Rosie - Mobile Robot Worksystem for Decommissioning and Dismantling Operations

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Abstract

RedZone Robotics, Inc. has undertaken development of an advanced remote worksystem — *Rosie* — specifically designed to meet the challenges of performing a wide range of decontamination and dismantlement (D&D) operations in nuclear environments.

The Rosie worksystem includes a locomotor, heavy manipulator, operator console, and control system for remote operations. The locomotor is a highly mobile platform with tether management and hydraulic power onboard. The heavy manipulator is a high-payload, long-reach boom used to deploy a wide variety of tools and/or sensors into the work area. Rosie's advanced control system, broad work capabilities, and hardening/reliability for hazardous duty make it a new and unique capability that facilitates completion of significant cleanup projects throughout the Department of Energy (DOE) and private sector.

Endurance testing of the first Rosie system from September 1995 to March 1996 has proven its capabilities and appropriateness for D&D applications. Design enhancements were incorporated into the second Rosie system to improve and add features necessary for deployment at a DOE facility decommissioning. This second Rosie unit was deployed to the Argonne National Laboratory's CP-5 reactor facility in early December 1996, and it is currently being used in the decommissioning of the reactor there. This report will overview this second Rosie system and the design enhancements made to it based on the lessons learned during the design, fabrication, and testing of the first Rosie system.

The Rosie system has been designed to be a versatile and adaptable tool that can be used in many different applications in D&D work at nuclear facilities. It can carry a wide variety of tooling, sensors, and other robotic equipment at the tip of its heavy manipulator, and it can deploy those items to many different hazardous work areas. Rosie's capabilities and system design address the need for durability and reliability in these environments. Rosie was designed and built for multi-purpose applications and may be used by both the Government and private industry in the performance of tasks such as piping and process equipment removal, structural demolition, vessel segmentation, waste handling and transport, wall and floor decontamination and/or cleaning, and surface and structure depainting.

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1: Executive Summary

1.1 Program

RedZone Robotics, Inc., has completed the fabrication, testing, and deployment of an advanced remote worksystem — *Rosie* — specifically designed to meet the challenges of performing a wide range of decontamination and dismantlement (D&D) operations in nuclear environments in support of the Department of Energy's (DOE) Environmental Restoration and Waste Management (EM) Program.

The project was funded by the DOE's Environmental Management Office of Technology Development through the Federal Energy Technology Center (FETC). While tailored to the specific needs of the Argonne National Laboratory CP-5 reactor dismantlement effort, the goal of the Rosie project was to develop a technology that would be useful for general D&D operations throughout the DOE's EM program.

1.2 Technology Description

Rosie is a mobile robot worksystem developed for nuclear facility D&D. Rosie is shown in Figure 3-1. Its primary function is to perform a variety of dismantlement tasks remotely by deploying tools, sensors, and/or other robotic equipment into hazardous areas. Rosie's capabilities and system design address the need for durability and reliability in these environments, and enable performance of tasks such as piping and process equipment removal, structural demolition, vessel segmentation, waste handling and transport, and wall and floor decontamination.

The system includes a tethered robot, a power distribution unit (PDU), and a control console for robot operation. The robot consists of two major subassemblies, the locomotor and the heavy manipulator. The locomotor is a hydraulically powered, omni-directional platform with onboard tether management. It provides mobility to transport the heavy manipulator, tools, or other payloads within the work area. The heavy manipulator is a four degree of freedom, high-payload, long-reach mechanism capable of carrying a variety of tools, one or more dexterous manipulators, or any other payload of up to 900 kg (2,000 lb.) throughout a generous work envelope. The work envelope is the entire range of positions in which the tip of the heavy manipulator can be positioned relative to the locomotor. Rosie is a tele-operated system with low-level

automation features that facilitate more efficient remote operations and allow a single operator to maneuver and work effectively.

1.2.1 Locomotor

The locomotor is a hydraulically powered mobile platform with a welded aluminum frame which supports wheel modules at each corner. Each wheel module has independent drive and steering motions providing an omni-directional capability.

The front two wheels are mounted on extensions which can change the front wheel tread width from 193 cm (76 in.) to 345 cm (136 in.). The two rear wheels are mounted on a pivoting beam which allows each wheel ± 5 cm (± 2 in.) of vertical travel for obstacle negotiation.

Located within the locomotor is the hydraulic power supply, which is a 45 kW (60 HP) supply, providing 114 l/min (30 GPM) of hydraulic fluid at 207 bar (3,000 psi) for all robot motions. The hydraulic fluid reservoir is located at the front center of the locomotor. Directly behind it is the hydraulic pump and its electric drive motor. All of the control valving for the system is located above the pump and motor, inside the locomotor frame. Filters, an accumulator, and the hydraulic fluid cooling equipment are all located on the right side of the locomotor, in one of two side enclosures suspended from the frame. The other enclosure, on the left side of the frame, contains all onboard control electronics for the system. At the rear of the machine is the tether reel which can carry up to 50 m (165 feet) of tether. Up to 100 m (335 ft) of unreeled tether can be included to extend the vehicle's range.

1.2.2 Heavy Manipulator

The heavy manipulator is mounted on the deck of the locomotor. It is a four degree-of-freedom mechanism providing a long-reach, high-payload capability for tool deployment. The heavy manipulator consists of four joints; a waist rotation 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.

1.2.3 Power Distribution Unit (PDU)

The Power Distribution Unit (PDU) located between the console and robot provides a location to input site electrical power needed for onboard functions. When operating in a contaminated area, the PDU can be located outside of containment, minimizing the number of conductor penetrations required through containment. The PDU is where the site electrical interface connections are made, and it serves as the interface between the robot and the operator control console.

1.2.4 Control System and Console

The Rosie control system is comprised of an operator control console (shown in Figure 3-2) and onboard control system components linked by a telemetry system. Control system functions are distributed across two primary computers (CPUs) – one in the console and one onboard the robot. The control console CPU displays status and sensor data coming from the robot, interprets signals from joysticks and other switches on the console control panels, and sends appropriate commands to the onboard CPU. The onboard CPU executes commands from the console by closing motion control loops, acquiring sensor data, coordinating axes, and activating video and other onboard equipment. Both CPUs perform continuous error checking and monitoring of communications between the robot and console.

Using this control system, a single operator stationed at the console can control the Rosie worksystem. The control console incorporates ergonomic design considerations for long duration operation. Primary system functions—locomotor, heavy manipulator, system power, tether, and cameras—are controlled using switches and joysticks on the control console panels. Less frequently used functions and status information are accessed through the touch screen. Three video monitors, each with quad-splitting capability, display the onboard camera views. The operator can select any camera view for any of the monitors using the touch screen controls. In this way, each operator can configure the control console monitors to suit his or her particular preferences. In addition, the views can be changed during operation of the system, as needs arise.

1.2.5 Tooling

A wide variety of tools or dexterous manipulators can be deployed from the heavy manipulator or locomotor deck, depending on application needs. Highly accurate variable-speed motion control allows an operator to position tools quickly and perform work tasks effectively. The Rosie work envelope allows floor to ceiling reach with most tools in most D&D settings. Both hydraulic and electric power are available at the boom tip to power tools. Any user specified tooling can be deployed subject to power availability (57 l/min hydraulic fluid at 207 bar (15 GPM at 3,000 psi) and 120 VAC at 20 Amps) and payload weight (up to 900 kg (2,000 lb)) constraints.

1.3 Results

RedZone has been able to design fabricate, test, and deliver the Rosie system within two weeks of the original scheduled delivery date. The system was delivered to Argonne National Laboratory on November 26, 1996, was installed early the next week, and has been in operation there since December 3, 1996. During the month of December several Argonne personnel were trained in the operation and maintenance of the Rosie system.

A hydraulic breaker was installed at the tip of the heavy manipulator boom at Argonne. As a test and demonstration, the breaker was used to remove concrete from a

section of the upper annular shield plug which had already been removed from the reactor. Concrete was manually removed from two other sections of the plug before Rosie arrived at Argonne. This was accomplished using jack hammers with technicians in full contamination suits. Based on this test, it is estimated that the concrete was removed between five and ten times faster using Rosie than with the manual method. In addition, with Rosie, no personnel were exposed to hazardous materials.

1.4 Future Activities

Funding on the current Rosie contract with FETC has been completely expended. RedZone is seeking additional funding from Argonne National Laboratory (ANL) to provide continuing support during the operations of Rosie at the CP-5 site. If this funding is approved, it would allow RedZone personnel to provide additional training for ANL personnel, as well as both operational and maintenance support while Rosie is being used in support of the CP-5 dismantlement.

1.5 Other Rosie Activities

In addition to the planned activities at ANL, other applications for the Rosie worksystem have been identified in support of D&D operations in the DOE and the commercial nuclear industry. Also, several tasks outside of D&D operations have been identified for which Rosie might be useful, including depainting and surface cleaning. It would be particularly applicable in areas where paint being removed was hazardous (lead based) or where the process could be automated.

1.6 Conclusions and Recommendations

The experience gained during the design, fabrication, and testing of the first Rosie system has been the basis for the enhancements made to the second system, which has been deployed at the Argonne CP-5 site. Preliminary indications are that these enhancements have significantly improved the performance of the Rosie system, from both an operational and maintenance standpoint.

