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Robot Deveopment For Nuclear Material Processing

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ABSTRACT

The Department of Energy is seeking to modernize its special nuclear material (SNM) production facilities and concurrently reduce radiation exposures and process and incidental radioactive waste generated. As part of this program, Lawrence Livermore National Laboratory (LLNL) lead team is developing and adapting generic and specific applications of commercial robotic technologies to SNM pyrochemical processing and other operations. A working gantry robot within a sealed processing glove box and a telerobot control test bed are manifestations of this effort. This paper describes the development challenges and progress in adapting processing, robotic, and nuclear safety technologies to the application.

Introduction

The Department of Energy (DOE) is seeking to modernize its special nuclear material (SNM) production facilities and concurrently reduce radiation exposures and process and the incidental radioactive waste generated. As part of this program, the Lawrence Livermore National Laboratory (LLNL) is developing and adapting generic and specific applications of commercial robotic technologies to SNM pyrochemical processing and other operations. The LLNL development and engineering efforts have led to:

- A working gantry robot within a sealed processing glove box
- Hardening of in-box equipment for the radiation environment
- A telerobot control test bed
- Development of special hard tooling
- Adaptation of advanced metal reduction furnaces for robotic operation
- Design and procedures to meet industrial robot safety and nuclear material and radiation safety criteria.

Features of SNM processing give it a high potential payback for robotic applications. These features include:

- Repetitive manual manipulation of standard objects

- Hazardous human exposure
- Finite working volumes
- Variety of processes involving similar manipulation tasks and work space
- Hazardous-waste generation specifically caused by human operations
- High-value product
- High current cost.

In addition to general suitability for the processing features above, robotic technologies can add better control and recording and remote real-time control for nonrepetitive tasks.

Some of the special aspects confronting development of systems for use in SNM processing are identified below:

- The need for component and material selection that will withstand the cumulative radiation doses or prolong the usable life in the radiation environment and in contact with radioactive materials
- The use of non-air atmospheres, which include inert gases, no humidity, and/or readily ionized gases providing poor electrical insulation
- Pervasive grit
- The imposition of stringent nuclear material controls and safety standards
- Need for an emergency manual-recovery capability
- Desirability of minimizing human access to the equipment (to minimize radiation exposures)
- Desirability of minimizing the amount of equipment exposed to SNM contamination to reduce future hazardous waste caused by national policies and costs of handling, shipment, and disposal
- Costs in radiation dose and effort of decontamination of items removed from a glove box for repair
- Restraint on human manipulation within the glove box caused by use of built-in gloves.

DOE laboratories and production facilities have continuous missions to examine and recommend potential improvements in equipment, procedures, and processes. LLNL has a history of examining and applying automation, remote control, and other technical advances to material processing and handling operations. These have formed the background and starting points for the further and on-going projects. Prior developments include an early integration of a prototype gantry robot in a simulated glove box, advanced automated linked glove-box systems, and applications of teleoperation and remote control.

The LLNL automated SNM processing efforts are being aided by participation by and input from other national laboratories, other elements of the DOE complex, and support contractors. The principal external support is coming from the Los Alamos and Sandia National Laboratories, Rocky Flats and Savannah River production operations, IBM, and Science Applications International Corp.

Approach

The objectives of the LLNL automated processing development efforts have been to exploit the available technologies and to advance the states of the art where necessary to gain benefits in reduced radiation doses, increased yields and productivities, and reduced high- and low-level radioactive wastes. The specific current efforts grew from analysis of potential SNM production facilities that showed that currently used procedures and equipment would not satisfy goals for minimizing human doses to as low as is reasonably achievable, or maximizing production output from the investment in new plant.

The automated-processing project was developed around the following stated and inferred guidelines:

- Develop an automated system that complies with existing industrial and nuclear safety requirements and with the logical extensions of nuclear safety requirements to the system where current documentation does not encompass the type of equipment and operations involved.

- Minimize risk through making maximum use of commercially available equipment proven in industrial production. [This was determined to be feasible by preliminary surveys of SNM production facilities and of commercial robot systems. These determined that the IBM "Electrical Cantilevered Robot" (ECR) could readily be adapted to glove-box geometry and could provide the weight-carrying and flexibility capabilities probably necessary.]

- Provide radiation hardening and other protection against hostile environments by backfitting alternative components and using substitute materials in the commercial configuration rather than by new mechanical design.

- Develop a system suited to a selected few specific processing applications with high potential for improvement through robotics, but with recognition that the basic system could serve as a prototype for a generic robotic glove-box capability.

