REMOTE RETRIEVAL AVAILABLE TECHNOLOGIES AND OPERATIONS FOR RECOVERY FROM A ROOF FALL DURING THE BIN SCALE TEST PROGRAM*

Rodney A. Palanca
Advanced Repository Technology
Waste Isolation Division
Westinghouse Electric Corporation

ABSTRACT

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is a Department of Energy (DOE) research and development installation dedicated to the safe disposal of transuranic wastes through permanent emplacement 2,150 feet below the surface in salt beds. Various unmanned vehicle and remote control technologies were evaluated for their application to the remote retrieval of waste containers from an underground location. Remote equipment considered suitable to the task was collected at the WIPP. A roof fall simulation was assembled in the WIPP underground using materials representative of those that would be present in a bin-scale test room failure. The remote equipment was demonstrated suitable for remote retrieval of test waste containers and for cleanup of the test room by recording the requisite remote operations on videotape.

BACKGROUND

A series of experiments involving representative waste samples, termed Bin-scale Test Experiments will be carried out in an underground test room.(1)(2) This room has been specially outfitted for the experimental program with a supplementary roof support system, electric power and lighting, a volatile organic compound removal and sampling system, and a computer based experiment monitoring system.

During the experiments, the test wastes will be doubly contained. The inner containers are called bins. Bins are leak tight boxes provided with flexible tubing connections and thermocouples allowing the accurate measurement and analysis of gases generated by the waste under simulated repository conditions. The outer containers are called standard waste boxes (SWBs). The SWBs are normally handled using a forklift adaptor that engages handling clips located on each of two long vertical sides. Each SWB has a volume of 1788.5 liters and can weigh up to 1814.4 kilograms when loaded with a test bin. This arrangement is shown in Fig. 1 without the flexible tubing and thermocouples in place.

Each experimental setup is comprised of two SWBs stacked one above the other connected to a common instrument board. The setups will be spaced approximately 3 feet apart along both sides the underground test room as shown in Fig. 2. Mined from salt, the test room is 33 feet wide by 13 feet high and 300 feet long. The room has a fully engineered and implemented supplemental roof support system.(3)

Radioactive wastes placed in the WIPP must remain retrievable during the Test Phase. Concerns have been raised over the ability to retrieve test wastes from the underground test room if the roof support system failed and there was a roof fall. Retrieval demonstrations have been conducted for all foreseeable non-failure conditions; however, specific equipment and operating procedures had not been developed for failure conditions since experience and the system design have indicated that an unanticipated roof fall was highly unlikely. In fact, no plausible scenario for such a catastrophic fall has been identified.

OBJECTIVE

The driving need for remotely controlled equipment during this particular retrieval operation is the unacceptable risk