One small demonstration has already shown that the Rosie system is capable of performing real world work in a hazardous environment, faster and more efficiently than trained technicians. Rosie provides the added benefit of not requiring any personnel exposure to the hazardous environment near the CP-5 reactor. It is fully expected that Rosie will prove to be a valuable tool during the remainder of the dismantlement work at the CP-5 site over the next year.

2: Introduction

RedZone Robotics has developed and built a tethered, mobile, remotely operated robotic worksystem, called Rosie, for decontamination and dismantlement operations in nuclear environments to support the dismantlement of the Chicago Pile Reactor (CP-5) located at Argonne National Laboratory (ANL).

The development of the original Rosie worksystem has occurred in three separate phases. The first consisted of gaining a knowledge of the DOE's decontamination and dismantlement (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 (Rosie) to perform D&D operations based on knowledge gained in Phase I. During the third phase Rosie was tested extensively to determine general capabilities to deploy tools and perform D&D tasks, as well as assess reliability and maintenance issues.

The tasks and constraints which characterize D&D applications are essential background in the development of this technology. The environment in which such worksystems must perform D&D operations range from areas in which no worker protection is needed, to areas in which human entry is precluded. Dangers can include exposure to alpha, beta, and gamma radiation; uranium, plutonium, and tritium; volatile organics; acids and caustics; mercury; transuranic waste; asbestos; and mixed waste. 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 hazards present, and the difficulty in predicting conditions or comprehensively understanding task needs, remote technology must be highly versatile and reliable. These worksystems require capabilities to handle a variety of tools, they must combine brute force for heavy work with dexterity for fine manipulation, they must be reliable for extended use in areas where human intervention is difficult or impossible, and they must be adaptable to a wide range of work conditions and settings.

The second phase of this project encompassed the design and fabrication of a worksystem specifically tailored to D&D needs. The Phase I study demonstrated that

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 D&D needs, a concept was selected that was capable of addressing a major segment of tasks for which current technology is inadequate.

The application of this second Rosie system, whose basic design was originally developed under the DOE's Program for Research and Development Announcement (PRDA), is to support the decommissioning and dismantlement of the CP-5 reactor and facility at Argonne National Laboratory. After the original Rosie system was designed and built, it was extensively tested at Oak Ridge National Laboratory (ORNL). The results of this testing revealed several areas where enhancements could be made to improve the performance of Rosie, or simplify its maintenance procedures. In addition, during the redesign of the second Rosie system, a formal external design review was held. The results of this review were several more recommendations for improvements to the system. All of these design enhancements have been incorporated into the second Rosie system in order to meet the requirements for the hot operations in the CP-5 reactor at ANL. This redesign included the following enhancements:

- Radiation resistant materials and components were substituted for existing materials and components that have lower tolerances for radiation exposure.
- The maintenance and repair procedures for the system were simplified in order to reduce personnel exposure during these operations.
- The tether management system fair lead was completely redesigned to improve its function and reliability.
- Reinforcements were added to several areas on the heavy manipulator to reduce deflections and localized stresses.
- Fastening hardware and other components were better secured against long duration vibration loads, especially on the heavy manipulator.
- The control console was redesigned for more efficient, less strained operations (switch and touch screen layout, joysticks, etc.).
- The complexity of the onboard control electronics was reduced to increase reliability and simplify maintenance.
- The cooling capacity of the hydraulic system was increased.
- A separate filtration loop was added to the hydraulic system to better control fluid cleanliness.
- The hydraulic control valving was changed from proportional valves to servo valves to improve stability and reliability, to increase radiation hardness, and to simplify the control electronics.
- The hydraulic hosing was changed from braided hose to smooth hose to reduce potential contaminant entrapment.

- Four additional fixed cameras were added, two on each side of the locomotor, to make driving the vehicle easier and more efficient.
- The wheel steering resolvers were remounted in a location that provided more protection against damage from debris and their electrical cables were routed internally instead of through a cable loop.
- Covers were added to the wheel module brackets to prevent debris from entering where the resolvers and plumbing are located.
- The hydraulic plumbing throughout the system was simplified and improved through the use of more manifolds and better hose and tubing routing.
- Counterbalance valves were added to the actuation cylinders on the shoulder axis so that in the event of a hose failure, the axis would lock in place rather than fall freely.
- A lifting hook with a load cell was added at the boom tip before the wrist axis. The readout of the load cell is at the operator's console. This allows a load to be lifted by the main boom of the heavy manipulator to determine how much it weighs before it is lifted by the wrist.
- A two axis tilt sensor was added to the locomotor with its readout at the operator's console. This gives the operator positive indications when the locomotor starts to tilt in any direction. A threshold alarm was also provided.
- All of the welds on the locomotor frame weldment were inspected with a liquid penetrant test to ensure their integrity.

In addition, during the redesign process, an effort was made to improve the decontaminability of the system so that it can be more easily cleaned after use in a radiologically contaminated environment. This will help to ensure that maintenance personnel exposure will be minimized when working on the system to change tooling, to perform normal maintenance procedures, or during shipping or storage of the system.

RedZone has completed the design fabrication, and testing of the second Rosie system. It was delivered to the Argonne National Laboratory CP-5 reactor site on November 26, 1996, and was installed early the following week. It has been in operation there since December 3, 1996. It is expected that over the next year, the system will be used extensively in D&D operations at the CP-5 site.

3: System Description

Rosie is a mobile robot worksystem developed for nuclear facility D&D. Rosie is shown in Figure 3-1. Its primary function is to perform a variety of dismantlement tasks remotely by deploying tools, sensors, and/or other robotic equipment into hazardous areas. Rosie's capabilities and system design address the need for durability and reliability in these environments, and enable performance of tasks such as piping and process equipment removal, structural demolition, vessel segmentation, waste handling and transport, and wall and floor decontamination.

Figure 3-1 Rosie-C Robot

The system includes a tethered robot, a power distribution unit (PDU), and a control console for robot operation. The robot consists of two major subassemblies, the locomotor and the heavy manipulator. The locomotor is a hydraulically powered, omni-directional platform with onboard tether management. It provides mobility to

transport the heavy manipulator, tools, or other payloads within the work area. The heavy manipulator is a four degree of freedom, high-payload, long-reach mechanism capable of carrying a variety of tools, one or more dexterous manipulators, or any other payload of up to 900 kg (2,000 lb) throughout a generous work envelope. Rosie is a tele-operated system with low-level automation features that facilitate more efficient remote operations and allow a single operator to maneuver and work effectively.

3.1 Locomotor

The locomotor is a mobile platform with a welded aluminum frame that supports wheel modules at each corner. Each wheel module has independent drive and steering motions providing an omni-directional capability.

The front two wheels are mounted on extensions that can change the front wheel tread width from 193 cm (76 in) to 345 cm (136 in). The two rear wheels are mounted on a pivoting beam that allows each wheel ± 5 cm (± 2 in) of vertical travel for obstacle negotiation.

Located within the locomotor is the hydraulic system which provides high pressure hydraulic fluid for all robot motions. The hydraulic system consists of three major parts, the reservoir, which is located at the front of the locomotor, the electric motor, hydraulic pump, and main manifold, which are located in the center of the locomotor, and the hydraulics enclosure on the right side of the locomotor, which houses the heat exchanger, filters, kidney loop filtration circuit, and accumulator. The left side enclosure contains all onboard control electronics for the system. At the rear of the machine is the tether reel which can carry up to 50 m (165 ft) of tether (up to 100 m (335 ft) of unreeled tether that can be included to extend the vehicle's range).

3.2 Heavy Manipulator

The heavy manipulator is mounted on the deck of the locomotor. It is a four degree-of-freedom mechanism providing a long-reach, high-payload capability for tool deployment. It can carry up to 900 kg (2,000 lb) with a 6,800 Nm (60,000 in.-lb) moment load, at a distance of 6 m (20 ft) from the shoulder joint. The heavy manipulator consists of four joints; a vertical axis waist rotation motion on the locomotor deck, a shoulder pitch motion, a linear 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 heavy manipulator is capable of lifting its rated load in any position. However, due to the possible tip over of the locomotor on which it is mounted, it cannot lift this load at full extension over its entire work envelope. With the front wheels fully extended, a 680 kg (1,500 lb) counterweight mounted on the manipulator turret, and the rear pivoting axle in its locked position, the full load can be carried at full extension for about ± 45 degrees of waist rotation. As the waist rotates further, the full extension

load capacity must be reduced to prevent tip over of the locomotor. This subject is discussed further in Section 3.10.3, Heavy Manipulator Load Limits.

3.3 Video System

The audio/video system takes multiple camera views and microphone inputs from the robot and displays them at the console. Rosie-C can accommodate up to twelve cameras. The following eleven are included with the system:

- Four fixed position cameras for driving (two on each side of locomotor)
- Two full function cameras at the left and right shoulders (with pan, tilt, zoom, focus, lights, and microphone)
- One fixed camera on top of the boom outer tube near the shoulder (with light)
- One full function camera at the tip of boom (with pan, tilt, zoom, focus, lights, and microphone)
- One tilt camera at the tip of boom (with light)
- One fixed camera at the tip of boom (with lights)
- One tilt camera at the rear of locomotor to monitor tether (with light)

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

3.4 Tether

The tether management system consists of a hydraulically powered tether reel and level wind mechanism with a fair lead, located at the rear of the locomotor. This system is controlled by the operator by means of a proportional switch that governs payout/take-up. A moveable camera located above the tether reel enables the operator to monitor the position and length of the tether paid out behind the locomotor.

