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ROBOTIC AND NUCLEAR SAFETY FOR AN AUTOMATED/TELEOPERATED GLOVEBOX SYSTEM*

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ABSTRACT

Lawrence Livermore National Laboratory (LLNL) is developing a fully automated system to handle the processing of special nuclear materials (SNM). This work is performed in response to the new goals at the Department of Energy (DOE) for hazardous waste minimization and radiation dose reduction. This fully automated system, called the automated test bed (ATB), consists of an IBM gantry robot and automated processing equipment sealed within a glove box. While the ATB is a cold system, we are designing it as a prototype of the future hot system. We recognized that identification and application of safety requirements early in the design phase will lead to timely installation and approval of the hot system. This paper identifies these safety issues as well as the general safety requirements necessary for the safe operation of the ATB.

INTRODUCTION

In early 1990 a team of scientists from various disciplines were assembled to apply robotics to various nuclear material processes. The first process targeted for automation was the Direct Oxide Reduction (DOR) process. This process is designed to reduce PuO_2 to Pu metal in a tilt pour furnace. We had developed a cold furnace that simulated the hot operation by turning a Pu surrogate, CeO_2, to metal. Automation of this process involved installing an IBM gantry robot, the cold tilt pour furnace, a lid lifting mechanism for removing the top of the furnace and automation tooling in a specially designed glove box (Figure 1).

Current SNM processing operations are performed manually in specialized glove boxes where doses to personnel are a significant concern (Figure 2). The end goal of this project is to design a nuclear-qualified automated system that will reduce the radiation dose to operation and service personnel. We also expect to reduced process by-product and generated radioactive waste while improving yields and productivity.

For timely qualification of a hot system, we are introducing all aspects of safety required for a nuclear qualified system as early in the design as possible. To do this we identified appropriate safety guidelines, developed the modifications to hardware, written appropriate procedures and presented the training necessary for management, operation and service personnel. All this is being documented for the final design and for future systems.

The IBM gantry robot, tilt-pour furnace and the glove box itself all add their unique hazards to the ATB. The safety requirements that address these hazards are covered under federal, state, national, DOE, LLNL, and industry standards. In this paper, these requirements are outlined; the hazards analysis is discussed, and the impact of these safety requirements on the system is presented.

SAFETY REQUIREMENTS

The most unique and hazardous aspect of the ATB is the IBM gantry robot. We quickly recognized that its autonomous action and freedom of motion through out the glove box required special hazards analysis. The ANSI/RIA "American National Standard for Industrial Robots and Robot Systems-Safety Requirements"[1] and its most recent revision[2] provided us with the most comprehensive guidelines for safe operation of the robot in the glove box. This standard is intended to enhance the safety of personnel and equipment associated with industrial robots by establishing guidelines for the installation, operation, maintenance, and operator training for industrial robots. It is also probable that this standard will eventually be

