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Explosive Ordnance Disposal Technology Demonstration Using The Telerobotic Small Emplacement Excavator

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June 1994

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Explosive Ordnance Disposal Technology Demonstration Using The Telerobotic Small Emplacement Excavator

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TABLE OF CONTENTS

APPENDIX

ABSTRACT

The small emplacement excavator (SEE) is a ruggedized military vehicle with backhoe and front loader used by the U.S. Army for explosive ordnance disposal (EOD), combat engineer, and general utility excavation activities. In order to evaluate the feasibility of removing personnel from the vehicle during high risk EOD excavation tasks a development and demonstration project was initiated to evaluate performance capabilities of the SEE under telerobotic control. This feasibility study was performed at the request of the Ordnance Missile and Munitions Center and School (OMMCS) at the Redstone Arsenal to help define requirements for further joint service development activities. Development of a telerobotic SEE (TSEE) was performed by the Oak Ridge National Laboratory (ORNL) in a project funded jointly by the U.S. Army Project Manager for Ammunition Logistics (PM-AMMOLOG) and the Department of Energy (DOE) Office of Technology Development (OTD) Robotics Technology Development Program (RTDP). The TSEE features teleoperated driving, a telerobotic backhoe with four degrees-of-freedom, and a teleoperated front loader with two degrees-of-freedom on the bucket. Remote capabilities include driving (forward, reverse, brake, steering), power takeoff shifting to enable digging modes, deploying stabilizers, excavation and computer system booting. The system is operated with an intuitive hand controller at a remotely located portable, suitcase-size base station or can be operated manually using a customized electromechanical actuator package to replace the conventional mechanical levers and foot pedals.

A technology demonstration of the TSEE was conducted at McKinley Range, Redstone Arsenal, Huntsville, Alabama, on September 13-17, 1993. The primary objective of the demonstration was to evaluate and demonstrate the feasibility of remote EOD. During the demonstration, approximately 40 EOD specialists were instructed on telerobotic operation of the TSEE and then were asked to complete a series of simulated EOD tasks. Upon completion of the tasks, participants completed an evaluation of the system including human factors performance data.

Analysis of the human factors performance data indicates that 70% of the demonstration participants found the tasks were as easy or easier to accomplish utilizing the remote system than an unmodified system. Similarly, 80% of the participants found the TSEE hand controller was as easy or easier to use than the normal manual controls. Nearly 70% of participants found that the Graphical User Interface (GUI) provided all the information they needed. Camera usage varied significantly among demonstration participants, on average, the middle TV camera, mounted on the backhoe boom, was used the most, followed closely by the GUI animated backhoe display.

1. INTRODUCTION

The Telerobotic Small Emplacement Excavator (TSEE) was developed at the Oak Ridge National Laboratory (ORNL) in a joint project funded by the Department of Energy (DOE) Office of Technology Development Robotics Technology Developement Program and the U.S. Army PM-AMMOLOG, Picatinny Arsenal. The primary DOE interest in the project is the application of remote excavation controls technology to buried waste removal. The U.S. Army's primary interest is to utilize the technology for retrieval of unexploded ordnance; however, a secondary application with huge potential is range clearance. The remotely operated excavator decreases the need for human intervention at hazardous work sites, making it attractive for a variety of commercial uses as well. The TSEE project and potential applications have been described in more brief form elsewhere [references 1-5]. Figures referred to in the text have been compiled in Appendix A. The human factors survey and EOD test results are compiled in Appendices B, C, and D.

2. REMOTE EXCAVATION TECHNOLOGY DEMONSTRATIONS

2.1 REMOTE EXCAVATION AND RETRIEVAL BY BACKHOE TELEOPERATION

First demonstrations of backhoe teleoperation using the TSEE were performed in December, 1992, at ORNL. The TSEE was used to excavate and retrieve a 55-gallon drum buried in a test pit near the Robotics and Process Systems Complex at ORNL. The objective of this demonstration was to meet an intermediate milestone on the development path toward major system demonstrations scheduled in 1993. This first demonstration included teleoperation of the backhoe only, and utilized an early version of the Graphical User Interface (GUI) along with an intuitive hand-controller. In addition to presenting both the DOE and PM-AMMOLOG sponsors a hands-on demonstration of technical status, this event also heralded the first opportunity for representatives from various DOE sites involved in remote excavation to discuss development and demonstration plans with representatives from three branches of the Department of Defense (DOD). Attendees included representatives from the U.S. Air Force (Tyndall Air Force Base), U.S. Navy (Indian Head EOD), and U.S. Army (Redstone Arsenal EOD School and PM-AMMOLOG). The demonstration successfully illustrated the improved dexterity of the TSEE rate controls compared to manual operations and user friendliness of the intuitive hand controller and GUI. Figure 1 shows a photograph of the TSEE with the 55-gallon drum test piece cradled in the backhoe bucket. References 1-5 provide additional information on the system status at the time of this demonstration.

2.2 OVERBURDEN REMOVAL AND BURIED WASTE RETRIEVAL

In June and July, 1993, a series of waste retrieval technology demonstrations sponsored by the DOE OTD Buried Waste Integrated Demonstration (BWID) was completed at the BWID Cold Test Pit at the Idaho National Engineering Laboratory (INEL). The two primary objectives of these tests were to evaluate and demonstrate feasibility of remote overburden removal and remote excavation of simulated buried waste. A test pit was prepared with four different cells each approximately a cube with 10-ft sides. Simulated waste of different types or configurations were placed in each cell. Tests were performed measuring overburden removal rates and dig depth accuracies. Then a "containment" structure was erected and further tests conducted focusing on retrieval tasks. Along with these retrieval tests BWID conducted dust suppression and contamination control experiments as well. The retrieval tests included rate and accuracy measurements as well as human factors performance tests. Results of the BWID tests may be found in Reference 6. Figure 2 shows the front loader used for remote overburden removal test. Figure 3 shows the TSEE during retrieval tests at INEL. A 10-min videotape has been prepared describing the TSEE system including operational footage [7].

2.3 EXPLOSIVE ORDNANCE DISPOSAL TECHNOLOGY DEMONSTRATION

A series of tests similar in nature to the buried waste tests described above but focused on EOD tasks was completed September 13-17, 1993, at the U.S. Army Redstone Arsenal, Huntsville, Alabama. The demonstration was hosted by the OMMCS with the objective of evaluating the performance of the TSEE and demonstrating the feasibility of remote explosive ordnance disposal. This report describes and summarizes this EOD demonstration and the findings of the human factors tests performed using primarily instructors and students at the Redstone Arsenal EOD School. Figure 4 shows the TSEE during the EOD test.

3. SYSTEM DESCRIPTION

The major components constituting the TSEE system; the vehicle, portable control station and communication system, and the GUI are described below. An inventory of the significant parts required to developed the TSEE is provided in Appendix F. Essentially, all design drawings required for fabrication and assembly of the TSEE are provided in Appendix E.

3.1 EXCAVATOR AND ON-BOARD SYSTEMS

The SEE is a commercially available system, built for the U.S. Army by Freightliner, Inc. The SEE has both a backhoe and a front-end loader (Fig. 1 and 2). The backhoe is an adaptation of the Case 580E commercial backhoe and the vehicle is a modified Mercedes Benz Unimog truck.

The ORNL modifications to the vehicle center around modifying the hydraulic and pneumatic systems for computer control as shown in Fig. 5. High-performance proportional valve components were used to improve dexterity over the existing manual valves. Each joint of the backhoe, stabilizers, and front loader were modified for computer control. Hydraulic pressure sensors at each joint provide limited indications of force exerted by the backhoe. This force feedback has been converted to a measure of torque and provided as an operator display at the control station. Remote driving capabilities were achieved by installing pneumatic actuators on the clutch, power take-off, and shift levers of the vehicle (the SEE is available with manual transmission only). A hydraulic motor was attached to the steering wheel to provide remote steering capability. The backhoe and front-end loader have been outfitted with customized resolvers for measuring joint position. This feedback is required for robotic operation and also used to drive a graphical model of the backhoe in the GUI. More detail about the computer overall block diagram is available in Appendix E, drawing SEE-47. This diagram is also a good functional index for the schematic package.

