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MONITORED RETRIEVABLE STORAGE / MULTI-PURPOSE CANISTER ANALYSIS: SIMULATION AND ECONOMICS OF AUTOMATION*

Phil C. Bennett
Sandia National Laboratories**
PO Box 5800 MS 0952
Albuquerque, New Mexico 87185-0952

Joe B. Stringer
Duke Engineering & Services, Inc.
P.O. Box 1004
Charlotte, North Carolina 28202-1004

ABSTRACT

Robotic automation is examined as a possible alternative to manual spent nuclear fuel, transport cask and Multi-Purpose Canister (MPC) handling at a Monitored Retrievable Storage (MRS) facility. Automation of key operational aspects for the MRS/MPC system are analyzed to determine equipment requirements, through-put times and equipment costs is described. The economic and radiation dose impacts resulting from this automation are compared to manual handling methods.

I. INTRODUCTION

As part of the Civilian Radioactive Waste Management System (CRWMS), TRW Environmental Safety Systems, Inc., the Management and Operating Contractor, has developed conceptual designs for the MPC system and an MRS facility that will handle the MPC. The MPC is a sealed metallic canister conceived for storage, transportation and disposal of spent nuclear fuel (SNF) assemblies throughout the CRWMS. MPCs are sealed to provide a dry, inert environment for SNF and are over-packed separately and uniquely for the various system elements of storage, transportation, and geologic disposal.

Robotic automation has been proposed as a means of substantially reducing occupational dose at the MRS. As a part of the design process, graphical simulation tools have been used to help analyze facility design and potential automated handling processes for transport casks, SNF, MPCs, and storage containers. This paper describes the simulation and analysis approaches taken to address key operational aspects of the MPC system, and the results of the MRS and MPC simulations performed by Sandia National Laboratories (SNL) in conjunction with the MRS and MPC conceptual design activities.

The results of these analyses compare the economic and radiation dose impacts of automated handling methods to manual handling methods for receiving and storing/transporting spent nuclear fuel at a MRS facility. Parts of the analysis, including MPC welding and MPC transfer, are applicable to a proposed spent nuclear fuel Utility Transfer System. Total lifetime costs and cost per unit dose (person-rem) are calculated and compared for each method.

Major issues continue to arise concerning process design for maintaining radiation doses as low as reasonably achievable (ALARA) at handling facilities; potential solutions include automation of MPC handling and welding. The results presented in this paper are imperative towards the effective use of MPCs, and acceptance of MPCs by utilities and each of the DOE system elements (Waste Acceptance, Transportation, MRS and Repository). This work is directly applicable to similar activities to be accomplished at any facility that will handle MPCs. The results of the simulations are critical to identifying work flow aspects where improvement in operational flow can be achieved, thus reducing handling time, cost and occupational exposure. Potential areas of further design studies to continue ALARA design and automation of MPC activities are identified. Specific results are presented for the MRS transfer facility operations and MPC welding operations.

II. SIMULATION

Facility layout and process flow models are based on the MRS conceptual design report (CDR) and amendments.[1] Facility automation is broken into four areas (workcells) for evaluation: Shipping/Receiving,

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Cask preparation, MPC transfer, and MPC welding. Each of these four areas are described in the following sections.

Modeling and simulation were executed using IGRIP software from Deneb Robotics, Inc., on SiliconGraphics workstations. IGRIP was used to accurately model the dimensional and kinematic characteristics of the robots, facility, casks, and ancillary equipment. Embedded into this modeling is a high degree of component detail with programmable machine parameters to match most commercially available robotic systems. This accuracy, together with previous validation of the IGRIP modeling environment using SNL industrial robot systems[2], leads to high-confidence estimates of the through-put of each workcell.