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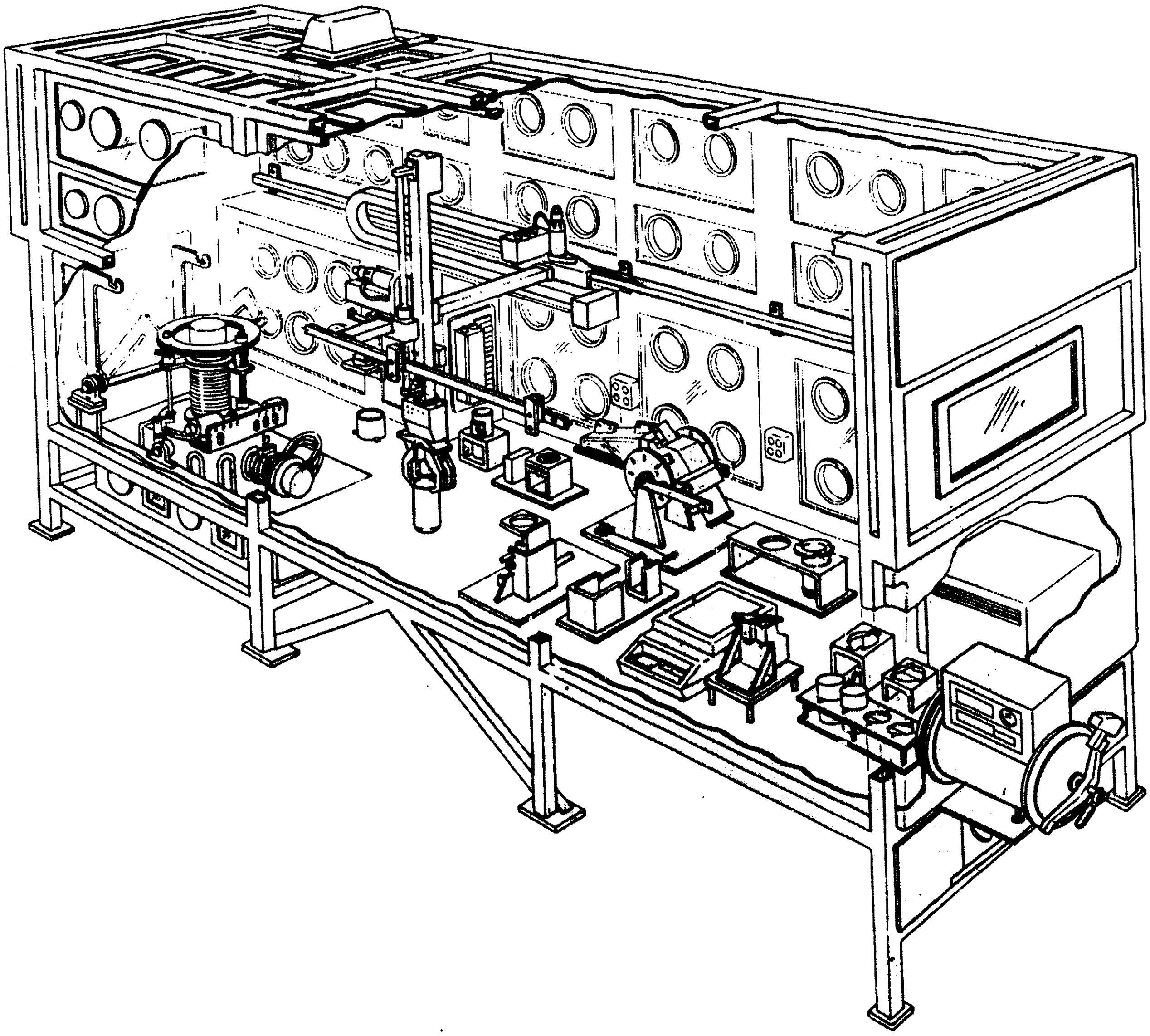

Fig. 1. Artist's cutaway of automated glove box test bed at LLNL.

incorporated into federal or state regulations. The Occupational Safety and Health Administration (OSHA) Publication 8-1.3, "Guidelines for Robotic Safety"[3] has provided additional guidance for the ATB's hazard analysis and identification of safety requirements.

The primary safety concerns addressed in the ANSI/RIA guidelines include:

- The need to recognize the hazards associated with automatic control and an insensitive controller,
- The need to minimize the hazards when a human must enter the work space of energized or operating equipment,
- The need to curtail chance access to the equipment working area,
- The need for safety training, and
- The need to control hazards anticipated for all foreseeable malfunctions.

Since the robot will eventually handle SNM, we recognized the need to meet the necessary requirements for safe handling of radioactive material.[4] To accomplish this we are verifying that the appropriate physical safeguards and procedural measures are in place so that:

- Criticality does not occur,
- There are no uncontrolled releases of nuclear materials, which could be a hazard the public or the workforce,
- The public and the workforce are not subjected to or put at risk of experiencing radiation levels higher than permitted by regulation,
- Nuclear materials remain readily retrievable, and