3.5 Power Distribution Unit (PDU)

A Power Distribution Unit (PDU) is located between the console and robot and provides a location to input site electrical power needed for onboard functions. When operating in a contaminated area, the PDU can be located outside of containment, minimizing the number of conductor penetrations required through containment.

3.6 Power and 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 tether is used to transmit all power, control, and video signals to and from the robot. All signals from the console pass through the PDU and are combined with the power and routed into the tether.

The heart of the electrical system onboard the locomotor is contained in a sealed shock mounted enclosure located on the left side of the frame. This enclosure houses transformers, control computing, power supplies, video modulation equipment, and heat exchanger units.

Figure 3-2 Control Console

3.7 Operator Interface

The Rosie-C control system is comprised of an operator control console (shown in Figure 3-2) and onboard control system components linked by a telemetry system. Control system functions are distributed across two primary computers (CPUs) – one in the console and one onboard the robot. The control console CPU displays status and sensor data coming from the robot, interprets signals from joysticks and other switches on the console control panels, and sends appropriate commands to the onboard CPU. The onboard CPU executes commands from the console by closing motion control loops, acquiring sensor data, coordinating axes, and activating video and other onboard equipment. Both CPUs perform continuous error checking and monitoring of communications between the robot and console.

Using this control system, a single operator stationed at the console can control the Rosie-C worksystem. Primary system functions — locomotor, heavy manipulator, system power, tether, and cameras — are controlled using switches and joysticks on the control console panels. Less frequently used functions and status information are accessed through the touch screen. Three video monitors, each with quad-splitting capability, display the onboard camera views. The operator can select any camera view for any of the monitors using the touch screen controls. In this way, each operator can configure the control console monitors to suit his or her particular preferences. In addition, the views can be changed during operation of the system, as needs arise.

3.7.1 Operator Control Station

The Rosie operator control station consists of two parts: the control console and the controller cabinet. These are described in the following sections:

Control Console

The control console provides for remote operation of the Rosie-C system and consists of the console furniture, the video monitors, and the operator panel assembly. The console furniture, manufactured by Anthros, is of a modular, rugged, and flexible design that can be configured to the requirements of the operator. The wrap around console shelf, which supports the three 48 cm (19 in.) video monitors, is adjustable in 2.5 cm (1 in.) increments for setting the proper monitor height and adapting to different monitor sizes. The shelf measures 60 cm deep by 183 cm wide (23.5 in. deep x 72 in. wide). It is constructed of 2.5 cm (1 in.) thick, industrial grade particle board and is covered with a high pressure, scratch resistant laminate and vinyl edge trim. A second identical shelf, located just below the monitor shelf, supports the touch screen monitor electronics and keyboard, as well as serving as a storage shelf for other items, such as the system log books, electrical schematics, and mechanical drawings. The shelves are supported by 16 gauge steel tube legs that can support 68 kg (150 lbs). In front of the wrap around shelves is a large, spring balanced, adjustable height work surface that has been modified to become the control panel. A quick release lever under the control panel allows the operator to adjust the height within a 30 cm (12 in.) range. The tilt angle of the control panel can also be adjusted for operator comfort and preference.

Three video monitors are provided with the control console. The monitors, SONY Model PVM-1954, are high resolution 48 cm (19 in.) color displays. They are used to display the views from the cameras onboard the Rosie system, from the VCR in the console rack, or from an external source. The views displayed on each monitor can be rearranged to the operator's preference using the controls on the touch screen. The monitors are mounted on the top shelf of the console furniture and are angled toward the operator.

The operator panel assembly replaces the desktop supplied with the Anthros furniture. It contains all the controls and feedback necessary for operation of the Rosie-C system.

Status Panel

The status panel for the Rosie-C system is the tilted, 79 X 24 cm (31 X 9.5 in.) rectangular portion of the operator panel assembly shown in Figure 3-3. It is arranged in functional sections. The left side of the status panel contains the switches and indicators for Console Power, Onboard Electronics, and the HPS (Hydraulic Power Supply). The right side of the status panel contains the switches and indicators for the Front Extensions, Rear Suspension, Wrist Tracking, and Auxiliary Functions. Across the top of the panel is a red area that contains the fault reset switch, the emergency stop switch, and footswitch tooling on indicator. The switches and indicators are grouped

Figure 3-3 Status Panel

logically according to functions, and the functions are arranged in the typical sequence required for system start-up and operation. A detailed description of the function of each switch and/or indicator in each section follows:

Console Power

- **Ready Indicator Light (Green)** - This indicator light illuminates when the console CPU has finished booting and is ready for operation.
- **On/Off Keylock Switch** - A two position key operated switch that is used to turn all electrical power to the control console on and off. Power is off when the switch is turned counterclockwise to the Off position, and on when it is turned clockwise to the On position. This switch is used to mechanically lock the system in the off condition in order to prevent unauthorized access.
- **Lamp Test Switch** - A momentary contact style push-button switch that is used to verify the operation of all indicator lights on the operator panel assembly, except for the Onboard Electronics On indicator, the HPS On indicator, and the Auxiliary Functions indicators.

Onboard Electronics

- **Ready Indicator Light (Green)** - This indicator light illuminates when the onboard electronics CPU has finished booting and is ready for operation.

- **On/Off Rocker Switch** - A momentary contact rocker switch that is used to turn the onboard electronics on or off. A green indicator light is located above the switch. This light is illuminated when the onboard electronics is on.
- **Onboard Temperature High Indicator Light (Green)** - This indicator light illuminates when the temperature inside the onboard electronics enclosure rises to an unacceptable level. When this light come on, the audible alarm also sounds to alert the operator.

HPS

- **Ready Indicator Light (Green)** - This indicator light illuminates when the system is in a condition where it is possible to turn on the main hydraulic power supply.
- **On/Off Rocker Switch** - A momentary contact rocker switch that is used to turn the main hydraulic power supply on or off. A green indicator light is located above the switch. This light is illuminated when the main hydraulic power supply is on.
- **Fluid Level Low Indicator Light (Red)** - This indicator light illuminates when the fluid level in the hydraulic reservoir on the locomotor is low. When the fluid is below the recommended level, the light is on continuously. When the fluid level is critically low, the light blinks. When this light come on, the audible alarm also sounds to alert the operator.
- **Fluid Temperature High Indicator Light (Red)** - This indicator light illuminates when the fluid temperature in the hydraulic reservoir on the locomotor is high. When the fluid temperature is above the recommended temperature, the light is on continuously. When the fluid temperature is critically high, the light blinks. When this light come on, the audible alarm also sounds to alert the operator.
- **System Pressure Low Indicator Light (Red)** - This indicator light illuminates when the pressure of the hydraulic fluid in the system is low. When this light come on, the audible alarm also sounds to alert the operator.
- **Filter Clogged Indicator Light (Red)** - This indicator light illuminates when any of the three hydraulic fluid filters on the locomotor becomes clogged. When this light come on, the audible alarm also sounds to alert the operator.
- **Kidney Pump Fault Indicator Light (Red)** - This indicator light illuminates when the kidney pump motor is in a fault condition and is not operating. When this light come on, the audible alarm also sounds to alert the operator.
- **Main Starter Fault Indicator Light (Red)** - This indicator light illuminates when the starter for the main hydraulic power supply motor is in a fault condition. When this light come on, the audible alarm also sounds to alert the operator.

Front Extensions

- **Left Wheel Extend/Retract Rocker Switch** - A momentary contact rocker switch that is used to manually extend and retract the left front wheel extension. Two green indicator lights, one labeled "Extended" and one labeled "Retracted", are located above the switch. If the lights are alternating, it indicates that the position of the extension is

not defined. If one of the lights is blinking, it indicates that the extension is moving toward that position. If one of the lights is on continuously, it indicates that the extension is in that position. After this switch has been pressed to extend or retract the left front wheel extension, one light will blink to indicate that the extension sequence has started. When the extension sequence is finished, the light will illuminate continuously, a double beep will be heard from the audible alarm, and a message will appear in the message window on the touch screen that says "Extension Move Completed".

- **Right Wheel Extend/Retract Rocker Switch** - A momentary contact rocker switch that is used to manually extend and retract the right front wheel extension. Two green indicator lights, one labeled "Extended" and one labeled "Retracted", are located above the switch. If the lights are alternating, it indicates that the position of the extension is not defined. If one of the lights is blinking, it indicates that the extension is moving toward that position. If one of the lights is on continuously, it indicates that the extension is in that position. After this switch has been pressed to extend or retract the right front wheel extension, one light will blink to indicate that the extension sequence has started. When the extension sequence is finished, the light will illuminate continuously, a double beep will be heard from the audible alarm, and a message will appear in the message window on the touch screen that says "Extension Move Completed".

Rear Suspension

- **Suspension Mode Switch** - A momentary contact style push-button switch that is used to change the mode of the rear suspension from unlocked to locked or from locked to unlocked. Two green indicator lights, one labeled "Unlocked" and one labeled "Locked", are located above the switch. If neither light is illuminated, it indicates that the condition of the rear suspension is not defined. If one of the lights is on continuously, it indicates that the rear suspension is in that mode. After this switch has been pressed to unlock or lock the rear suspension, one light will blink to indicate that the suspension mode change sequence has started. When the suspension mode change sequence is finished, the light will illuminate continuously, a double beep will be heard from the audible alarm, and a message will appear in the message window on the touch screen that says either "Suspension Unlocking Completed" or "Suspension Locking Completed".

