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APPLICATION OF GLOVE BOX ROBOTICS TO HAZARDOUS WASTE MANAGEMENT *

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I. ABSTRACT

Lawrence Livermore National Laboratory (LLNL) is developing a semi-automated system for handling, characterizing, processing, sorting, and repackaging hazardous wastes containing tritium. The system combines an IBM developed gantry robot with a special glove box enclosure designed to protect the operators and minimize the potential release of tritium to the atmosphere. All hazardous waste handling and processing will be performed remotely using the robot in a telerobotic mode for one-of-a-kind functions and in an autonomous mode for repetitive type operations. The system will initially be used in conjunction with a portable gas system designed to capture any gaseous phase tritium released into the glove box. This paper presents the objectives of this program, provides background related to LLNL's robotics and waste handling program, describes the major system components, outlines system operation, and discusses current status and plans.

II. INTRODUCTION

The short term objective of this program is to provide a practical tritium legacy waste handling and characterization system incorporating existing LLNL developed robotics technology. The long term objective is to demonstrate that a glove box/robotics system can be reliably used for other types of Department of Energy (DOE) hazardous or mixed waste handling and characterization functions.

This development effort is being sponsored by both the DOE Waste Management Program (EM-30) and the DOE Office of Technology Development/Robotics Technology Development Program (EM-50). The overall project is being managed by the LLNL Environmental Protection Department (EPD) Hazardous Waste Management (HWM) Division. HWM will also own and operate the system after it has been completed.

The LLNL Environmental Technologies Projects/Robotics Section is responsible for supplying the robot and controller, checking out the robot system, developing the operational software, and defining the design criteria for the control console and robot interface. In addition, they are also responsible for managing the robot controls and manipulator hardware procurement contract which was placed with the IBM Corporation in August 1993.

The LLNL Tritium Facility Projects Group (TFPG) has responsibility for designing and fabricating the waste processing enclosure and associated support systems. This includes design of the glove box and container handling tools, robot integration, building layouts, tritium monitoring, and tritium processing using an existing Portable Tritium Processing System (PTPS).

III. BACKGROUND

There are approximately 1,200 legacy waste containers listed on the LLNL Hazardous Waste Management database which contain quantities of tritium ranging from about 10^{-6} μCi to about 0.5 Ci. These items are stored in various containers such as DOT 7A (4 x 4 x 7) boxes, 55 gallon drums, carboys, etc. The physical status of some of the stored waste is unknown. Therefore opening of the containers, characterization of the waste, and repackaging needs to occur within a sealed environment in order to minimize any chance for release of tritium gas to the environment. Any releases which may

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occur during this work will be contained in the enclosure and cleaned up using an existing tritium gas processing system.

DOE and LLNL have been developing glove box automation technology for Defense Programs and environmental restoration and waste management (ER &WM) activities over the last four years. The work has largely been focused on a collaborative effort with the IBM Corporation to adapt an existing commercial robot system to perform glove box processing applications. Initial developments were funded as part of the LLNL Special Isotope Separation (SIS) program. Later funding was continued through the DOE/HQ Office of Technology Development, Robotics Technology Development Program. Several demonstration glove box/robotic facilities have been in operation at LLNL since April 1991. One system, developed as an automated nuclear material processing system, combined technological advances in robotics with an advanced pyrochemical processing furnace. Another system was used to demonstrate fully automated and remote disassembly of nuclear weapon components and surface decontamination of surrogate lead material. Both of these demonstration test beds utilized an existing IBM Series I autonomous controller. Current robot technology development has been focused in two areas: the development of an improved controller (dubbed the Series II) to replace the now obsolete IBM Series I controller; and the development of a more robust manipulator (higher lift and torque handling capacities) for handling of hazardous waste.

In May of 1993 these robot technology development areas were combined with the tritium legacy waste removal project and a cooperative effort was initiated between the Environmental Technologies Projects/Robotics Section, the HWM Division, and the TFP Group at LLNL. The effort consists of decontaminating LLNL legacy waste containing tritium using this developed robotics technology in conjunction with an existing LLNL developed portable gas treatment system. Funding for development of the robot hardware and an upgraded controller is provided by the DOE/HQ Office of Technology Development, Robotics Technology Development (EM-55). Funding to purchase and build the robot manipulator, the robot controller hardware, and the hazardous waste handling enclosure (glove box) is provided by DOE/HQ Office of Waste Management (EM 30/31).

