PIT DISASSEMBLY MOTION CONTROL

LA-UR: 01-3988

Lowell T. Christensen
NMT-15–Pit-Disassembly &
Nuclear Fuels Technology
Los Alamos National Laboratory
Los Alamos, NM 87545

Pete C. Pittman
ESA-EPE–ESA Energy &
Process Engineering
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

A Department of Energy (DOE) Pit Disassembly and Conversion Facility (PDCF) is being designed for the Savannah River Site in South Carolina. The facility will recover plutonium from excess nuclear weapon pits defined in START II and START III treaties. The plutonium will be stored and used to produce mixed oxide reactor fuel at another new DOE facility. Because of radiation dose issues, much of the pit disassembly work and material transfer will be automated. Automated material handling systems will interface with disassembly lathes, conversion reactors that produce oxide for storage, robotic container welding stations, vault retrieval systems, and nondestructive assay (NDA) instrumentation. The goal is to use common motion control hardware for material transfer and possibly common motion controllers for the unique PDCF systems. The latter is complicated by the different directions manufactures are considering for distributed control, such as Firewire, SERCOS, etc., and by the unique control requirements of machines such as lathes compared to controls for an integrated NDA system. The current design approach is to standardize where possible, use network cables to replace wire bundles where possible, but to first select hardware and motion controllers that meet specific machine or process requirements.

PIT DISASSEMBLY MOTION CONTROL

PDCF

The mission of the Pit Disassembly and Conversion Facility (PDCF) is to convert surplus weapons pits and other surplus plutonium metal into plutonium oxide for use in mixed oxide nuclear fuel or for indefinite storage. Incoming pits and metal will be unloaded and placed in secure vault storage. Pits selected from the vault will then be bisected and the plutonium hemishells sent to oxide conversion reactors. The plutonium oxide will be calcined at high temperatures to eliminate moisture and control particle size. The oxide will then be stored, blended, and placed in crimp-lid "convenience" cans. A convenience can will be sent to a robotic welding station where it will be placed in a stainless steel "inner" can. An orbital welder will weld a lid on the “inner” can. The "inner can" will then be placed in a stainless steel "outer" can which will also be seal welded. This package will then be sent to nondestructive assay and on to a product vault storage.

PDCF AUTOMATION

The PDCF will have a central control room with a distributed control system (DCS) to control facility systems (such as HVAC), monitor alarms, and control some processes. Local DCS stations or programmable logic controllers (PLCs) with human machine interfaces (HMI) stations will be used to control most glovebox reactors and chemical processes. Automated material handling systems will be designed to reduce worker radiation dose, to control material inventories, and to lift and move heavy loads. It is the automated material handling systems that are the main focus of this paper.

FACILITY AND PROCESS CONTROLS

The facility controls and PLC reactor controls are fairly common industrial systems, but the nature of the PDCF work requires some specialized robotic systems developed by Sandia National Laboratory. These include:

1) SHIPPING CONTAINER UNPACKING

A Weigh and Leak Check System (WALS) using a Fanuc robot was developed originally for unpackaging pits at Pantex. A modified version of the WALS will be used in the PDCF to unpack pit containment vessels from incoming shipping containers.

2) VAULT STORAGE AND RETRIEVAL SYSTEMS

Pits will be stored in a vault inside of their containment vessels, which will be stored and retrieved using automated guided vehicles.

3) CONTAINER WELDING STATIONS

The welding of cans containing plutonium oxide is a high dose operation if done manually. In the PDCF a Fanuc robot will load convenience cans of oxide into "inner" storage cans that will be welded by an automated orbital welder. The robot will move the welded can to a leak check station and then into a chamber where it will be electrochemically cleaned. Another Fanuc robot will unload the cleaned can and perform leak check and alpha contamination detection. Another robotic system will weld the "inner" can into an "outer" can.

MATERIAL MOVEMENT

Most of the remaining automated systems in the PDCF are for material movement and placement. These automated systems will be controlled at a shielded local station by a PLC or specialized motion controller appropriate for the system. The goal is to have standardized HMIs and controllers wherever possible; but each system is unique, and each was designed by a separate group of engineers, some at different DOE facilities, so standardization is difficult and expensive.