- Develop automated system such that the work cycle can be completed by manual operations, in gloves, should the automated equipment malfunction at any point.

- Provide for future technology growth through selection of control system capabilities and available interfaces, and prepare for such future enhancement through research, development, and application of advanced telerobotic and sensor-based control.

- Perform advanced capability development by the integrated team, but on separate equipment, so as not to interfere with early fielding of the basic nuclear material-qualified automated system.

The automation project is in progress. The approach followed to date and projected for the future is outlined below:

1. Define program and project objectives. Test validity through surveys of the DOE production complex and by examination of commercially available capabilities.

2. Perform functional analyses of the processes that are candidates for automation. Determine parameters of current operations.

3. Identify and select suitable commercially available equipment and application engineering support based on projected physical and performance parameters, equipment usage history, and support-team experience.

4. Concurrently prepare a demonstration of the basic capability of the selected equipment in performing selected processing cycles by the commercial application engineering group, and assemble the in-house expertise for the further research-and-development effort.

5. Design and obtain the demonstration glove-box robot system modified for the glove box and by substitution of components for limited radiation hardening, and appropriate hard tooling for the initial applications. Assemble, install, integrate, and program the development engineering model as a testbed.

6. Perform functional, comparative times, time to repair or replace, and reliability testing; performance mapping; and demonstrations using the testbed robot system. Test advanced technology applications for potential integration (see 10 below). Perform concurrent safety analyses.

7. Determine potential additional applications and perform similar tooling and process development and testing.

8. Define the production prototype configurations for the robot, robot controller, and glove box through a deliberate configuration-control system. Integrate adopted advanced developments into the basic system.

9. Acquire, test, and demonstrate the prototype nuclear-qualified system with surrogate (nonradioactive) materials (e.g., cerium) and then in a pilot "hot" application.

10. Concurrent with 3. through 9. above, and continuing, examine advanced mechanical and control technologies for potential incorporation as standard or optional elements of the basic system. Where appropriate because of special needs, extend and develop the technologies or their application. Develop and use a separate test facility to support these efforts.

Challenges

The principal challenges in the automated SNM processing glove-box development which extend that effort beyond the level of one more extensive application engineering project relate to special environmental conditions, atypical cost-benefit relationships, nuclear waste-minimization policies, and the absolute requirements associated with nuclear material safety and control.

SNM processing involves radiation doses for equipment components within the enclosed working volume (typically a controlled-atmosphere glove box), pervasive actinide metal and oxide grit, and atmospheres without moisture and/or without gases with significant specific heat and/or with poor electrical insulation capability (e.g., argon). A survey of processing glove boxes has shown that the equipment inside may be subject to combinations of hazards, including:

- Radiation: primarily alpha radiation from surface contact, and lower levels of beta, gamma, and neutron radiation

- Intrusive highly gritty dust

- Gaseous fill other than natural air, including dehumidified air, nitrogen, and noble gases.

The variety of current processing environments and the harshness of some of those environments effectively preclude design and selection of in-box automated systems that would be proof against the entire spectrum of conditions. The alpha radiation, for example, can be expected to change the properties of some surfaces impacted. The changes may be limited to the light depth of alpha penetration, unless there are mechanical actions that may cause the surface to be abraded and further exposed.

The tradeoff between system hardness and number of potential applications versus development and eventual procurement costs was addressed by determining the relative numbers of potential using processes for the generic automation capabilities, versus the levels of harshness of the respective environments. The resulting selection oriented the design to those associated with pyrochemical processing.

Hardening, especially against alpha-emitting dust, may be accomplished through a variety of approaches. These include such dust control measures as:

- Sealing and enclosing components sensitive to the alpha radiation and/or SNM dust emitting it. This also increases the total contaminated material and may prolong the time required for maintenance personnel to access enclosed components, and thus increase their personal doses.

- Frequent cleaning of surfaces. This may involve additional operator time in gloves or additional equipment in the box (which will eventually require disposal). However, cleaning is a necessity to prevent buildup of SNM and to aid in its inventory. Cleaning could be by use of vacuum systems, blowers, brushes, or adhesive wipers.

- Removing dust in suspension or resuspended by cleaning actions by use of an in-box or external filter or other dust-separator system.

The automated glove-box system design is complicated by the special economics of radioactive material handling. The pyrochemical processes are similar to those that may be used for a variety of metals, but the value of the materials is high.

Small changes in yield and in increasing the ability to recover and recycle process waste can have major returns. Intangibles must be considered in order to make comparative assessments. These include the doses received by the operators, changes in the threat of accidental release, or reduced volume of waste. Tradeoffs must be made in the design and procedures between factors such as costs of removal, decontamination, repair, and replacement by small subassemblies, versus the reduced radiation doses accompanying removal and disposal and replacement of larger modules, involving less aggregate human radiation dose.