IV. SYSTEM DESCRIPTION

A. Robot Manipulator

The robot manipulator is a gantry system which 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 robot is mounted on two rails mounted on each side of the glove box and extending 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 is able to reach 42 inches down into a 7A type storage box (nominally 42" deep, 48" wide, and 84" long), grasp objects which weigh up to 150 pound, and lift them out of the box and onto a working surface inside the enclosure. The robot pitch axis can handle torque loads of up to 60 ft-lbs.

The robot manipulator has six degrees of freedom, three linear and three rotary. The primary linear axis (defined as Axis 1) allows the robot to move back and forth a total of 282" in the direction parallel to the length of the glove box. It consists of a truss structure mounted perpendicular to the two glove box rails and supported at each end by roller bearings which ride on the rails. It is designed to maintain absolute orthogonality of the truss structure with respect to the gantry rails. Axis 2 allows movement of the robot manipulator in a direction perpendicular to the glove box length (back and forth across the glove box) for a total travel of 27". It consists of a carriage assembly (dual joint) which supports the vertical axis (Axis 3B) and rides back and forth on a cross bar attached to the Axis 1 truss. Vertical movement of the manipulator is accomplished by using two different third axis systems. Axis 3A consists of two synchronized motors mounted on each end of the truss structure. These motors drive the Axis 2 cross bar and dual joint assembly for a vertical travel of 42". Axis 3B consists of a motor which drives a single vertical bar up and down the Axis 2 dual joint for a vertical travel of 18". The combination of Axes 3A and 3B motions allows the robot manipulator to have a total vertical travel of 60". Pressurized gas cylinders are used to counterbalance the weight of each of the vertical axes, thereby requiring the Axis 3A and 3B motors to support only the weight of lifted process components. A sketch of the robot manipulator assembly showing only the linear axes (the gimbal with the rotary axes is not shown) is enclosed as Figure 1.

