# ADVANCED HANDLING TECHNOLOGY PROJECT AND IMPLICATIONS FOR CASK DESIGN

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## INTRODUCTION

Sandia National Laboratories (SNL) supports the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management in ~~the development of technology for the safe transport~~ of nuclear waste. Part of that development effort includes investigation of advanced handling technologies for automation of cask handling operations at nuclear waste handling facilities. Although low radiation levels are anticipated near waste transport casks, cumulative occupational exposure at a repository can be significant. Remote automated cask handling has the potential to reduce both the occupational exposure and the time required to process a cask. Thus, automated handling is consistent with DOE efforts to reduce the lifecycle costs of the waste disposal system and to maintain public and occupational radiological risks as low as reasonably achievable (DOE 1987).

This paper describes the results of the ongoing Advanced Handling Technologies Project (AHTP) at SNL. AHTP was initiated in 1986 to explore the use of advanced robotic systems to perform cask handling operations at radioactive waste handling facilities and to provide guidance to cask designers regarding the impact of robotic handling on cask design. The proof of concept systems developed in AHTP are intended to extrapolate from currently available commercial systems to those that would be available by the time that an actual repository would be open for operation. These systems provide test facilities for the investigation of the robotic handling of alternate cask design features. The following sections describe 1) the approach used in AHTP to select operations for proof of concept robotic systems and to identify the cask design implications, 2) the separate proof of concept robotic systems developed in AHTP, and 3) preliminary insights into the impact of cask system design features on the feasibility of robotic performance of cask handling operations.

## APPROACH

The Advanced Handling Technologies Project was initiated to provide guidance to transport cask designers regarding design to accommodate remote and robotic handling at nuclear waste processing facilities. The basic approach used in AHTP to develop insights on the impact of cask system design on robotic performance of handling operations is to 1) select operations that might be performed robotically, 2) build proof of concept systems to investigate those operations, and 3) identify cask system design features that impact the performance of the robotic systems.

Selection of operations for which to build proof of concept robotic systems was based upon the estimates of the radiological dose associated with cask handling operations and the need for development of enabling robotic systems technology (Strip 1987a). The operations that result in the largest doses when performed manually are 1) cask head operations including bolting/unbolting and gas sampling, 2) removal of impact limiters and cask tiedowns, 3) washdown including radiation and contamination surveys, and 4) removing the cask from its transporter and placing it on a cart for transport within the handling facility (Schneider et al. 1987). The high dose from these operations results from the radiation field close to the loaded cask, the time required to perform the operations, and the frequency of the operations.

Initial investigations into robotic performance of cask handling operations have been performed at the Hanford Engineering Development Laboratory (HEDL) using currently available robot technology (Berger et al. 1986). Since DOE commercial waste handling facility designs have not yet been finalized, and will not be operational for 10–15 years, robotic systems that might be used in such facilities are expected to incorporate technological advancements over currently available commercial robots. Current commercial robotic manipulator systems are typically programmable devices capable of only limited manipulation of objects in their environments due to sparse sensory systems, limited dexterity and relatively low payload to weight ratios ($<$1:10). Furthermore, current robot control technology is typically restricted to the repetitious return to previously *taught* locations. *Teaching,* which is the most common mode of robot programming, involves manually moving the robot manipulator's end point to a location in the environment and storing that position in the robot's computer memory. With restricted personnel access to the robot work space and the need to deal with off-normal conditions, this manual approach to robot programming is difficult.

The proof of concept robotic systems developed in AHTP start with the findings of the HEDL cask handling work and incorporate advanced technological features that are expected to become commercially available over the next 10–15 years. Based on experience in the design and operation of these systems, insights into the impact of robotic handling on cask design features have been developed (Griesmeyer and Thunborg 1988).

## AHTP PROOF OF CONCEPT ROBOTIC SYSTEMS

Much of the control for future robot systems will be through supervisory computers using models of the robots and their environment including manipulated objects. Sensor–based control (e.g. force control) currently demonstrated in laboratory systems (Petterson and Jones 1987) will be available. While vision systems will be available to locate objects and build the models of the environment used by robotic systems, vision–based servo control will probably not be available in commercial systems in the next 10–15 years. The use of models allows for intelligent error recovery when model–based expectations are not met. This results in reliable system operation. The proof of concept robot systems developed for AHTP emphasize the integration of sensor information such as force and vision into model–based supervisory control of the various robot system components. These laboratory robotic systems (Thunborg 1987, Thunborg 1986) have already demonstrated significant progress in model–based supervisory control.