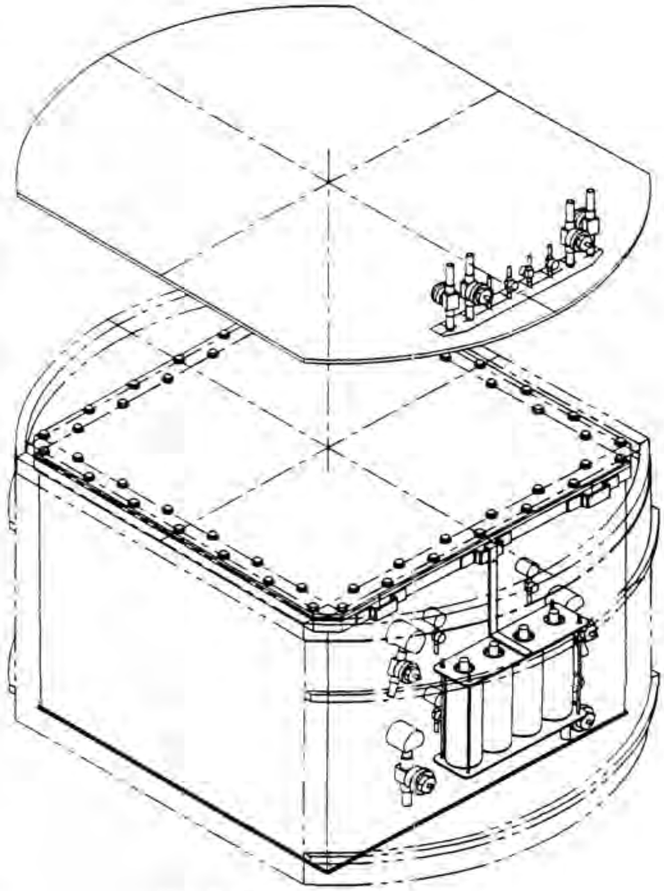

Fig. 1. Dry test bin arrangement.

* Work supported by U.S. Department of Energy under DOE Contract No. DE-AC04-86AL31950 DOE/WIPP 92-052.

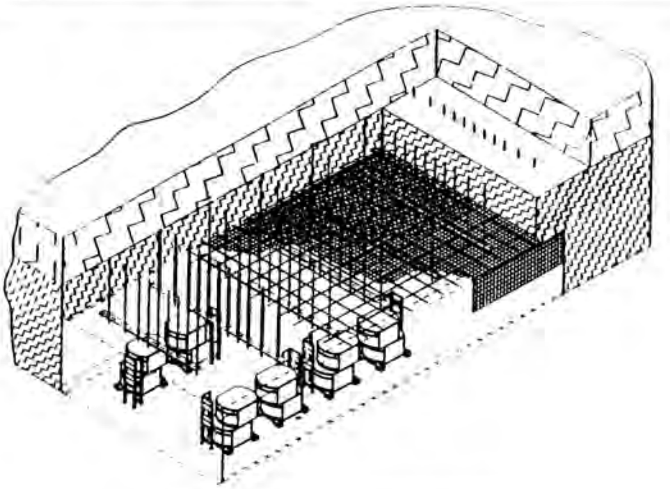

Fig. 2. Test room arrangement.

to operating personnel presented by the possibility of further roof falls. Additionally, direct visual contact during operation of the retrieval equipment is precluded by the establishment of radiological contamination barriers. The overall objective was to document on videotape the availability of the requisite technology to accomplish this operation under realistic conditions.

The containment, repackaging, and removal from the mine of the test wastes and any suspect radioactive materials resulting from breaches of the test bins was not addressed by this demonstration. These operations would be done manually outside the roof fall area, requiring no special remote handling equipment. Additionally, this type of operation has been demonstrated during previous retrieval demonstrations.

EQUIPMENT

Hypothetical roof support system failure consequences were examined to develop specifications for special (i.e., remote controlled) equipment to carry out retrieval of the waste materials. An approach was proposed to address what was considered the worst case scenario - a major roof fall where a majority of the SWBs have been covered or damaged and extensive debris removal is necessary for access and retrieval (4).

A retrieval process under failure conditions must deal not only with salt and waste containers but with the supplementary roof support system materials and the bin-scale experimental support systems materials as well.

The following is a summary of the equipment used in conducting the demonstration along with a discussion of their specific functions:

An ANDROS Mark VA hazardous duty robot, manufactured by REMOTEC, Inc. of Oak Ridge, Tennessee, was selected for the mobile survey robot. This unit performed reconnaissance of the roof fall area for mission planning, supported the operation of other retrieval equipment through the use of its two cameras and manipulator, and deployed the three mission modules described below.

A portable CCTV system, consisting of a television camera equipped with zoom lens, pan and tilt head, lights, and a microphone in a freestanding package was developed and loaned to WIPP by the Robotics Development Group of the Westinghouse Savannah River Company, Aiken, SC. Power, control signals, video and audio signals were connected to the remote control station via a pair of cables. Combined with the two cameras on the mobile survey robot, and the camera on the work vehicle, up to four camera views were available to the operators during the course of the excavation.

A WILD TM 3000 automatic (laser) survey station, manufactured by Wild Leitz USA, Inc., was connected to the remote control station by a cable. Used to map the internal contours of the damaged room at the outset of the retrieval effort, it provided a baseline against which comparisons could be made to predict further localized roof falls.