Wrist Tracking

- **Wrist Tracking On/Off Rocker Switch** - A two position rocker switch that is used to turn the wrist tracking function on the heavy manipulator on or off. Two green indicator lights, one labeled "Off" and one labeled "On", are located above the switch. One of the two lights is always illuminated to indicate the state of the wrist tracking function.

Auxiliary Functions

- **Auxiliary 1 and Auxiliary 2 Rocker Switches** - Two, two position rocker switches are located in this area. These switches have no function at this time. They are here in case

other functions are added at a later date. Each switch has two green indicator lights with no labels.

Top of Status Panel

The red bar across the top of the status panel includes two switches and one indicator as follows:

- **Fault Reset Switch** - A momentary contact style push-button switch that is used to turn off the audible alarm and reset any latched faults that have occurred in the control logic.
- **E-stop (Emergency Stop) Switch** - A large round, red, illuminated, two position push switch that is used to shut down the main hydraulic power supply and the kidney loop pump motor on the locomotor. Pushing this switch in shuts down the system and lights up the head of the switch. Pulling the switch out enables the system so that the kidney loop pump motor and the main hydraulic power supply can be started, provided that all other interlocks are cleared. This switch is hard wired in series with both the E-stop switch on the PDU and the pendant E-stop switch on the locomotor. If any of these three switches are pushed in, the HPS cannot be started.
- **Footswitch Tooling On Indicator Light (Green)** - This indicator light illuminates when the console footswitch has been actuated to provide power to whatever tooling has been selected using the touch screen Tool Control Configuration menu.

Control Panel

The large 125 X 60 cm (49 X 23.5 in.) flat portion of the operator panel assembly is the control panel for the Rosie-C system. It is shown in Figure 3-4. It is arranged in functional sections. The left side of the control panel contains a complete set of camera control switches and indicators, and the joystick, mode switch, and mode indicators for the control of the locomotor. The right side of the control panel contains another complete set of camera control switches and indicators, and the joystick, mode switch, and mode indicators for the control of the heavy manipulator. The center of the control panel has an area that is reserved for a Mini-master controller arm for a Schilling manipulator arm, should one be installed at the end of the heavy manipulator.

Figure 3-4 Control Panel

Camera Controls

There are 11 color cameras mounted on the Rosie-C system, five on the locomotor and six on the heavy manipulator. The views from each of the cameras can be displayed on any of the three video monitors at the console, as well as in any of the four views of the quad view, which can be displayed on any of the three monitors. The camera controls can be used to select and control any of the cameras that are displayed on the monitors. There are two identical sets of camera controls on the control panel, one set on the left side and one on the right side. The controls are wired in parallel, so only one camera can be controlled at any time. The layout of the camera controls is shown in Figure 3-5. The function of each of these controls is described below:

- **Camera Selector Switches** - Six momentary contact, latching, push-button switches allow the operator to select any of the six possible camera views that can be displayed on the three video monitors.

Each switch has an integral indicator which illuminates when that switch (and its corresponding camera) is selected. Only one camera can be selected at a time. Pressing a non-illuminated switch illuminates the indicator on that switch, selects the camera corresponding to that switch, disables the previously selected camera, and turns off the indicator light on its switch.

Figure 3-5 Camera Controls

The four uppermost camera selector switches are labeled "Quad Monitor". These four switches are used to select the cameras that are displayed on whichever monitor is displaying the quad view. (Only one monitor can display a quad view at any time.) If no monitor is currently displaying a quad view, the upper left "Quad Monitor" switch will select the camera displayed on the center monitor (monitor number 2).

The two lower camera selector switches are labeled "Left Monitor" and "Right Monitor". These two switches are used to select the cameras that are displayed on left most and right most monitors which are not displaying the quad view.

Immediately after the control console electronics has been booted, no camera will be selected and one of the camera selector switches must be pressed before the camera controls will function. In addition, immediately after the onboard electronics has been booted, the camera functions (pan, tilt, zoom, focus, and lights) will not be

available until the E-stop has been cleared and the kidney loop pump has been turned on once. After the E-stop has been cleared once, the camera functions will remain available until the onboard electronics are rebooted. (This happens because the console electronics does not recognize the "heartbeat" of the onboard electronics until the E-stop has been cleared once.)

- **Pan and Tilt Switch** - A four quadrant momentary contact rocker switch that is used to control the pan and tilt functions of a selected camera, when either or both of those functions are available on that camera. Pressing on the upper portion of the diamond shaped switch (labeled "Tilt Down") causes the camera to tilt down. Pressing on the lower portion of the diamond shaped switch (labeled "Tilt Up") causes the camera to tilt up. Pressing on the left portion of the diamond shaped switch (labeled "Pan Left") causes the camera to pan towards the left. Pressing on the right portion of the diamond shaped switch (labeled "Pan Right") causes the camera to pan towards the right.
- **Zoom In and Out Switch** - A momentary contact rocker switch that is used to zoom the lens of the selected camera in or out, if that camera has a zoom lens. Pressing the upper half of the switch (labeled "In") causes the camera to zoom in for a closer view. Pressing the lower half of the switch (labeled "Out") causes the camera to zoom out for a wider angle view.
- **Focus In and Out Switch** - A momentary contact rocker switch that is used to manually focus the lens of the selected camera in or out, if that camera has a lens that can be focused, and if the auto focus function has been disabled. Pressing the upper half of the switch (labeled "In") causes the camera to focus closer in. Pressing the lower half of the switch (labeled "Out") causes the camera to focus farther out. The auto focus function is enabled and disabled using the "Axis Disable" menu on the touch screen.
- **Lights On and Off Switch** - A momentary contact rocker switch that is used to turn the light(s) of the selected camera on or off, if that camera has a light(s). Pressing the upper half of the switch (labeled "On") causes the camera light(s) to illuminate. Pressing the lower half of the switch (labeled "Off") causes the camera light(s) to turn off. The brightness of the lights cannot be controlled, they can only be all the way on, or all the way off.

Locomotor

There are only two controls needed to drive the locomotor, a four axis joystick and a driving mode selector switch. The function of each of these controls is described below:

- **Locomotor Joystick** - A four axis joystick that is used to control the driving and steering of the locomotor and the payout and take-up of the tether from the tether reel at the rear of the locomotor. The function of this joystick is dependent on the driving mode that is currently selected by the Locomotor Mode switch. The function of each axis, in each of the three driving modes is as follows:

• **4 Wheel Mode** - In this mode, the front and rear wheels steer in opposition, allowing a turn of any radius, from a pivot about the vehicle's center, to a straight line. In this mode the joystick functions as follows:

- ◆ **Trigger Switch** - enables all active joystick functions. Releasing the trigger immediately stops any locomotor or tether motion.
- ◆ **Front to Back (X Axis)** - drives all wheels forward or backward at a speed proportional to the amount of forward or backward movement of the joystick.
- ◆ **Side to Side (Y Axis)** - no function in this mode.
- ◆ **Twist (Z Axis)** - turns the wheels so that the front of the locomotor will drive toward the direction of the twist. Twisting the joystick all the way to either stop will cause the wheels to turn to a position where the locomotor will rotate about its center.
- ◆ **Thumb Switch** - turns on the tether reel to either payout or take-up the tether. Moving the switch to the left causes the tether to be paid out from the reel. Moving it to the right causes it to be taken back up onto the reel. The farther the switch is moved to either side, the faster the tether is paid out or taken up.

• **Crab Mode** - In this mode, all four wheels steer in the same direction, allowing the locomotor to translate in any direction, forward, backward, side to side, or at any angle relative to its centerline.

- ◆ **Trigger Switch** - enables all active joystick functions. Releasing the trigger immediately stops any locomotor or tether motion.
- ◆ **Front to Back (X Axis) and Side to Side (Y Axis)** - in this mode, these two axes are used together. All four wheels will be steered in the same direction that the joystick is moved toward. The wheels will be driven at a speed proportional to the amount of this movement.
- ◆ **Twist (Z Axis)** - no function in this mode.
- ◆ **Thumb Switch** - turns on the tether reel to either payout or take-up the tether. Moving the switch to the left causes the tether to be paid out from the reel. Moving it to the right causes it to be taken back up onto the reel. The farther the switch is moved to either side, the faster the tether is paid out or taken up.

• **Point Mode** - In this mode, the wheels are automatically steered to a position that allows the locomotor to rotate about a predetermined point. Presently this is the point directly below the tip of the boom at the time the joystick trigger is pressed.