Remote viewing is provided by three color television cameras mounted on the vehicle. Two cameras with pan, tilt, and zoom mechanisms are mounted on the truck body behind the cab (Fig. 1) and provide a view either forward to support front loader operation and remote driving or backward to support backhoe operation. A fixed focus color camera mounted on the backhoe boom allows the operator to look either directly into the dig zone or into the cupped bucket, depending on the position of the bucket. Though the boom camera was not a part of the original design concept, it has proven to be extremely useful during operation. For a small amount of additional effort and cost, this camera could be replaced with pan, tilt, and zoom capabilities as well.

A number of additional sensors were mounted onboard to provide operator feedback or vehicle status data (Fig. 6). Tilt sensors were mounted on the vehicle to provide both lateral and longitudinal tilt measurements. During the overburden removal tests described above, a global positioning system (GPS) antenna was mounted on the cab and a second GPS antenna was provided at the control station for differential position measurements. A microphone was mounted onboard to provide audio feedback to the operator. System status indicators such as fuel level, water temperature, computer enclosure temperature, battery charge, and oil pressure were also provided and interfaced to the onboard computer system. A water-tight enclosure was mounted on the vehicle to house the onboard computer, radios, sensor interfaces, and signal processing equipment. A solid state air conditioning unit was mounted on this enclosure to protect the controls equipment from overheating during hot weather operations. Sufficient heat is generated by the hardware in this enclosure so that operation in cold weather would not be hindered.

3.2 CONTROL STATION

The base station for the TSEE is a compact and rugged console which packs all the necessary computers, control input devices, computer monitors, and television screens into a single, easily transportable "suitcase" controller.

To meet the military's need for a field deployable system, capable of being operated from a foxhole rather than a command trailer, major changes in the existing backhoe manual controls were required. An intuitive hand controller was developed to replace the two foot pedals and five hand levers of the manual system. The assembly consists of a single axis joystick for the left hand and a three axis joystick on its side for the right hand. The arrangement is shown in Fig. 7.

Included on the control panel is a set of joysticks for camera pan, tilt, zoom, and focus controls; buttons for backhoe startup and shutdown; and a trackball for menu selections on the computer screen. During the Huntsville demonstration, an emergency shutdown button, which turns off computer control of the vehicle, was provided separate from the controller. This "panic button" has since been built into the control panel itself.

Another area of the control station that required a significant design effort was the monitor screens for the computer and the video cameras. By using active matrix liquid crystal displays (LCD), a dramatic size reduction was achieved compared to the traditional cathode ray tubes (CRT). The computer display is a 25 cm, 256 color LCD made by Sharp Electronics that is presently being used in several laptop computers. This 640 x 480 pixel screen has proven to be a good compromise between the suitcase size limitations and the display requirements. The video is displayed on two 23 cm color LCDs, also made by Sharp.

To reduce the size of the workstation computer imbedded in the console, the workstation was implemented with a Sun-compatible VME CPU card made by Themis. The system is presently equipped with a disk drive and keyboard to support software development activities, although these will not be present in a fielded system. Also contained in the VME rack is an analog-to-digital converter for the joysticks and an extra computer for communications processing.

Finally, the collection of hardware was mounted in a suitcase-shaped container made by the Zero corporation. This watertight, military grade container is 47 x 27 x 52 cm and contains the hardware mentioned above plus the power supplies and the fiber optic communication hardware. As shown in Fig. 7, the computer screen is embedded in the main container, the two video screens are embedded in the container's front lid, and the joystick panel is stowed under the container's rear lid. Power for the station is 24 volts DC which can be supplied from another military vehicle battery or from a 110V to 24V supply. If necessary a battery pack could be adapted for field use.

The communications system between the vehicle and base station consists of two microwave video channels and an Ethernet data radio. The data radio is a sophisticated, spread spectrum Ethernet packet radio made by Telesystems. Vehicle status and position indicators, audio from the work site, and video displays are transmitted from the vehicle to the control station over the data link while command and control data are transmitted from the control station to the vehicle. Transparent operation of the Ethernet radio enables flexible operation for the computer system. A remote kill switch is also enacted through a separate radio frequency. The frequencies used for radio communications were reserved for this project at Oak Ridge and three other DOE sites where related experiments are planned. For U.S. Army applications where a secure communication channel may be required, a fiber-optic bundle may be used. The fiber optic cable reel would be stowed on the SEE vehicle. At the time of the EOD demonstration at McKinley Range, the fiber optic communications option was not yet implemented and dedicated radio frequencies were not made available; therefore, communications were implemented using coaxial cable.

3.3 GRAPHICAL USER INTERFACE

The GUI on the TSEE is designed to supplement the information that an operator gets through the cameras. The GUI provides the remote driver with audio and video feedback, graphics displays, position indicators, torque and tilt information, as well as dig depth and camera direction. A remote operator who is limited to two camera views is deprived of much information about the work area that an on board operator would have. To help the operator recover from the loss of depth perception, the GUI has animated displays that allow an operator to obtain information on relative positions of objects by modeling some features that cannot be seen. In addition, the GUI provides other highly useful operational status data that are not available to an operator sitting on the backhoe performing excavation tasks but must be monitored by a second operator or require the primary operator to interrupt digging. The GUI is also used for job setup providing services for camera positioning and selection, dig depth limits, control system modes, auto dump mode setup, and graphical markers. Many of the features discussed in this section are illustrated in Fig. 8-11.

Using menu selections, the operator can select from a number of windows that provide information or act as control panels for operation of various features of the system. The system was designed to be portable, which means that the GUI will be used on a small display. Each window provides selected information and can be accessed the operator using the mouse and operator controls provided with the windowing system on the computer. Allowing the operator to choose which windows are on screen and which windows are in front negates the need for a large screen displaying all the information all the time.

The main window of the GUI is a plan view of the work area. This plan view is an animated graphic that provides a top down view of the work area. The outline of the vehicle is drawn in the bottom center of the view and the position of the backhoe is drawn as if it were viewed from above.

The second most frequently used display is the side view display. This display shows the position of the excavator as if it were viewed from the side. The operator can see the position of the bucket, boom and dipper links that position the bucket. The ground is drawn with lines at 1-ft intervals allowing the operator to judge the bucket depth. The bucket is modelled in sufficient detail that the operator can use the graphic to adjust the bucket to the proper angle for the task at hand.

Using icons in the plan view, an operator can reposition the two vehicle cameras by dragging sight lines on the screen with the mouse. If the dig zone or dump zone positions are known or can be determined by "touching" them with the backhoe, then a graphical marker can be placed in those locations. A corresponding marker is automatically drawn in the side view window and is coordinated with the plan view marker so that it appears at the appropriate distance from the swing pin and appears only when the excavator is over the mark on the plan view. Markers in the side view graphic can be moved up or down in depth and can be adjusted in size if the operator knows the approximate size and location of the object being represented, for example, either a buried object or perhaps an above bin or obstacle. This feature allows the operator to return to the same position in a dig or judge how high a receptacle is in a retrieval operation. It can also be used to mark known positions of buried objects since the markers show their position in feet when selected with the mouse.

Other information available from the side view includes the torque indicators. These provide an indication of the force being exerted at each excavator joint and attempt to replace the sense of feel that a remote operator loses. This information is provided by means of a pie chart located on the joints. The portion of the pie that is colored in, along with the direction that is colored in, provides the torque information. At a preset limit, the color changed to from gray to red and the system beeps an audio alarm indicating a high torque is being applied. The pie chart is scaled such that the pie is full at the point that the vehicle would be picked up or moved by the excavator. The beeping will start at that point calling the operator's attention to potential need for adjusting the load.