It is a stated objective of the DOE that future processing plants reduce waste to a minimum. This impacts even design analyses and tradeoff evaluations of such developments as the automated glove box. Criteria or questions that become part of the input to design and assessment include:

- Keeping radioactive waste concentrated for more efficient handling, shipping, and disposal (as long as the concentration does not threaten criticality). This affects the use and handling of filters, decontamination practices, and designing the structural and mechanical systems to facilitate the eventual decommissioning.

- Designing the system for compatibility with current, acceptable plant decontamination and disposal practices. In the case of the automated system, this also involves projecting the implications of current policies to the waste-disposal practices and environment that will exist when the system is put in place.

Resulting Automated Glove Box

The principal physical results of the efforts to date are reflected in the operating gantry robot system in the automated test bed located at LLNL. The physical appearances are not expected to change much, although both the glove box and robot will undergo further configuration changes before the system is considered ready for test, demonstration, and use in production. Figure 1 shows various views of the glove box. Overall dimensions are approximately 1.65 x 5.7 x 3.8 meters (65" wide x 225" long x 151" high). Figure 2 shows the layout of the current test facility for the automated gantry robot glove-box system. Figure 3 provides an external view of the principal equipment.

The present test set-up includes an adapted tilt-pour furnace built into a recess in the box floor, another furnace for other pyrochemical operations, and special tooling for the specific operations being examined. The special tooling includes the following:

- Positioner and vibrator combination used to transfer and spread powdered SNM oxide for furnace operation
- Can opener to open the containers of input materials
- Canister lids adapted for ready gripping by the robot
- Fixture and positioner to support separation of the metallic SNM from the residual salt and to hold the the metal slug while the robot cleans residual salt from the metal's surface
- Interchangeable autochange grippers for the robot's end effector, suited to gripping and manipulating cannisters, crucibles, metal slugs, can lids, dropped items, and special trays used for transfer and furnace feed, and for general gripping
- Built-in racks for the interchangeable tooling
- Special-purpose autochange robot attachment for spreading powdered SNM oxide within a special furnace crucible
- Furnace and tray attachments positioned by the robot in making material transfers
- Automatically recording scale.

The gantry robot has been adapted from commercial equipment by IBM, Federal Sectors Division in Austin, TX, for the glove-box application. Features of the robot and its adaptation are described below:

- Lift capacity: more than 25 kg
- Cartesian motion ranges within the glove box: approximately 5 meters X-X, 1 meter Y-Y, and 1 meter Z-Z
- Wrist: 3 rotational axes
- End effector: parallel-action fingers adapted for autochange of attachable grippers and other tools

- Actuation: all-electric sealed motors
- Encoders: currently pulse counting
- Installed sensors: diode and photocell to determine if an object is between the end effector fingers and three-dimensional force sensing on the end effector
- Settable proximity sensors and hard stops on Cartesian coordinates to restrict robot operating volume and provide normal operating limits
- Revised and consolidated cable routing through flexible cable trays, with standard military specification connectors and specially selected cable materials
- Use of special grease for the hostile environments
- Use of track wipers to reduce wear caused by dust
- Avoidance of nylon in bushings caused by potential lack of humidity (dimensional changes in the nylon).

The current test-and-demonstration system has proved to be sufficient to show the suitability of the concept and to obtain quantitative data on performance and for comparison with present manual systems. Lessons learned with the current configuration and procedures are being incorporated into the planned "hot" system baseline. This follow-on system is to be developed in 1992 and is to constitute the prototype and probable initial production use of the development program's products.

Conclusions

The LLNL robotic research efforts include development of a gantry robot system modified for the environments and tailored to fit in a special glove box as an initial SNM-processing support system. This is in its second stage; the eventual SNM-suitable system is being designed based on the lessons and experimental information being collected on the current test-and-demonstration model. Potentials for programmed and remote teleoperation to minimize further the need for human manipulation of tools and performance of maintenance within the glove box are being explored by tests.

Although the "market" for equipment tailored to a single operation, such as in-glove-box support of a specific pyrochemical furnace, is relatively small, the potentials for human dose reduction, waste minimization, and increased productivity among the 1,000 DOE glove boxes and additional enclosed processing lines are large.