A portable beta-gamma radiation detection instrument was carried into the retrieval area in the gripper while the instrument reading was observed on the manipulator mounted camera.

A Melroe Bobcat model 753, with remote control modifications made by Robotech Industries Ltd. of Canada, served as the work machine. This radio controlled vehicle was driven out of the retrieval area as necessary to change out attachments for accomplishing specific tasks. A description of these attachments follows:

Robotech cooperated with RSI Research Ltd. of Canada to adapt a Kodiac 1000 manipulator into a remote controlled attachment for the Bobcat. The manipulator was used to deploy a hydraulic shear and a hydraulically powered abrasive wheel cutoff saw. It was also used for attaching rigging hooks to the SWB lifting clips. A rate control joystick was connected to the manipulator via a cable.

A toothed front loading bucket attachment was used to remove loose salt and to aid in breaking up salt that had started to reconsolidate.

A hydraulic breaker attachment was utilized for breaking salt blocks into pieces small enough for the front loading bucket.

A grapple bucket attachment was used to grab and drag the roof support materials out of the retrieval area.

Once roof bolts and other materials are encountered, the effectiveness of the front loading bucket is greatly impaired. A remote controlled Melroe Bobcat model 743 with a backhoe attachment, loaned to WIPP by the Robotics Development Group of the Westinghouse Savannah River Company, was used to reach between obstacles and pull out loose salt and debris.

The Robotics Laboratory of Sandia National Laboratories of Albuquerque, New Mexico, loaned a pendant controlled Caterpillar MIOOB lift truck for use in the demonstration. An SWB forklift adaptor was fitted to this unit and was used to remotely handle those SWBs that were not disturbed by the roof fall.

ROOF FALL SIMULATION

A simulated test room roof fall was assembled in room 7 of panel 1, some 620 feet from the actual test room (room 1, panel 1). Diagrammed in Fig. 3, the simulation contained two standard waste boxes (SWB) buried beneath the same types of materials that would be seen in a failure of the supplementary roof support system.

One SWB was turned on its side as if it had been knocked over by the fall, the second box was left upright. The roof

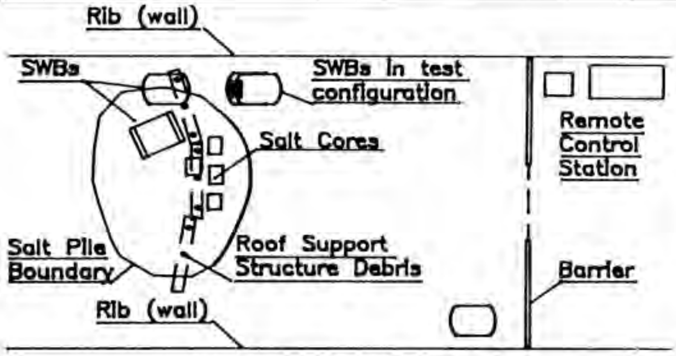

Fig. 3. Roof fall simulation.

support structure materials were laid on next in the configuration shown in Fig. 4. These structures consisted of 15" wide U channels, 3/4" plywood, 1" diameter roof bolts, 10 AWG expanded metal, 4" x 4" welded wire mesh, and 5/8" diameter steel wire rope. The roof fall was simulated by a combination of loose mined salt and 38" diameter solid salt cores piled six feet high over the top of the above materials. Another pair of SWBs, arranged in the bin test configuration, were placed adjacent to the salt pile to represent a test setup unaffected by the roof fall. A barrier was established approximately 40 feet back from the simulation representing the boundary between the accessible (safe) area and the roof fall (unsafe) area. An empty SWB was positioned just inside the barrier to receive salt and materials as they were removed from the simulated test room.

