REMOTE TECHNOLOGIES FOR BURIED WASTE RETRIEVAL

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ABSTRACT
A demonstration to test an innovative end effector/dust free dumping system, remote conveyance vehicle, and remote excavator was sponsored by the U.S. Department of Energy's Office of Technology Development through the Idaho National Engineering Laboratory during September, 1994. Within the Department of Energy complex, 181,400 m³ of waste containing transuranic and hazardous material was buried before 1970. Remote technologies that minimize dust generation and the spread of airborne contaminants during buried waste retrieval are being evaluated as one option for handling this buried waste. The demonstration, conducted at RAHCO International's Spokane, Washington, facility, evaluated equipment performance and techniques for digging, dumping, and transporting buried waste remotely. Parameters measured included retrieval rates, human factors design, remote control system effectiveness, and the ability of the equipment to control airborne contamination spread. The demonstration showed that this technology is a viable option for the remote retrieval of buried waste. Results will be used to further develop the system and to aid the Department of Energy's Environmental Restoration Program in their decisions regarding buried waste sites.

INTRODUCTION
In the past, much of the Department of Energy's (DOE's) transuranic and hazardous waste was disposed of in shallow pits and trenches that are similar to landfills. At the Idaho National Engineering Laboratory (INEL) alone, over 65,000 m³ of transuranic and hazardous waste was buried in shallow pits and trenches between 1950 and 1972 in the Subsurface Disposal Area at the Radioactive Waste Management Complex.¹ Commingled with this waste is up to 283,000 m³ of fill soil. Over the entire DOE complex, 181,400 m³ of transuranic and hazardous waste was buried before 1970.² Transuranic waste requires particular care because the transuranic contaminants tend to be micron-sized particles that are easily suspended in air and breathed into the lungs. The uptake (amount breathed into lungs) limits for transuranic contaminants (e.g., plutonium) are extremely small because uptake quantities on the order of a microgram of transuranic contaminant result in a lifetime body burden (i.e., a lifetime dose of radiation).

Now the DOE is evaluating what should be done with this buried waste. Although the radioactive waste is not particularly mobile unless airborne, some of it was buried with volatile organics and/or other substances that tend to spread easily to surrounding soil or water tables. Volatile organics are hazardous materials (such as trichloroethylene) and require clean-up at certain levels in drinking water. There is concern that the buried volatile organics will spread into the water table and contaminate drinking water. Because of this, the DOE is considering options for handling this buried waste and reducing the risks of spreading or exposure. There are two primary options: containment and stabilization, or retrieval. Containment and stabilization systems would include systems that would leave the waste where it is, but contain and stabilize it so that the radioactive and hazardous materials would not spread to the surrounding soil, water, or air. For example, an in situ vitrification system could be used to melt the waste into a composite glass-like material that would not leach into the surrounding soil, water, or air. Retrieval systems are those that would remove the waste from its burial location for treatment and/or repackaging for long term storage.

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This project investigated using remote controlled equipment to retrieve buried waste from the burial location and move it to a treatment facility. At the INEL, the Environmental Restoration Program will use information gathered from this and other projects to determine the best approach for handling the INEL's buried waste sites. This project was funded by the DOE Office of Technology Development through the Buried Waste Integrated Demonstration (BWID) program. The concept and design of the system was developed by RAHCO International in conjunction with SPAR Aerospace Ltd., and RSI Research Ltd. A full scale non-radioactive demonstration of the equipment was conducted at RAHCO International's facilities in Spokane, Washington, during September, 1994.

OBJECTIVES
The objective of this project was to develop and demonstrate remote technologies that would minimize dust generation and the spread of airborne contaminants during buried waste retrieval. Remote technologies are essential for the retrieval of buried waste because they remove workers from the hazardous environment and provide greater automation, reducing the chances of human error. Minimizing dust generation is also essential to increased safety for the workers and the environment during buried waste retrieval. The main contaminants within the waste are micron-sized particles of plutonium and americium oxides, chlorides, and hydroxides, which are easily suspended in air and spread if disturbed. Reducing dust allows for increased worker safety during bubble suited operations such as maintenance and repairs, as well as reducing the risk that airborne contaminants will be released to the environment.

DESCRIPTION OF THE EQUIPMENT
In order to meet the objectives of remote control and dust reduction, three technologies were developed: an innovative end effector (IEE) for dust free dumping, a telerobotic transport vehicle (TTV) to convey retrieved waste from the digface to a treatment facility, and a remote operated excavator (REMEX) to deploy the innovative end effector and perform waste retrieval operations.