The third graphic window is the instrument panel. This is a column of edge meters drawn with labels and scales. The meters represent the following engine and vehicle operating data: a tachometer; fuel, oil pressure, and water temperature indicators; voltage indicators for the battery and auxillary battery; box temperature indicator; and indicators displaying the status of the air to the brake system and replacement brake. In addition to the normal indicators, the tilt sensors (pitch and roll) and the steering wheel angle are provided for use during remote driving.

There are several dialog boxes that can be selected from the menu. A dialog box is a small control panel that appears on screen, allowing the user to input information and select operating modes. One dialog box controls the dig depth. The operator uses a slide bar to select the depth of an artificial dig floor. The operator can also set the slope of that floor on two axes. A line that reflects the depth and slope of the dig floor is drawn on the side view window. Other dialog boxes are provided for auto dump setup, and camera manual controls.

4. TECHNOLOGY DEMONSTRATION OF THE TSEE MCKINLEY RANGE, REDSTONE ARSENAL, HUNTSVILLE, ALABAMA

4.1 DESCRIPTION

The TSEE was transported to Redstone Arsenal from Oak Ridge, Tennessee, by flat bed truck on September 13, 1993. The vehicle was positioned in a field about 200 ft beyond an instructional building at McKinley Range (Fig. 4). The control station was located in this building in an area large enough to accomodate the TSEE technical team, test participants, onlookers, and provide space for completing the human factors evaluation forms (Appendix B). The fiber optic Ethernet communications system had not been implemented at the time of the demonstration and provision for dedicated radio frequencies was not pursued, therefore, communications with the vehicle was accomplished using coaxial cables. By the end of the day, September 13, the system was unloaded, setup, checked out, and ready to commence testing.

During the demonstrations on September 14 and 15, approximately 40 EOD specialists including students and instructors from the OMMCS were briefed on telerobotic operation of the TSEE and given an opportunity to operate the system for a mock bomb retrieval exercise (Fig. 12). The soldiers' experience in manual operation of the SEE ranged from 0 to 1000+ hours. Upon completion of the mock EOD tasks, participants completed an evaluation of the system including human factors performance data. A sample evaluation form is provided in Appendix B. A briefing and hands-on demonstration was held on September 16 for the OMMCS Commandant, Colonel Stirling, and other distinguished guests. A 48-min videotape was made of the briefings presented including footage of system operation [reference 8]. Interested persons may request a copy of this tape from the authors or from the project sponsor PM-AMMOLOG.

Demonstration participants were required to accomplish remote overburden removal and retrieval of dud bombs buried at a depth of up to 2.5 meters (Fig. 8). Training prior to initiation of the task was limited to a very brief description of the functions on the control panel, brief overview of the GUI, and less than a minute per person of hands-on training with the hand controller. Because of the user-friendliness of the controls and intuitiveness of the hand controller, no further instruction was required for the participants to begin the test tasks.

4.2 EOD TEST RESULTS

Results of the human factors evaluations are presented graphically in Appendix C. Written comments provided by these participants are included as Appendix D. Many of the participants, particularly the officers and other distinguished guests, opted not to complete an evaluation form. A summary of the results is presented below. Of the 35 participants who completed evaluation forms, 8 had less than 1 hour of experience operating the TSEE manually, 14 had experience ranging from 1 to 99 hours, 10 had experience ranging from 100 to 499 hours, and three participants had 500 or more hours of experience.

4.3 SUMMARY OF HUMAN FACTORS PERFORMANCE DATA

4.3.1 Task Accomplishments

Approximately 70% of participants found that using the remote system was as easy as or easier than using the normal system. The average experience using the manual system for these participants was 39 hours. Of the participants with less than 1 hour experience in manual operation, 7 out of 8 found the task easier to accomplish remotely.

Of the 35 participants queried, 100% stated they could accomplish the required demonstration task most of the time and that the errors they encountered were small and unimportant to task accomplishment. Only 5 of the 35 participants stated that the task was not easily accomplished, while 30 of the 35 found that it was easily accomplished. For the 5 participants who found the task difficult, manual operations experience ranged from 10 to 75 hours for 4 of them while 1 person was very experienced, having about 800 hours.

4.3.2 Hand Controller

Eighty percent of participants found the TSEE hand controller was as easy or easier to use than the SEE manual controls. With a minimum of training using the intuitive hand controller, one hundred percent of evaluation participants were able to accomplish the mock EOD tasks.

4.3.3 Realism

When asked whether the television screens and sound system made participants feel like they were working at the remote site, only eleven percent gave a negative response. Experience in manual operation for these respondents averaged 109 hours, and ranged from 60 to 200 hours. Approximately 90 of all participants stated that sound from the remote area was important during the task. Demonstration participants were evenly split when asked whether they felt like they were really out there on the excavator while performing the task remotely.

4.3.4 Displays

Nearly 70 of participants found that the GUI provided all the information they needed. Twenty-nine percent of participants stated that some displays (temperature, tilt, joint position, torque, status, etc.) were not useful. Due to the short duration of the retrieval tasks, participants did not need some of this information to complete the task. Had the exercise been more prolonged, more of the status indicators would have been useful; for example, fuel level, oil pressure, and water temperature.

Forty percent of participants stated that they could not have accomplished the task without the animated backhoe display, while forty-three percent stated they could. Seventeen percent were indifferent. Of those participants who felt that they could have accomplished the task without the display, experience with SEE operation averaged 200 hours. Only one participant responded that the backhoe display was not useful, while greater than 60% found it extremely useful.

Camera usage varied significantly among demonstration participants. On average, the boom camera was used the most, followed closely by the GUI animated backhoe display. Approximately 60% of camera usage was split among these two displays. Participants relied more heavily on the right TV camera than the left. This was due mainly to the fact that the dig area was slightly right of center behind the backhoe. Sun angle and glare on the cameras also contributed to camera selection. Usage of other parts of the GUI such as the status windows was negligible for most participants.

Approximately 74% of respondents felt that the vehicle mounted cameras were in the best location to do the assigned task. When asked whether the TV monitors were the best size for the work or if they were too small, responses were evenly split.

None of the participants responded that the camera controls were hard or confusing to use and less than 20% of respondents stated that the TV picture quality was not good enough to do the job well.

4.4 Other Demonstration Results

Although OMMCS requirements focused on backhoe telerobotic operation, the evaluation participants frequently commented that they could make good remote use of the front loader as well. The front loader is often used for stabilization and lifted during minor repositioning of the vehicle. Appendix D provides a summary of comments made by the evaluation participants.

5. CONCLUSIONS

The technology demonstration of the TSEE for remote EOD operations at Huntsville, Alabama, provided both feasibility and human factors data that will be used to evaluate the TSEE design and potential applications of the telerobotic system. A significant finding of the demonstration is the fact that individuals with and without experience in manual operation of the vehicle were able to accomplish the assigned task easily with very little instruction. The intuitive hand controller coupled with the GUI makes an otherwise complicated task, requiring hours of training, simple and easily accomplished. The demonstration has shown that the TSEE can be a valuable tool for EOD operations, accomplishing the required tasks remotely with an increase in dexterity and negligible productivity losses due to remote operation, while decreasing risk to operators.

Based on the results of the demonstration, the following design modifications were implemented: The emergency computer control shutdown button was added to the control panel; a trackball was added to the control panel (eliminating the need for a mouse and eliminating the keyboard in field deployments); and automatic camera switching capability was added (cameras can be set to switch automatically to left or right cameras based on the position of the boom). Additional modifications which are under consideration include adding color to the vehicle status displays on the instrument panel and replacing the current boom camera with a zoomable camera with automatic iris adjustment.

6. FUTURE ACTIVITIES

A grappling end-effector and associated additional hand controller are currently under development at the ORNL for integration with the TSEE. The new end-effector and controls development are sponsored by DOE and will allow the system to manipulate a variety of tools. The grappling end-effector is initially intended to manipulate rigging equipment to facilitate the retrieval and removal of concrete waste containment casks. A "hot" field test of the system is scheduled for August 1994 at the Hill Cut Test Facility in Solid Waste Storage Area 6 at ORNL. Other follow on activities related to environmental applications demonstrations, range clearance, combat engineer, battle field cleanup, and EOD concept employment evaluations by the U.S Army have been discussed but are not underway at this point.