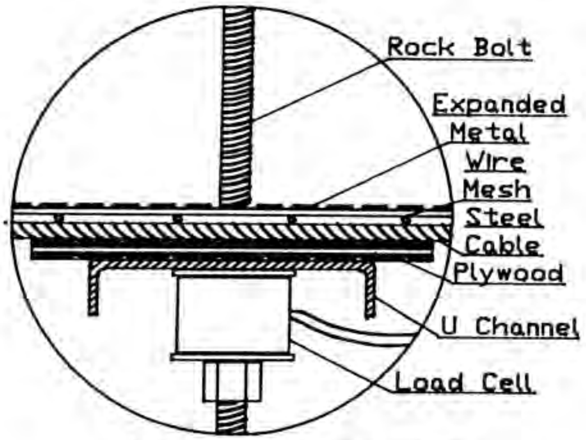

Fig. 4. Support system materials.

DEMONSTRATION CONDUCT

On April 27, 1992, all elements supporting the demonstration were on site. Television monitors and a VCR were set up at a remote control station set up behind sheets of plywood acting as safety shields and to block direct visual contact between the simulation area and the remote vehicle operators. The survey robot control console was set up adjacent to the monitors.

The survey robot was sent into the room, and the images sent back were recorded by the VCR. This survey was used to assess the extent of the fall and the amount of damage suffered by the waste containers. This would aid in planning the retrieval operation.

The automatic laser ranging system was deployed on a trailer towed by the survey robot. Once positioned in the vicinity of the roof fall, it transmitted data back to the remote control station for computer storage and interpretation. This survey provided a baseline contour map of the room's ceiling (back). Repeated at regular intervals during the retrieval operation, this survey would help in determining if further roof falls are imminent.

The portable TV camera was transported into the simulation area by the survey robot and positioned as required by the operators. The indirect views greatly enhanced the operators' performance. The camera onboard the working vehicle was found to be satisfactory for normal driving, but it did not provide the perspective needed for accurate positioning or control of dexterous operations.

The salt pile initially blocked the access to the undamaged SWBs. Removal of salt was accomplished by the work vehicle equipped with a front loading bucket as depicted in Fig.5. The work vehicle transferred the loose salt to the SWB positioned just inside the simulation barrier. In an actual cleanup, this box would be located in an area accessible to personnel in protective clothing for survey, processing, packaging and transfer out of the immediate vicinity of the test room.

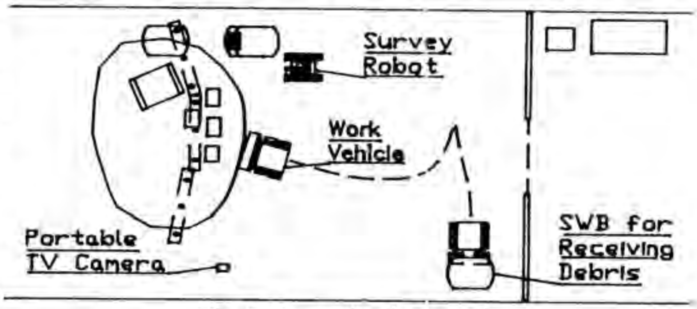

Fig. 5. Removing loose salt.

Once access to the undisturbed SWBs was cleared, the connections between the SWBs and the bin instrument boards had to be cut. Although these connections could probably be severed by the brute force of pulling them apart, this would cause unnecessary damage to the experimental setups. Contamination spread caused from cutting these connections is considered remote since the gas lines are internally HEPA filtered and the thermocouples do not penetrate the bins. Equipped with the manipulator attachment and a hydraulic shear, the work vehicle cut the connections as shown in Fig.6. This would have been an extremely tedious and time consuming task without the aid of the cameras on the mobile survey robot and the portable camera setup. The power for the shear was provided by the auxiliary hydraulic supply of the work vehicle. When the shear was positioned around the article to be severed, the manipulator was locked in position, and hydraulic control was shifted from the manipulator back to the

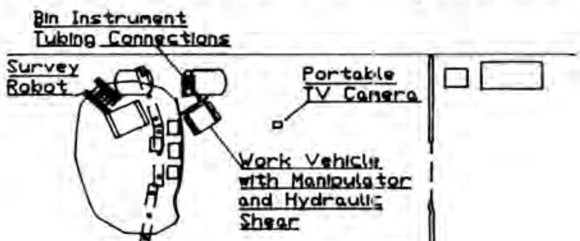

Fig. 6. Cutting instrument tubing.

vehicle to operate the shear. The work vehicle was then driven out of the retrieval area and the shear removed from the manipulator.