The IEE (see Figure 1) is a full sized excavator end effector that features a hydraulically actuated thumb and a detachable bucket for waste transfer. The detachable bucket allows for transfer of the excavated waste from the digface with minimal dust generation because it eliminates the inherently dusty dumping operation. The detachable bucket holds approximately 1 m³ of debris and soil, or two 55 gallon drums. The detachable bucket features a flared skirt for easy attachment to the IEE and an overflow slot to prevent overfilling the bucket. Sensors provide the remote operator with information about whether the bucket latches are engaged or released. The thumb provides flexibility during excavation because it can be used to guide items into the detachable bucket or to pick up large objects, with or without the bucket attached. The thumb has proven to be extremely versatile, dexterous, and productive in handling the waste forms expected during buried waste retrieval.

Figure 1. The multipurpose end effector and detachable bucket system (left photo) integrates innovative features with proven excavation and retrieval technology. The TTV (right photo) carries full detachable buckets or other waste in the closing waste transport container, and empty buckets in the spring loaded cradle.
The TTV, as shown in Figure 1, is a remote-operated, tracked vehicle that is capable of maneuvering on the rugged terrain and soft soils that are expected in buried waste retrieval areas. The TTV control system uses a radio frequency link to transmit controls from the remote control station to the vehicle. The guidance system consists of forward and rear mounted pan and tilt cameras and an ultrasonic ranging system. The camera views are used during all portions of driving the vehicle remotely, and the ultrasonic sensors are used to provide additional information about distances during parking at the free standing target. The waste transport container lid is opened and closed by a lift bar that is operated from the remote operator's control station. Emergency stop buttons are located on the TTV, on the remote control station, and on a supervisor's emergency shut-off belt module. Full detachable buckets, $4 \times 4 \times 8$-foot boxes, or large objects are transported away from the digface inside of a sealed waste transport container on the vehicle, and empty buckets are returned to the remote excavator in a spring loaded cradle. One remote operator controls the vehicle driving (track control), camera pan and tilt functions, and waste container operations.

The REMEX (see Figure 2) is a 40,000-lb class Hitachi EX-200LC standard excavator that had been modified previously for remote operations by SPAR and RSI. The REMEX was modified for this project to accommodate the innovative end effector in a front shovel configuration. The front shovel configuration was chosen to increase digging efficiency and limit dust generation when the excavator digs into the waste pile because the waste tends to fall into the bucket rather than away from it. The REMEX control system (see Figure 2) uses coordinated control and a four degree of freedom, human factors designed joystick to control the boom and stick motions. The joystick essentially replaces the arm of the operator's chair and functions so that motions of the operator's arm and hand are translated into motions of the boom and stick of the excavator. The thumb is controlled by a toggle switch on the control panel. The forward and reverse motion (track control) of the excavator is controlled by conventional foot pedals located in the remote control station. For remote operations, the operator controls digging, travel, and engine shut-off from the remote control station using the joystick, foot pedals, and video cameras for visual feedback. When operated remotely, the REMEX is tethered to the control station with a telemetry cable that can extend up to 609 meters (2,000 feet). The REMEX can also be operated manually from the cab using a coordinated control joystick like the one in the remote control station.

Figure 2. The REMEX (left photo) is a conventional excavator that has been modified with a sophisticated coordinated control system. A filled detachable bucket is shown inside the waste transport container on the TTV. After releasing the bucket, the lid on the TTV is closed and the TTV is repositioned to allow the REMEX to pick up the empty bucket staged on the back of the TTV. The REMEX continues retrieval operations while the TTV transports the waste to a processing or storage facility. The REMEX is operated telerobotically via a four degree of freedom joystick and operator's control station (right photo).

The integrated approach to the design of all three systems contributed significantly to the success of the project. For example, the detachable bucket was designed to work as part of the digging mechanism on the end effector and to be an integral part of the remote conveyance vehicle during waste transport.
DESCRIPTION OF THE DEMONSTRATION

The demonstration was divided into two phases. The Phase I demonstration consisted of a full-scale test to assess the ability of the IEE to control dust generation and the potential spread of contamination during dumping operations. The test was performed inside of a building where environmental conditions could be controlled to simulate those expected in a retrieval containment structure. The simulated waste consisted of dry INEL soils mixed with waste materials such as steel beams, 55 gallon drums of dry concrete, concrete rounds, and recycled newspaper. The waste pile was spiked with praseodymium, a rare earth tracer (a non-hazardous, non-radioactive material) that has been shown to closely match the air suspension of radioactive materials. Dust and rare earth tracer spread data were collected using high volume air monitors. The air monitors pull air through a paper filter of known weight, collecting dust and tracer on the filter. The filter is later weighed to determine dust loading and analyzed on an Inductively Coupled Mass Spectrometry machine to determine the rare earth tracer (simulated contaminant) levels. This information about the amount of dust and tracer suspended in air at various locations, combined with air monitor placement information, is used to determine the primary sources of dust generation. The demonstration included both digging and dumping operations; however, the primary objective was to test the ability of the system to reduce the generation and spread of dust during the dumping operation.