Prior to fielding the TSEE system in large numbers, a few modifications are recommended. Chief among these modifications is replacement of the developmental computer hardware on-board the vehicle with more compact and ruggedized processors. This can be accomplished by burning the software into a Programmable Read-Only Memory (PROM) and removing the onboard disk drive. The PROM will not only prevent inadvertent software changes, but will also decrease the size required for the onboard computer, controls and communications enclosure.

7. ACKNOWLEDGMENTS

The authors wish to express their appreciation to all those who assisted in the completion of the development and demonstration of the TSEE. In particular, thanks go to Robert Rossi of PM-AMMOLOG and Steven Herman of OMMCS who provided direction, feedback, and support to the ORNL staff from the inception of the TSEE project. Thanks to the OMMCS Commandant, Colonel Stirling, and his staff for hosting this EOD demonstration, especially those involved in operation of the McKinley Range at the Redstone Arsenal. We also wish to thank Dr. John Draper of ORNL for assistance preparing the human factors evaluation form and Lesli Alcorn and Kyra Donnell for assistance in the data compilation, analysis, graphing, and many other aspects of preparing this summary report. We appreciate the cooperation of the two DOE program managers, Dr. Linton Yarbrough and Dr. Jaffer Mohiuddin, who, jointly with the U.S. Army PM-AMMOLOG, sponsored the development and demonstration of the TSEE as a remote excavation technology test bed. Finally, we would like to thank the demonstration participants for their cooperation and the benefits of their experience. This demonstration event was a great opportunity to get prototype system operation and design feedback from the real experts, the intended operators.

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APPENDIX A
FIGURES

Fig. 1 Telerobotic Small Emplacement Excavator photograph during a backhoe teleoperation demonstration in December 1992 at ORNL. Retrieval of a buried 55-gallon drum was used to simulate buried waste or unexploded ordnance retrieval.

Fig. 2 The Telerobotic Small Emplacement Excavator can be remotely driven and the front loader, shown here, can also be remotely operated.

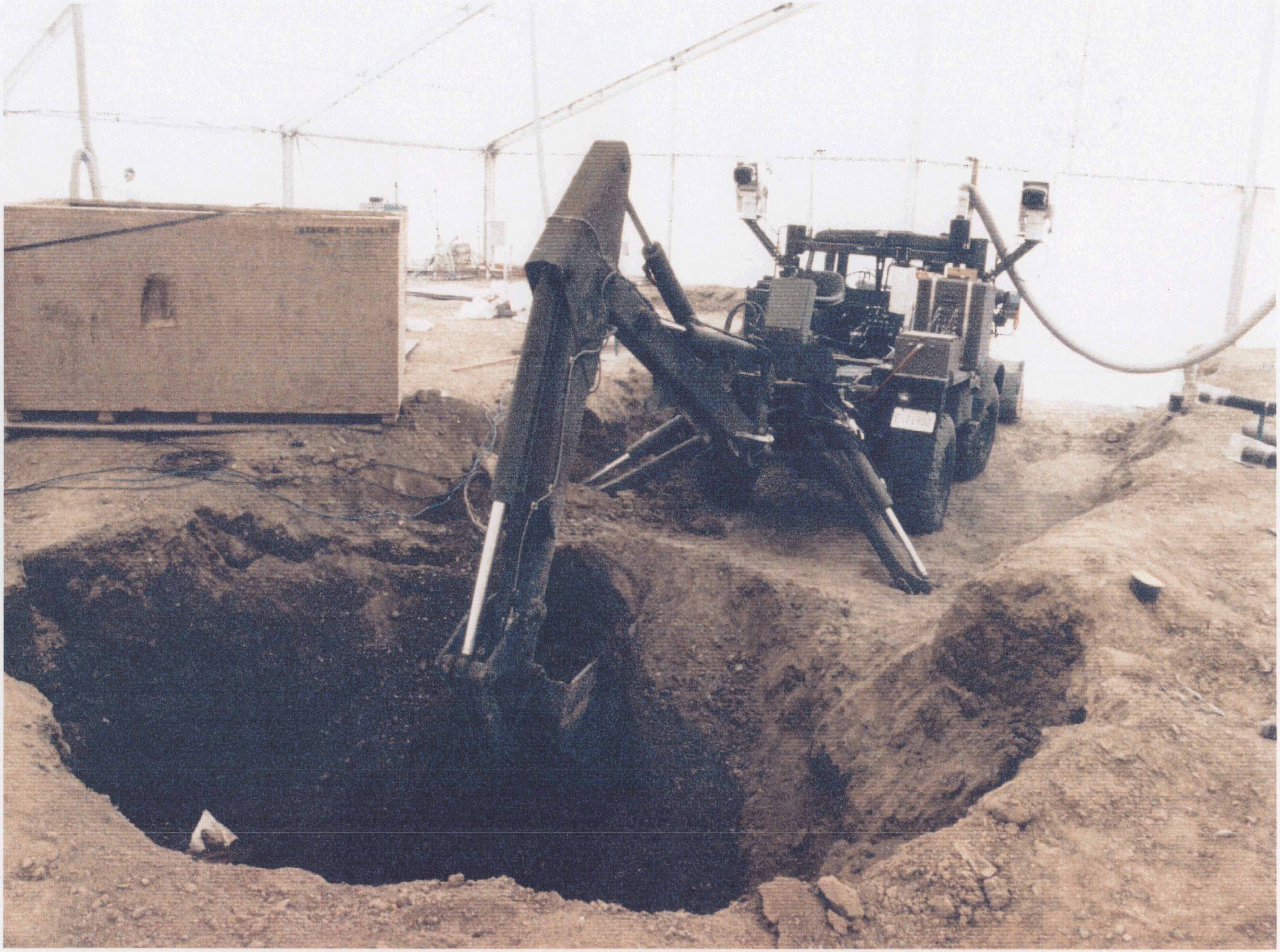


Fig. 3 Telerobotic Small Emplacement Excavator photographed during buried waste retrieval tests in June 1993 at the BWID Cold Test Pit at INEL.

Fig. 4 Telerobotic Small Emplacement Excavator photographed during EOD tests in September 1993, at the McKinley Range, Redstone Arsenal, Huntsville, Alabama.