COMMON HARDWARE

MOTORS

Motors for glovebox applications must be reliable, easily replaced, and sealed to prevent contamination. An integrated motor, drive, and control—coupled with networking such as DeviceNet, Profibus, and SERCOS — would offer several advantages such as simplified wiring and maintenance, but servo motors will be selected based on how they integrate with the complete glovebox system.

RAILS

LANL uses high performance linear rails proven to be reliable in glovebox applications.

CONTROLLER

Using a common controller for all PDCF material movement applications would be ideal. However, each application has unique control requirements, so standardization is difficult. A distributed control scheme is preferred within the PDCF for a variety of reasons. The key reason is that there are a large number of gloveboxes containing automation. This will require control, both process and motion, and therefore will require a large number of cables to be run into the boxes. Space is expensive and the cable bundles greatly complicate the design of the gloveboxes and internal equipment. A single hermetically sealed connector that is used to pass conductors into the glovebox can cost on the order of $1000, and hundreds of such connectors will be needed for the facility. The distributed control scheme allows a small cable bundle to be shared with all the equipment inside the box, thereby simplifying the design.

The distributed control approach has application to both process control as well as material handling and servo control. There are currently several established protocols including DeviceNet, Fieldbus, and ProfiBus that may be used for process control. But there is only one established approach for motion control, which is called SERCOS. The process control architectures cannot do synchronized motion well due to the limited speed of the bus. SERCOS was developed in Germany in the machine tool industry in the late 80's but has been slow to catch on in the this country. Recently, there have also been several other approaches that run on Firewire and even USB, both of which come out of the personal computer market. However, there is no standard protocol for these, and none of them have really caught on except in small pockets.

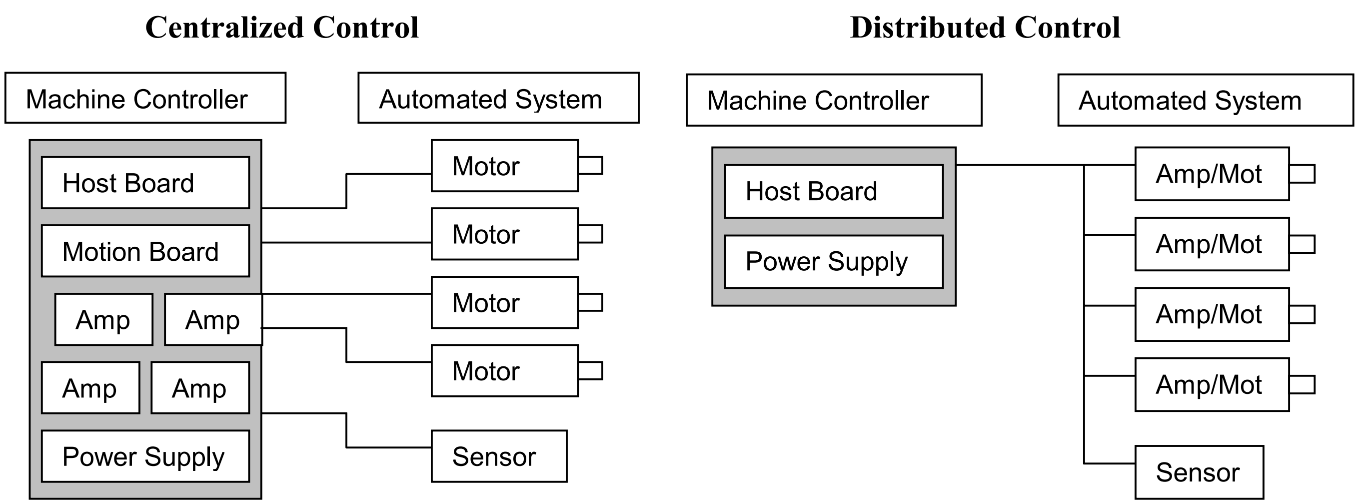


FIGURE 1: CENTRALIZED CONTROL VS. DISTRIBUTED CONTROL

ROBOTIC SYSTEM

The basic PDCF robot system used for material movement will be a 4 degree-of-freedom (DOF) gantry system. It is fabricated from off-the-shelf industrial components and consists of linear modules arranged in a gantry configuration as seen in Figure 2. The X-axis is along the length of the glovebox. There are dual X-axis rails, both driven by servo motors.