A. Shipping / Receiving Bay

The shipping/receiving (S/R) bay, shown in Figure 1, is the venue for receiving and shipping operations for the transport casks. Transport casks are moved into the S/R bay and their positions located by robotic machines. Personnel barriers are removed and the cask is identified and surveyed for radiation and surface contamination levels. Operations required to release the cask from the transport platform are carried out in the S/R bay as well, including impact limiter removal, tie-down release, cask uprighting and lifting. When unloading of the casks is complete, the S/R bay can reverse these operations to prepare the casks for return shipment.

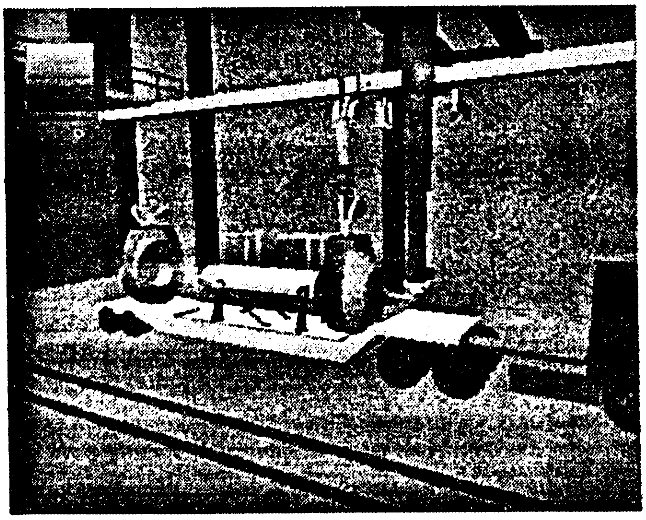

Figure 1. Simulation of impact limiter removal on a GA 4/9 fuel transport cask

The model of the S/R bay is based on the MRS CDR. The equipment specified is commercially available and proven in industrial use. This includes two 200-ton programmable cranes for lifting the casks, each with a 25-ton auxiliary hook for lifting impact limiters and other equipment, and two gantry-type robots for executing dexterous operations such as cask surveys, tiedown and impact limiter release operations. The two cranes reside on one set of rails, providing mutual support both in normal operations and in the case of failure of one of the cranes.

B. Cask Preparation Station

The purpose of the cask preparation station (Figure 2) is to prepare the transportation cask for opening. Operations include cask washdown, location, cavity gas sampling and venting, mating adapter installation, cask lid lifting device (pintle) installation, and bolt removal. These operations are simulated using a PAR XR6100 gantry robot, a monorail crane, and a wash ring. After bolt removal, the cask is moved under the transfer cell where it is mated to the transfer port. A telescoping collar mates with the mating adapter, completing the unloading preparation operations.

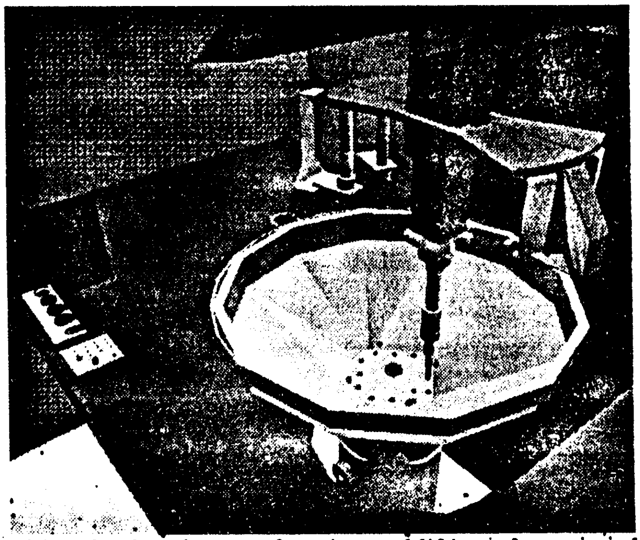

Figure 2. Attachment of mating and lifting adapters, and lid bolt removal in the Transport Cask Preparation Station

C. MPC Transfer Room

The bulk of the MPC operations are executed in the MPC transfer room, illustrated in Figure 3. The transport cask is moved into the room by automated guided vehicle (AGV), and located by machine vision. Once the location is verified, the cask is opened by removing cask closure bolts using a 40-ton capacity stewart platform crane, its dexterous (removable) wrist and modified tooling. After attaching lifting adapters, the MPC is removed from the transport cask by the stewart platform and transferred to a waiting storage cask. The storage cask is closed and an automated radiation survey conducted. Finally, Both casks are removed from the room by AGVs.