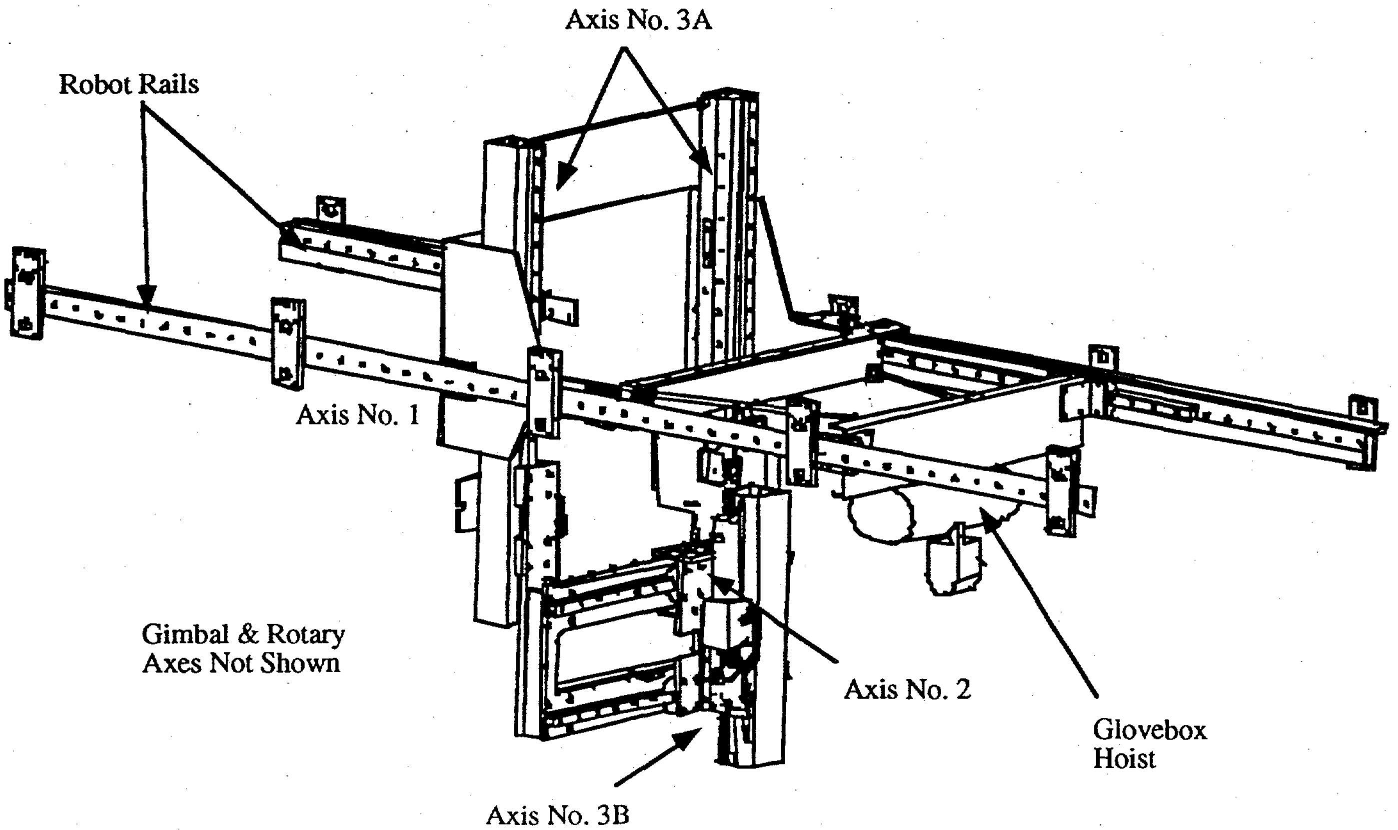

Figure 1 Robot Manipulator

A gimbal assembly is mounted on the bottom of the Axis 3B vertical bar and supports all three rotary axes motors. The yaw axis (Axis 4) allows the entire gimbal assembly to be rotated through a total of 365^{o} of motion. The pitch axis (Axis 5) allows the robot gripper to be swiveled up and down through a 185^{o} arc. The roll axis (Axis 6) allows the robot gripper itself to be rolled through a total of 365^{o} of rotation.

Two television cameras are mounted on the robot arm. One is at the upper level of the carriage assembly (dual joint) of the robot. It provides a field of view directly down the vertical axis (Axis 3B) to assist the operator in orienting the gimbal when it is inside a waste container. The other camera utilizes 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.

B. Robot Controller

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 which will enable the operator to easily transfer between the teleoperation 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 Reference 1.

The robot controller system consists of a computer work station, an operator console, and an annunciator console The work station consists of electronics racks containing an IBM RISC 6000 computer, a power control unit (PCU), a robot controller, and a programmer work station. This station will be used by an experienced computer/robot programmer to develop detailed autonomous robot motions using Robline simulation software and to perform some limited operational teaching of the robot. The work station and all the electronics are located in racks located next to the glove box and are connected to the robot through a conduit channel which goes from the racks to the top of the glove box. Additional control cables run through a flexible line between the work station racks and the operator console.

The operator console is an assembly which has been designed to be moved back and forth along the length of the glove box as required by the operator during operation of the robot. 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. This console is tethered through a flexible cable back to the stationary robot work station racks described in the previous paragraph. A sketch of the operator console is shown in Figure 2.

The annunciator console contains all the alarm panels and interlock devices for the overall glove box/robotic system. A programmable logic controller (PLC) is used to monitor and control all the various alarms and interlocks.