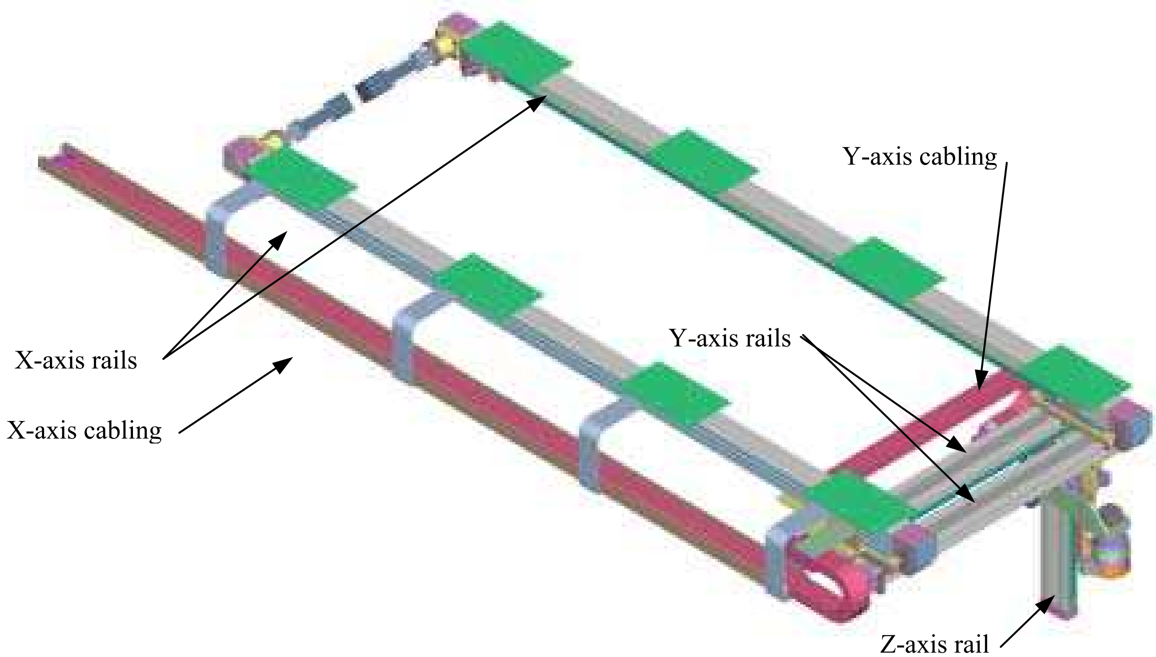


FIGURE 2: ARIES ROBOT, TOP VIEW.

The Y-axis axis is across the width of the box. The Z-axis is vertical. The X, Y, and Z axes are linear rails with 95.5, 36, and 15 inches of travel respectively. The X-axis is belt driven. The Y and Z axes are ball screw driven. The fourth DOF is provided by a yaw assembly which doubles as an extension to offset the robot envelope. The Yaw axis has 338 degrees of travel. The axes were chosen to maximize travel within the glovebox.

The robot utilizes four servo-controlled drive axes and one stepper-controlled yaw axis. The three Cartesian axes, X, Y, & Z, are powered by servo motors. Two servo motors are used on the x-axis in gantry mode for mechanical simplicity. In gantry mode, one motor is defined to be a master and the second motor a slave to the master. To the motion control software, both motors appear as one axis and the motion controller firmware maintains synchronization. The y and z axes are also servo-powered. For simplicity, all servo motors are identical. The Yaw axis consists of a micro stepper motor with a harmonic drive for increased step resolution.

A six-axis force-torque transducer is located on the end of the z-axis. The transducer provides three axes each of force and torque data in real time. The transducer provides data used for crash protection during moves through what should be free space. Additionally it provides data for controlling the end of movements where contact occurs with a rigid surface or in force guided moves. A force-torque transducer was chosen with six-axis capability, digital interface, over-range capability, and proven history. The robot system design, first developed for the NDA system, has been modified to provide specific material transfer capabilities for the other PDCF systems.

SAFETY FEATURES

All PDCF motion controllers will have safety interlocks and controls.

TABLE 1: MOTION CONTROLLER SAFETY FEATURES

E-Stops	A series-connected string of normally-closed, emergency-stop switches are located around the perimeter of the glovebox to de-energize the prime power contactors for the motor amplifiers.
Light Curtain	A light beam positioned just inside the box protects the glovebox glove ports. When a beam is broken, robot motion is stopped.
Soft Stop	These allow the robot to be stopped in a controlled manner without the need of recovery routines. In addition, there is software monitoring of the force sensor located at the robot end effector.