AHTP consists of several subprojects that address the ~~high dose~~ operations mentioned above. The Remote Radiation Survey and Analysis System (RRSAS) (Thunborg 1987), completed in August, 1987, locates a half scale cask mock–up with a stereo vision system, identifies the cask using bar codes and then performs non–contact radiation and visual surveys. These are followed by a contact surface contamination survey using force controlled contact swiping of random locations on the cask surface. The radiation and surface contamination surveys were chosen for the first proof of

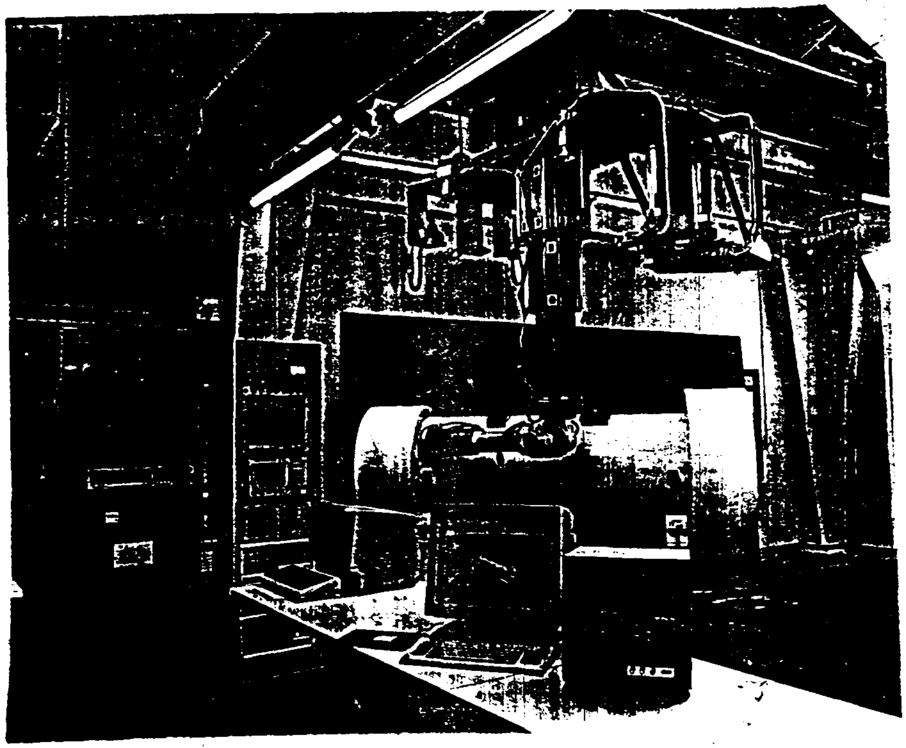

Figure 1: Remote Radiation Survey and Analysis System (RRSAS)

concept system to be built for AHTP because they required demonstration of key enabling technologies: model–based automatic planning and programming of robot movements, sensor integration which provides model updates and allows detection and possible recovery from off–normal conditions, and force control to maintain contact with the cask surfaces during contamination surveys. Figure 1 shows RRSAS and the cask mock–up. Model–based control with sensor integration permits the RRSAS system to consistently perform the contamination survey using a specified swiping force (4 ± 1 lbs) (Thunborg 1987). Furthermore, automatic monitoring and recording of the operations reduces the time for record keeping with the result that RRSAS can perform the complete contamination survey faster robotically than it can be performed manually. The technologies demonstrated in RRSAS are used extensively in the other AHTP robotic systems.

The Cask Head Operations (CHO) project investigates robotic performance of cask head operations required before and after fuel unloading. These operations include leak detection, gas sampling (port cover removal/replacement and coupling/uncoupling of the sampling apparatus to the port), and bolting and unbolting operations. The CHO project has developed a modular test facility for investigating the impact of various cask design features on robotic operations. First demonstration of the CHO robotic system was in September, 1988. The CHO system has been used to develop robust algorithms for performing robotic operations such as mating the torque wrench to the various boltheads on a cask head mock–up using force feedback. Figure 2 shows the CHO system torque wrench and the cask-head mock–up. The limited workspace of floor mounted robots such as that used in CHO makes access to side features on the cask difficult, suggesting that actual cask handling facilities at a repository may be better performed using gantry type robots.