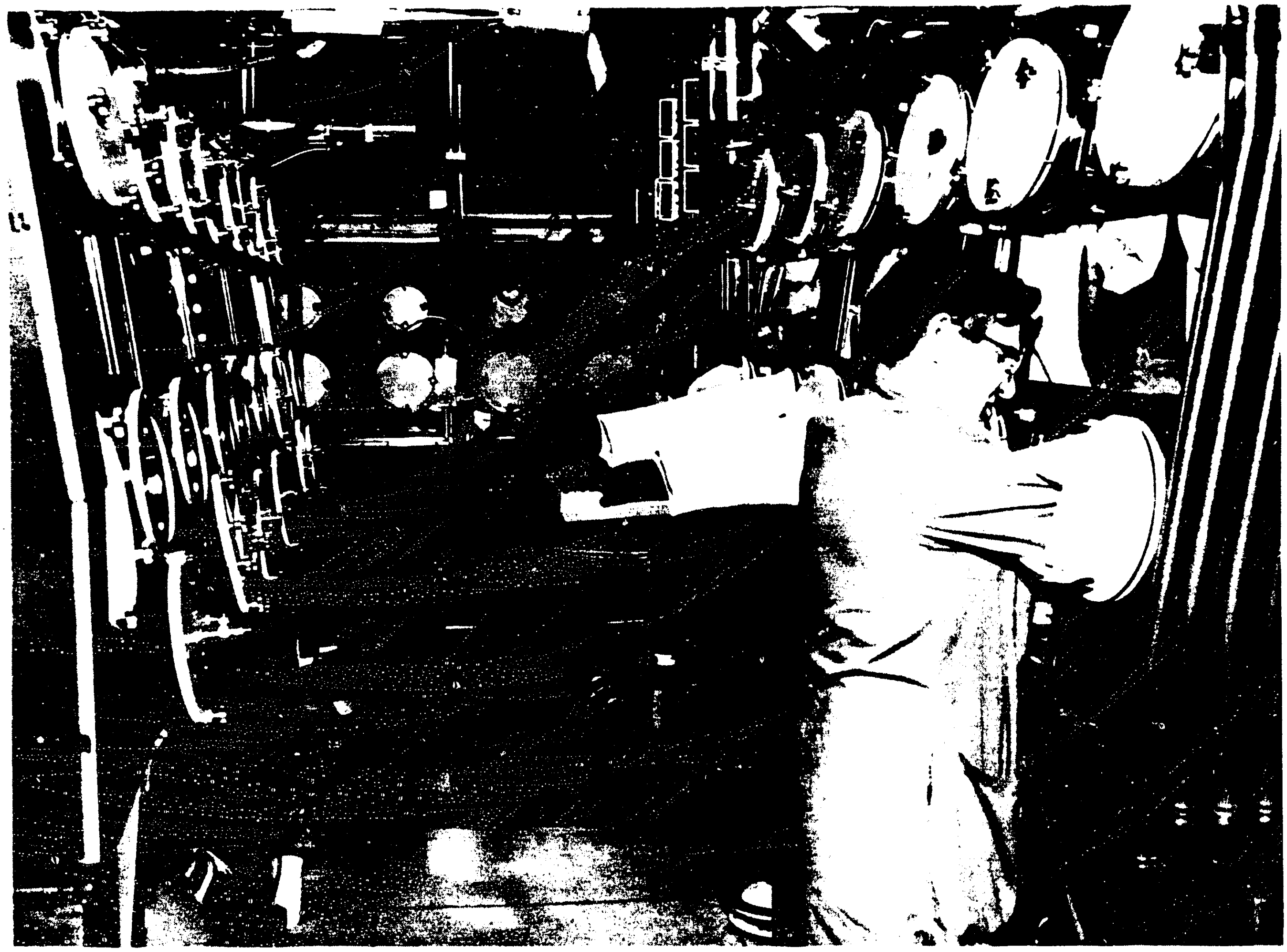

Fig. 2. An operator in LLNL's Material Processing Laboratory manipulating a stationary furnace component through gloves.

- The above are conclusively demonstrated through hazard analysis.

Operations that involve SNM need to be performed so that occupational doses are "as low as is reasonably achievable" (ALARA). This necessitates that the design of the ATB be reliable so that doses due to maintenance and servicing operations are not greater than the reduced dose attributed to the process automation.

Experiments at LLNL are installed and operated under guidance outlined in DOE orders and additional LLNL site specific health and safety policy and procedures. A formal safety analysis must be performed during the development stage of every experiment at LLNL. Engineering safety notes or operational safety procedures (OSPs) may be required to control the hazards identified in the safety analysis.

An engineering safety note documents how the system design mitigates the identified safety concerns. These subject to peer review and checked for conformance to applicable regulations national standards. An OSP is written to identify hazards and responsible individuals and to document controls for those hazards. The OSP for an operation must be reviewed and understood by all individuals involved with that operation. OSP guidance and industrial safety requirements for the automated glove box are best outlined in the LLNL "Health and Safety Manual."[5]

While the current system is designed to be a cold glove box, we have begun to design a hot ATB for Pu handling. Guides such as ASTM C852, "Design Criteria for Plutonium Gloveboxes,"[6] provides guidance on this design. We also recognize that DOE is developing internal review capabilities modelled on Nuclear Regulatory Commission (NRC) reviews for private industry. To address this issue we have utilized consultants familiar with NRC reviews to assist with the analysis of the ATB.

HAZARD ANALYSIS

Robot safety standards and DOE guidance lead to the performance of a hazard analysis. Systematic hazard analyses identify and classify conditions, possible occurrences and possible trains of events that could result in injury, death or equipment or product damage.

