CONF-940859--20

ADVANCED ROBOTICS FOR DECONTAMINATION AND DISMANTLEMENT*

William R. Hamel and Dennis C. Haley
Robotics & Process Systems Division
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, Tennessee 37831-6304

To be presented at
ISRAM '94
Fifth International Symposium on Robotics and Manufacturing
Maui, Hawaii
August 14-17, 1994

*Research sponsored by the Office of Technology Development, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy System, Inc.

ADVANCED ROBOTICS FOR DECONTAMINATION AND DISMANTLEMENT*

WILLIAM R. HAMEL and DENNIS C. HALEY
Oak Ridge National Laboratory
P.O. Box 2008, Building 7601
Oak Ridge, Tennessee 37831-6304

ABSTRACT

The decontamination and dismantlement (D&D) robotics technology application area of the U.S. Department of Energy's Robotics Technology Development Program is explained and described. D&D robotic systems show real promise for the reduction of human exposure to hazards, for improvement of productivity, and for the reduction of secondary waste generation. Current research and development pertaining to automated floor characterization, robotic equipment removal, and special inspection is summarized. Future research directions for these and emerging activities is given.

INTRODUCTION

Hundreds of contaminated and nonoperational facilities such as hot cells, reprocessing canyons, glove boxes, and reactor facilities exist at U.S. Department of Energy (DOE) sites throughout the United States. These facilities have undergone, or will eventually undergo, various levels of decontamination and dismantlement (D&D) intended to satisfy regulations and reduce potential hazards to the public and environment. Most nonoperational facilities go through a transitional sequence from shutdown through deactivation and, eventually, to the standby surveillance and maintenance (S&M) state. The deactivation and S&M phases pose many of the same problems that are expected in final decommissioning when facilities will be demolitioned or reconditioned for new uses. Deactivation and S&M activities place emphasis on characterization, data capture, and selective dismantlement to define and minimize the risks and costs associated with long-term custodianship of inoperative facilities.

The Robotics Technology Development Program (RTDP) is a major effort within the DOE Office of Technology Development in the Office of Environmental Restoration and Waste Management that is performing applied research and development (R&D) pertaining to the practical application of robotics to site cleanup projects. One of the technology applications areas being pursued is D&D robotics. The emphasis in D&D robotics is on practical systems and capabilities that can be used in facility deactivation and ongoing S&M activities that will reduce costs, enhance safety, and improve quality.

---

*Research sponsored by the Office of Technology Development, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy System, Inc.

D&D PROCESSES AND HAZARDS

Hazards associated with the D&D of facilities at DOE sites include ionizing radiation, radiological contamination, toxic and carcinogenic materials, and intrinsically dangerous demolition-style operations. Because of these hazards, deactivation, S&M, and ultimate decommissioning activities for many of the facilities will have to be performed remotely. Characterization of areas performed by using remote systems will protect personnel from both known and undefined hazards. Characterization will include radiation mapping, radioactive contamination swiping, and chemical contaminant analysis sampling. D&D operations also include disassembly of process equipment; cutting of pipes; reduction of equipment size; transport of piping and equipment out of the facilities; decontamination of equipment before removal; and decontamination of floors, walls, and remaining equipment in facilities entering S&M. Robotics may also be applicable to dismantlement of the facility structures.

D&D is accomplished through a series of operations depicted in Fig. 1. Characterization involves the use of sensors to map contaminants before and after decontamination. Decontamination is the "cleaning" process used to remove contaminants from materials, equipment, and building structures. Dismantlement is the operation of taking things apart and processing the resultant waste materials for disposition. Ultimate facility decommissioning is accomplished through these steps as a facility is transformed to a safe and/or reusable condition. Robotics and remote operations can, in general, be applied to each of these steps and, as shown in Fig. 1, are expected to provide positive benefits in reducing human exposure to hazards, in improving productivity, and in reducing secondary waste generation.

