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ROSIE: A Mobile Worksystem for Decontamination and Dismantlement Operations

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DISCLAIMER

ROSIE: A MOBILE WORKSYSTEM FOR DECONTAMINATION AND DISMANTLEMENT OPERATIONS

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ABSTRACT

RedZone Robotics, Inc. and Carnegie Mellon University's Field Robotics Center have undertaken a contract to develop a next-generation worksystem for decommissioning and dismantlement tasks in Department of Energy (DOE) facilities. This project is funded by the DOE's Environmental Management Office of Technology Development through the Morgantown Energy Technology Center. Currently, we are closing the second phase of this three phase effort and have completed the design and fabrication of the worksystem: Rosie.

INTRODUCTION

Rosie includes a locomotor, heavy manipulator, control center, and control system for robot operation. The locomotor is an omni-directional platform with tether management and hydraulic power capabilities. The heavy manipulator is a high-payload, long-reach system intended to deploy tools into the work area. The heavy manipulator is capable of deploying systems such as the Dual-Arm Work Module—a five degree-of-freedom platform supporting two highly dexterous manipulators—or a single manipulator for performing simpler, less dexterous tasks. Rosie is telerobotic to the point of having servo-controlled motions which can be operated and coordinated through the control center.

MAIN BODY

Project Background - Phase I

This project is separated into three separate work phases. The first phase consisted of gaining a knowledge of the DOE's D&D needs, upgrading a pre-existing worksystem with state-of-the-art technologies and enhanced controls for ease of operation, then undertaking a program to test the system and determine its capabilities and weaknesses. The second phase involved developing a second-generation worksystem to perform D&D operations based on knowledge gained in Phase I. In the third phase Rosie will perform capability demonstrations in a mock-up facility. The time frame for these phases is presented in Table 1 below.

	Start Date	End Date
Phase I	10/1/92	10/1/93
Phase II	10/1/93	7/1/95
Phase III	7/1/95	12/1/95

Table 1: Project Schedule

DOE D&D Background. We began the Phase I effort by trying to gain an understanding of how a mobile system could assist with the D&D needs of the DOE. The environment in which these worksystems will have to perform D&D operations range from areas in which no special clothing is needed to protect workers to areas in which the risk of human entry is great. Dangers can include exposure to alpha, beta, and gamma radiation; uranium, plutonium, and tritium; volatile organics; acids and caustics; mercury; TRU waste and mixed waste, and asbestos. Facilities in which D&D is likely to occur include uranium enrichment facilities, including gaseous diffusion plants, centrifuge plants, and other separation plants; research and production reactors; hot cells, canyons, and vaults; stacks and cooling towers; silos and waste storage tanks; analytical research labs; and weapons production and assembly facilities.

Given the wide range of tasks that must be executed, the weak structure of the settings in which they are to occur, it is impossible to build one machine to meet all needs. It is more likely that a variety of different systems will be required. These worksystems require versatility to handle a variety of tools and perform a wide range of tasks, they must combine brute force for heavy work with dexterity for fine manipulation, they must be reliable for extended use, and adaptable to a range of work conditions and settings to meet this challenge.

The RWV I. Concurrent to gaining a working knowledge of the D&D needs, during Phase I we took an existing robot, Remote Work Vehicle (RWV), and upgraded it to provide a testbed which could be used to determine the key features of a mobile worksystem. The RWV is one of three mobile teleoperated systems originally developed for accident recovery activities at Three Mile Island Unit-2. It was conceived specifically to fulfill a set of task objectives and required attributes for work in the Reactor Building Basement (RBB) where radiation exposure precluded the use of a human workforce. The RWV design was based on the experience of predecessor robots at TMI-2 and technologies, system philosophies and operating methods proven to work in other adverse environments.

The RWV was tailored to remediate a particular area of the RBB (Zone 1) and would hopefully be amenable to recovery efforts in other areas of the RBB. In addition to access and maneuvering requirements, performance capabilities specified for the RWV included the ability to deploy tooling from floor to ceiling (6.5 meters) for tasks including de-watering flooded areas, removing sediment, decontaminating surfaces, abating radiation sources by demolition and emplacing shielding, applying surface treatments, and packaging and transporting materials. Goals were also set for reliability (assured egress), operability, decontaminability, extensibility, and maintainability.