Hazards were identified and then classified by probability of occurrence and hazard level. Corresponding design modifications or administrative measures were then developed, analyzed, and applied. The final analysis should be able to demonstrate that potential problems have been eliminated or controlled by design or procedures. For current operations and future nuclear material handling activities at the ATB, special attention is focused on the following:

- Events or degradations that could result in breach of the containment of the glove box,
- Electronic component failures or malfunctions that would not result in shutdown,
- False positives or negatives from sensors and displays,
- Operator error,
- Recovery from an upset, drop, or spill of nuclear material, and
- Injury due to operator entry in the robot or tilt pour furnace work are while power is applied.

IMPACTS ON SYSTEM DEVELOPMENT

For virtually all of the designers and operators of the ATB this was the initial introduction to modern industrial robots. Aspects that contributed to a safe system include the strong, LLNL "safety culture" widespread safety awareness, management recognition of the importance of a safe system, and a dedicated safety oversight team.

Following a review of the safety related guidance documentation and the results of the hazard analysis, the following areas of the ATB were targeted for modification:

- Modification to and strict controls over use of the robot teach pendant,
- Integration of warning lights and emergency stops in the system,
- Provisions for limit switches and fixed stops for robot travel to limit the robot work space,
- Addition of an automatic brake with a manual release to the robot's vertical mast,
- Inclusion of all internal to the glove box systems in the emergency stop circuit,
- Minimum and selective use of sensors in interactive control,
- Design to make nuclear safety independent of any controller action and thus independent of potential robot movements (to the extent of foreseeable use),
- Design to ensure that the supported process can be completed manually from any point in the work cycle, and
- Structural design for the extreme California earthquake.

The design of the safeguarding system was based on the referenced guidance documentation and the results of the hazard analysis. This system was developed to protect anyone interacting with system. The safeguarding system includes:

- Physical barriers: The glove box walls function as the perimeter barrier to prevent inadvertent entry into the restricted envelope (the interior volume that can be accessed by the robot—Figure 1). Interior and exterior gloveports are installed over the gloveports that restrict entry of arms into this volume.
- Emergency stop devices: Emergency stop buttons are located on the teach pendant, at the operator control station, and on the controller and at four other points on the exterior of the glove box. Currently a foot controlled emergency stop device is being considered for future applications.
- Restricted envelope identification: Signs are mounted on the exterior of the glove box warning of the hazards and informing personnel of the significance of the status lights.
- Awareness signal: Robot status lights, are mounted at four locations, which indicate if the robot is energized or in a safe state.
- Awareness barriers: Chains or ropes on temporary supports are used to warn when the glove box is open to preclude inadvertent entry into the glove box when a side panel is removed. Visitors are continually visiting the ATB therefore controlled areas are must be clearly marked on the floors.
- Oxygen sensor: Since the box is purged with a inert gas (N_2), any leaks in box could lead to a local oxygen deficient atmosphere in outside the box. An oxygen sensor is stationed near the box to detect this hazard.
- Confined space: The glove box interior can be a hazard because it is normally purged with a inert gas (N_2). It is easily accessible by removal of a panel and is a confined space. Special procedures have been developed to preclude personnel access to the ATBs oxygen deficient atmosphere.
- Procedures: An Operational Safety Procedure has been prepared that includes the automated glove box system. In this procedure responsibilities are identified, and hazards and their controls are identified.
- Training: A robot safety training course for the ATB was developed and is required for personnel who

operate and maintain the system. The course gives and overview of the system, describes routine operating procedures and emergency procedures. It also identifies specific hazards of the ATB and describes the measures required to control them.

- Responsibilities delineated: Clear by-name assignments of responsibilities are used to ensure system safety. The "Senior Responsible Person Present" has responsibility for control of the full system and all affected personnel.

LLNL is addressing additional ATB modifications to satisfy nuclear safety requirements. The most significant requirement is to ensure that the robot cannot be commanded to or malfunction such that it can cause a breach in the radioactive confinement of the glove box. This requires that the glove box walls and viewports be sufficiently resistant to impact and tearing. It also requires procedural controls and/or interlocks prevent robot motion if glove are not secured and can be torn or removed by the movement of the robot. This will also prevent personnel injury since the robot will not function if the operators arm is in a glove.

SUMMARY

Ensuring system safety for the automated glove box system requires consideration of safety from the initial phase through the installation and operation phase. Safety analysis of the LLNL ATB is on-going.

Early safety participation in the system development is considered to have shortened the time for eventual installation of a hot system by a year. Additionally, safety input has impacted the glove box design and has identified robot and tilt pour furnace modifications. It has also influenced the design of the safeguarding system and has resulted in the development of specialized procedures and training.

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