The philosophy of D&D robotics is to emphasize generic requirements and solutions that will have broad applicability across the full range of heterogeneous requirements (e.g., type of prior use, equipment sizes, radiation levels, age) associated with facilities D&D. Technically speaking, D&D robotics is

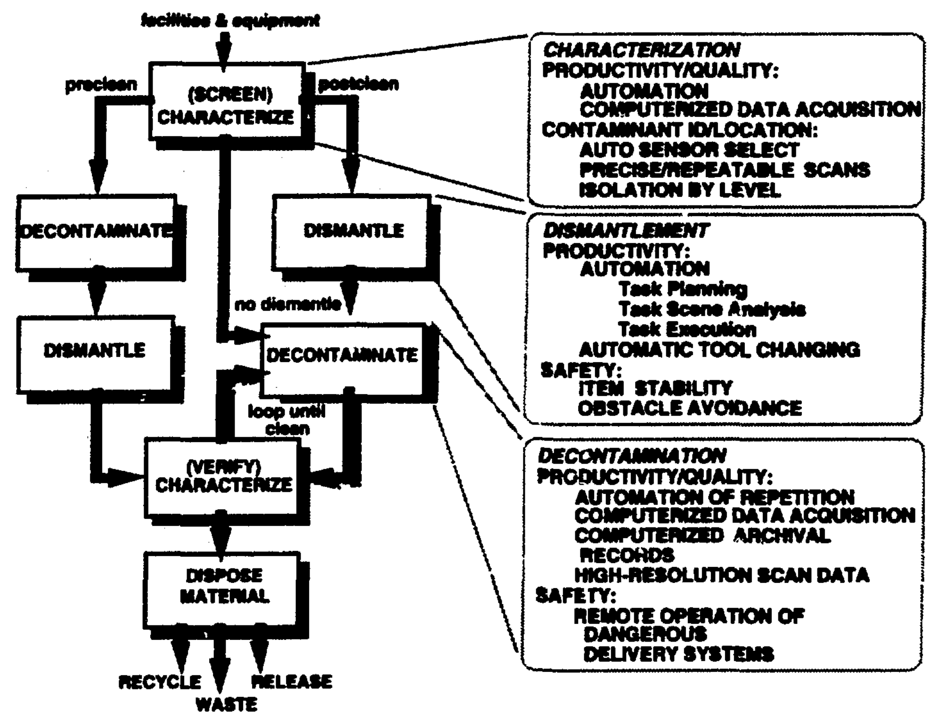

FIG. 1. D&D sequence.

concentrating on reconfigurable and modular hardware/software technologies that can be "assembled" to meet specific requirements while minimizing recurring R&D costs. This objective of this approach is to amortize R&D costs as widely as technically feasible. In the following sections, the current set of "generic" development activities in D&D robotics is presented.

MAPPING, CHARACTERIZATION, AND INSPECTION

Three facets of preliminary and actual S&M operations are costly and labor intensive. These facets are physical mapping of equipment and facilities, characterization of the magnitudes and locations of contaminants, and continuing facility inspections. Physical mapping involves the development of "as-built" drawings for facilities and equipment. Generally, the D&D program is addressing facilities that are no longer in operation and that are quite old. In most cases, accurate design information is not available and is needed for the development and evaluation of deinventory, deactivation, and ultimate D&D strategies. Similarly, characterization, or mapping, of the locations and magnitudes of contaminants on walls, floors, ceilings, equipment, etc., is required for the development of effective decontamination strategies and for the verification of their thoroughness and final certification. Floor characterization of these huge areas by manual methods is slow, is prone to error, does not produce accurate location data corresponding to survey data, and generates significant secondary waste from worker protective clothing. It is desirable for mapping and characterization data to be in a computer-compatible form for today's engineering environment. Finally, facilities in the S&M phase of operation require routine physical inspections to ensure the security of the facilities, to verify the status of operations, and to verify the storage of sensitive materials. All of these functions are now performed manually by technicians or guards by conventional measurement devices and practices. The cumulative costs of such activities represent major DOE budget requirements.