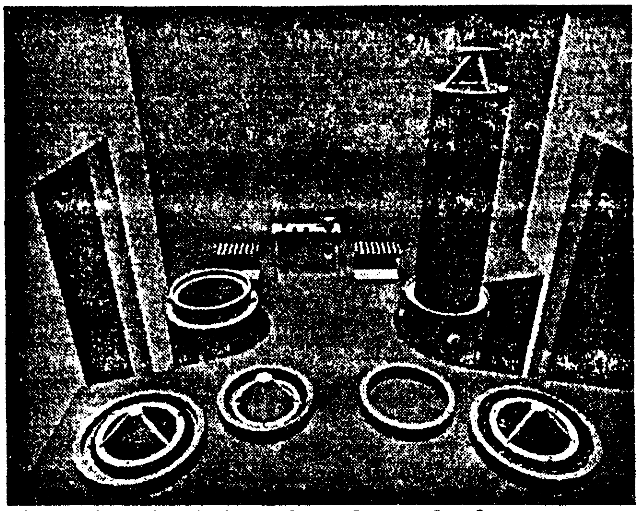

Figure 3. Simulation of MPC transfer from transport cask to storage cask.

D. MPC Welding Facility

The MPC closure welding is performed in the storage cask preparation room of the MRS (Figure 4). The layout consists of a loading station and two cask preparation stations. In the preparation stations, the casks are prepared for loading in much the same way as in the transport cask preparation station, including closure release and cavity preparation. The loading station is located below the bare-fuel transfer cell, connecting the cell with the cask. The MPC shield plug is installed in the transfer cell, then sealed at the preparation station by welding an inner lid onto the MPC, placing a layer of honeycomb over the inner lid, then welding an outer lid onto the MPC. A cask lid is then installed and the cask containing the MPC is moved out of the room for transfer to the cask transporter, which takes the cask to its storage or transport destination.

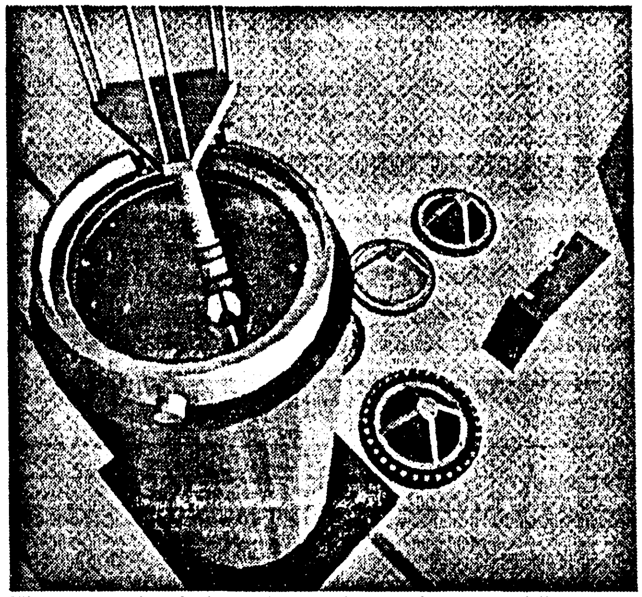

Figure 4. Simulation of MPC inner closure welding

III. ECONOMIC ANALYSIS

The economic analysis method used to compare the robotic and manual handling methods is a Benefit-Cost Analysis using net present value and related outcome measures as defined by the Office of Management and Budget.[3] All of the known cost drivers required over the life of the project are included in the analysis.