The RWV was never deployed into the RBB and was eventually returned to Carnegie Mellon. In Phase I we brought the RWV back into operation, implemented several upgrades on the worksystem and control console, adapted tooling, and tested system performance, creating the RWV I. The main tasks we performed on the RWV were:

Worksystem. We stripped the RWV platform down and performed a check of all components. Upgrades to the system included:

- Addition of feedback and hydraulic servo valves on the three boom axes (raise, extend and tilt) to allow coordinated control of the boom motion.
- Addition of feedback to indicate wheel rotation on the four wheels.
- Repair of any onboard components that had worn or failed.

Tooling. The original tooling for the system was not recovered from Three Mile Island, necessitating development of new tools. The tooling included:

- A six degree-of-freedom electro-hydraulic servo manipulator with a 50 lb payload for dexterous work with light tools and end effectors such as: a high pressure wash system, a spray gun for application of sealant or other materials, a vacuum for removing loose solids from the work area, a crow bar, and a barrel lift.
- A two degree-of-freedom electro-hydraulic tool deployment platform to position heavier tools such as: a power grinder for cutting objects, a reciprocating saw for cutting, and a pipe sheer for cutting small pipes.

Control Console. The original control console for the system employed three operators and 12 video monitors. The control system was redesigned with the following:

- A single operator control station, with video feedback, audio feedback and a three-dimensional view of the robot configuration.
- A local area network communication system between the robot and the control console to provide higher bandwidth control.
- On-board computing to monitor all sensing and servo all motions to commands generated at the control console.
- Upgrade of the controller to servo more axes than the original machine and allow coordination of axes, such as drive and boom motions.

Software. We developed a real time controller for the RWV I test bed that is designed for modularity and reusability in the RWV II. This included a new VME-based onboard computer running the VxWorks operating system.

Phase I Test Results

After the upgrades were complete we began a testing program to determine the usefulness of the RWV I in performing D&D operations. Our test plan was developed to provide us with some quantitative information about the RWV I's performance as well as a qualitative measure of the system's effectiveness.

We identified a list of tasks typical of what will be seen in D&D operations. The tasks were in increasing complexity and included items such as:

- Drive the robot through a designated slalom or maze path.
- Touch several different points on the floor and walls using the boom.
- Retrieve several objects located in the mock-up to a given location.
- Paint/coat a surface or wall.
- Remove a pallet or drum from the work area.
- Cut off vertical and horizontal pipe segments.

We selected four "primary" operators proficient in the use of the RWV I and used them as our primary operators. Each task was performed by all operators and after each test, operators filled out a form to elicit their approach to the task, key features or deficiencies of the system, and other factors associated with the RWV I's design and operations.

Based on the results of the testing we identified several key features of the RWV I which we wanted to integrate into the design of a new generation worksystem. In addition, some deficiencies were noted which were avoided. Some of these items are listed in Table 2 below:

Advantages	Disadvantages
Omni-directional driving capability	Limited 3 DOF boom motions
Large reach/work envelope	Many custom actuators
Telescoping boom design	Hydraulic complexity/redundancy
Console layout with touchscreen control of "secondary" functions	Stifflegs restrict mobility while using boom
Stainless steel for decontamination	Limited hydraulic power
	Difficult to access/service machine

Table 2 RWV I Advantages/Disadvantages

Rosie

In the second phase of this project we undertook the design and fabrication of a D&D worksystem. As we discovered in our Phase I study, the requirements for a worksystem are very diverse, ranging from human-scale manipulation tasks to large, industrial-scale equipment removal. While it is impossible to build one system capable of meeting all of the D&D needs, we selected a concept capable of addressing a wide variety of tasks. We have named the robot Rosie (see Figure 1).