SEE Actuator Architecture

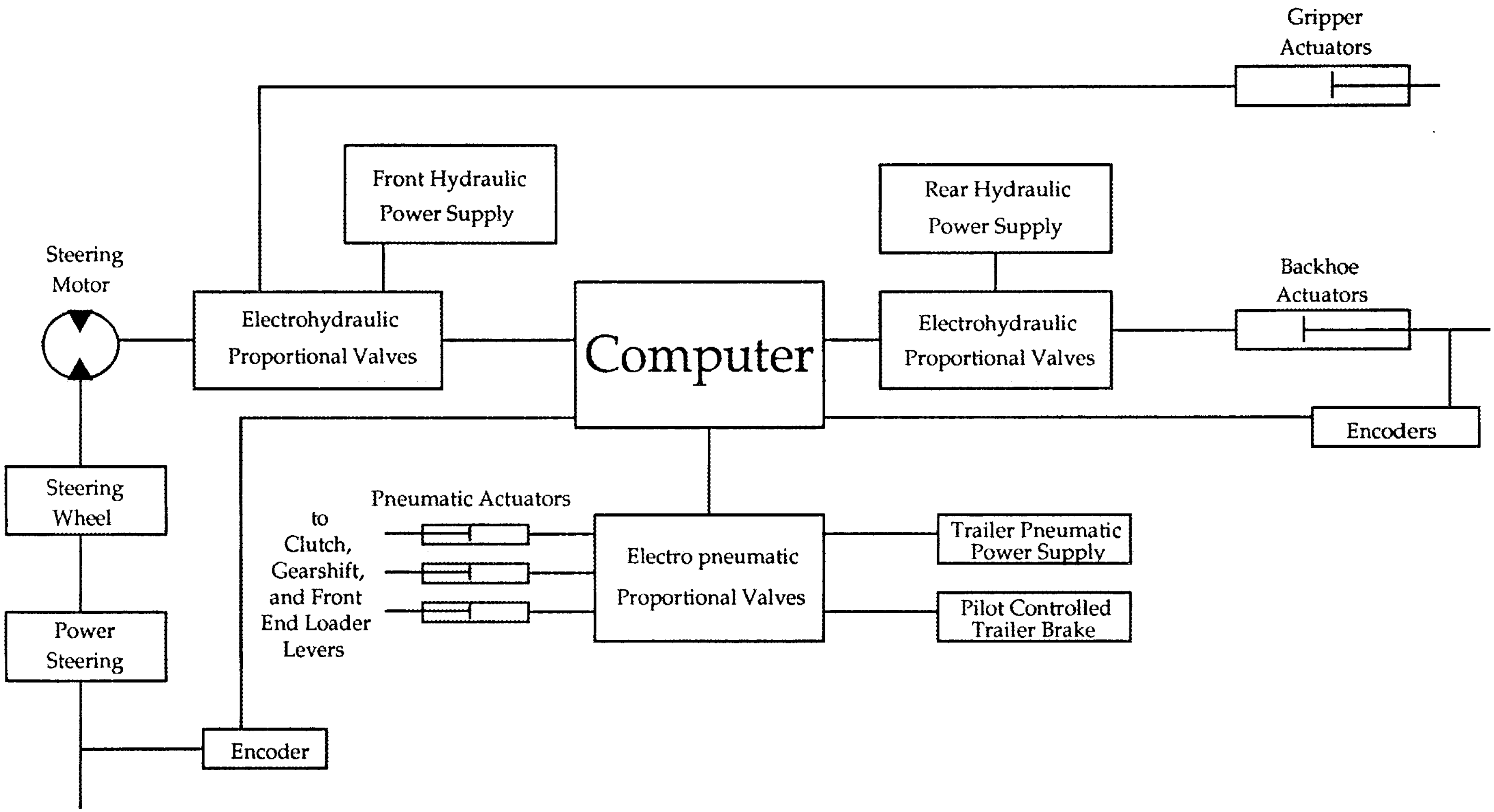


Fig. 5 Computer control architecture schematic for the hydraulic and pneumatic actuator systems of the TSEE.

SEE Control System Schematic

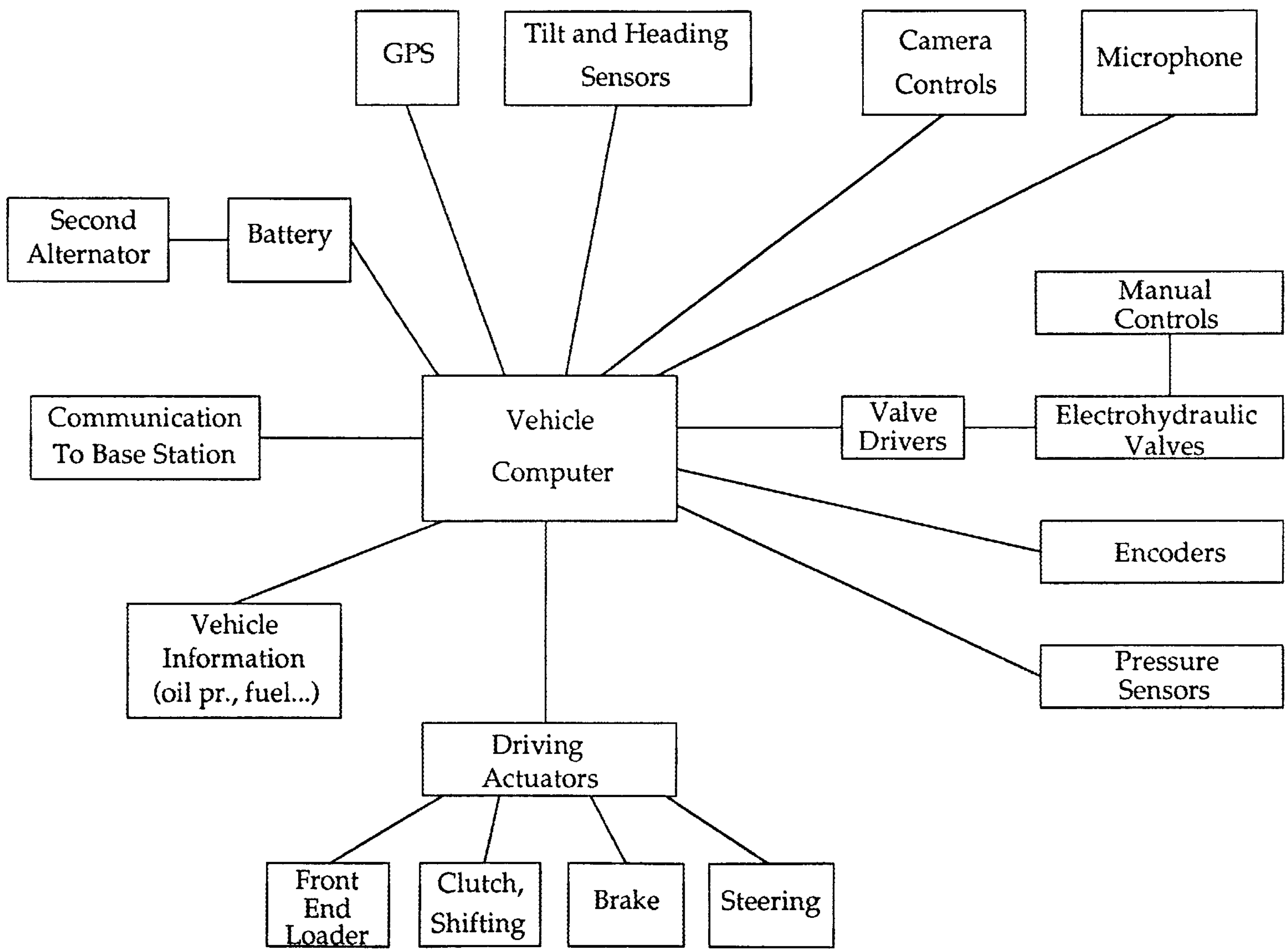


Fig. 6 The TSEE has a large number of on-board sensors to provide operator feedback.

Fig. 7 The control station for the TSEE is a compact and rugged suitcase-sized controller, convenient for field use.