Mobile robotic systems can perform a significant fraction of the mapping, characterization, and inspection functions associated with S&M. Development of the mobile robot platforms and associated sensor technologies that can accomplish these functions is planned in the years ahead. Off-the-shelf autonomous mobile robots can be used to survey operating floor areas with major reductions in total characterization costs. Surface characterization using mobile robotic systems is faster; produces reliable, repeatable data; and reduces waste generation and personnel exposure. With the addition of manipulators, such robots will be capable of characterizing floors, walls, and more complex equipment surfaces. These advanced systems will be developed in the out years. New standoff laser range cameras offer promise for these mobile platforms to be capable of moving about older facilities and acquiring three-dimensional data necessary for the construction of "as-builts." These same mobile platform technologies can also be used to implement inspection-type robots as well.

Automated floor characterization has been identified as the principal mapping, characterization, and inspection D&D robotics activity currently being addressed since hundreds of acres of floor space exist in DOE facilities that will require characterization and ultimate decontamination. These floors must be characterized before, during, and after decontamination procedures to meet regulatory requirements. This is the type of task that is ideal for robotic execution because of the large amount of floor space and the inherently repetitious nature of health-physics survey tasks. The Savannah River Technology Center (SRTC) has built and operated a mobile survey robot called SIMON [1], shown in Fig. 2, which has been very successful in improving floor characterization results. Using this work as a foundation, SRTC and Oak Ridge National Laboratory are in the process of developing the Mobile Automated Characterization System (MACS). MACS will

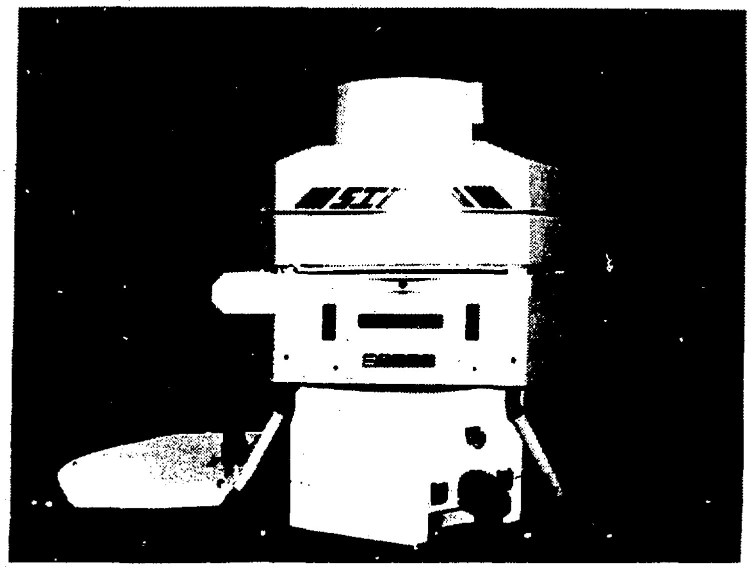

FIG. 2. SIMON–SRTC's mobile survey robot.

be based on the SIMON Cybermotion chassis, and will also incorporate improvements in the radiation survey instrumentation, the navigation system accuracy, and the operations station where the system is controlled and data are viewed and analyzed. MACS will be computer-controlled and will include integrated data analysis and presentation tools, all of which are intended to further advance the efficiency of both setup and characterization operations. The system will undergo initial test and evaluation in early 1995.

SELECTIVE EQUIPMENT REMOVAL

Perhaps the most complex D&D operations are those associated with actually disassembling and dismantling equipment and structures. Such tasks include, for example, disassembly of process equipment; cutting of pipe; size reduction of equipment and materials; transport of resulting debris out of the facilities; decontamination of materials before removal from a facility; and decontamination of floors, walls, and remaining equipment in facilities to be refurbished. Robotics may also be needed for the dismantlement of facility concrete and steel structures. Suitably engineered and hardened robotic systems can provide the remote and automated capabilities necessary to accomplish these operations with reduced worker exposure to the work site hazards.