Disconnected from the bins, the bin instrument boards were free standing and were removed from the retrieval area using the work vehicle and manipulator arm.

If the SWBs are not overturned or severely damaged by the roof fall, they can be handled using the SWB adaptor on a forklift. Figure 7 shows the arrangement used by the forklift that was controlled from outside the retrieval area using a pendant control box connected to the rear of the unit by a cable. There were no cameras on the forklift, so accessing and removing the SWBs was controlled entirely by watching the operation on the portable camera and mobile survey robot cameras. Sideshift capability is extremely helpful in this application since the indirect views provided by the mobile cameras made it difficult to determine the alignment of the adaptor hooks with the SWB clips.

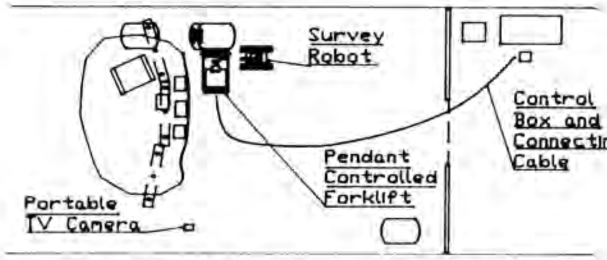

Fig. 7. Forklift removing SWB.

Experience has shown that roof falls may produce solid salt blocks too large for removal by the front loading bucket. Therefore, the work vehicle demonstrated a hydraulic breaker attachment breaking up the 38 inch diameter solid salt cores as shown in Fig. 8. Intended for the demolition of concrete or roadway structures, this attachment made quick work of these salt cores.

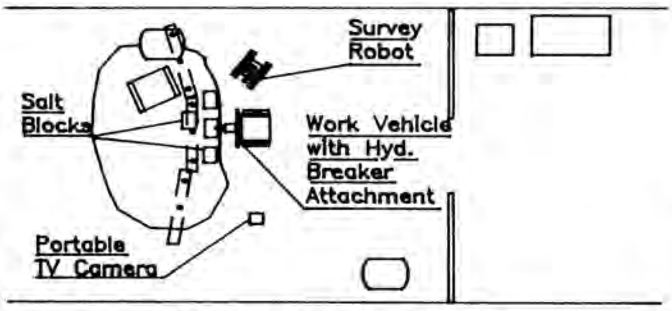

Fig. 8. Salt block size reduction.

The work vehicle continued to remove salt with a front loading bucket attachment until it was blocked by the roof support system rock bolts extending up through the salt pile. Fig. 9 shows the second remote controlled Bobcat using a backhoe attachment to reach over and between the broken elements of the roof support system, bringing the salt out to where it was again accessible. A backhoe is a standard attachment to the Melroe Bobcat line, and the basic work vehicle could probably carry one at all times. However, it may be advantageous to provide a dedicated vehicle for this purpose.

With the elements of the roof support system exposed, the manipulator attachment was returned to the area, this time

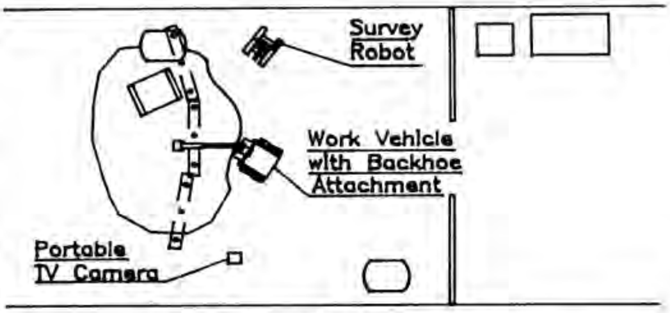

Fig. 9. Remote backhoe operation.

