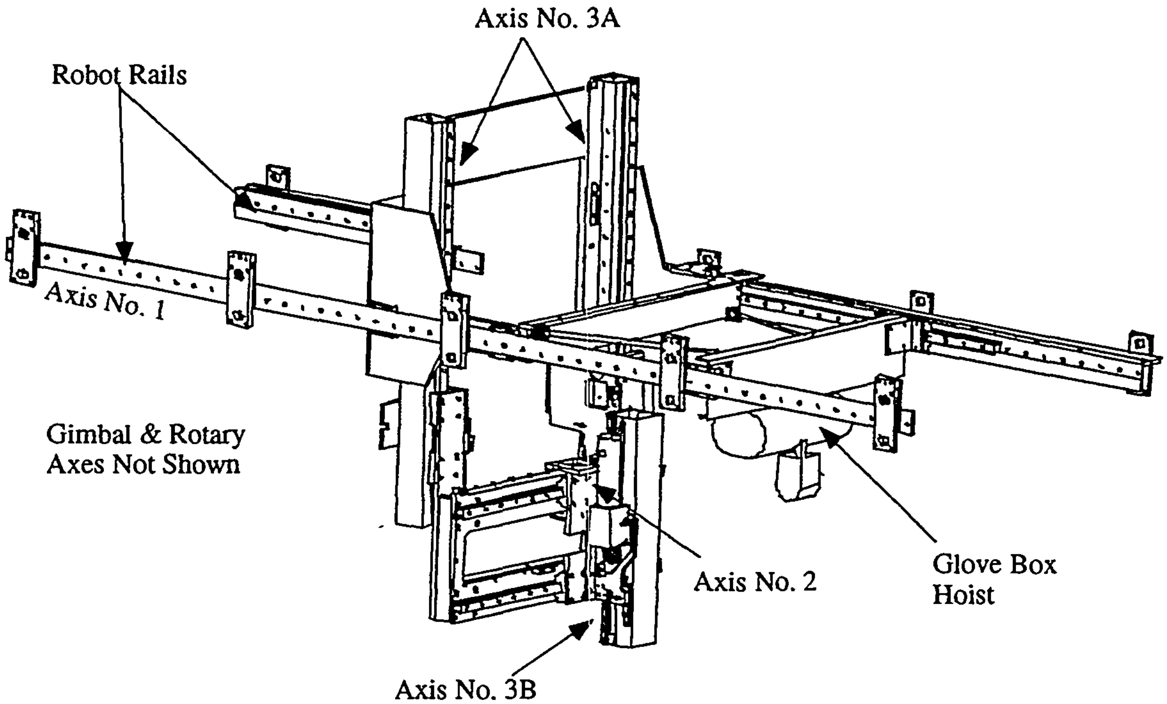

Figure 3. Robot Manipulator (Linear Axes Only).

inside the enclosure. The robot pitch axis can handle torque loads of up to 34 N·m (25 ft-lbs). An air-operated, quick disconnect end effector is used to hold specially designed grippers that can be picked up from a storage rack as needed to perform the various tasks. Figure 3 is a sketch of the robot manipulator assembly showing only the linear axes (the gimbal with the rotary axes is not shown).

Two television cameras are mounted on the robot arm to facilitate operation and enhance operational safety. One is at the upper level of the vertical axis of the robot. It provides a field of view directly down the vertical axis to assist the operator to orient the gimbal inside a waste container. The other camera uses a fiber optic light pipe mounted right down at the robot gimbal, just above the gripper. This camera can be used by the operator for observing detailed, close-in operation of the gripper. In addition to these cameras mounted on the robot, two other cameras with wide fields of view are mounted at each end of the glove box/ enclosure for overall viewing of the operation.

A new Series II controller is being developed by IBM and LLNL for use with this facility. This controller will have the capability to allow both teleoperational (operator-driven) and autonomous (pre-programmed) control of the robot. An integral part of this capability will be a seamless mode transfer feature that will enable the operator to easily transfer between the teleoperational and autonomous modes of robot control and select from an ensemble of established robot programs to accomplish specific, well-defined tasks. Only general information describing the controller is presented here. More specific details related to the robot controller design are outlined in Merrill et al. (2).

The robot controller system consists of a computer workstation, an operator console, and an annunciator console. The workstation consists of electronics racks containing an IBM RISC 6000 computer, a power control unit (PCU), and a robot controller. The operator console is an assembly that has been designed to be moved back and forth along the length of the glove box as required during robot operation. This console contains a force ball manipulator for performing telerobotic functions, two television camera monitors, gripper controls, hoist system controls, emergency power shutdown (crash) switch, and a computer terminal monitor. The annunciator console contains all the alarm panels and interlock devices for the overall glove box/robotic system. A PLC is used to monitor and control all the various safety alarms and interlocks.

An enclosure compatible with tritium handling considerations is being built to accommodate the robot. The enclosure has been designed to hold two DOT 7A storage boxes, one on each end, separated by a working surface at gloved worker level. An overhead hoist, which is attached to the robot truss structure and is supported by the robot rails, will be used to lift items that weigh more than the 27-kg (60-lb) limit of the robot. Feed-throughs are provided to accommodate the connections from the robot controller, the portable tritium gas treatment system, the video cameras, and other various support equipment inside the glove box. Various other tools and grippers are provided to accomplish specific unloading and decontamination tasks.