The Phase II demonstration consisted of a full-scale retrieval of simulated buried waste using the TTV, IEE, and REMEX. The purpose of this phase was to assess the ability of the end effector, waste conveyance system, and REMEX to effectively handle, transfer, and transport the waste from the digface. This phase of the demonstration was performed outdoors at a simulated waste pit that was made by recycling the soil and waste from the Phase I demonstration. The Phase II demonstration included all elements of the waste conveyance and end effector systems. During the Phase II demonstration, observations and measurements were taken to determine how efficiently the equipment excavated the waste, worked around and handled large objects, and conveyed the waste from the excavation site. An assessment of the conveyance system's maneuverability, precision, accuracy, flexibility and control system was made. Observations were made of the overall system integration between the IEE, TTV, and REMEX.

TEST RESULTS

Phase I Demonstration Results
The primary parameters measured during the Phase I demonstration were dust and rare earth tracer spread. In addition, information was gathered about the spillage, ability to handle various waste forms, and overall system effectiveness.

The test showed that with the IEE, dust levels that were two orders of magnitude below the test goal were achieved. The release of the detachable bucket from the excavator at the transfer point was accomplished with virtually no visible dust generation. The Phase I demonstration successfully proved that the concept of eliminating dumping at the digface is a viable, practical approach to limiting potential contamination spread during buried waste retrieval. Following transport to a treatment facility, the detachable buckets may be dumped in a glove box enclosure where contamination control systems are more easily implemented. In order to limit dust generation in the digging operation during an actual retrieval, use of contamination control such as soil fixatives at the digface is recommended.

The results from the Phase I test showed that the IEE with its detachable bucket is a very effective and reliable system for retrieving and removing buried waste from the digface. The IEE is rugged and well suited for digging heterogeneous buried waste. The IEE was very effective at handling the various waste forms present in the demonstration. In particular, the flexibility of being able to detach the bucket and work with the IEE thumb to pick up objects and place them in the bucket or move them around the digface added to the ability of the system to handle a large variety of waste forms. The IEE with its thumb was found to be dexterous and capable of handling waste forms ranging from 55 gallon drums to loose paper and soil. The integration between the IEE, detachable bucket, and REMEX was excellent and added to the successful completion of the Phase I demonstration.

Phase II Demonstration Results
The test parameters measured during the Phase II demonstration included throughput, ability to handle large objects, maneuverability, effectiveness of the remote control system, human factors design, and system integration.
During the Phase II test, the calculated throughput was 34.75 m$^3$/day. With minor modifications to the TTV, the goal of 60 m$^3$/day (80 yd$^3$/day) could easily be met. The primary factor in the lower throughput was the insufficient horsepower of the TTV, which reduced its speed significantly.

The ability of the system to handle large objects was excellent. No large objects were dropped or slipped during the retrieval. Large objects were picked up and placed into the waste transport container by the IEE and thumb, with the bucket removed from the IEE. One of the large objects was a Datsun pickup truck bed, which the IEE easily crushed and folded into a size that fit into the waste transport container. The combination of the thumb, detachable bucket, and waste transport container worked very well at digging and removing the waste forms and large objects.

Piloting the TTV was impaired by the lack of adequate horsepower and uneven power to the tracks. These were both worked around through equipment modifications and creative piloting methods so that the TTV was successfully used for the demonstration. In order to provide greater torque for turning and improved maneuverability, the hydraulic system pressure was increased, reducing the speed of the TTV. The TTV navigated the 10 degree slope and the loose mounds of soil in the test area very well after the horsepower was tuned as described above. The vehicle turned about a 6.7 meter (22 foot) diameter. During the demonstration, it was found that operator proficiency plays an important role in vehicle maneuverability.

The effectiveness of the remote control system included tests of the telemetry system, video system, ultrasonic sensors, and emergency stop functions. The TTV telemetry system functioned well, and easily met the 150 meter (500 foot) range goal. The wireless video worked well and provided a clear video signal to the TTV operator, although there was some interference from the antenna mast in specific positions and the range was limited to less than 75 meters. The ultrasonic sensors provided information to the operator when parking at the targets. Unfortunately, some crosstalk between the ultrasonic sensors occurred, which gave erroneous distance readings. As a result, the TTV was positioned within the 30 radial cm. zone only 77% of the time. A minor software change would have eliminated the sensor crosstalk, but was not easily implemented in the field. The radio frequency emergency stop malfunctioned repeatedly and shut the TTV down, so one relay had to be bypassed to continue the demonstration.