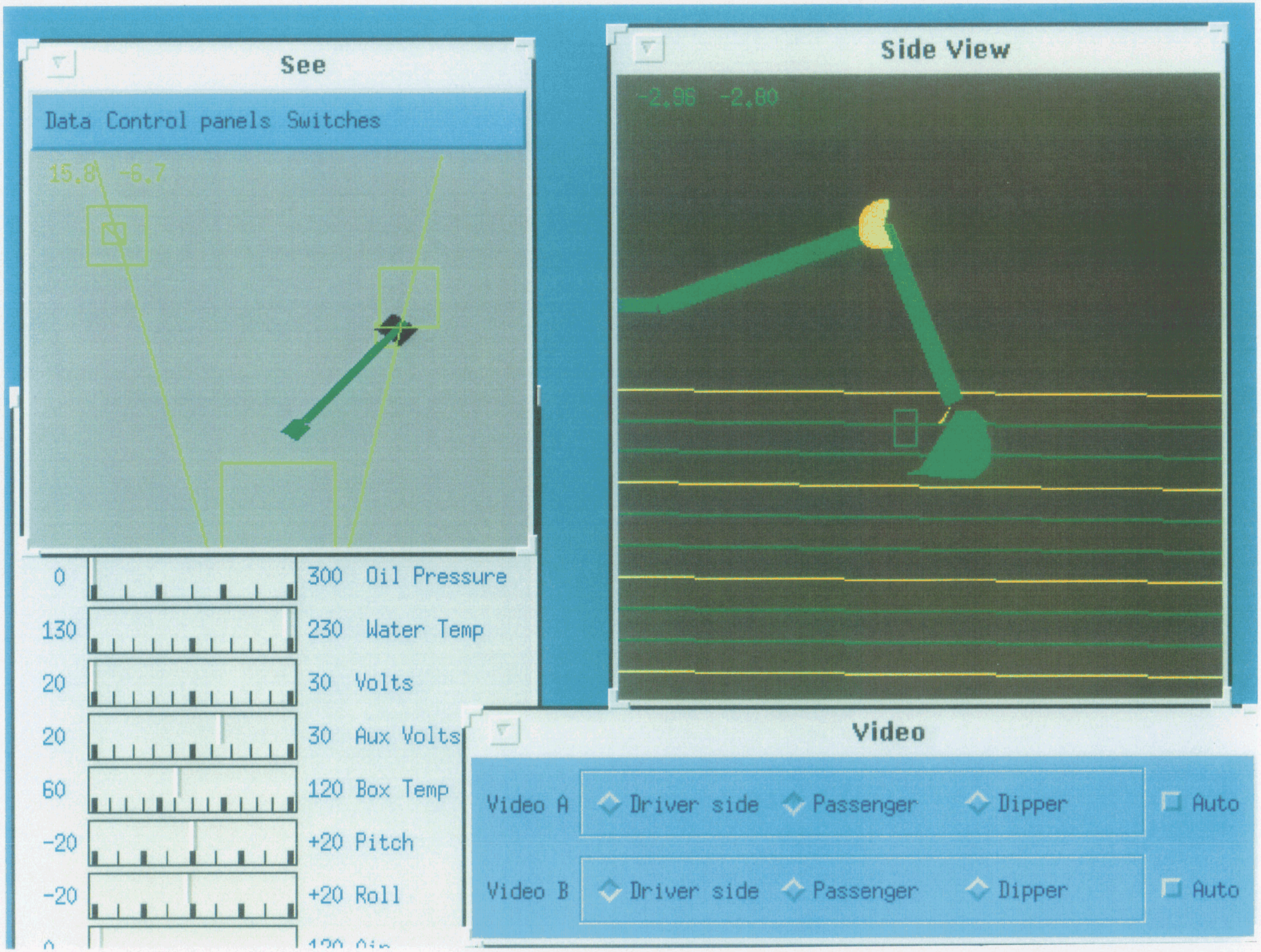


Fig. 8 The TSEE has a graphical user interface. This photograph illustrates the typical window arrangement during operations.

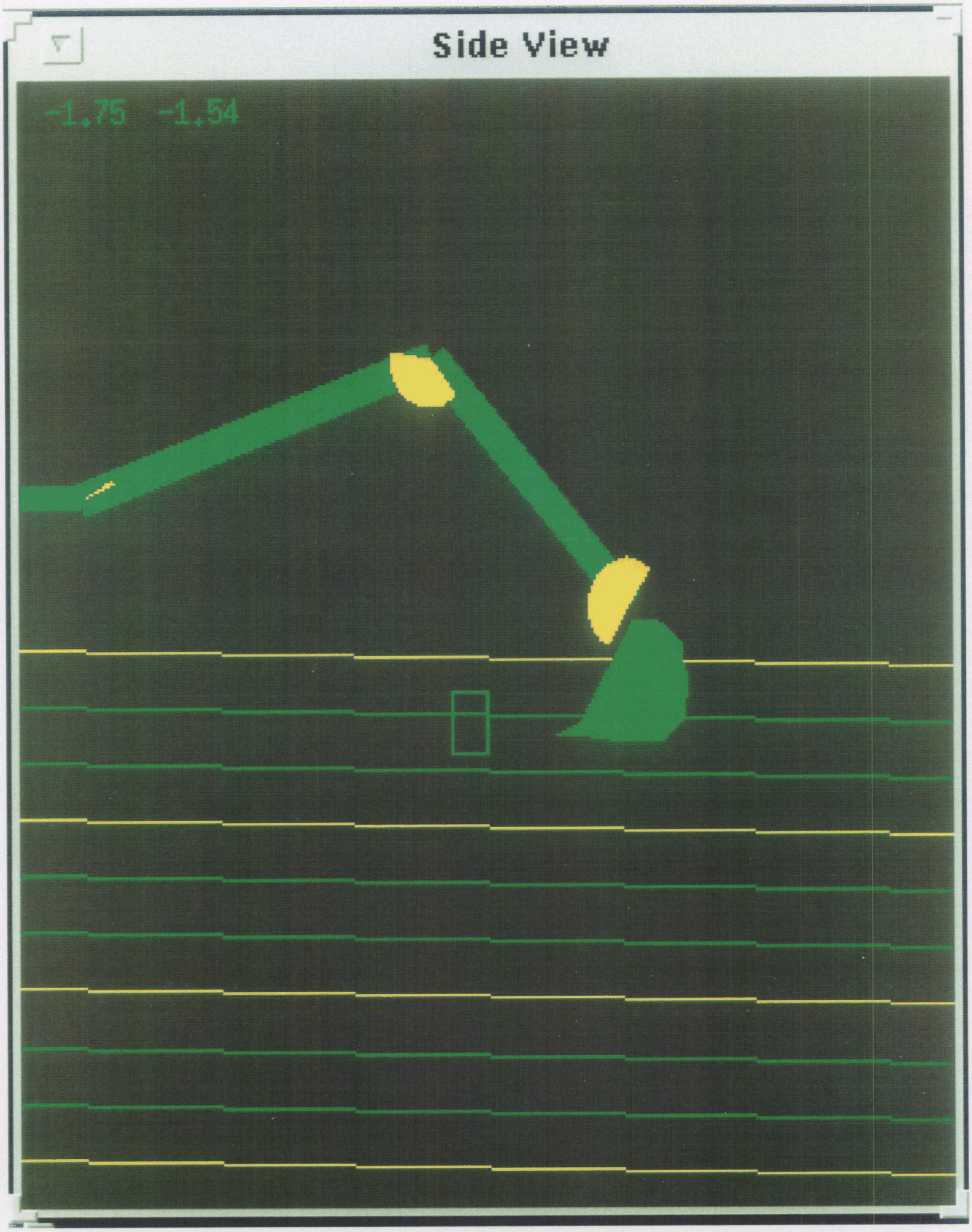


Fig. 9 The TSEE has a graphical user interface. This photograph illustrated the backhoe model in side view. Lines indicating depth below the surface are indicated.