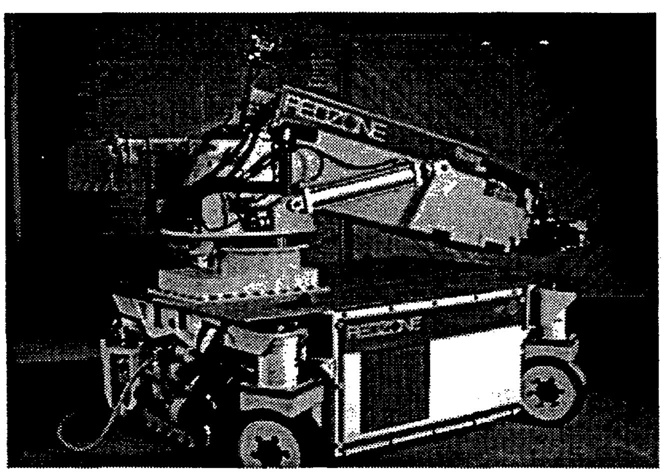

Figure 1 Rosie

Modularity. Rosie's design is modular in nature to allow components to be added or removed, yielding several different configurations. The two main modules are the locomotor and the heavy manipulator. The locomotor provides mobility to carry the heavy manipulator to the work area. The heavy manipulator can then deploy tools or smaller more dexterous manipulators from its tip.

In this modular concept, the heavy manipulator can be removed from the locomotor allowing other equipment to be deployed from its deck. Concepts include systems such as a variable geometry truss (being developed at Pacific National Laboratory) or a scissors lift mechanism which could provide a high lift capability. Alternatively, the heavy manipulator could be deployed from some other platform, such as an overhead gantry crane.

The heavy manipulator can accommodate a variety of more dexterous equipment, including the Dual-Arm Work Module (developed by RedZone under a separate contract). This module provides two manipulators mounted on a five degree-of-freedom platform (see Figure 2). The actuated motions are: a variable offset from center for each manipulator, an adjustable center pivot to orient the arms side by side or above and below each other, and a pivot at each manipulator allowing orientation from elbows-up to elbows down. An alternate tool which will be deployed from the heavy manipulator is a single manipulator. The lower weight of the single manipulator permits greater reach with the heavy manipulator to the sides and rear of the locomotor, but restricts dexterity to single arm tasks.

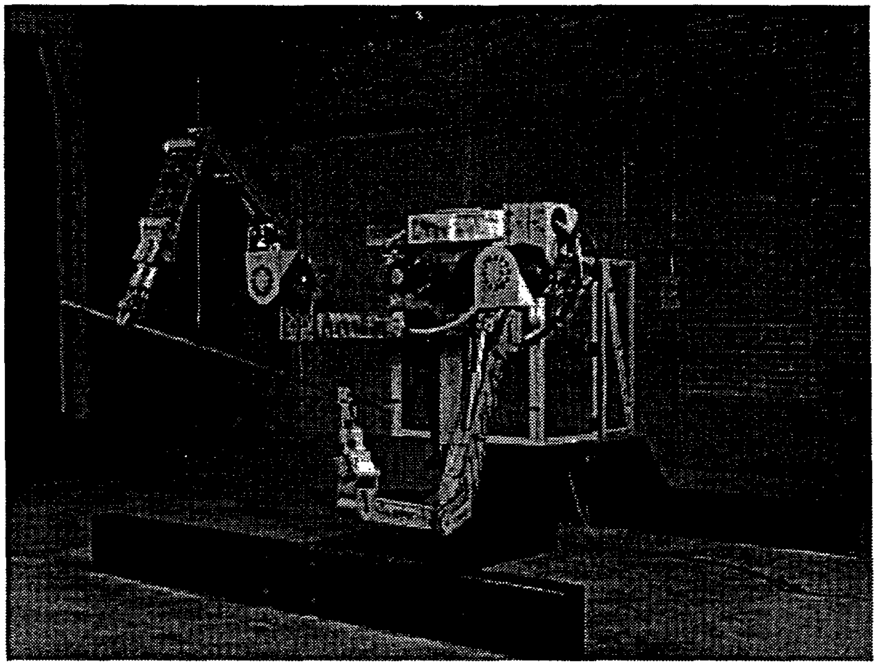

Figure 2 Dual-Arm Work Module

This modular approach to technology development allows us to build various elements of a tool kit which can be configured in a way which best suits the task at hand. Also, future development can create other modules with capabilities to supplement the tool kit as different task requirements are encountered.

Operations. Several work scenarios are possible with Rosie: it could be a direct assistant to human workers; several robotic systems could be deployed together; or Rosie alone could be deployed to perform hazardous or dangerous tasks. We have targeted a "construction quality" design for Rosie. The system is able to survive inadvertent collisions with obstacles while driving or manipulating. As much as possible, all cables and hoses are protected from damage by running them internal to the structure. Critical components in the system are easily accessible. In radioactive situations, whole modules—such as the tether reel or electronics enclosure—are removed for remote maintenance.