LATHE

The Lathe glovebox is the first step in the PDCF processing line and is used to cut the pit to be dismantled open. The system consists of a lathe, a 4 DOF robot, a glovebox that houses them, and a universal controller that resides outside the glovebox and controls all equipment.

Dose reduction is the primary justification for implementing automation within the glovebox that houses the lathe. Early Los Alamos National Laboratory (LANL) prototypes required an operator to manually run a lathe or other bisecting mechanism to cut the pit in half. This tended to be a high dose operation because it involved handling the pit directly for extended periods. For some pits, the operator exceeded the 500mrem per operator dose limits set for the PDCF. With the use of an automation system, that dose is essentially eliminated and, in most cases, the operator should only be exposed to the background dose levels. In addition, some of the operations were physically challenging due to the weight of the component that had to be handled with difficult reach or other glovebox limitations.

In the prototype design, LANL decided to use the same controller as the lathe uses to control the material movement robotics. This provides a uniform interface for the operator, thus making the system simpler to run and maintain.

ROBOT TASKS

These are tasks that must be accomplished by the robot within the glovebox:

- Receiving pits in the glovebox. The pit arrives into the box on a conveyor and the robot is required to retrieve the pit from the tray. The pit is held on a stand on the tray to maintain a repeatable orientation.
- Weighing the pit after entering the glovebox. After the pit is retrieved from the conveyor, the robot moves it to a scale to be weighed.
- Loading pits into the lathe chuck. The loading and alignment process is an iterative process that normally increases the dose an operator would receive.
- Changing the chuck on the lathe to accommodate different pits. The chuck loading operation requires high precision to ensure proper alignment. This procedure is difficult to do manually, and is particularly difficult given the glovebox environment and the reach that is required with a heavy chuck.
- Changing tools or cutters on the lathe tool post. This was automated with the lathe when it was procured, but the mechanism was large and complex.
- Handling pit halves. This is a particularly important task as dose is often higher when the pit is separated.
- Weighing pit components. All components must be weighed before exiting the glovebox.

All automation in this environment is required to be proven industrial technology. It must be simple, reliable, and maintainable. The complete system consists of a lathe, the robot, all associated tooling for the lathe, and the glovebox that encloses it all. This may be seen in Figure 3. In this figure, the glovebox is shown semi transparent to allow the other equipment to be seen.