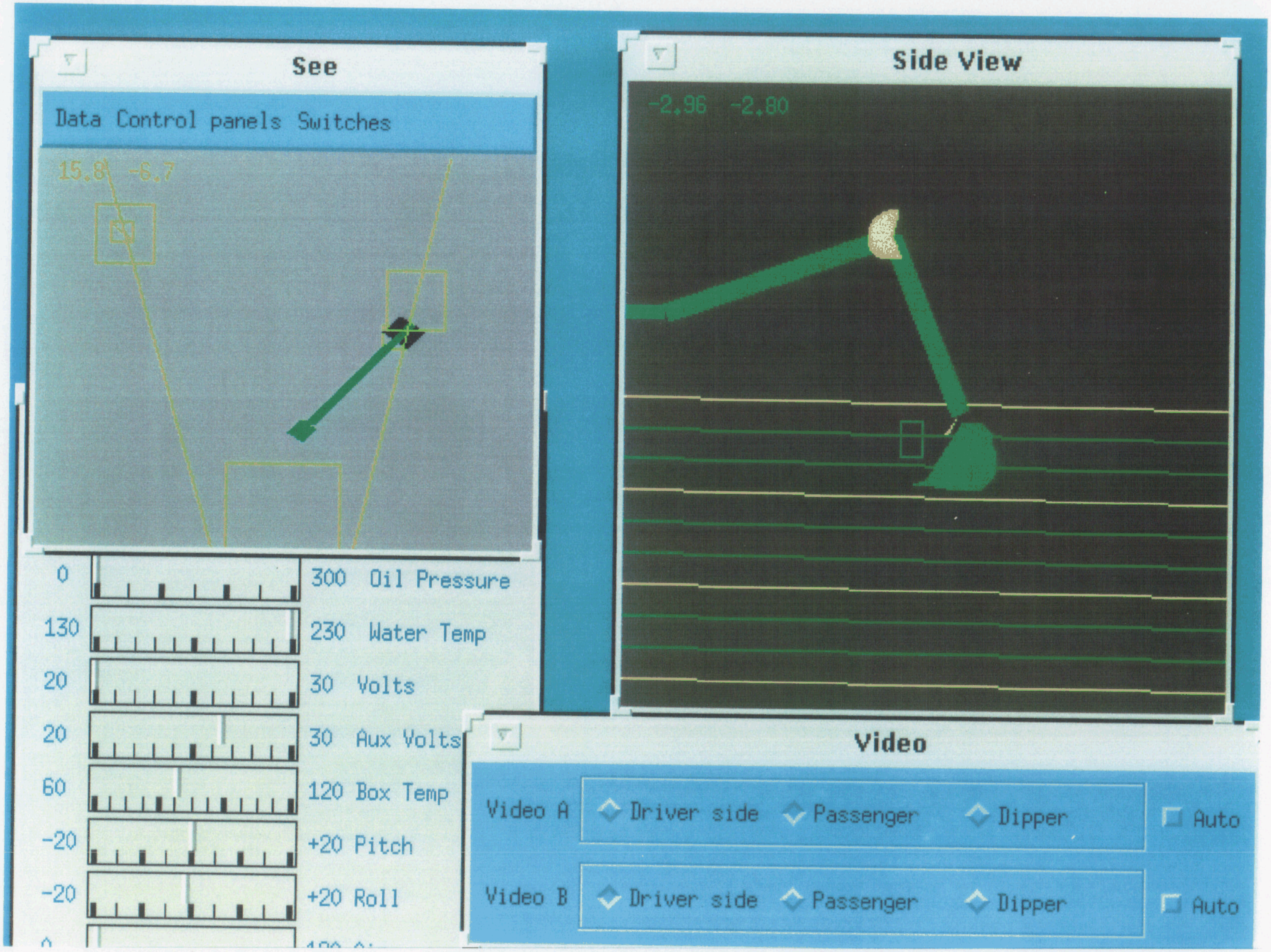


Fig. 10 The TSEE has a graphical user interface. This photograph illustrated the backhoe model on plane view. Icons can be drawn to indicate dig zones, dump zones, and other objects or regions of interest. Camera sight lines are also indicated.

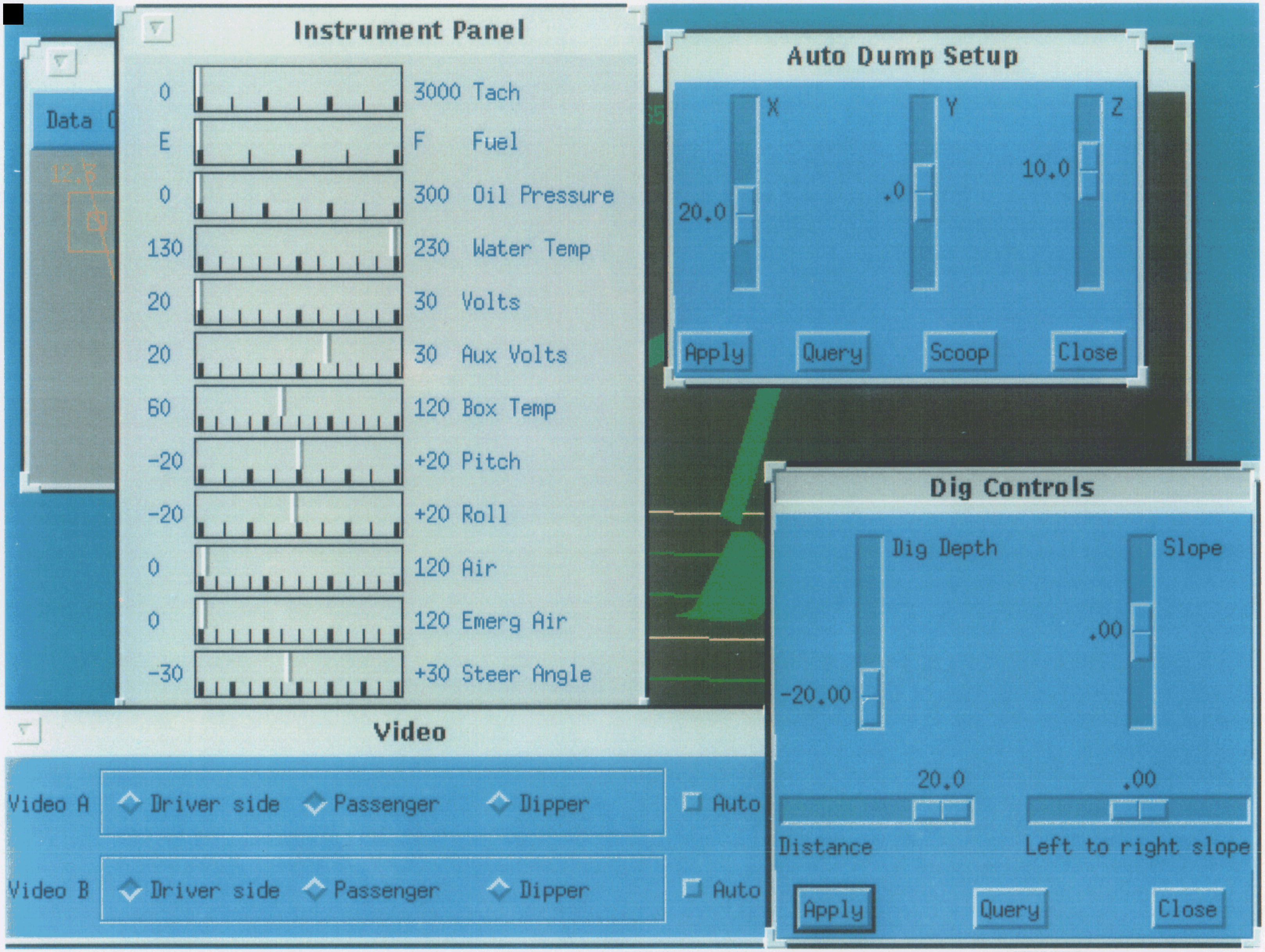


Fig. 11 The graphical interface has several sub-menus that are temporarily called up with the trackball to adjust parameters and check the vehicle status.

Fig. 12 This photograph was taken while an Army EOD specialist operated the TSEE during EOD tests at McKinley Range in September 1993.

APPENDIX B
HUMAN FACTORS EVALUATION SHEET

Name:

About what percent of time did you spend using each of these views during the task?