equipped with a cutoff saw using an abrasive wheel, powered from the work vehicle's auxiliary hydraulic system, depicted in Fig. 10. Starting with the rock bolts, the cutoff saw proceeded to cut up and section the roof support materials. The expanded metal, welded wire mesh and plywood were all cut at the same time and pulled back exposing the channels. The channels were the most difficult and time consuming items to cut. Care was needed to prevent binding of the abrasive wheel as the channel was being cut. Finally, the steel cables around the periphery of the salt pile were cut while being held by the manipulator arm on the survey robot. There was some concern over danger to personnel outside the simulation area from the missile hazard presented if the cutting wheel were to disintegrate. Two different wheels were used in this operation and neither one was noted to chip or fragment, even after being severely flexed by a falling rock bolt. Flame cutting of the metal materials would have been faster; however, abrasive cutting was opted to reduce the likelihood of igniting the plywood.

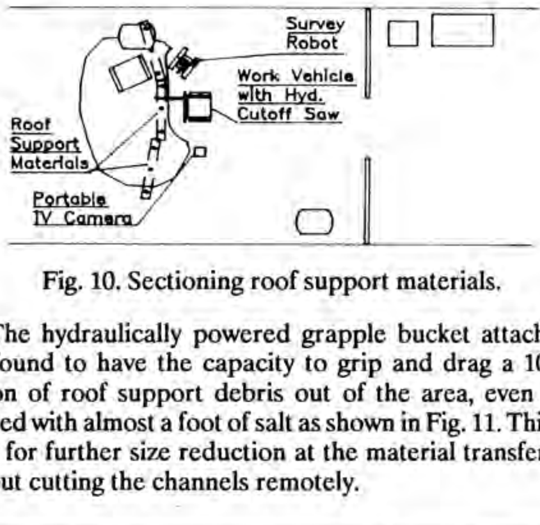

Fig. 10. Sectioning roof support materials.

The hydraulically powered grapple bucket attachment was found to have the capacity to grip and drag a 10 foot section of roof support debris out of the area, even when covered with almost a foot of salt as shown in Fig. 11. This may allow for further size reduction at the material transfer area without cutting the channels remotely.

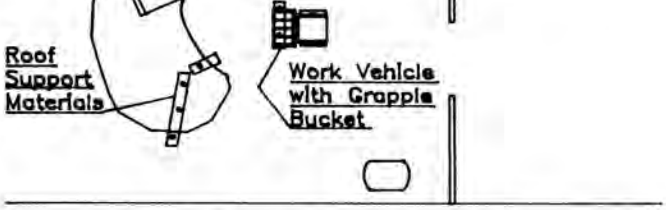

Fig. 11. Removing roof support debris.

Two containers were simulated damaged and inaccessible to the forklift. Figure 12 portrays rigging being attached to the SWB lifting clips by the manipulator. A standard two part strap type rigging sling with captive hooks at the end of each leg was used. It was connected to the center of the work vehicle manipulator attachment. The hooks were hung over a bar making them accessible to the manipulator gripper. The operation of the remote manipulator proved to be more difficult that envisioned. Using a force feedback control system for the manipulator and a special hook designed to match the manipulator gripper and the SWB lifting clip configuration should significantly reduce the time and difficulty of this operation. Future improvements to this attachment should include a tool rack so that the tool assortment can be carried on the attachment and changed out without manual assistance. In this simulation, the Bobcat dragged the SWBs out of the retrieval area; however, in actual practice, a fully loaded Bin and SWB might exceed the capacity of the Bobcat. In this case, the assistance of another vehicle or a winch anchored outside of the room might be required.

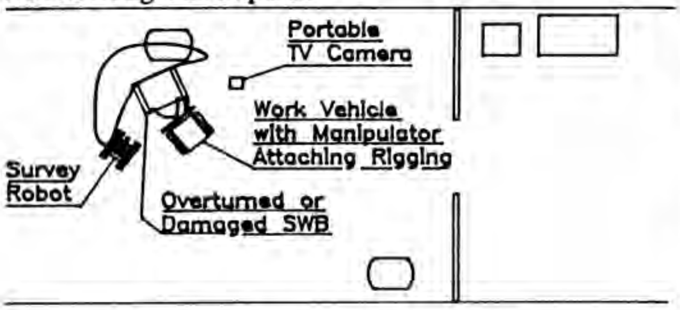

Fig. 12. Removing damaged SWB.