Total dismantlement is not normally included in the establishment of effective S&M. Selective dismantlement where specific systems and equipment are removed is always included to some degree. Current robotic dismantlement R&D is focusing on the class of selective dismantlement. Research activities include the development of a selective equipment removal system (SERS) comprising a dual-arm work module [2], various types of transporter systems, a task space scene analysis capability necessary for unstructured task automation, and overall operator control and interface provision. The dual-arm work module mounted on a rigid-boom overhead bridge-carriage transporter is shown in Fig. 3 This system will begin initial systems integration and testing in April of this year. The integrated SERS will be installed in the remote operations and demonstration facility at Oak Ridge

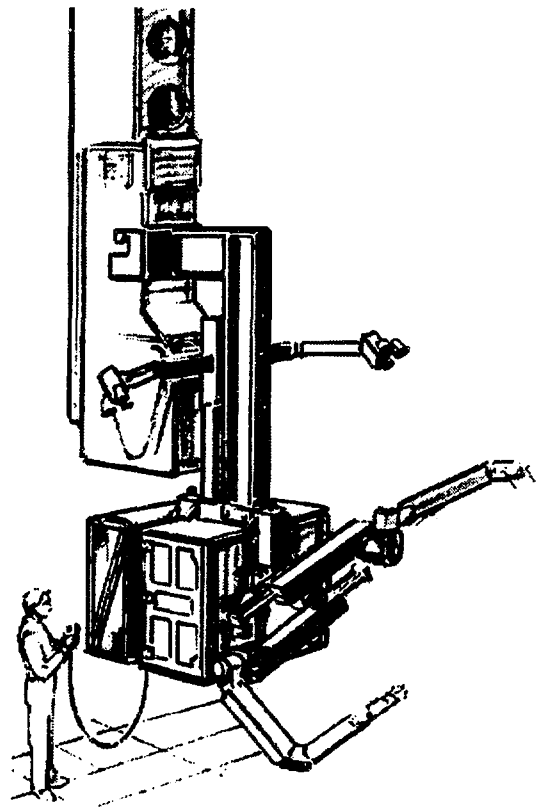

FIG. 3. Dual-arm work module mounted on an overhead transporter.

National Laboratory, where it will be used to evaluate telerobotic performance enhancements under realistic D&D tasks that combine disassembly and dismantlement in the years ahead. A critical SERS subsystem is the task space scene analysis system (TSSAS) [3], which allows the operators to interactively develop geometrical three-dimensional models of the near-field work area to facilitate programmed execution of disassembly and dismantlement subtasks. The essence of the SERS telerobotic concept is the integration of manual and automatic control such that operators can accomplish their tasks more quickly and with fewer errors. The TSSAS will incorporate binocular vision and laser ranging to accomplish this function.

In future years, the dual-arm work module will be reconfigured for deployment and evaluation by using a mobile platform being developed by the Carnegie Mellon University and by using a stabilized crane-hook approach pioneered in France by the Atomic Energy Commission. The mobile deployment configuration is shown in Fig. 4. The SERS will be used to demonstrate the workability of the modular and reconfigurable system elements in a number of demonstrations pertaining to the different types of facility D&D that have been discussed. Ultimately, characterization and mapping data from the MACS will be transferred, under appropriate facility scenarios, to the SERS for use in the selective dismantlement operations. In addition to the basic SERS, auxiliary features such as tooling and operator interfacing will be studied in detail as well.

SPECIAL CHARACTERIZATION AND INSPECTION SYSTEMS

In addition to the MACS robotic characterization activity, two specialized inspection and characterization systems have been identified and are being pursued. These pertain to the evaluation of enclosed spaces associated with piping and ventilation ductwork. Piping and duct characterization has been clearly defined as one the most pervasive and difficult tasks to be faced.

Small Pipe Characterization

Throughout the DOE complex are numerous facilities identified for D&D with piping that has been placed on the contaminated list because of the risk of internal contamination. Much of this piping is inaccessible because it is buried in concrete or because it runs in hot cells. In spite of the vase amount of R&D that has been performed in pipe and vessel nondestructive testing, no robotic/remote systems are capable of characterizing pipe in the 1- to 3-in.-ID range. Characterization of this piping is essential before, during, and after D&D activities. By identifying those portions of the piping that are not contaminated, instead of performing unneeded decontamination, the amount of material sent to waste handling facilities or the amount of waste generated can be greatly reduced.