The Swing Free Transport and Unloading (SWIFT-U) project has developed control algorithms

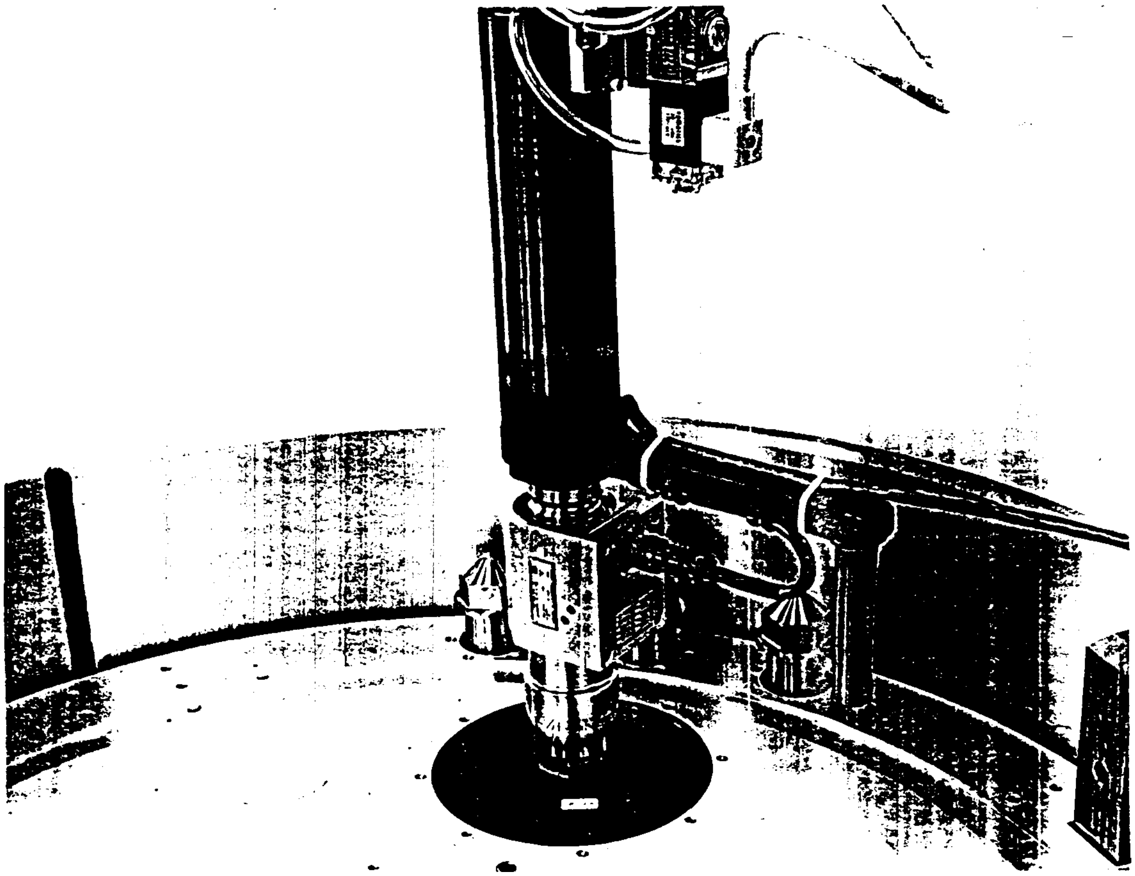

Figure 2: Cask Head Operations (CHO) System

that allow transport of suspended objects with no residual swing (Jones and Petterson 1988). Thus, swing damping is not required at the end of transport. These algorithms have been applied to the suspended movement of quarter scale mock-ups of a cask and fuel assemblies. SWIFT-U also has successfully uprighted a scaled cask mock-up under force control, significantly reducing the time for the uprighting operation when compared with manually controlled uprighting.