CONCLUSIONS

A good measure of the utility and ease of operation of the working vehicles and the survey robot in this unique application was the fact that this demonstration was conducted with no prior coordinated practice or training. Essentially, once all the safety concerns, such as ventilation requirements for the diesel powered equipment and safe standoff distances for the remote controlled equipment, had been resolved, the demonstration was conducted according to the script. When the script called for an operation, cameras and lighting were set up and the operation was performed and recorded. All the equipment and operators performed the prescribed operations the first time. With practice, various operations would probably go faster, but the learning curve appears to be short.

The extra camera views provided by the survey robot and the portable camera setup proved indispensable to the success of this exercise. The full time mobility of the untethered survey robot allowed for timely repositioning of the cameras at the request of the work vehicle operators. These working vehicles and camera platforms should perform equally as well in surface hazardous or radioactive waste radiation of buried waste sites. Equipped with their manipulators, both the Bobcat and the ANDROS could be utilized to conduct site surveys and sampling.

Most of the special tooling for the work machine could also be deployed by suitable forklift attachments or by stand alone vehicles. For example, a teleoperated manipulator attachment could just as well be adapted to a forklift or to a front loading hauler.

This demonstration has shown that sufficient technology exists to conduct a full scale remote retrieval of test wastes in the extremely unlikely event of a test room failure and that the demonstrated equipment could be rapidly mobilized to conduct a retrieval. A period of only 16 weeks elapsed from the time direction to conduct the videotaped demonstration was received until all the remote equipment was assembled in the WIPP underground. Considering the special modifications required to add a remote manipulator to the work vehicle, this was an extremely brief schedule. Now that this development work has been accomplished, it is likely that the schedule for the assembly of the specialized equipment could be duplicated or improved on.

Based on the four days it took to retrieve these four SWBs, it has been estimated, that at the rate of between one to two SWBs removed per day, working 5 days a week, one 8 hour shift per day, it would take approximately three months to retrieve a fully loaded test room. This period, of course, starts after all preparations have been completed, such as: the equipment assembled, the material transfer area setup, procedures and retrieval plans finalized and approved, personnel trained, and special ventilation controls established.

REFERENCES

1. MARTIN A. MOLECKE, "Test Plan: WIPP Bin-Scale CH TRU Waste Tests," Sandia National Laboratories, (January 1990).
2. MARTIN A. MOLECKE and ALLEN R. LAPPIN, "Test Plan Addendum #1: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests," SAND90-2082, Sandia National Laboratories, (December 1990).
3. Waste Isolation Pilot Plant Supplementary Roof Support System Underground Storage Area Panel 1, Room 1, DOE/WIPP 91-057, Westinghouse Electric Corporation, Waste Isolation Division, (October 1991)
4. "Remote Technologies and Operations for Roof Fall Recovery, Conceptual Approaches," *9164-REPT-001.0*, Redzone Robotics, Inc., 2425 Liberty Ave., Pittsburgh, PA 15222-4639, (December 1991).

12. Survey Robot transporting the portable CCTV system to a suitable location
13. Work Vehicle #1 clearing loose salt as seen from the Remote Control Station
14. Work Vehicle #1 depositing salt in a SWB
15. Cutting flexible tubing with the Hydraulic Shear
16. Cutting thermocouple wires with the Hydraulic Shear
17. Removing detached Bin Instrument Board
18. Removing undamaged SWB with the Forklift
19. Forklift operations as seen from the Remote Control Station
20. Breaking 38 inch solid salt cores with the Hydraulic Breaker Attachment
21. Removing broken salt cores with Front Loading Bucket
22. Hydraulic Cutoff Saw just after cutting a roof bolt
23. Cutting the remaining Roof Support System materials
24. Survey Robot manipulator holding a cable for the Cutoff Saw
25. Removing sectioned Roof Support System debris with the Grapple Bucket Attachment
26. Attaching rigging using the Manipulator Attachment
27. Removing a "damaged" SWB