Idaho National Engineering Laboratory is leading an effort to develop a multistage pipe-crawling device that can deliver visual and contaminant sensors within 1- to 3-in. internal piping. Emphasis is being placed on crawler mobility that can follow typical pipe routes and can negotiate pipe branches, vertical runs, and horizontal runs. Because of the small pipe size being addressed, this development activity involves the use of microactuator and microsensing technologies. A working prototype is planned for completion around October 1994.

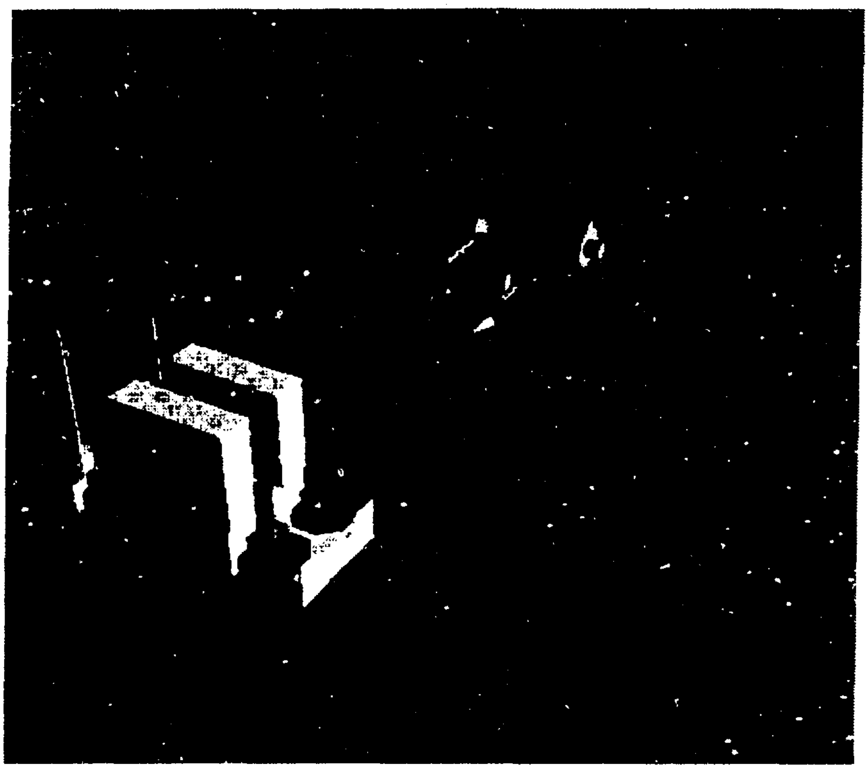

FIG. 4. Dual-arm module mounted on a floor-mobile transporter.

Internal Duct Characterization

Throughout the DOE complex are numerous facilities identified for D&D with ductwork that has been placed on the contaminated list because of the risk of internal contamination. Generally, this ductwork was used for process equipment ventilation and contamination control and, as a result, has typically accumulated significant quantities of contaminants over the years of process operation. Much of this ductwork is inaccessible because it is buried in concrete, routed through radioactive areas, or physically difficult to reach. Characterization of ductwork is extremely difficult because of varying size and direction of travel. Characterization of this ductwork is essential before, during, and after D&D activities. By identifying those portions of the ductwork that are not contaminated, instead of performing unneeded decontamination, the amount of material sent to waste handling facilities or the amount of waste generated can be greatly reduced. Conventional methods have been applied to the characterization of ductwork with some success but at the expense of human exposure to high levels of contamination. Limited-capability remote ductwork characterization systems are commercially available. A robotic/remote duct characterization system with extended travel capability is needed that can perform chemical and radiological contaminant characterization and selected hot-spot decontamination or partial ductwork dismantlement.