Finally, several cask feature mock-ups are in fabrication or final design. Impact limiter concepts will be investigated for feasibility of robotic removal and installation. Cask tiedown systems are being added to the cask mock-up used in RRSAS and to a quarter scale cask mock-up. Algorithms for robotically operating the tiedown systems will be developed when fabrication of the mock-ups is complete. For both the impact limiter and cask tiedown mock-ups, the impacts of alternate design features on the robotic operations will be identified. The quarter scale cask will also be used for further cask uprighting and swing free transport investigations.

## IMPACT OF ROBOTIC HANDLING ON CASK SYSTEM DESIGN

Table 1 summarizes preliminary design guidance to facilitate remote handling (Griesmeyer and Thunborg 1988). Critical to the success of the model-based supervisory control used in AHTP and expected to be a fundamental part of future robotic systems is the computer model of the robot and the objects in its environment. The model allows the supervisory computer to interpret sensory data and automatically direct robot motions based upon this sensory information. Simple cask geometries greatly facilitate task planning and supervisory control using models. Thus, cask design should employ geometries that are as simple as possible without compromising cask functionality. Model-based control of commercial robots incorporating a single force sensor in

Table 1: Summary of Cask Design Considerations for Robotic Handling

**Configuration and Construction**

- Construction of the cask should minimize variations between cask systems of the same model and allow the geometrical description of the cask system to be as accurate as possible.
- No surface cavities or tight angles ($< 90°$) should exist on the cask or on the transporter with personnel barriers in place.
- Stepped surfaces on the cask and on the transporter with personnel barriers in place should be minimized.
- Cask and transporter surfaces should have simple mathematical descriptions.
- Obstructions on the personnel barriers and cask surfaces should be minimized. Unavoidable obstructions should have simple mathematical descriptions.
- Surfaces should have uniform color except for vision targets and identification markings.
- To the extent possible, lifting mechanisms should be integral with the component being lifted.
- Where possible lifting points should be directly over the center of gravity of the object to be lifted.

**Approaches and Clearances**

- Clearance should be provided for: tool end points, tool bodies, robot arms (including tool mount plates) and maneuvering.
- Approaches normal to workpoint surfaces are preferred. Threading through obstacles should not be required to reach a workpoint.
- Lifting by cranes requires enough lateral clearance to permit engagement of the lifting mechanisms

**Mating and Engagement of Components**

- Self-guided mating should be provided to accommodate alignment errors.
- Storage of removable components requires self-guided mating to the storage location to ensure proper position for retrieval by the robot or crane.
- Rigid connections should be provided between the robot and components to be lifted in order to minimize swing.
- Two stage mating may be useful when tight tolerances are required for coupling.

**Latches, Fasteners and Other Mechanisms**

- Torque reaction points should be provided to reduce the loads transmitted to the robot arm when necessary.
- Quick release and single action mechanisms with self-guided mating should be used if feasible.
- Fastening mechanisms should be captured when possible to reduce storage and retrieval operations.
- Bolts should be captured with spring return and crossthread prevention features and self-guided mating to sockets.

**Vision Targets for Location**

- Vision targets should be isolated from other surface features (e.g., edges and protrusions) and have a high contrast color relative to the rest of the component surface.
- Three vision targets with known position and separated as far as possible should be placed upon each movable component in the cask and transporter system.
- Special workpoints requiring extra precision can be provided with separate vision targets.

**Identification**

- Model and serial number information markings for all separable components of the cask/transporter system should provide for both automated and manual reading.

proof of concept systems has allowed robots to perform a wide range of contact-based manipulation tasks such as mechanical assembly (Thunborg 1986) and radiological swiping (Thunborg 1987) previously not demonstrated. In fact, radiological swiping operations in the AHTP proof of concept system for RRSAS could be performed faster robotically than manually due in part to the use of a cask mock-up with well defined geometries.

Cask design for robotic handling must accommodate the *limited dexterity* of robots. Limited degrees of freedom and the reliance on special tools to perform various tasks require that clearances be provided on the cask for the approach of the often bulky end effector and changer mechanism. The extra clearance required because of robot system position errors is on the order of 0.5 inches for the RRSAS system. In 10–15 years robot systems might reduce that error to about 0.05 inches (Griesmeyer and Thunborg 1988). However, approaches that require the robot to thread through or reach around obstacles must provide clearances for the robot arm as well as the attached tool. For example, special clearance considerations were required for placement of the attachment bolts for one of the AHTP impact limiter mock-up designs that was attached to the cask with bolts on the side of the cask rather than on the ends. The expense of the robotic systems and path planning constraints provide incentive to employ only one multifunction robot in a given workspace. Overhead gantry robots are likely candidates because of their large workspace. Thus, clearances for straightline overhead approaches are desirable.