System Description. Rosie is a tethered machine whose primary motions are hydraulically powered. The system consists of three components, the control center, the power distribution unit, and the robot, which includes the locomotor and heavy manipulator (see Figure 3). The locomotor base measures 2 m (6.5 feet) wide by 2.9 m (9.5 feet) long and 1.1 m (3.5 feet) high, but the heavy manipulator extends outside of this envelope making the overall dimensions 2 m (6.5 feet) wide by 4.3 m (14 feet) long and 2.4 m (8 feet) high. The weight of the machine is about 6,350 kg (14,000 lb).

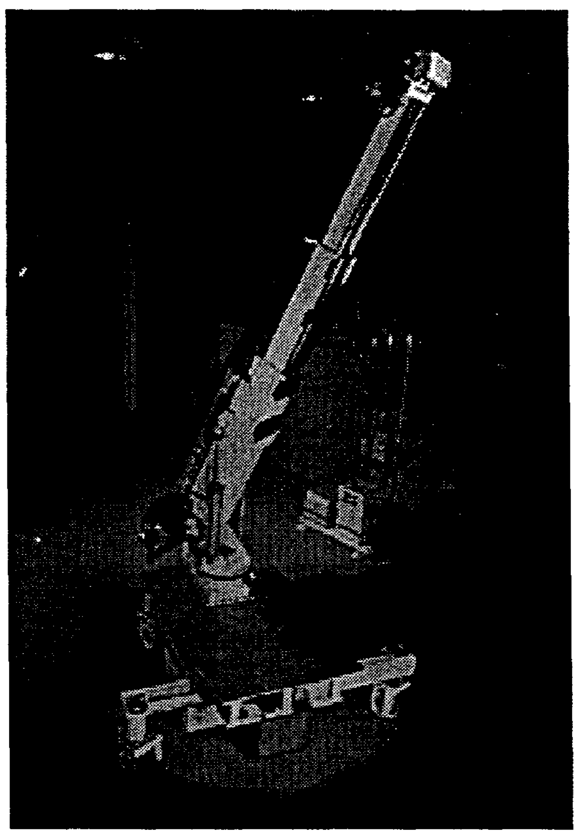

Figure 3 Vehicle Configuration

Locomotor.

Width (extensions in)	193 cm	76 in
Width (extensions out)	345 cm	136 in
Height	107 cm	42 in
Length	290 cm	114 in
Obstacle Climb	10 cm (max.)	4 in (max.)
Ground Clearance	15 cm	6 in
Min. Turning Radius	about center	about center
Max. Speed	0.6 m/sec	2 ft/sec

Table 3: Locomotor Specifications

The locomotor is a mobile platform with specifications as shown in Table 3. The frame is a truss structure which supports wheel modules at each corner. Each wheel module has independent drive and steer motions providing an omni-directional capability. The wheels are controlled in any of three driving modes:

> *4-wheel steer* mode allows the front and rear sets of wheels to steer in opposite directions. This mode allows Rosie to drive along the path of an arc whose center is on the centerline pointing to either side of the machine.
>
> *Crab steer* mode allows all four wheels to steer in the same direction, allowing Rosie to translate linearly in any direction.
>
> *Rotate about a point* mode allows the operator to define a point in space that Rosie is to rotate about. In this mode, Rosie can rotate around the tip of the heavy manipulator, around the center of an axle, or around the center of the robot.

The front two wheels are mounted on extensions which can extend the front wheel spread from 193 cm (76 in) to 345 cm (136 in). The rear two wheels are mounted on a beam which pivots at the center to provide ±5 cm (±2 in) of vertical travel for obstacle negotiation.

Located within the locomotor frame is the hydraulic power supply, which is a 45 KW (60 HP) supply, providing 114 l/min (30 GPM) at 20.7 MPa (3,000 psi) for all robot motions. Filters and all locomotor valving are located in one of two side enclosures on the frame. The other side enclosure contains all control electronics for the system. At the rear of the machine is the tether reel which carries up to 61 m (200 feet) of cable.