- ◆ Trigger Switch - enables all active joystick functions and causes the point about which the locomotor will rotate to be selected. Releasing the trigger immediately stops any locomotor or tether motion.
- ◆ Front to Back (X Axis) - drives all wheels so that the locomotor rotates counterclockwise (forward) or clockwise (backward) as viewed from above. The wheels will be driven at a speed proportional to the amount of forward or backward movement of the joystick.
- ◆ Side to Side (Y Axis) - no function in this mode.
- ◆ Twist (Z Axis) - no function in this mode.
- ◆ Thumb Switch - turns on the tether reel to either payout or take-up the tether. Moving the switch to the left causes the tether to be paid out from the reel. Moving it to the right causes it to be taken back up onto the reel. The farther the switch is moved to either side, the faster the tether is paid out or taken up.
- **Locomotor Mode Switch** - A momentary contact style push-button switch that is used to change the driving mode of the locomotor. Three green indicator lights are located above the switch. The illuminated light indicates which driving mode the locomotor is currently in. One light is labeled "4 Wheel", one is labeled "Crab", and one is labeled "Point". The mode switch is used to toggle the locomotor from one mode to another and only one mode can be selected at any time. The modes toggle from "4 Wheel" to "Crab" to "Point" and then back to "4 Wheel".

Heavy Manipulator

There are only two controls needed to operate the heavy manipulator, a four axis joystick and a control mode selector switch. The function of each of these controls is described below:

- **Heavy Manipulator Joystick** - A four axis joystick that is used to control the motions of each of the four axes on the heavy manipulator. The function of this joystick is dependent on the control mode that is currently selected by the Heavy Manipulator Mode switch. The function of each axis, in each of the two control modes is as follows:
 - **Coordinated Mode** - In this mode, the operator is able to steer the tip of the heavy manipulator directly along the X, Y, and Z axes without having to move the four joints of the manipulator individually. The system automatically moves all four joints to achieve the Cartesian motions commanded by the joystick. In this mode the joystick functions as follows:
 - ◆ Trigger Switch - enables all active joystick functions. Releasing the trigger immediately stops all heavy manipulator motions.

- ◆ Front to Back (X Axis) - moves the tip of the heavy manipulator along the X axis, which is the vertical axis. Pushing the joystick forward moves the boom tip straight down, while pulling it backward moves it straight up. The speed of the boom tip is proportional to the amount of forward or backward movement of the joystick.
 - ◆ Side to Side (Y Axis) - moves the tip of the heavy manipulator along the Y axis, which is the side to side axis. Pushing the joystick to the left moves the boom tip toward the left in a straight horizontal line, while pushing it to the right moves it toward the right in a straight horizontal line. The speed of the boom tip is proportional to the amount of side movement of the joystick.
 - ◆ Twist (Z Axis) - moves the tip of the heavy manipulator along the Z axis, which is the front to rear axis. Twisting the joystick counterclockwise (as viewed from the top) moves the boom tip straight toward the rear in a horizontal line, while twisting it clockwise moves it straight forward along a horizontal line. The speed of the boom tip is proportional to the amount of twist of the joystick.
 - ◆ Thumb Switch - rotates the wrist axis either up or down. Moving the switch to the left causes the wrist axis to rotate up (angle increases) while moving it to the right causes it to rotate down (angle decreases). The farther the switch is moved to either side, the faster the wrist axis will rotate. This switch is only functional when the Wrist Tracking function is turned OFF. When the Wrist Tracking function is turned ON, the position of the wrist axis is automatically determined by the system.
- **Joint Mode** - In this mode, the operator is able to individually control each of the four joints of the heavy manipulator using the four axes of the joystick. In this mode the joystick functions as follows:
- ◆ Trigger Switch - enables all active joystick functions. Releasing the trigger immediately stops all heavy manipulator motions.
 - ◆ Front to Back (Shoulder Axis) - rotates the shoulder joint of the heavy manipulator either up or down. Pushing the joystick forward rotates the joint downward (angle decreases), while pulling it backward moves it upward (angle increases). The rotational speed of the shoulder joint is proportional to the amount of forward or backward movement of the joystick.
 - ◆ Side to Side (Forearm Extension Axis) - extends or retracts the forearm extension axis. Pushing the joystick to the left retracts the extension (to a shorter configuration), while pushing it to the right extends it to a

longer configuration. The speed of the retraction or extension motion is proportional to the amount of side movement of the joystick.

- ♦ **Twist (Waist Axis)** - rotates the waist joint either clockwise or counterclockwise. Twisting the joystick counterclockwise (as viewed from the top) moves the waist joint counterclockwise (as viewed from the top) which increases its angle, while twisting the joystick clockwise moves the joint clockwise, which decrease its angle. The rotational speed of the waist joint is proportional to the amount of twist of the joystick.
- ♦ **Thumb Switch** - rotates the wrist axis either up or down. Moving the switch to the left causes the wrist axis to rotate up (angle increases), while moving it to the right causes it to rotate down (angle decreases). The farther the switch is moved to either side, the faster the wrist axis will rotate. This switch is only functional when the Wrist Tracking function is turned OFF. When the Wrist Tracking function is turned ON, the position of the wrist axis is automatically determined by the system.
- **Heavy Manipulator Mode Switch** - A momentary contact style push-button switch that is used to change the control mode of the heavy manipulator. Two green indicator lights are located above the switch. The illuminated light indicates which control mode the heavy manipulator is currently in. One light is labeled "Coordinated" and one is labeled "Joint". The mode switch is used to toggle the locomotor from one mode to the other and back. Only one mode can be selected at any time.

Touch Screen Monitor

The touch screen monitor is mounted on a small shelf that is attached to the right side of the main console furniture. If desired, the shelf can be mounted on left side. The touch screen monitor contains menus and controls for system functions that are not used as often as the ones on the operator panel assembly. A description of these menus and controls and their functions follows:

Main Screen Display

When the control console is first booted up, several menus and display areas appear on the touch screen. A description of each of these items follows:

Figure 3-6 Pop-up Menu Bar Window

- **Pop-up Menu Bar Window** - Across the bottom of the touch screen is the Pop-up Menu Bar window which is shown in Figure 3-6. Six touch buttons on the bar

bring up six different menus which are used to modify or control various functions. A description of each of these menus follows:

Figure 3-7 HPS Startup Menu

- ♦ HPS Startup Button - This button brings up the HPS Startup menu which appears in the upper left hand corner of the touch screen display, as shown in Figure 3-7. This menu must be used every time the main hydraulic power supply (HPS) on the locomotor is started up. This menu makes the system operator do three things: 1) acknowledge that the robot work area is clear of equipment or personnel that might be damaged or injured, 2) choose the startup condition for the rocker arm suspension, and 3) choose the startup condition for the front wheel extensions. When this menu is first brought up, the "OK" button will not be active. This button will not become active until the operator performs the following:
 - a) Verifies that the Rosie system work area is clear of personnel and equipment, then presses the "Rosie Work Area Clear" button.
 - b) Selects the desired condition for the rear suspension rocker arm by pressing either the "Unlocked" or "Locked" buttons in the "Rocker Arm" area of the menu.
 - c) Selects the desired condition for the front wheel extensions by pressing either the "Leave as is", the "Both extended", or the "Both retracted" buttons in the "Front Wheel Extensions" area of the menu.
 - d) Presses the "OK" button. (This will turn on the kidney loop pump motor, enable the rocker arm and front extension choices, and close the HPS Startup window.)

NOTE: If the "OK" button does not highlight at this time, it indicates that the Emergency Stop window has not yet been cleared. Part of that window should be

visible somewhere on the screen. Touch that part to activate the window, and then press the "OK" button to clear the EMERGENCY STOP message.

Figure 3-8 Control Velocities Menu

- ♦ Control Velocities Button - This button brings up the Control Velocities menu which appears in the upper left hand corner of the touch screen display, as shown in Figure 3-8. This menu is used to change the maximum allowable velocities on both the heavy manipulator and the locomotor. This menu contains two slide bar displays, one labeled "Heavy Manipulator" and one labeled "Locomotor". The number above the slide bars indicates the percentage of maximum achievable velocity that the allowable velocity is set to. The operator can change the allowable velocity by touching each slide bar and moving it side to side to change the allowable percentage. Pressing the "Cancel" button closes the menu window without changing the velocities. Pressing the "OK" button applies the new velocities to the system and also closes the menu window. When the velocities are changed, a message will appear in the touch screen message window to indicate the new velocities.

Figure 3-9 Tool Control Configuration Button

- ◆ Tool Control Configuration Button - This button brings up the Tool Control Configuration menu which appears in the upper left hand corner of the touch screen display, as shown in Figure 3-9. This menu is used to select which tooling function will be controlled by the console footswitch. When the system is delivered, only one of these selections is available, the "Boom Electrical Outlet". This options chooses both the electrical outlet on the locomotor deck and the outlet on the boom tip. The "Tool 1" and "Tool 2" solenoid selections will not be available until tooling is installed and wired at the boom tip. Pressing the "Cancel" button closes the menu window without changing the tooling selection. Pressing the "OK" button applies the new tooling selection and also closes the menu window.

Figure 3-10 Teach/Playback Menu

- ◆ Teach/Playback Button - This button brings up the Teach/Playback menu which appears in the upper left hand corner of the touch screen display, as shown in Figure 3-10. This menu is used to control the automated teach/playback mode of operation for the heavy manipulator. This mode allows the operator to manually perform a series of movements with the heavy manipulator while the computer memorizes these motions. The same sequence of motions can then be "played back" automatically by the computer. Operation of the system using the teach/playback feature is an advanced mode of operation.
- ◆ Axis Disable Button - This button brings up the red Axis Disable menu which appears in the middle of the touch screen display over the top of any other windows that are currently open, as shown in Figure 3-11. This menu is used to enable or disable any of the axes on either the locomotor or heavy manipulator. After a selection is made, pressing the "Recover" button will apply the selected changes and close the

window. A "Recovery Complete" message will then appear in the message window on the touch screen. Pressing the "Cancel" button closes the menu window without changing the condition of any of the axes. Pressing the "Shutdown" button turns off the main HPS on the locomotor if it is running and also closes the menu window.