Robot approach directions and clearances are important for lifting as well as manipulation. Overhead gantry robots typically consist of three translational axes coupled with up to three wrist-like roll axes to achieve their rated degrees of freedom. The rated weight carrying ability (i.e. payload) is usually defined by the strength of the weakest roll axis. The strength of this joint is usually far less than that of the translational axes. Thus, maximum lifting capability is provided by coupling directly to the three translational axes. This requires direct overhead clearance to lifting points on the cask.

Given the restrictive capabilities of robotic systems, design of the robot's work environment is extremely important to the success of applying robotic systems to remote handling tasks. Experience at SNL (Thunborg 1987, Petterson and Jones 1987, Thunborg 1986, Jones and Petterson 1988) indicates that modest design changes which do not change the functionality of major components can significantly affect the ability to execute various tasks robotically. Symmetries and alignment tapers for self guiding assembly reduce both the requirement for accurate parts fixturing as well as the complexity of robot control algorithms. Self guiding can reduce the time for robotic insertions by an order of magnitude or more over designs without these features (Strip 1987b). In the development of a maintenance robot for a test nuclear reactor (Thunborg 1986), two simple design changes greatly facilitated robotic operations. Two bolts were moved two inches to allow for clearance and provided with spring capture mechanisms with the result that an unbolting operation could be completed in ten seconds. Before the design change, the unbolting task was very difficult to perform robotically, requiring special tools and several minutes to complete. Similarly, a connector with push/pull locking was substituted for a bayonet connector reducing the connector assembly/disassembly time by a factor of 10.

Accommodation of the limited dexterity and the sparse sensory information available to the robot controller requires attention to details and simplification of operations that result in systems that are easier to operate manually as well as robotically.

Oscillation damped movement of suspended heavy objects (Jones and Petterson 1988) has shown that properly controlled crane movements can transport objects over distances of 20–30 feet in less than 10 seconds with little residual pendulum motion. Previous estimates have suggested 15 minutes would be required to accomplish such movements because of the time required to damp the pendulum oscillations induced during manual operation of cranes (Nyman et al. 1987). Designs which allow grasping of objects directly over the center of gravity, thus reducing second

Table 2: Potential Benefits of Design For Robotic Cask Handling

| Benefit | Reason for Benefit |
|---|---|
| Higher QA | Programmability allows automated *audit trail.* |
| Lower Occupational Radiation Exposure | Operators are removed from the radiation environment |
| Faster Cask Processing | Programmed operation requires little operator interaction — faster than master/slave and some manual operations. |
| Improved Manual Handling | Design for robotic handling (*i.e.* for limited dexterity and sparse sensors) also simplifies manual operations |
| Improved Safety | Computer structuring and monitoring of operator interaction with the system limits opportunity for operator errors. In addition, personnel are not in direct contact with equipment and exposed to potential mishaps. |

order pendulum effects, facilitate *swing-free* transport.

## CONCLUSIONS

Experience with the development and operation of the proof of concept robotic systems of the Advanced Handling Technologies Project indicates that robotic systems have significant potential for improved handling of nuclear waste transport casks. These benefits are summarized in Table 2. However, experience has shown that design detail is critical to the successful application of robotic systems to remote handling. Thus, cask designers should consider the needs of robotic handling during design in the event that cask handling facilities use robotic systems. Typically, minor design modifications can significantly impact the feasibility of robotic handling and the design process becomes one of attention to detail rather than of radical alterations of concepts.

The main conclusions from AHTP to date regarding design for remote handling are: 1) incorporation of cask system design features which facilitate robotic cask handling can be achieved with minimal impact on cask functional features, 2) proper cask design allows robotic cask handling operations from manipulation of cask tie-down mechanisms to radiation surveys to be performed quickly and reliably without direct human intervention (Thunborg 1987), and 3) design for remote handling also facilitates manual handling operations.

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