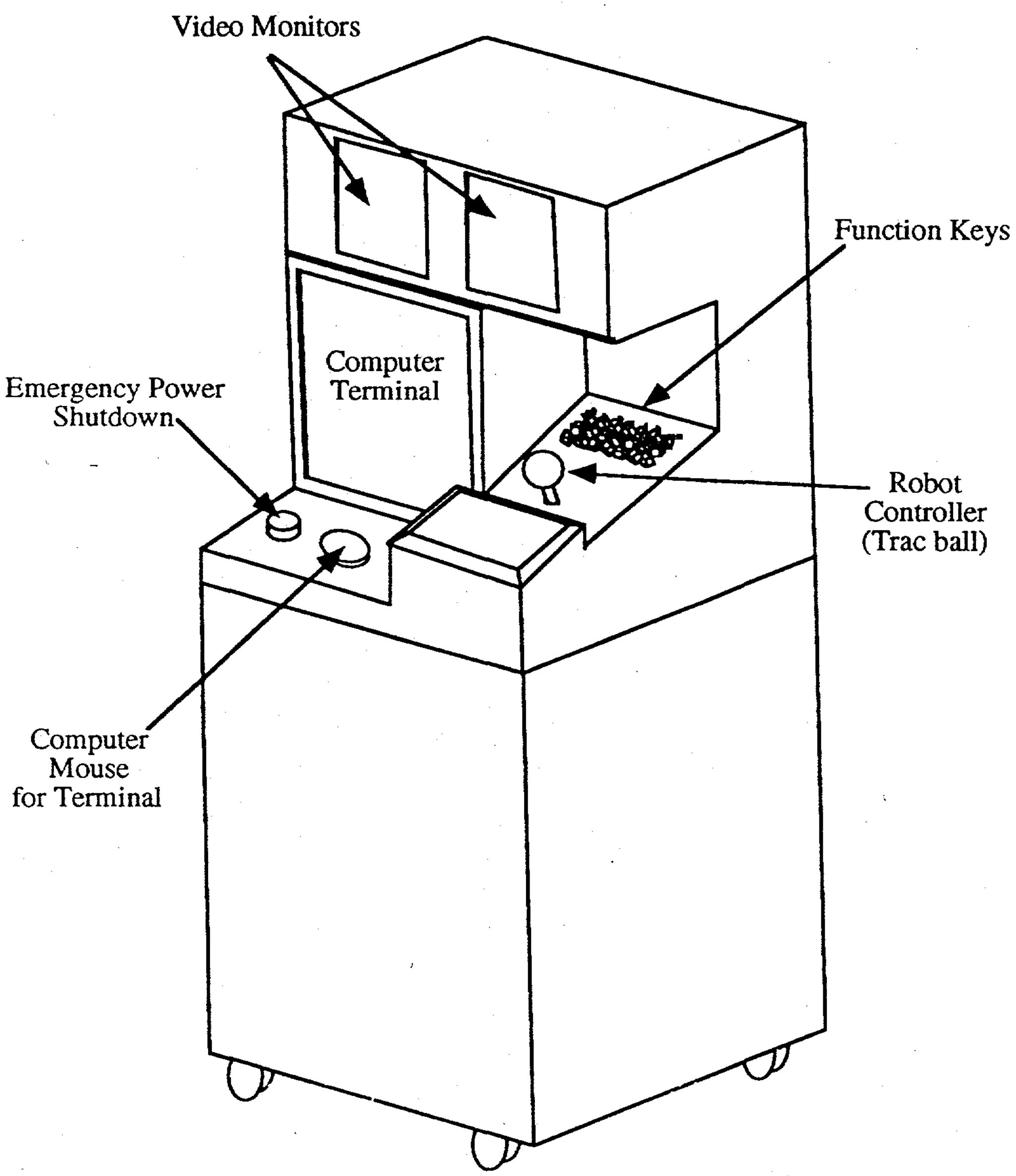

Figure 2 Operator Control Console

C. Enclosure

An enclosure is being built to accommodate the robot and to be compatible with tritium handling considerations. The enclosure has been designed to hold two 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 which weigh more than the 150 pounds 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/grippers are provided to accomplish specific unloading and decontamination tasks.

The enclosure itself consists of a glove box approximately 27 feet long, 5 feet wide and 10 feet high containing the gantry robot and the various tooling required to support the waste characterization and handling procedures. This system will initially be installed within the Tritium Facility at LLNL but will be made in three modular sections in order to make it transportable for hazardous waste treatment operations at other facilities. The center section is about 12 1/2 feet long and contains a waist height worktable for performing sorting and characterization activities and a pass-through chamber which is sized large enough to allow insertion of an entire 55 gallon drum into the glove box. Attached to each end of this center section are two 7 foot long full height end sections. These end sections contain sealed doors which, when open, allow a full size DOT 7A (4' wide x 42" deep x 7' long) waste storage container to be passed into the glove box. 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. A sketch of the enclosure is shown in Figure 3.

The enclosure is designed to be operated in a closed mode with no detectable leaks greater than 1×10^{-6} cc/sec (helium). This mode of operation will be maintained 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 over pressure 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 331 stack is maintained at 125 LFM.