Figure 3-11 Axis Disable Menu

Figure 3-12 Axis Jog Menu

- ♦ **Axis Jog Button** - This button brings up the Axis Jog menu which appears in the upper left hand corner of the touch screen display, as shown in Figure 3-12. This menu is used to move any of the steering or heavy manipulator axes in very small increments. The angular axes will be moved in 0.1 degree increments and the linear extension axes will be moved in 0.1 inch increments. To move an axis, the operator selects the axis with its button and then presses the left or right arrow buttons. The selected axis will then move one increment for each push of the button. Each axis can be moved in either direction. Pressing the "Done" button closes the menu window.
- **Video Monitor/Camera Selection Window** - On the left side of the touch screen display, above the pop-up menu bar window, is a window area which is used to control the selection of camera views on the video monitors. This window is shown in Figure 3-13. The lower portion of this window has three rectangular buttons which represent the three video monitors on the control console. Each button will have a name in it corresponding to a camera view, either on the Rosie system or from an external source. Below each of these buttons, is a smaller rectangular button that is labeled either "Quad ON" or "Quad OFF". Pressing a button labeled "Quad ON" will cause the quad video view to appear in the corresponding monitor. Pressing the "Quad OFF" button will cause the quad view to disappear from the corresponding monitor.

Figure 3-13 Video Monitor/Camera Selection Window

The upper portion of the video monitor/camera selection window has 14 buttons arranged in two horizontal rows. Twelve of these buttons are labeled with

camera locations on the Rosie system. One is labeled "Ext. Source" and one is labeled "VCR Playback". These buttons are used to select which camera view or video source is to be displayed on which console monitor.

To display a particular camera view on a particular monitor, press the button labeled with that camera view (from the 14 small buttons) to make that button active, then press the button corresponding to the monitor where the view is to be displayed (either as a full display or as one of the four views in a quad display). This will cause the label of the selected camera view to appear in the button of the selected monitor, as well as causing the selected camera view to appear on the actual monitor. Any camera view or video source can be displayed on any monitor (or in any of the four quad views) and the touch screen can be used to change these views at any time.

- **Message Window** - On the right side of the touch screen display, directly above the pop-up menu bar window, is a window which is used to display informational messages from the system software to the operator. This window is shown in Figure 3-14. The right side of this window has a scroll bar which can be used to view messages that were sent previously, but have scrolled up and out of view. Some of the messages that appear in this window are accompanied by a double beep of the audible alarm to make the operator aware that a message has appeared.

Figure 3-14 Message Window

- **Status Window** - On the right side of the touch screen display, directly above the message window and extending to the top of the screen, is a multi-colored window which is used to display the status of various items. This window is shown in Figure 3-15. This window is divided into five different colored areas, each of which displays the status of a related group of items. A description of each of these areas follows:

Figure 3-15 Status Window

- ◆ **Steering Angle** - The lower portion of the window (rose colored) displays the steering angle of each of the four locomotor wheels in degrees. The displays are labeled "Lf Ft Steer", "Rt Ft Steer", "Lf Rr Steer", and "Rt Rr Steer". Positive angles are counterclockwise as viewed from above the locomotor.
- ◆ **Tilt Sensor Angle** - The next higher portion of the window (lavender colored) displays the readout of the tilt sensor onboard the locomotor in degrees. The sensor has two axes and displays both front to rear tilt,

labeled "Ft/Rr Tilt (deg)", and side to side tilt, labeled "Rt/Lf Tilt (deg)". Positive angles indicate that the front is higher than the rear or the right is higher than the left.

- ◆ Lifting Hook Load - The next higher portion of the window (light green colored) displays the readout of the load cell on the lifting hook at the tip of the heavy manipulator boom in pounds. This display is labeled "Load (lbs)". The displayed load is rounded off to the nearest ten pounds.
- ◆ Heavy Manipulator Joint Positions - The highest portion of the window (light blue colored) displays the positions of the joints of the heavy manipulator. The rotational joints are displayed in degrees and the forearm extension joints are displayed in inches. The forearm extension axis has two displays, one for the outer portion of the joint and one for the inner portion. Two displays are shown because the joint has two separate position sensors. Zero degrees on the waist joint display, labeled "Waist (deg)", indicates that the boom is straight ahead toward the front of the locomotor frame. A positive angle indicates counterclockwise rotation of the waist axis as viewed from above. Zero degrees on the shoulder joint display, labeled "Shoulder (deg)", indicates that the centerline of the boom is parallel to the deck of the locomotor, with positive angles indicating that the boom is angled up above that position. The forearm extension axis is displayed in two parts, labeled "Outer Ext (in)" and "Inner Ext (in)", corresponding to the larger outer tube and smaller inner tube portions of this axis respectively. These displays indicate inches, with zero inches indicating that the extension is fully retracted. Zero degrees on the wrist joint display, labeled "Wrist (deg)", indicates that the mounting face of the wrist axis is perpendicular to the centerline of the boom, with positive angles indicating that this mounting face is tilted up from this position.
- ◆ Motion Enabled/Disabled - At the very bottom of this window a message is constantly displayed. This messages is either "Motion Enabled" or "Motion Disabled". The first message indicates that the various axes of the system can be commanded to move. The second indicates that the axes cannot be moved for some reason, even though the hydraulic power supply may be running.

Special Display Windows

When important or unusual circumstances occur, a special window may be displayed on the touch screen. This window will be colored red and it will appear on top of all other windows that are currently open on the touch screen. A description of each of these windows follows:

Figure 3-16 EMERGENCY STOP Window

- **EMERGENCY STOP Window** - When an emergency stop switch (E-stop) has been pressed, or the system software generates a software E-stop condition, the red EMERGENCY STOP window, shown in Figure 3-16 will appear. The reason for the E-stop condition should be determined before continuing with operations. If it is safe to continue, the E-stop should be pulled out (if one has been mechanically pushed in) and the "OK" button in the window should be pressed. This action will reset the E-stop circuit.

Figure 3-17 STARTUP TIMEOUT Window

- **STARTUP TIMEOUT Window** - If the E-stop circuit has been reset, and the HPS Startup menu has been activated and closed, but the HPS has not been turned on, the system software will initiate a time-out after about three minutes, and the red STARTUP TIMEOUT window, shown in Figure 3-17 will appear. When this happens, follow the instructions in the window and press either the "HPS is ON" button or the "HPS is OFF" button to indicate the current state of the main hydraulic power supply.

Figure 3-18 HPS Pressure Switch Disabled Window

- **HPS Pressure Switch Disabled Window** - If the pressure switch that monitors the output pressure of the hydraulic power supply develops a problem during operations, it can be disabled using the Axis Disable menu. If this is done, whenever the HPS is first turned on, the red HPS Pressure Switch Disabled menu, shown in Figure 3-18 will appear after about 10 seconds. If the pressure switch really has been disabled by the operator, press the "OK" button to continue. Pressing the "Cancel" button will shut down the HPS.

Controller Cabinet

The controller cabinet is a standalone 19 inch rack mount cabinet which houses the electronics that operate the control console including the console controller, long haul modem, audio equalizer, VCR, video demodulators, quad splitter, video router, and video jack panel. There are no user serviceable parts located within the controller cabinet. All connections are made on the rear of the cabinet (see Figure 3-19).

Figure 3-19 Controller Cabinet

Operator Chair

No operator chair is provided with the system. An operator may use the system continuously for several hours at a time. One or more comfortable, adjustable chairs, should be provided at the installation site in order to ensure operator comfort and efficiency during operation of the system. (It is possible for more than one operator to be working with the system at one time, so more than one chair may be needed.)

3.8 Tooling

A wide variety of tools or dexterous manipulators can be deployed from the heavy manipulator or locomotor deck. Highly accurate variable-speed motion control allows an operator to position tools quickly and perform work tasks effectively. The Rosie-C work envelope allows floor to ceiling reach with most tools in most D&D settings. Both hydraulic and electric power are available at the boom tip to power tools. Any user

specified tooling can be deployed subject to power availability (57 l/min hydraulic fluid at 207 bar (15 GPM at 3,000 psi) and 120 VAC at 20 Amps) and payload weight (up to 900 kg (2,000 lb)) constraints.

3.9 System Specifications

The following is a summary of the system specifications:

Table 3.9-1 Rosie Specifications

System Requirements		
Power		
PDU	480 VAC, 3Ø	@ 125 Amps
Control Console	120 VAC, 1Ø	@ 15 Amps
Operating Temperature, ambient	2°C - 38°C	36°F - 100°F
Storage Temperature, ambient	-18°C - 60°C	0°F - 140°F

Robot Size and Weight		
Wheels and Manipulator Retracted, L X W X H	422 cm X 221 cm X 290 cm	166 in. X 87 in. X 114 in.
Wheels and Manipulator Extended, L X W X H	726 cm X 356 cm X 290 cm	286 in. X 140 in. X 114 in.
Locomotor	3,900 kg	8,600 lb.
Heavy Manipulator	1,950 kg	4,300 lb.
Counterweights	680 kg	1,500 lb.
Total	6,530 kg	14,400 lb.