Heavy Manipulator. The heavy manipulator is mounted on the deck of the locomotor towards the rear. It is a four degree-of-freedom mechanism providing a long reach, high load capability for Rosie. It can carry up to 770 kg (1,700 lb) with a 6,800 Nm (60,000 in-lb) moment load, at a distance of 6.1 m (20 feet) from the shoulder joint. The heavy manipulator consists of four joints; a waist motion on the locomotor deck, a shoulder pitch, a forearm extension and a wrist pitch at the tip of the forearm. Each of the four joints has integral position feedback and is servo controlled based on operator commands. The joints can be controlled in either of two modes:

> *Joint motion* mode allows the operator to individually control each joint on the heavy manipulator. This mode allows the operator to directly control the configuration of the system.

Coordinated motion mode allows the operator to control the Cartesian position of the endpoint of the heavy manipulator while the computer calculates the resulting joint positions. This motion mode is useful for tasks where the operator must move parallel to a floor or wall or is not moving in a confined area.

The configuration of the heavy manipulator are shown in Figure 4.

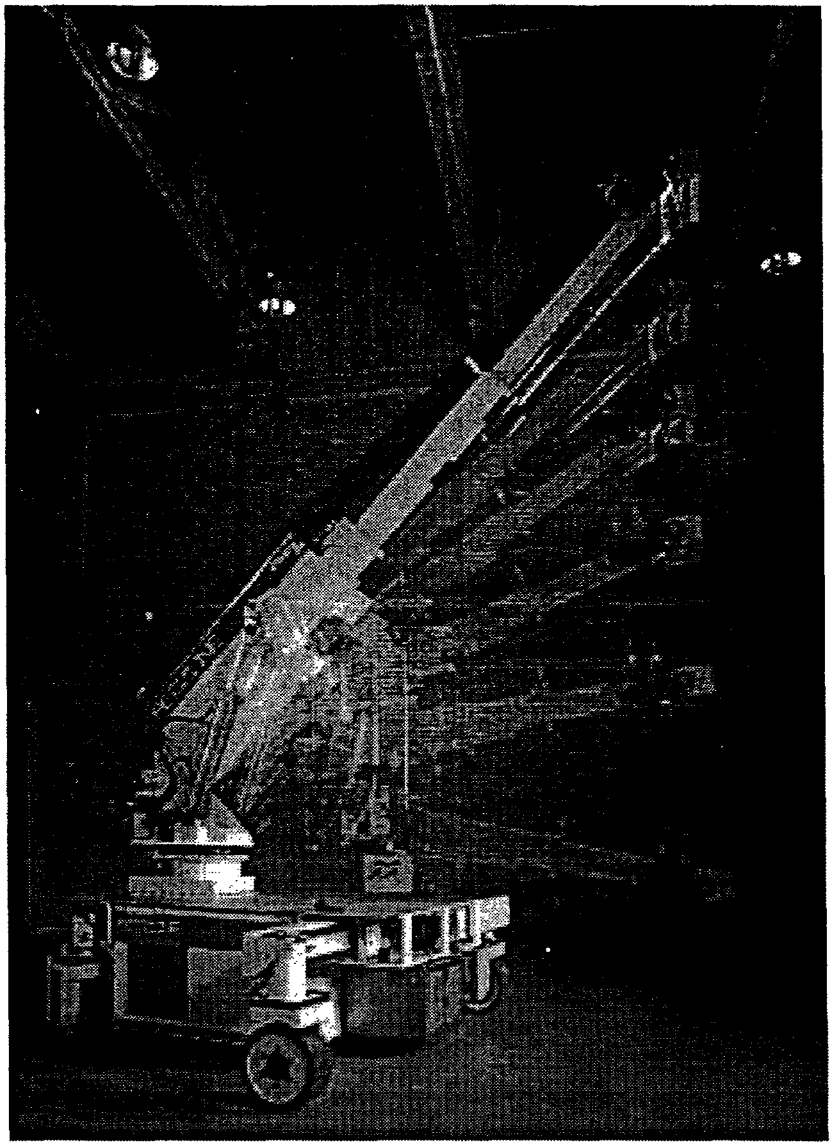

Figure 4: Heavy Manipulator Configuration

We have performed an analysis of the load capability of the heavy manipulator. The limits are driven primarily by tip-over concerns. The tip-over limits are monitored by the system software so that a tip-over condition is never reached. This is accomplished by sensing the actuator hydraulic pressure (and thus moment load) at the shoulder joint, while monitoring the position of the boom. When the software senses that a tip-over condition is being approached, it alerts the operator and restricts the movement of the boom.