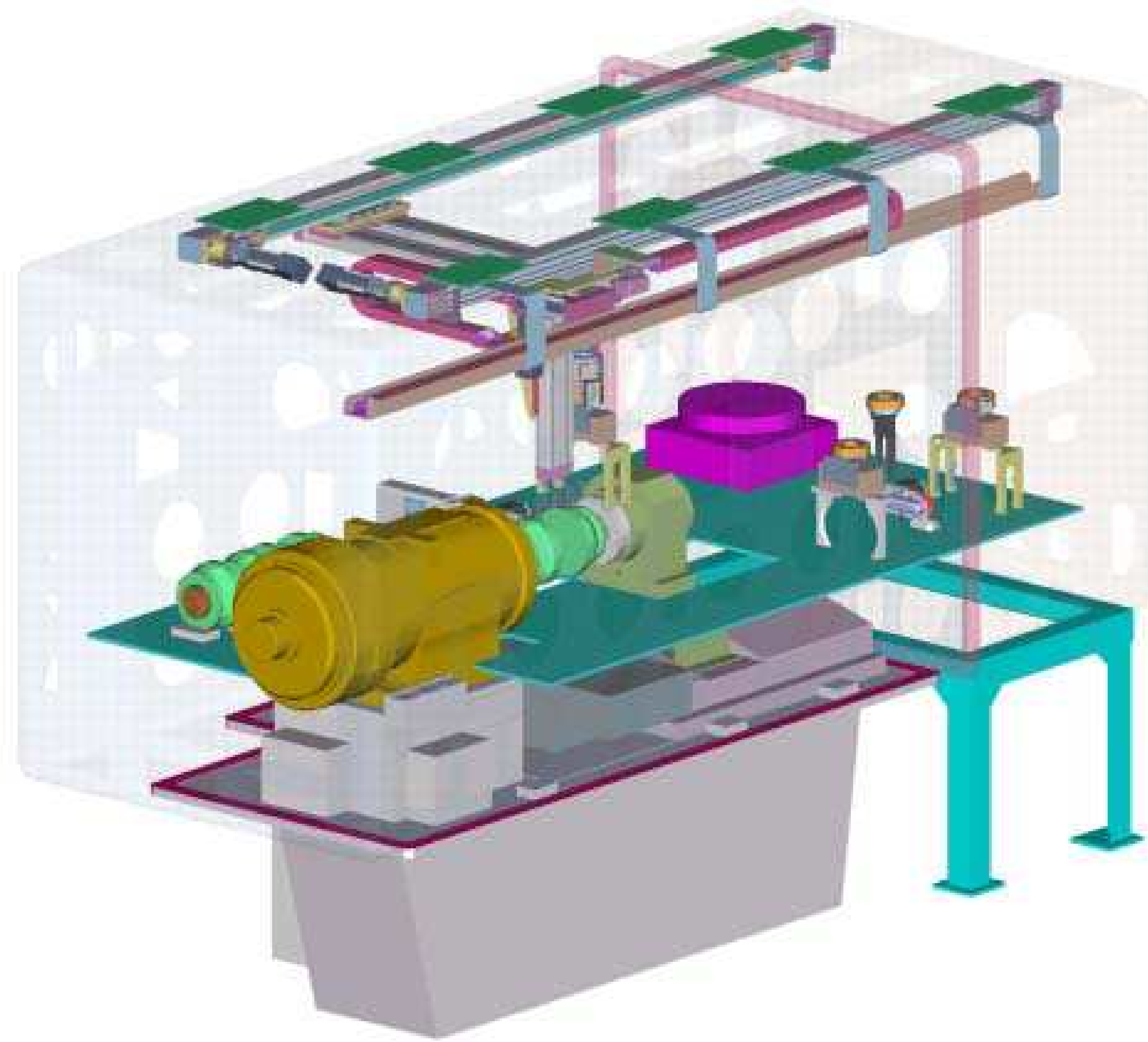


FIGURE 3: MODEL OF LANL PROTOTYPE LATHE WITH ROBOT AND GLOVEBOX.

TOOLING

The robot tooling, and some of the lathe tooling is shown in Figure 4. The tooling is as follows from top, left: pot chuck gripper, pit gripper, hemishell gripper, Linear Variable Differential Transformer sensor, slitting saw, lathe tooling gripper, pot chuck, pot chuck interface plate.

The robot tooling uses a standard robot tool changer to allow different tooling to be swapped out and used. The lathe uses a tool changer (clamp) to secure tooling on the tool post.

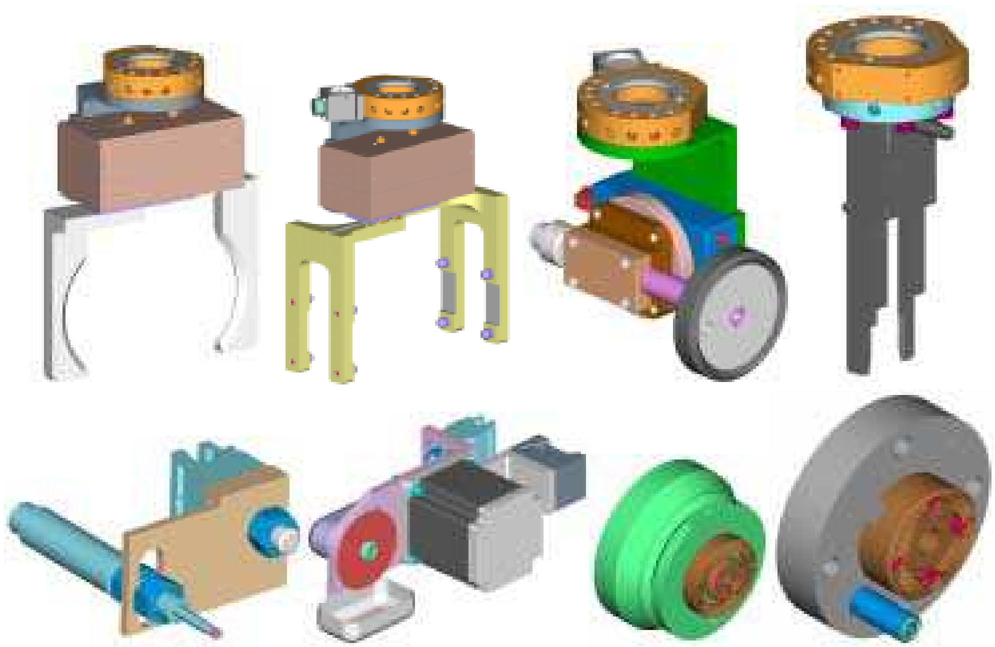


FIGURE 3: ROBOT AND LATHE TOOLING.