Locomotor		
Weight	3,900 kg	8,600 lb.
Dimensions, L X W X H	310 cm X 221 cm X 107 cm	122 in. X 87 in. X 42 in.
Ground Clearance	15 cm	6 in.
Driving Speed	0 to 0.6 m/sec.	0 to 2 ft/sec

Locomotor (Continued)		
Range of Motion		
Front Wheel Extensions	76 cm	30 in.
Rear Wheel Suspension		
Vertical Travel	± 5 cm	± 2 in.
Steering, all wheels	$\pm 135^\circ$	
Obstacle climb (maximum)	10 cm	4 in.

Hydraulic Power Supply		
Motor size	45 kW	60 HP
Maximum Pressure	207 Bar	3,000 psi
Maximum Flow	114 l/min	30 GPM
Reservoir Capacity	284 l	75 gal
Pump	Variable displacement, pressure compensating	
Fluid	Houghto-Safe 620, water glycol based	

Heavy Manipulator		
Payload Capacity		
Weight	900 kg	2,000 lb
Moment	6,800 Nm	60,000 in.-lb
Boom Tip Services		
Hydraulic	57 l/min @ 207 bar	15 GPM @3,000 psi
Electric	120 VAC	@ 20 Amps
Weight	1,950 kg	4,300 lb
Counterweight Capacity	0 to 680 kg	0 to 1,500 lb

Heavy Manipulator (Continued)		
Axis Motions and Speeds	Motion	Speed
Waist Rotation	+201° to -153°	±0 to 3 deg/sec
Shoulder Pitch	-20° or -13° to +90°	±0 to 3 deg/sec
Forearm Extension	3 to 6 m	±0 to 15 cm/sec
	10 to 20 ft	±0 to 6 in./sec
Wrist Pitch	± 90°	±0 to 3 deg/sec

Video Feedback	
Locomotor	
Driving Cameras (4)	Fixed cameras with fixed focal length Underwater, color CCD camera Two on each side of locomotor, one facing forward and one facing rearward
Tether Camera (1)	Fixed focal length with wide angle lens Underwater, color CCD camera Equipped with tilt motion One 75 Watt wet/dry light
Heavy Manipulator	
Shoulder Cameras (2)	Zoom lens (8:1) with auto/manual focus Underwater, color CCD camera Equipped with pan and tilt motions Integral microphone Two 75 Watt wet/dry lights
Shoulder Top Camera (1)	Fixed camera with fixed focal length Underwater, color CCD camera One 75 Watt wet/dry light

Video Feedback (Continued)	
Boom Tip Cameras (3)	(1) Zoom lens (8:1) with auto/manual focus
	Underwater, color CCD camera
	Equipped with pan and tilt motions
	Integral microphone
	Two 75 Watt wet/dry lights
	(1) Fixed focal length
	Underwater, color CCD camera
	Equipped with tilt motion
	One 75 Watt wet/dry light
	(1) Fixed camera with fixed focal length and wide angle lens
	Underwater, color CCD camera
	Two mini 75 Watt wet/dry lights

Tether		
Diameter	29.2 mm	1.15 in.
Overall length	75 m	250 ft
Length stored on reel	50 m	165 ft
Maximum possible length	150 m	500 ft

PDU		
Weight	475 kg.	1,050 lb.
Dimensions, L X W X H	168 cm X 76 cm X 188 cm	66 in. X 30 in. X 74 in.
Cable Length		
PDU to Control Console	38 m	125 ft

Control Console		
Controller Cabinet		
Weight	115 kg	250 lb
Dimensions, H X W X D	130 cm X 64 cm X 81 cm	51 in. X 25 in. X 32 in.
Control Console		
Weight	205 kg	450 lb
Dimensions, H X W X D	140 cm X 183 X cm 127 cm	55 in. X 72 in. X 50 in.
Video Monitors (3)	Sony PVM-1954Q	48 cm (19 in.)
Touch Screen Monitor (1)	Tektronix XP217C	40 cm (16 in.)
Cable Lengths		
Control Console to PDU	38 m	125 ft
Control Console to Controller Cabinet	7.5 m	25 ft

3.10 Robot Operation

Operating the Rosie system requires extensive and specific training. Only properly trained and qualified operators should operate the system at any time.

3.10.1 Locomotor Driving

The locomotor is controlled and driven using the locomotor joystick on the left side of the control console. This joystick can be used in any of three different driving modes, 4 Wheel mode, Crab mode, and Point mode. At the top of the joystick is a thumb switch which is used to take up or payout the tether, onto or off of, the tether reel. This action can be monitored using the tether reel camera, which is mounted just above the reel. The thumb switch provides a variable speed control for the tether reel operation. The farther the switch is pushed, the faster the reel will move. The tether operation is the same in all three different driving modes.

When the system is first started up, the rear rocker arm suspension and the front wheel extensions should be initialized. This is usually done automatically using the "HPS Startup" menu. When driving the locomotor, the preferred configuration is with the rocker arm unlocked and the front extensions in, though any configuration can be used at the operator's discretion.

The initial operation of the system is usually to drive the locomotor to the area where work will be performed. This is done using any or all of the three driving modes, as necessary, while paying out the tether as needed. The tether should never be dragged along the floor while being paid out or taken up. Driving operations can be monitored using any of the 11 onboard cameras. The two shoulder cameras and the four deck

cameras are usually the most helpful during driving operations. The boom tip cameras can also be quite helpful when driving, depending on how many cameras are mounted at the boom tip and their configuration.

After the locomotor arrives at the work site, it should be prepared for the operation of the heavy manipulator. If space is available, the front extensions should be extended to increase the stability of the locomotor. The shoulder and deck cameras can be used to monitor the extension of the front wheels. After the extensions are out, the rocker arm suspension should be locked to prevent the locomotor from tilting during operations.

3.10.2 Heavy Manipulator Operation

Once the locomotor has been prepared, the operation of the heavy manipulator can commence. The heavy manipulator is controlled using the heavy manipulator joystick on the right side of the control console. This joystick can be used in either of two different control modes, Joint mode and Coordinated mode. The heavy manipulator should now be used to perform the necessary work. Manipulator operations can be monitored using any of the 11 onboard cameras. The two shoulder cameras, the shoulder top camera, and the three boom tip cameras are usually the most helpful during manipulator operations.

After all desired work has been performed by the heavy manipulator, the preceding procedure can be reversed to remove the system from the work site. The locomotor should be prepared for driving by moving the manipulator to a safe position for driving, retracting the front extensions, and unlocking the rear suspension. The locomotor can then be driven backwards to its starting point, while carefully taking up the tether onto the tether reel. Once at the desired location, the system can be shut down.

3.10.3 Heavy Manipulator Load Limits

The heavy manipulator is capable of lifting at least 900 kg (2,000 lb) with the forearm extension fully extended. However, the locomotor does not have sufficient mass to counteract this load with the manipulator in all of its possible positions. Figure 3-20 shows the vertical load tip over limits for the heavy manipulator and locomotor as a function of the position of the manipulator. These limits have the following conditions and assumptions:

1. The front wheel extensions are both fully extended.
2. The rear suspension rocker arm is locked.
3. A 680 kg (1,500 lb.) counterweight is mounted on the heavy manipulator turret.
4. The 3, 4.6, and 5.8 m (20, 15, and 19 ft) radius circles shown are centered on the waist rotation.

5. The rated load is the vertical dead weight load measured at the face of the wrist load mounting platform, and does not take into account any additional moment loads caused by the payload.
6. The loads shown are dead weight loads and they include an additional 450 kg (1,000 lb.) load as a safety factor for dynamic considerations.

Figure 3-20 Heavy Manipulator Vertical Tip Over Limits

3.11 Decontamination

After operating in a contaminated environment for some period of time, the Rosie system may become covered with dust, dirt, radioactive particles, or other forms of contamination. The system has been designed to be waterproof, so that it can be washed down to remove or reduce such contamination. The system can be spray washed with hot water to clean off any contamination that may be present.

4: Results and Discussion

4.1 Rosie Worksystem Evolution

The original Rosie worksystem was tested for six months at Oak Ridge National Laboratory. The goal of this testing was to determine areas requiring refinement or modification and to quantify the system's overall capabilities. Over 180 hours of operations were logged deploying tooling in concrete demolition and metal cutting exercises. Concrete demolition was performed on more than ten reinforced concrete highway barriers and other pre-cast shapes using a hydraulic breaker tool mounted to the boom tip. Metal cutting tasks were performed using an abrasive wheel grinder deployed from a master-slave dexterous manipulator mounted to the boom tip. Most testing was performed outdoors with rain occurring on several occasions during testing. Operations were unaffected by the weather, and the system was stored outdoors when not in use for several weeks.

Overall, the system performed without failures. Some minor adjustments were necessary and several design enhancements were identified which could improve durability and operability. All of these enhancements were incorporated into the second Rosie system which is currently operating at the Argonne CP-5 reactor site. In addition, during the redesign process, an effort was made to improve the decontaminability of the system so that it can be more easily cleaned after use in a radiologically contaminated environment. This will help to ensure that maintenance personnel exposure will be minimized when working on the system to change tooling, to perform normal maintenance procedures, or during shipping or storage of the system.