Audio/Video System. The audio/video system takes multiple camera views and microphone inputs from the robot and displays them at the console. Rosie can carry up to ten cameras including:

- Four cameras with remote focus, zoom, lights, and pan and tilt motions
- Three cameras with remote lights and tilt motions (fixed focus)
- Three cameras with remote lights (fixed focus)

All cameras are modular to allow easy replacement or relocation in order to accommodate different tooling or task requirements.

Control Console. The control console provides a control location for the system. It combines hard controls for the primary motions of the robot with a touch screen for control of secondary and auxiliary functions. Software on the console monitors all operator inputs and displays system status. Onboard Rosie, the console commands are interpreted and turned into actuator commands. The control center is the human interface between Rosie and the work environment (see Figure 5).

There are several important issues to consider in designing the control center, including ergonomics, flexibility, and aesthetics. With respect to ergonomics, it is expected that the operator will spend long periods of time completing a D&D task. Therefore, it is important that the operator is comfortable, that all controls are placed within reach, that lighting and glare be considered, and that audio and video cues alert the operator to potential problems.

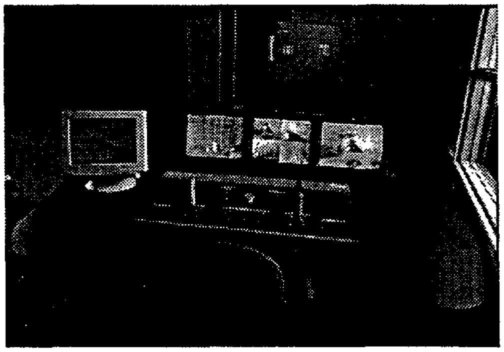

Figure 5: Control Console

Software. The onboard controller and console software runs on a VME-based 68040 Motorola CPU under the VxWorks 5.1.1 real-time operating system. The onboard software is responsible for communicating with the offboard console, monitoring all onboard sensors, and controlling all onboard actuators. The console software is responsible for monitoring the visual display/touch screen system and all additional hardware devices (e.g. switches and joysticks) at the console panel and sending the console information to the onboard software. The two systems communicate via an Ethernet connection.

The software is intended to be transparent to the operator. No keyboard or mouse is required to run the system. It was built upon an infrastructure developed previously at RedZone through other projects and internal development. The system is flexible and extensible to meet an anticipated wide range of uses that Rosie will encounter. Links and hooks to add additional features, such as alternate operating modes or higher level supervisory control, can be integrated at a later date.

Power & Telemetry. The power and telemetry subsystem allows power and signals to be transmitted from the console to the locomotor and routed onboard to the various sensors and actuators. A Power Distribution Unit (PDU) located between the console and robot provides a location to tie into the higher voltage site power used to power Rosie's hydraulic system. All signals from the console pass through the PDU and are combined with the power and routed into the tether. When operating in a contaminated location, the PDU can be located within containment, minimizing the penetration of conductors into containment. Rosie uses a tether to transmit all power, control, and video signals to and from the robot.

The heart of the electrical system on Rosie is enclosed in a sealed box mounted on the left side of the locomotor. This enclosure houses step-down transformers, two 6U VME controller subracks, power supplies, video modulation equipment, and four heat exchanger units.

Future Work

Now that Rosie is fully operational we are moving into the third phase of our project. In this phase we will be working to prove Rosie's ability and usefulness at performing D&D tasks. This effort will consist of two separate parts: first, we will be executing several "capability demos" in which we will exercise a particular piece of equipment, such as a pipe shear or plasma torch, to perform a task. This will show that Rosie is capable of handling a variety of different tools. Second, we will be performing a cold demonstration of Rosie performing D&D on a mock-up of a real DOE facility. The current candidate for this facility is Cell 3/4 of the Idaho National Engineering Laboratory *Rover* fuel processing system. Our approach is to focus on a complete D&D operation of this facility, with the overall goal of being selected to finally remediate the actual *Rover* facility.

REFERENCES

None