Acknowledgments

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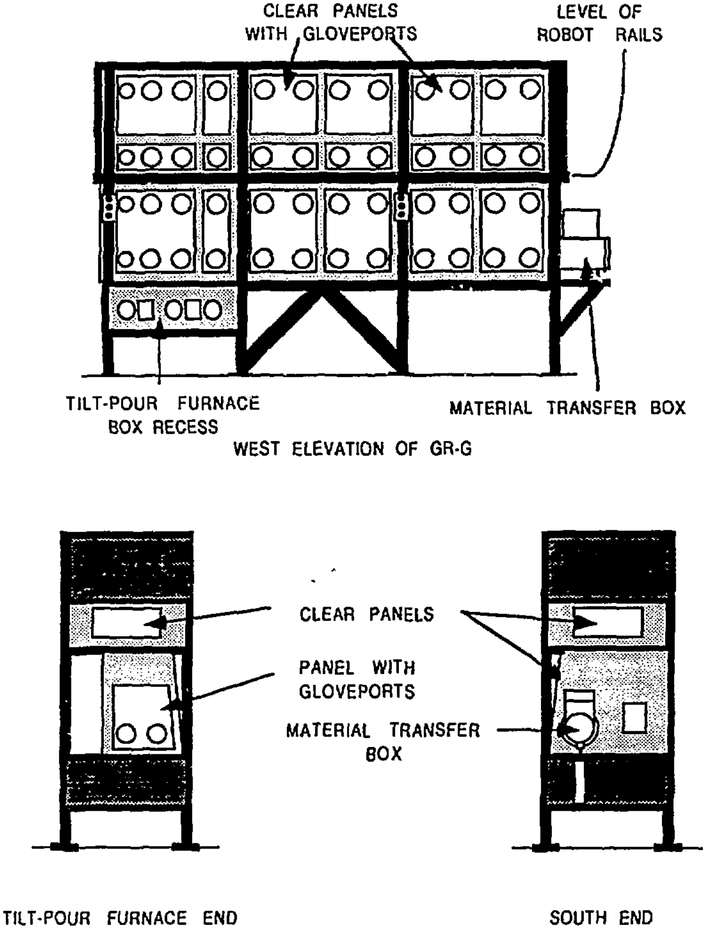

Figure 1 Glovebox Elevations

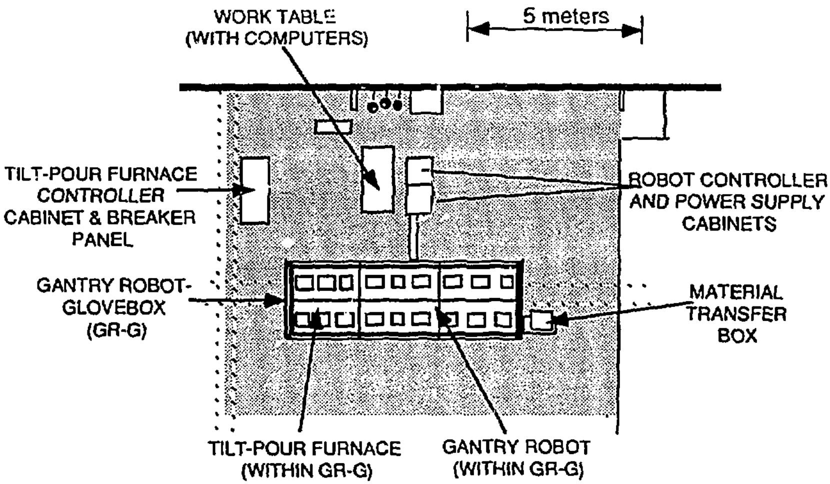

Figure 2 Layout of LLNL Gantry Robot Glovebox Test Facility Area

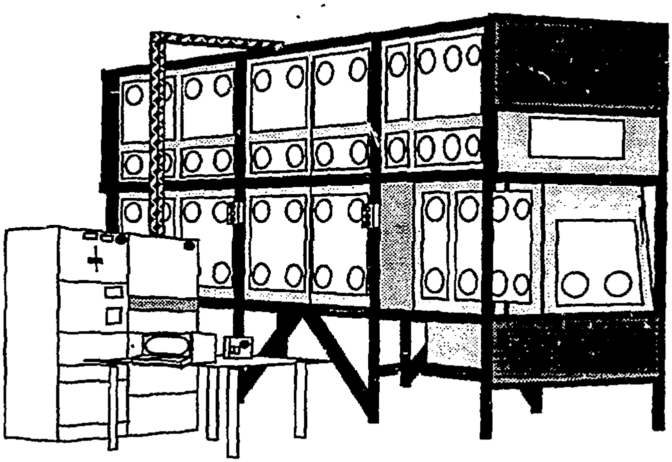

Figure 3 Principal Equipment