The human factors design of the control stations was evaluated qualitatively throughout the demonstration. The coordinated control joystick that was used to operate the REMEX was found to be intuitive and easy to use. Most conventional excavator control systems use two joysticks that must be operated separately, but in a coordinated manner to achieve the desired motion. With the coordinated control joystick, the operator's arm and hand motions are translated to the excavator motions, creating an intuitive control system. The close proximity of the TTV and REMEX operators was essential to the success of the demonstration. The operators were able to communicate easily, share camera views, and position the vehicles to aid in attaching and detaching the buckets easily.

The system integration between the IEE, TTV, and REMEX was excellent. Considering that the partnering companies were located in three cities ranging from the U.S. to Canada, the successful integration was especially noteworthy. For example, the systems design was evident in the way that the spring bed for the detachable bucket assisted with the easy alignment and transfer of detachable buckets to the TTV, and in the way that the tapered recess in the waste transport container assisted in alignment and transfer of full buckets into the TTV. Overall, the systems approach to the design and the integration of the systems contributed significantly to the project success.

**FUTURE DEVELOPMENTS**

During 1995, changes and improvements will be made to the equipment that was developed in 1994. The modified equipment will be used in an integrated demonstration with other BWID equipment at the INEL. The 1995 BWID demonstration will focus on retrieving a particular, small area of simulated waste called a "hot spot." In order to perform this demonstration, the REMEX will be modified to a backhoe configuration to accommodate an above grade retrieval. The TTV will be changed into a Self Guided Transport Vehicle (SGTV). This means that rather than being piloted continuously by a human operator, the vehicle will drive itself, using on-board sensors and a computer control system. Human operators will have the opportunity to resume telerobotic control if the need arises at any time. The IEE basic form and function will remain unchanged, but the size of the detachable bucket will be reduced. The orientation of the bucket on the SGTV will also change to...
accommodate easier interface with the backhoe configured REMEX. Many of the above changes (TTV to SGTV, etc.) were part of the original development plan. Others were based on data gathered during the 1994 demonstration, and are aimed at continuous improvement of the equipment. After the 1995 demonstration, the equipment and demonstration results will be evaluated by the Environmental Restoration Program to determine whether this is the best option for buried waste retrieval.

SUMMARY
The 1994 demonstration of remote technologies for buried waste retrieval showed that this is a practical, safe method of buried waste retrieval. Remote control technology combined with features that limit dust generation such as the IEE can greatly increase worker and environmental safety during buried waste retrieval.

The IEE with its detachable bucket performed very well throughout the retrieval process, eliminating dust at the dumping stage very effectively. The detachable bucket eliminates the inherently dusty dumping procedure at the digface, transferring it to a treatment facility where contamination control is more easily implemented. The thumb on the IEE increased its flexibility and improved its retrieval capabilities.

Although there were difficulties with the TTV's power, control, and sensor systems, all of these can be easily corrected. The demonstration of TTV showed that remote controlled vehicles can operate on rugged terrain and perform buried waste retrieval effectively.

The demonstration of the REMEX showed that remote controlled excavators are effective and useful in retrieving buried waste remotely. The human factors designed coordinated control joystick was particularly helpful in providing intuitive retrieval motions for the operator.

The integration between the IEE, TTV, and REMEX contributed significantly to the success of the demonstration.

Overall, the demonstration was a success, and showed that this equipment can be an effective remote controlled, dust limiting option for increased safety during buried waste retrieval.

REFERENCES


Biography
Ann Marie Smith is a Staff Engineer at Lockheed Idaho Technologies Company at the Idaho National Engineering Laboratory in Idaho Falls, Idaho. Her previous experience includes eight years of mechanical engineering at Hewlett Packard Company. She received her Bachelor of Science degree in Mechanical Engineering from the University of Minnesota in 1984. Ann Marie is the Society of Women Engineers Counselor to the Idaho State University Society of Women Engineers Student Section.

Phil Rice is an Advisory Engineer at Lockheed Idaho Technologies Company at the Idaho National Engineering Laboratory. His previous experience at General Dynamics included providing project engineering support for a number of mechanical design programs. Phil received his Bachelor of Science degree in Mechanical Engineering from the University of New Mexico in 1983.