Idaho National Engineering Laboratory is leading an industrial procurement project for the development of an internal duct characterization system that will meet a wide range of the duct characterization requirements pertaining to DOE facilities. Initially, this system will demonstrate sensor (e.g., color vision and radiation) mobility functions, and in future years it will address the functionality to obtain and retrieve material samples and to perform hot-spot decontamination (e.g., a special-purpose manipulator). This system is expected to be principally teleoperated, but shared or supervisory control functions that enhance operational efficiency and safety are being sought. Initial operation of the prototype is expected at the end of 1994.

RISK AND BENEFIT ANALYSIS

As discussed earlier, surveillance and maintenance functions dominate recurring costs pertaining to the custodianship of deactivated DOE facilities. Consequently, S&M cost reduction has been identified as a key target for robotics and automation technologies. Deactivation and S&M activities involve the effective rational use of characterization, data capture, and selective D&D. Clearly, it would be very useful to have some type of analytical methodology that could be used to evaluate the merits of candidate robotics concepts in terms of their value to the various of phases of D&D and S&M.

A multitude of risk and cost analysis tools exist and are being evaluated for their potential application to the technical details of D&D robotic system concepts. If a suitable analytical foundation of existing techniques is found, robotics-specific risk/cost trade-off tools will be developed and used in future analysis of robotic applications opportunities. Ideally, it is desired to compare robotic solutions with established baseline methods (e.g., human entry with air suits vs remote systems) in terms of risk and/or cost reduction. The development cost, operational cost during deactivation and S&M, and the potential for ultimate use during final D&D will be parameters evaluated relative to the use of robotic and remote systems for these tasks. If a suitable analytical foundation is not found, the pursuit of a generalized approach to robotic system risk and benefit analysis will be abandoned.

FUTURE DIRECTIONS

As funding allows, additional important aspects of characterization, mapping, and equipment removal will be pursued in future efforts. Specifically, host-microbot satellite concepts for the characterization of hard-to-get-to places will allow mobile floor characterization automation to be extended to more complex equipment surfaces. The SERS concept must ultimately be integrated with material transport systems that move debris from the worksite to other locations for further processing. The integrated control and operation of these multiple mobile robot systems will present many new challenges. SERS itself offers many research avenues pertaining to increasing levels of autonomy in a system, including combined mobility and manipulation, dual-arm coordinated control, and all in the context of tooling-constrained unstructured task execution. Finally, workcells that provide fully automated characterization, decontamination, and contaminant certification of D&D material items will be investigated.

SUMMARY

It is believed that robotics technologies can substantially reduce the costs, enhance the safety, and improve the quality of D&D projects within the DOE complex. D&D robotics activities associated with the DOE RTDP have been described. Various forms of mobile robotic systems for characterization, dismantlement, and inspection are being developed. Prototypic systems for these functions will be demonstrated over the next three years under realistic but simulated conditions. These activities are the combined efforts of several DOE laboratories, industrial firms, and universities.

ACKNOWLEDGMENTS

The D&D robotic technology activities are the result of the combined efforts of a team comprising staff members from Oak Ridge National Laboratory, Sandia National Laboratories, Pacific Northwest Laboratory, Idaho National Engineering Laboratory, and Savannah River Technology Center. Current university partners include The University of Tennessee, the University of Texas at Austin, Carnegie Mellon University, and the University of South Carolina. Industrial projects are currently under way with Schilling Development Corporation and RedZone Robotics.

REFERENCES

1. A.M. Dudar, D.G. Wagner, and G.D. Teese, "Mobile Autonomous Robot for Radiological Surveys," *American Nuclear Society's 40th Conference on Remote Systems Technology Proceedings,* Vol. 2 (1992).
2. W.R. Hamel and D.C. Haley, "Dual-Arm Manipulation Module for Use In Decontamination and Decommissioning Operations," *1994 International Symposium on Decontamination and Decommissioning,* (April 1994).
3. S. Thayer, C. Gourley, P. Butler, and H. Costello. "On-Line Stereo Vision and Graphical Interface for Decontamination and Decommissioning Applications Using the Advanced Servo Manipulator," *Proceedings of the ANS Fifth Topical Meeting on Robotics and Remote Systems* 287-294 (April 1993).