4.2 Deployment at CP-5

RedZone has completed the design, fabrication, and testing of the second Rosie system. It was delivered to the Argonne National Laboratory CP-5 reactor site on November 26, 1996, and was installed early the following week. It has been in operation there since December 3, 1996. Immediately after the initial deployment, the system was checked out and tested. It was found to be operating as expected and no significant problems occurred during installation and set up, which took only two days to complete. During the following two weeks, RedZone personnel trained several Argonne personnel in the operation of the system.

4.2.1 Preliminary Testing at CP-5

Before the Rosie system arrived at CP-5, the upper annular shield plug had been removed from the top of the reactor. This plug is 10 ft in diameter, 3 ft thick, and has a 6 ft diameter hole in the middle. It is a steel shell filled with high density concrete which contains iron punchings as its aggregate. Before the Rosie system was deployed, Argonne personnel had manually removed the concrete from two small pie shaped sections of the plug using jack hammers. Full isolation suits were required for the technicians due to the dust hazard. The whole effort took about two weeks.

Since the plug was still on the reactor room floor and easily accessible when Rosie arrived, Argonne agreed to allow RedZone to perform some operational testing on it. RedZone installed a hydraulic breaker (previously used on the first Rosie system during the Oak Ridge testing) at the tip of the heavy manipulator. The breaker was then used to remove the concrete from another of the pie shaped sections of the plug. Even though the tip of the breaker was not the correct length for this application, in about one hour, Rosie removed the same amount of concrete that had taken several days to remove manually. It is roughly estimated that Rosie removed concrete from the plug between five and ten times faster than the Argonne technicians were able to do manually.

4.2.2 Further Use at CP-5

Argonne has purchased a six degree of freedom, light duty manipulator arm. This arm will be installed at the tip of the heavy manipulator on Rosie. This arm will allow Rosie to perform more dexterous tasks, such as horizontal thimble removals and waste packaging for transport.

Training of Argonne personnel in the operation of the Rosie system will continue over the next few months. Rosie will be used in various aspects of the dismantlement of the CP-5 reactor during the next 3 to 6 months. Preliminary plans include segmentation of the lower shield plugs, which pose significant radiation hazards to personnel. In addition, Rosie may be used to remove instrumentation, piping, and other structures, as well as size reduce waste materials, package them, and transport them. Rosie may also be used to demolish the high density concrete in the reactor biological shield.

5: Future Activities

5.1 DOE D&D Applications

The Rosie system is useful in many different DOE D&D operations. Rosie can be deployed in a wide variety of D&D situations at either nuclear or non-nuclear facilities. Its primary function is to perform dismantlement tasks remotely by deploying tools, sensors, and/or other robotic equipment into hazardous areas. Rosie's capabilities and system design address the need for durability and reliability in these environments, and enable performance of tasks such as piping and process equipment removal, structural demolition, vessel segmentation, waste handling and transport, and wall/floor decontamination.

Rosie can be used in virtually any large scale D&D operation. It is only limited by the length of its tether and the creativity of its users. It can deliver hydraulically or electrically powered payloads that weigh up to 900 kg (2,000 lb.).

5.2 Argonne National Laboratory CP-5 Reactor Dismantlement

The first application of the Rosie system is to support the dismantlement and decommissioning of the CP-5 reactor at Argonne National Laboratory (ANL). Rosie has been delivered and installed, and two Argonne personnel have been trained in the operation of the system. However, funding on the current Rosie contract with FETC has been completely expended. RedZone is seeking additional funding from Argonne National Laboratory (ANL) to provide continuing support during the operation of Rosie at the CP-5 site. If this funding is approved, it would allow RedZone personnel to provide additional training for ANL personnel, as well as both operational and maintenance support while Rosie is being used in support of the CP-5 dismantlement.

5.3 Other Rosie Activities

In addition to the planned activities at ANL, other applications for the Rosie worksystem have been identified in support of D&D operations in the DOE and private sector. Also, several tasks outside of D&D operations have been identified for which Rosie might be useful.

5.3.1 Commercial D&D Applications

During the next few decades, many commercial nuclear facilities will be reaching the ends of their design lifetimes. These facilities will have to be shut down and then cleaned up. The Rosie system would be a useful tool in these situations. It can significantly reduce worker exposure during these cleanup efforts, especially during the larger scale or high exposure tasks such as concrete, piping, and vessel removal and other tasks which cannot be easily performed manually.

5.3.2 Non D&D Applications

Efforts are currently underway to determine if the Rosie system would be a suitable deployment vehicle for depainting or surface cleaning equipment. It could be used in areas where lead based or other hazardous surface coverings are present and manual removal presents a significant risk to the removal workers. Rosie's coordinate boom control mode is especially useful for applications where a tooling unit has to be moved along a flat surface, such as depainting a wall, floor, or ceiling.

Rosie could also be used to automate similar tasks that currently take too much time or manpower to complete. With appropriate proximity sensors at the tooling device, Rosie's computer could be programmed to make the tool automatically follow the contours of an irregular surface. It could also be programmed to remember the path that it followed so that similar or identical items could be treated without much additional effort.

6: Conclusion and Recommendations

6.1 Rosie Worksystem Enhancements

The three phases of the original Rosie project provided a solid basis for the redesign and fabrication of the second Rosie system. The experience gained during the extensive testing of the first system, along with a formal external design review, identified the areas where improvements were needed. Virtually all of the identified improvements were incorporated into the second system during the redesign effort. The lack of problems during assembly, integration, testing, and deployment of this system indicates that these enhancements have improved the system significantly compared to the first system.

6.2 Rosie-C System Performance

The Rosie-C system has been deployed at the CP-5 reactor site since early December 1996. Thus far, it has performed as well as, or better than, expected. It has shown that it can remove high density concrete significantly faster than can be done using manual methods, with virtually no worker exposure to hazardous materials. In addition, the Argonne personnel who have been trained to operate the system have adapted to it easily, and have been generally pleased with its operation and performance.

6.2.1 Maintenance and Reliability

The redesign of the system has simplified its periodic maintenance. An effort was made to make replacement or repair of major components easier, should they fail during service. These changes should significantly improve the reliability of the system, though this can only be proven as the system is used over a long period of time.

6.3 Operator Efficiency/Effectiveness Issues

6.3.1 Controls

Thus far, feedback from operators who have used both the first Rosie system and this new system, indicates that the redesigned control console is superior to the console supplied with the original Rosie system. The joysticks are easier to operate due to the

lower tension return springs. Operator fatigue is lessened during long work periods because the console panel can be positioned at different heights and angles to suit an individual operator's preference. Two identical sets of camera controls, one on either side of the control panel, allow the operator to use either hand to adjust the onboard cameras. Hard wired switches and indicators are laid out in a more logical arrangement consistent with the sequence in which they are normally used.

The operation of the touch screen has also been improved. The addition of continuous readouts of the steering angles for each wheel, as well as the positions of each joint on the heavy manipulator, have made control of the system easier for the operators. The sub-menus on the touch screen have also been revised so that they are now more intuitive and easier to use. Colors have been added to differentiate and group information on various parts of the screen. The readouts from the two axis tilt sensor on the locomotor are also continuously displayed on the touch screen. This gives the operator real time feedback on the attitude of the locomotor. The readout of the load cell on the lifting hook at the tip of the boom is also continuously displayed on the touch screen.

6.3.2 Cameras

Four fixed position cameras were added to the locomotor to assist in driving the vehicle. Thus far operators have indicated that these additional cameras are very useful in driving the locomotor. They allow the operator to move the vehicle forward and backward without having to reposition the shoulder cameras each time the direction of travel is changed. This allows much more efficient operations when driving. In addition, since they are fixed, these cameras provide a better view of each side of the locomotor during driving for obstacle clearance and avoidance. This makes it easier to align the vehicle when traveling through narrow passages while allowing the shoulder cameras to be used to monitor the areas above the level of the locomotor deck for obstacles or obstructions. These camera also provide visual feedback for the conditions of the two front wheel extensions.

6.4 Recommendations

RedZone believes that the Rosie-C Worksystem delivered to ANL will be a capable and reliable system during its use in the dismantlement of the CP-5 reactor. It has been enhanced as much as was possible given the time and budget that was available. RedZone recommends that the performance of this system be closely monitored during its operation at CP-5, so that any weaknesses or deficiencies can be determined. A review of Rosie's performance by ANL, ORNL, and RedZone personnel should be held after the completion of work at CP-5. At that time, a list of additional enhancements to the system should be made, so that the next Rosie system that is built can benefit from the experience gained using this system at Argonne.

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8: List of Acronyms

The following acronyms are used in this report:

ANL	Argonne National Laboratory
ANS	American Nuclear Society
CCD	Charge Coupled Device
COR	Contracting Officer's Representative
CP-5	Chicago Pile Reactor 5
CPU	Central Processor Unit
D&D	Decontamination and Dismantlement
DOE	Department of Energy
EM	Environmental Restoration and Waste Management
E-stop	Emergency Stop
FETC	Federal Energy Technology Center
HPS	Hydraulic Power Supply
ORNL	Oak Ridge National Laboratory
PDU	Power Distribution Unit
PRDA	Program for Research and Development Announcement
US	United States
VCR	Video Cassette Recorder