Worst and best case scenarios from the robotic application point of view are generated using the range of estimates for each of the drivers. "Worst Case" assumes those values that place robotic handling in the least desirable perspective. "Best Case" assumes those values placing robotic handling in its most desirable perspective, thus bounding the results of robotic application.

Table 1 lists the factors common to four workcells in the MRS/MPC facility. Receipt rates (not shown) are based on a 34-year cycle and are given in Reference 5. Table 2 lists the investment cost, dose rate and process time estimates compiled for each workcell. Dose rates for the GA-4/9 spent fuel casks are based on Duke Engineering and SNL studies.[4] Dose rates for the 125 ton MPC were determined by Duke Engineering & Services[5] and were assumed the same for the 75 ton MPC.

Table 1
Common Assumptions For MRS/MPC Workcells

Assumption	Worst Case		Best Case	
	Manual Method	Robotic Method	Manual Method	Robotic Method
Project Life (Years)	34	34	34	34
Annual Labor Cost (Operator)	$50,000	$75,000	$50,000	$75,000
Annual Dose Limit (Rem)	1	1	1	1
Dose Cost per Rem	$1,000	$1,000	$10,000	$10,000
Discount Rate	3.00%	3.00%	3.00%	3.00%
Annual Maintenance Cost	$0	$18,000	$0	$18,000
Down Time (%)	0.00%	20.00%	0.00%	5.00%
Minimum Operators / Cell	6	6	6	6
Energy Cost per kWh	$0.08	$0.08	$0.08	$0.08
Energy Requirement (kW)	0	20	0	20

Table 2
MRS/MPC Workcell Assumptions

Assumption	Worst Case		Best Case	
S/R Bay	Manual Method	Robotic Method	Manual Method	Robotic Method
Investment Cost	$1,750,000	$4,245,588	$1,750,000	$4,245,588
GA Casks:				
Dose Rate (Rem/Cask)	0.088	0.000	0.270	0.000
Process Time (Hrs.)	2.00	4.50	3.67	2.28
Cask Prep				
Investment Cost	$1,500,000	$6,259,224	$1,500,000	$6,259,224
GA Casks:				
Dose Rate (Rem/Cask)	0.036	0.000	0.438	0.000
Process Time (Hrs.)	1.67	1.08	2.87	0.72
MPC Transfer				
Investment Cost	$900,000	$6,052,812	$900,000	$6,052,812
Transfer MPC-125 Casks:				
Dose Rate (Rem/Cask)	0.403	0.000	0.403	0.000
Process Time (Hrs.)	4.18	7.77	4.18	4.85
Transfer MPC-75 Casks:				
Dose Rate (Rem/Cask)	0.403	0.000	0.403	0.000
Process Time (Hrs.)	4.18	7.77	4.18	4.85
MPC Weld				
Investment Cost	$900,000	$1,036,812	$900,000	$1,036,812
MPC-125 Casks:				
Dose Rate (Rem/Cask)	0.750	0.000	0.750	0.000
Process Time (Hrs.)	41.17	41.82	41.17	38.40

IV. RESULTS

A. Simulation

Equipment requirements and costs were determined from the simulations described in Section II. The equipment generally consisted of a single industrial robot and/or a programmable crane per workcell. In the case of MPC transfer, a Stewart Platform crane was assumed. All sensor and supporting computer hardware was included in the estimates that would allow the workcell to function as demonstrated at SNL.[2] Workcell investment costs are given in Table 2.

The simulations produced process time estimates for each workcell. Table 3 summarizes process time per cask for each of the major areas of the MRS. Note that these are based on full automation without the presence of human operators, thus reducing doses to background levels.

Allowable machine speeds are expected to be between 25% and 100% of maximum, depending on safety considerations. In some cases, robotic operations appear to be slower than manual operations. These timing differences may be partially offset by two points: a) Manual time estimates do not include breaks or dressing time; b) Robots are not necessarily affected by shift changes.