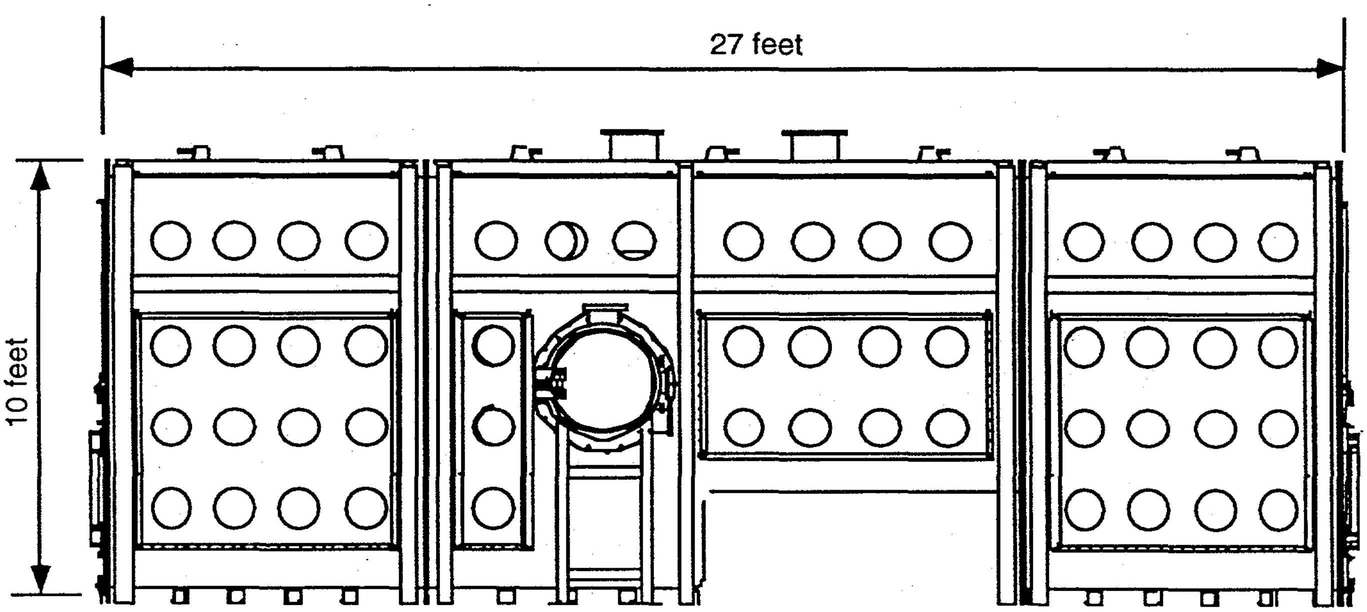

Figure 3 Robot Enclosure/Glove Box

D. Tritium Processing System

A Portable Tritium Processing System (PTPS) will be utilized with this robot/enclosure system to process any tritium which may be released to the glove box atmosphere during these activities. The PTPS was initially designed and developed to provide a modern processing system for the removal of tritium from the LLNL Tritium Facility, Bldg. 331. The system consists of three modules/carts which were built to accommodate the hardware necessary to perform the various functions required for processing tritium.

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 which converts the tritium gas to tritiated water. The tritiated water is then captured on molecular sieve dryers which are ultimately disposed of at an appropriate waste site.

Operation of the PTPS is performed through a programmable logic controller (PLC), with the system status displayed on a CRT. All pertinent information is displayed and easily assessable to the operator. More detailed information related to the PTPS is outlined in the Reference 2 document.

V. SYSTEM OPERATION

The system can handle both DOT 7A storage boxes and 55 gallon drums of hazardous or mixed waste. Typical DOT 7A storage boxes at LLNL are made from steel and have outer dimensions of 86" long, 46" wide, and 42" deep (total of 96 cu. ft.). The lids are attached using lid clips held on by special lid catches on the side of the box. Each box weighs about 630 pounds when empty and they can hold up to 5000 lbs. of waste. The drums are standard 55 gallon drums which are 34 1/2" high and 22 1/2" in diameter.

The glove box/enclosure is operated in the ventilated hood mode when the containers containing the tritiated waste are 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. Before loading the 7A box into the enclosure a temporary lid clamp is installed and the lid clips are removed. The box is then manually pushed 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 7A container. Once the waste container(s) are 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 will be removed from the waste container (the 55 gallon drums or the 7A box) either manually through the gloves or using the robot if the operation is straightforward with no stuck lids or other unforeseen circumstances. The robot can then be used in the teleoperational mode to enter the waste container, remove the various waste items, and transfer them to the glove box worktable for subsequent characterization and sorting. Any accidental release of tritium gas to the enclosure would be removed and processed using the PTPS connected to the glove box through an umbilical line. The tritiated waste items would be sorted and repackaged in new containers as required to facilitate their shipment to offsite treatment and storage facilities. Any tritium gases encountered would be processed into tritiated water using the PTPS.

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

VI. STATUS AND PLANS

The robot and controller is scheduled for delivery to LLNL during the second quarter of fiscal year 1995. Design, fabrication, and assembly of the tritium enclosure (glove box) is scheduled for completion during the last quarter of fiscal year 1995. Initial operation and check out of the system will take place during the first quarter of 1996 with full operation scheduled for March 1, 1996.

Future plans include the development of equipment to allow processing and treatment of reactive hazardous wastes, characterizing and repackaging of hazardous waste containers, and size reducing of radioactively contaminated equipment.

VII. REFERENCES

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