CONTROLLER

The lathe comes with a programmable motion control card incorporating the G-code programming capability required for complex lathe operations. This card provides up to sixteen axes of control. Stepper and servo motors are supported in any combination. It makes sense to use the same powerful controller to control all motion within the glovebox. Otherwise complex interfaces would have to be established between the lathe controller and the motion controller.

The controller consists of a 4-axis central card to which additional 4-axis expansion cards are added as needed. Each card can accept analog and digital I/O signals. All digital I/O is passed through OPTO-22 I/O modules for isolation and current-boosting requirements. The control system resides within a personal computer running Windows NT. This computer provides the environment for the HMI software and supports the physical environment necessary for the motion controller. All motion on the lathe and robot is generated electrically. Pneumatics (compressed argon & vacuum) are used for part gripping and air-bearing operation.

CONVERSION REACTORS

The Direct Metal Oxidation (DMO) reactor converts plutonium metal to an oxide powder that is transferred out of the base of the reactor into a lag-storage can. The DMO glovebox houses the DMO reactor vessel and two robotic devices. The robotics and reactor operations will be controlled by the system PLC at a HMI station in a shielded location.

ROBOT TASKS

These are tasks that must be accomplished by the two robots within the glovebox:

ROBOT #1

- Pick up a loaded reactor basket and load it into the reactor vessel where plutonium metal will be converted to Pu Oxide.
- Remove the empty basket after the conversion reaction is complete.

ROBOT #2

- Load an empty lag-storage can at the DMO reactor discharge flange.
- Move the filled lag-storage can from the reactor flange to the lid station.
- Secure a twist-on lid onto the lag storage can.
- Weigh the can.
- Move the can to the glovebox exit.

CONTROLLER

The DMO reactor will be controlled with a PLC, and it makes sense to use the reactor PLC to also control the motion control system. The PLC will include motion control cards with drives that are SERCOS-compliant, so smart motors will be used because of the simplified wiring and maintenance benefits in glovebox applications.

OXIDE STORAGE RETRIEVAL SYSTEMS

The oxide storage area will be a heavily shielded box with a gantry system that stores and retrieves lag-storage cans of oxide prior to blending and canning.

ROBOT TASKS

- Store filled cans of oxide from the DMO reactors in critically safe storage locations.
- Retrieve selected cans for blending.

CONTROLLER

Oxide storage and retrieval will be controlled by a PLC with a motion control card and SERCOS-compliant drives for robotic control.

NONDESTRUCTIVE ASSAY

The PDCF product NDA system will consist of two types of computer-based nondestructive assay instruments:

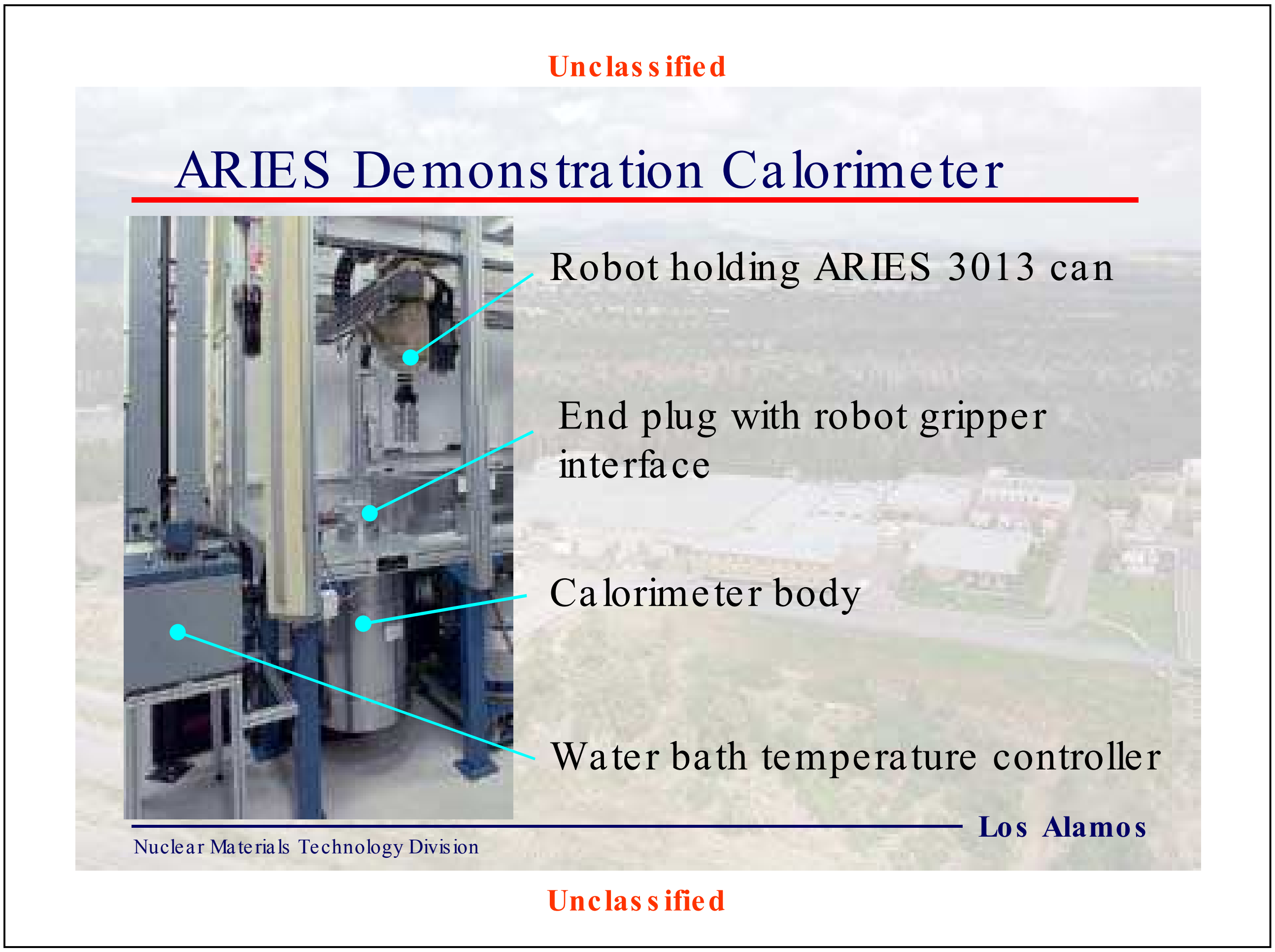
- Calorimeters measure the heat output generated by fissionable material.
- Gamma ray isotopic systems determine plutonium, americium, and uranium isotopic fractions by collecting gamma ray spectrum and analyzing the intensities emitted by the different isotopes. The calorimeter and isotopic measurements are used to calculate the mass of plutonium that is in a can of oxide.

- Neutron coincidence counter measurements (active and passive) may be used to assay cans containing uranium.

A robotic system will load and unload the instruments, and a host computer systems will direct the activities of the robot, sense and control instrument status, schedule measurements and calibrations, and archive the results of the assays.

ROBOT TASKS

- Load calibration samples into the instruments per the required calibration schedule.
- Pick up oxide cans from an automated can transport, scan the identifying barcode, and load the cans into the instruments in a programmed sequence. The gripper includes a force sensor that is used to detect collisions, verify contact with an item to be moved, and weigh the item.
- Load the assayed can into a vault storage rack that will be automatically transferred to the vault.



CONTROLLER

A host computer running Microsoft NT will control the NDA system. The computer will include a specialized motion control card for controlling the robot system. The motion controller must have superior video capability to interface with the robot's digital camera that reads the laser marked code on each can lid.

CONCLUSION

The PDCF requires reliable material movement systems to minimize operator radiation dose during pit disassembly operations. Standard motion control hardware and controllers will be used wherever possible, but each system is unique. Each will be designed with the best combination of motors, manipulation tools, rails, controllers, and HMIs to interface with the pit disassembly functions in the specific PDCF glovebox or room.

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