The enclosure itself consists of a glove box approximately 8.2 m long, 1.5 m wide and 3.1 m high (27 ft × 5 ft × 10 ft) containing the gantry robot and the various tooling required to support the waste characterization and handling procedures. Glove ports are located in enough locations in the enclosure walls to allow an operator to reach all critical points inside the glove box. Two wide-angle television cameras are mounted in each end of the glove box to assist the operator in maneuvering the robot arm. Figure 4 is a sketch of the enclosure.

When operated in closed mode, the enclosure is designed to have no detectable leaks greater than 1×10^{-12} m^3/sec (helium). Operations are in closed mode when the possibility exists for tritium levels inside the enclosure to be greater than 0.1 Ci/m^3. A portable abort system, which uses an evacuated abort tank, will be used to manage overpressure conditions without requiring venting to the building stack. The internal atmosphere of the glove box can be either air or nitrogen.

The enclosure can also be operated in a fume hood mode by opening one of the end doors. This is only allowed when tritium levels are less than 3 mCi/m^3. In this mode, a gate valve is opened and ventilation to the building stack is maintained at 38 linear meters per minute (125 linear feet per minute).

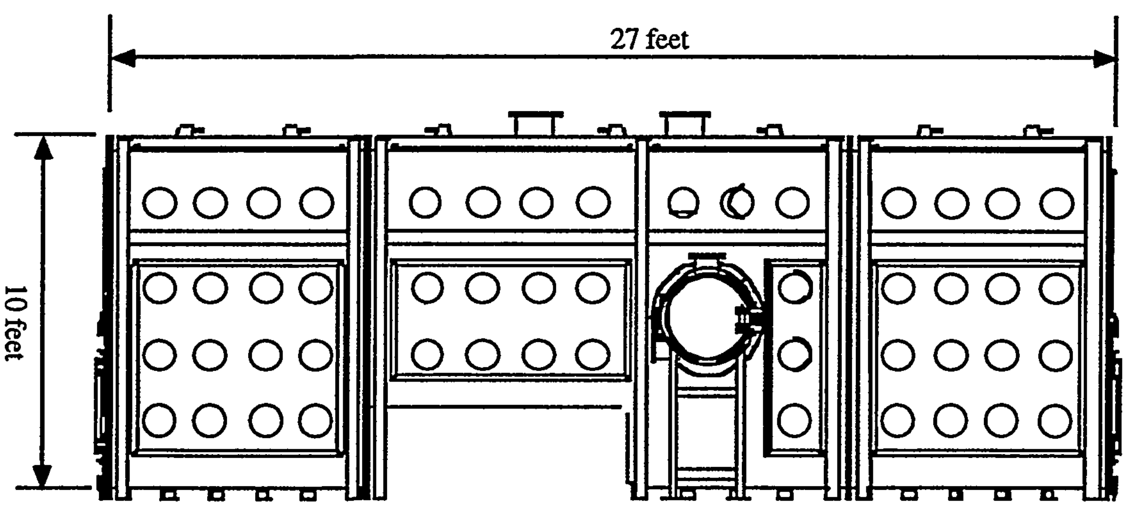

Figure 4. Robot Enclosure/Glove Box

A portable tritium processing system will be used with this robot and enclosure system to process any tritium that may be released to the glove box atmosphere during waste handling activities. The system consists of three modules/carts that were built to accommodate the hardware necessary to perform the various tritium processing functions. The operations performed by the system include: oil-free pumping, oil-free gas transfer, gas analysis, and gas-phase tritium scrubbing. The system is completely self contained. Gas samples are analyzed with the on-board partial pressure analyzer. Gases containing tritium are passed through a catalytic oxidation system that converts the tritium gas to tritiated water. The tritiated water is then captured on molecular sieve dryers that are ultimately disposed of at an appropriate low-level radioactive waste site.

The tritium processing system is operated through a PLC and system status is displayed on a CRT. All pertinent information is displayed and easily accessible to the operator. More detailed information on the system is outlined in Reitz et al. (3).

OPERATIONAL OVERVIEW

Remote Reagent Handling System

The normal reagents used with the Tank Farm are sulfuric acid (66 Be), sodium hydroxide (50% by weight), ferric sulfate (50% by weight), and hydrogen peroxide (30%–50% by weight). All these reagents have corrosive properties. Sulfuric acid is especially dangerous as a material dehydrator (it strips water from minerals and generates extreme heat). Hydrogen peroxide is a strong oxidizer that produces oxygen quite readily, providing a significant combustion hazard.