B. Cost

The economic analysis approach used to compare robotic and manual handling methods is a Benefit-Cost Analysis using net present value and related outcome measures as defined by the Office of Management and Budget. Cost drivers in the analysis include the labor, dose, investment, maintenance, and energy costs[6] for the required operations over the life of the facility.

Note that individual worker labor costs are assumed to be higher in the robotic case. The minimum number of full-time operators is six. However, the total number of operators is raised significantly by longer exposure times, higher dose rates and lower dose limits. The total number of operators directly impacts labor costs, which is the prime factor in total costs.

Labor requirements and labor cost break-out are shown in Figure 5. Results of the overall benefit/cost analysis are summarized in Table 4.

Table 3
Automation Timing Summary

Location	Process Hours With Machine Speed At:		Manual Speed Estimates
	100%	25%	(hours)
Shipping/Receiving bay	2.28	4.52	2.00 - 3.67
Cask preparation station	0.67	1.07	1.67 - 2.87
MPC transfer room	4.85	7.77	4.18
MPC welding facility	38.24	41.82	41.17

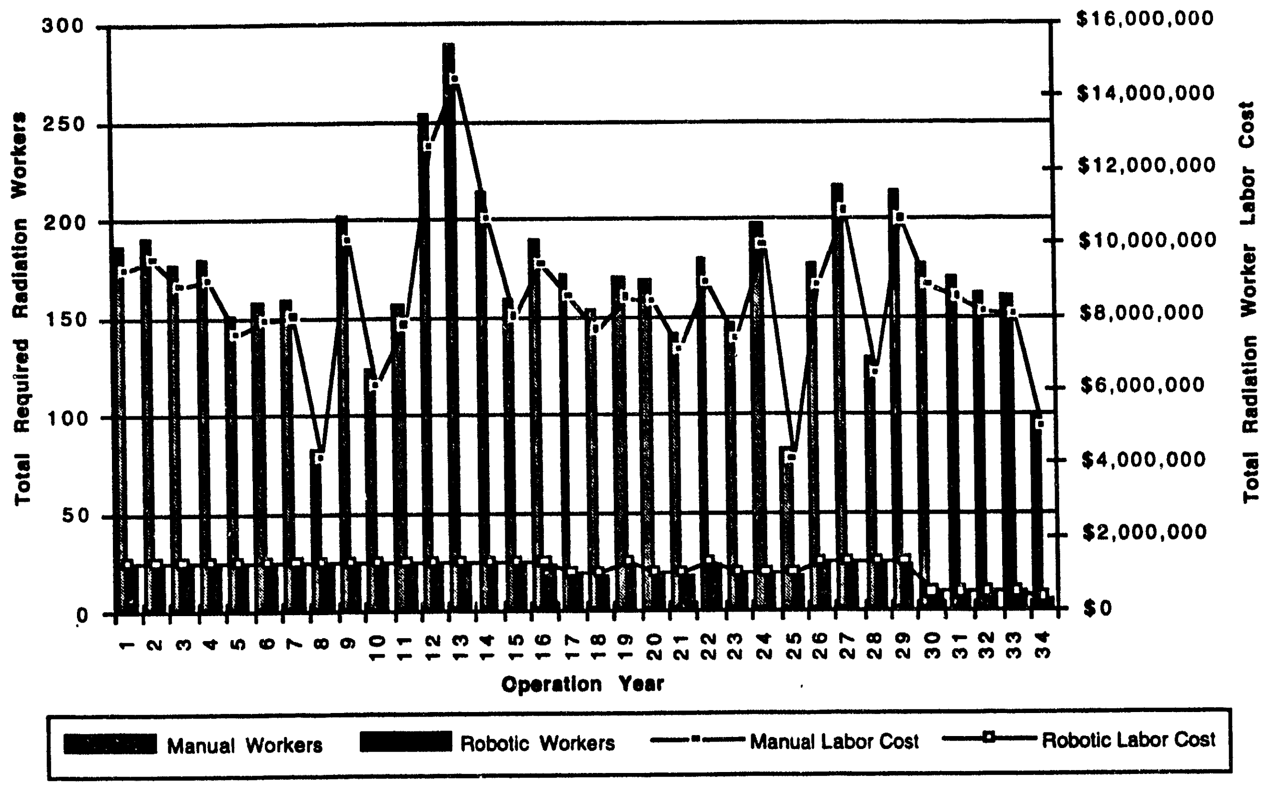

Figure 5. MRS/MPC Best Case Total Annual Labor Requirements and Costs, Manual *vs.* Robotic Handling

Table 4
Economic Analysis Results By Workcell

	Discounted Total Cost (Savings), Robotic	Amortization (Years)	Dose Savings (Rem, Project Life)	Cost(Savings) per rem
S/R Bay				
Best Case	($36,259,822)	1.17	1281.99	($28,284)
Worst Case	($5,616,105)	9.01	351.86	($15,961)
Cask Prep				
Best Case	($62,048,796)	1.23	2077.77	($29,863)
Worst Case	$4,633,057	-	143.94	$32,187
MPC Trans				
Best Case	($30,982,263)	2.25	1330.89	($23,279)
Worst Case	($26,445,555)	3.06	1120.75	($23,596)
MPC Weld				
Best Case	($18,868,478)	0.16	727.46	($25,937)
Worst Case	($17,964,923)	0.17	618.60	($29,041)

Discounted total cost indicates the total cost (savings) in 1992 dollars for implementing robotic handling in each workcell. In the best case for robotic handling, each workcell would save money by automating, each showing a "pay-back period" (amortization) of less than three years for the robotic equipment investment. In the worst case, all but one area, the Cask Preparation Cell, show a cost savings. Lifetime facility dose savings ranges from about

2200 person-rem to over 5400 person-rem. Cost (savings) per rem is provided to estimate the value of automation on a dose basis. Best case scenarios indicate a significant savings with automation. Under worst-case conditions, automation costs per rem for the Cask Preparation Station range over $32,000, roughly three times the design assumption of $10,000/person-rem.

V. CONCLUSIONS

Graphical animated simulations of MRS operational scenarios have been created and executed to identify operations that can be automated with robotic machinery. The results of these simulations showed how those operations can be executed automatically, identified equipment requirements and operational characteristics for the automation, and determined potential process times for each automated operation. Cost estimates for the identified equipment were used in the economic assessment.

A high-volume facility such as an MRS/MPC facility will have high cumulative doses to operators, even for routine, low-dose-rate cask and fuel handling operations. In a regulatory environment of low dose limits and pressure to reduce limits even further under an ALARA operating philosophy, it is essential to explore all reasonable means to reduce radiation exposure. A potential 5400 person-rem can be eliminated at the MRS/MPC facility in the workcells examined in this paper. This dose can be eliminated without significant capitalization cost and with substantial operational savings potential.

It is clear from this analysis that automation at MRS/MPC facilities is justified economically. Since $10,000 is an acceptable cost to eliminate a single person-rem from operational dose, a cost of $22 Million would be justifiable to prevent the estimated minimum reduction using automation. However, analysis indicators for the four automated workcells examined here show a potential savings over manually-operated counterparts. Potential facility lifetime savings total up to $148 Million.

The application of robotic and analytical techniques discussed in this paper may have application to similar activities at any site handling SNF. Clearly reduction of cumulative dose at each site is desirable. Additional studies are required to determine the feasibility of these techniques to individual sites and to determine if application is cost-justified.

The economic justification, together with the substantial dose reduction potential and demonstrated feasibility make a compelling case for robotic handling at MRS/MPC and other high-volume, high-level nuclear waste facilities.

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