Either sulfuric acid (H_2SO_4) or sodium hydroxide (NaOH) is added to adjust the pH of the waste, thus facilitating oxidation. The use of either the acid or the base depends upon the initial pH value of the waste. Hydrogen peroxide (H_2O_2) is added to raise the oxidation state of metals and break up the organics. Ferric sulfate ($Fe_2(SO_4)_3$) is used for coagulation and precipitation of particles out of the solution. From time to time, other reagents may be used to perform the following treatments: precipitation with sulfide and/or carbonate and/or hydroxide, chelation, coagulation with a polyelectrolyte, reduction of hexavalent chromium, and oxidation of cyanide. Most of the reagents used to perform these other treatments will be inserted manually or through the sodium hydroxide pump after a thorough cleanout.

The metering pump circuits can supply a precise reagent flow of about 170 L/h (45 gal/h) to the treatment tanks. Most treatments require 0–2 L (0–0.5 gal) of ferric sulfate or hydrogen peroxide, and about 11–38 L (3–10 gal) of sulfuric acid or sodium hydroxide per batch. During operation, the reagents are slowly added to the tank in a controlled manner while the pH, temperature, and liquid level are continuously monitored.

Tritium Handling System

The robot/glove box can handle both DOT 7A storage boxes and 55-gal drums of hazardous or mixed waste. Typical DOT 7A storage boxes at LLNL are made from steel and have outer dimensions 2.2 m long, 1.2 m wide, and 1.1 m deep (86 in. × 46 in. × 42 in.), for a total of 2.7 m^3 (96 ft^3). The box lids are attached with clips held on by special catches on the sides and lid of the box. Each box weighs about 286 kg (630 lb) when empty and can hold up to 2,270 kg (5,000 lb) of waste. The drums are standard 55-gal drums that are 0.9 m (34.5 in.) high and 0.6 m (22.5 in.) in diameter.

Before loading the DOT 7A box into the enclosure, the lid clips are replaced with temporary lid clamps. The box is then manually loaded into the enclosure on conveyer rollers mounted on the floor. If desired, several waste drums can be loaded into the glove box in place of a DOT 7A container. The robot/glove box is operated in the ventilated hood mode when containers of tritiated waste are being loaded into the system. In this mode, the exhaust gas is released through HEPA filters to the facility stack and either one (but not both) of the end doors can be opened. After the waste container(s) is inserted, the enclosure door is shut and the entire system is converted to the isolated glove box operational mode by closing the gate valve to the building ventilation system.

Once the system is in the isolated glove box mode, the lids are removed from the waste container (the 55-gal drums or the DOT 7A box) either manually through the gloves or, if the operation is straightforward and there are no unforeseen circumstances, by using the robot. The robot in the teleoperational mode can enter the waste container, remove the various waste items, and transfer the items to the glove box work table for subsequent characterization and sorting. Any accidental release of tritium gas to the enclosure would be detected, removed, processed into tritiated water, and trapped on the molecular sieve that is connected to the glove box through an umbilical line. The tritiated and mixed waste items would be sorted and repackaged in new containers, as required, for off-site treatment and storage.

Autonomous functions would be programmed to allow the robot to perform operations that are routine and repeatable. These functions would include, for example, removing waste container lids and storing them within the glove box, weighing items on a scale, decontaminating the inside of the glove box, and loading the sorted waste into the new containers. One-of-a-kind operations such as container unloading, waste sorting, and container reloading will be performed in real time in the telerobotic mode.

STATUS AND PLANS

Remote Reagent Handling System

Installation of the hardware for the remote reagent system was completed in September 1994. Checkout and acceptance testing on the system are currently being performed and are scheduled for completion by March 1995. Training of operating crews is also currently underway and detailed procedures are being written. As-built drawings are being completed and certified by independent engineers in order to meet the California Department of Toxic Substances Control regulatory requirements. This system has been incorporated in the existing LLNL Part B Permit application as a permit modification.

The PLC system has been expanded to control all operations of the wastewater treatment Tank Farm and vacuum filtration treatment unit. Plans are to incorporate the PLC into the operations of other LLNL waste treatment facilities. These other facilities include a cold vapor evaporator, a centrifuge, a blending station, and a carbon adsorption unit. The goal is to provide safe and efficient operational capability for all LLNL aqueous hazardous and mixed waste treatment facilities.

Tritium Handling System

The robot and controller are currently being fabricated and assembled by IBM Corporation in Austin, Texas. The checkout and acceptance tests on the robot and controller are scheduled for March/April 1995 in Austin; the complete robotic system is scheduled for delivery to LLNL during April 1995. Initial plans are to assemble the robot inside a structural framework and perform system testing and operator training while awaiting completion of the glove box enclosure assembly.

Design, fabrication, and assembly of the glove box enclosure are scheduled for completion during the first calendar quarter of 1996. The glove box will be fabricated by an appropriate glove box vendor to LLNL specifications. It will be shipped to LLNL and installed in a selected facility by November/December 1995. Installation of the robot and other systems into the enclosure should be completed by February/March 1996. Initial operation and checkout of the entire system is expected to be initiated in March 1996 with full operation scheduled for July 1996.

Future plans include the development of equipment to allow processing and treatment of low-level radioactive wastes and reactive hazardous wastes. Other plans are to use the system for size-reducing radioactively contaminated equipment. The system could be used to handle or open any container or piece of equipment that potentially could contaminate the environment if opened under non-contained conditions.

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