Left TV Camera ________

Right TV Camera ________

Middle TV Camera ________

Animated Backhoe ________

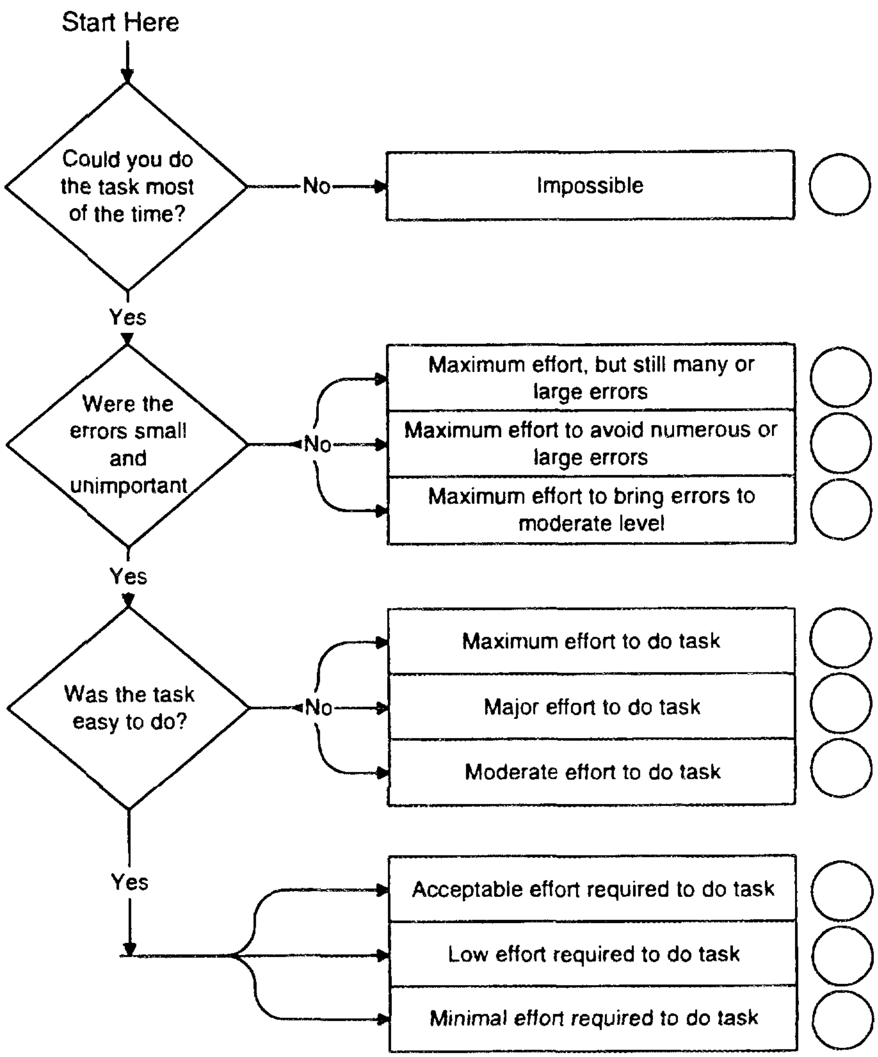
Other Part of Graphic Interface ________

Rank/Job Title:

About how many hours of experience have you had with the small emplacement excavator before using the remote control version?

About __________ hours.

At each diamond, follow the arrow that matches your answer (yes or no) to the question in the diamond. If you follow the arrow to a set of three boxes, choose the box from the set that best describes your experience, by placing a mark in the circle next to the box. When you are finished, go to the next page.



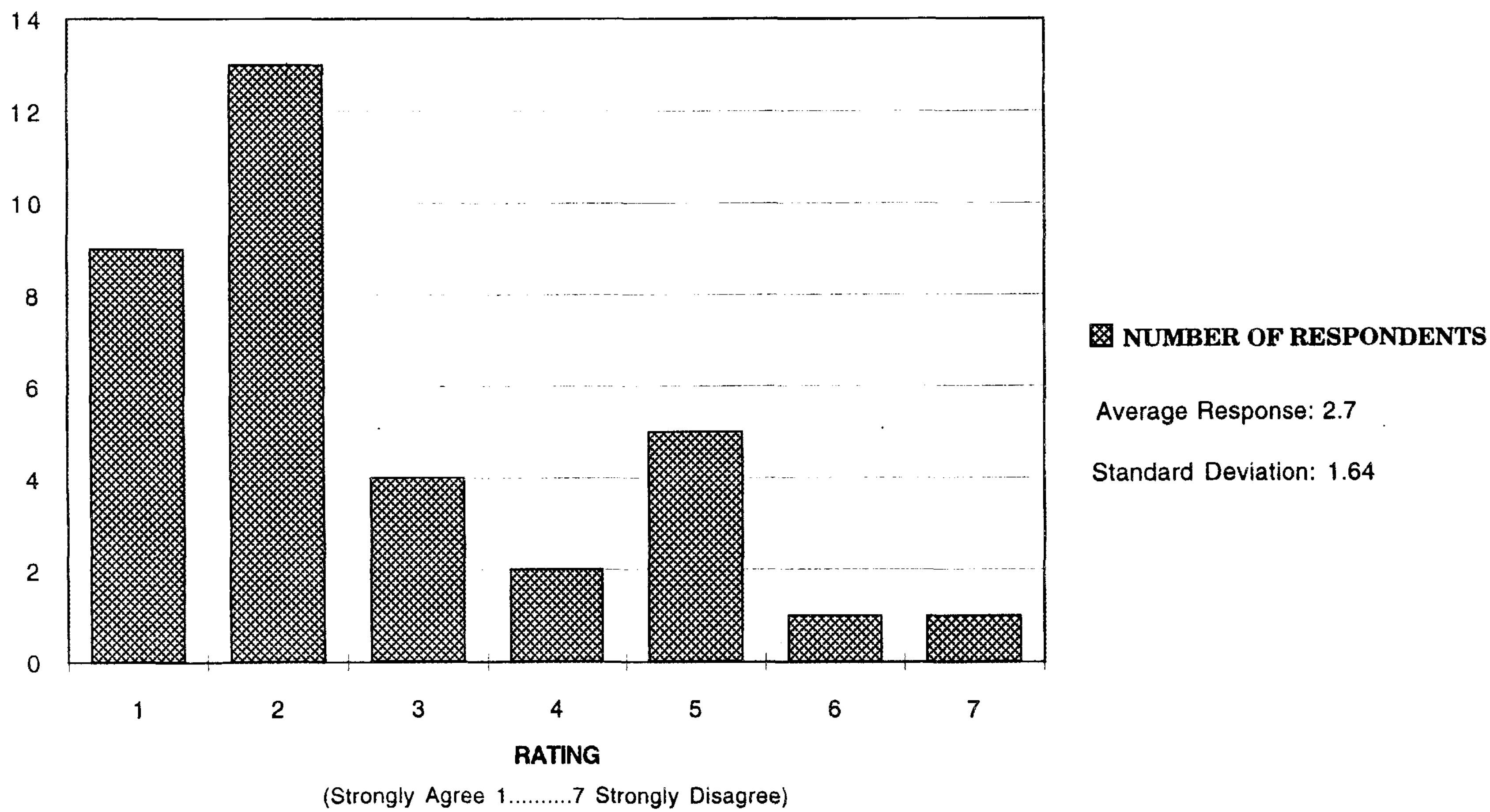
Read each question and place a mark in the space next to the question that best matches how much you agree or disagree with the question. For example, *if you agree with a question but not strongly*, you might place a mark above the line with the 3 under it; if you disagree, you might mark the one over the 5.

The hand controller was easier to use than the normal manual controls (levers and foot pedals).	Strongly Agree	1		3		5		7	Strongly Disagree
It was harder to do the task with the remote control system than with a normal system.	Strongly Agree	1		3		5		7	Strongly Disagree
The TV's and sound system really made me feel like I was there, working at the remote site.	Strongly Agree	1		3		5		7	Strongly Disagree
Some displays (temperature, tilt, joint position, torque, status, etc.) were not useful.	Strongly Agree	1		3		5		7	Strongly Disagree
The TV monitors were the best size for the work	Strongly Agree	1		3		5		7	Strongly Disagree
The TV monitors were too small.	Strongly Agree	1		3		5		7	Strongly Disagree
I couldn't have done the task without the animated backhoe display.	Strongly Agree	1		3		5		7	Strongly Disagree
The animated backhoe display was not useful during the task.	Strongly Agree	1		3		5		7	Strongly Disagree
The graphic interface gave me all the information I needed.	Strongly Agree	1		3		5		7	Strongly Disagree
The cameras aboard the vehicle were in the best locations to do the work.	Strongly Agree	1		3		5		7	Strongly Disagree
The camera controls were hard or confusing to use.	Strongly Agree	1		3		5		7	Strongly Disagree
The TV picture quality wasn't good enough to do the job well.	Strongly Agree	1		3		5		7	Strongly Disagree
When I was doing the task I felt like I was really out there on the excavator.	Strongly Agree	1		3		5		7	Strongly Disagree
The sound from the remote area was important during the task.	Strongly Agree	1		3		5		7	Strongly Disagree

Comments:

APPENDIX C
DATA SUMMARY GRAPHS

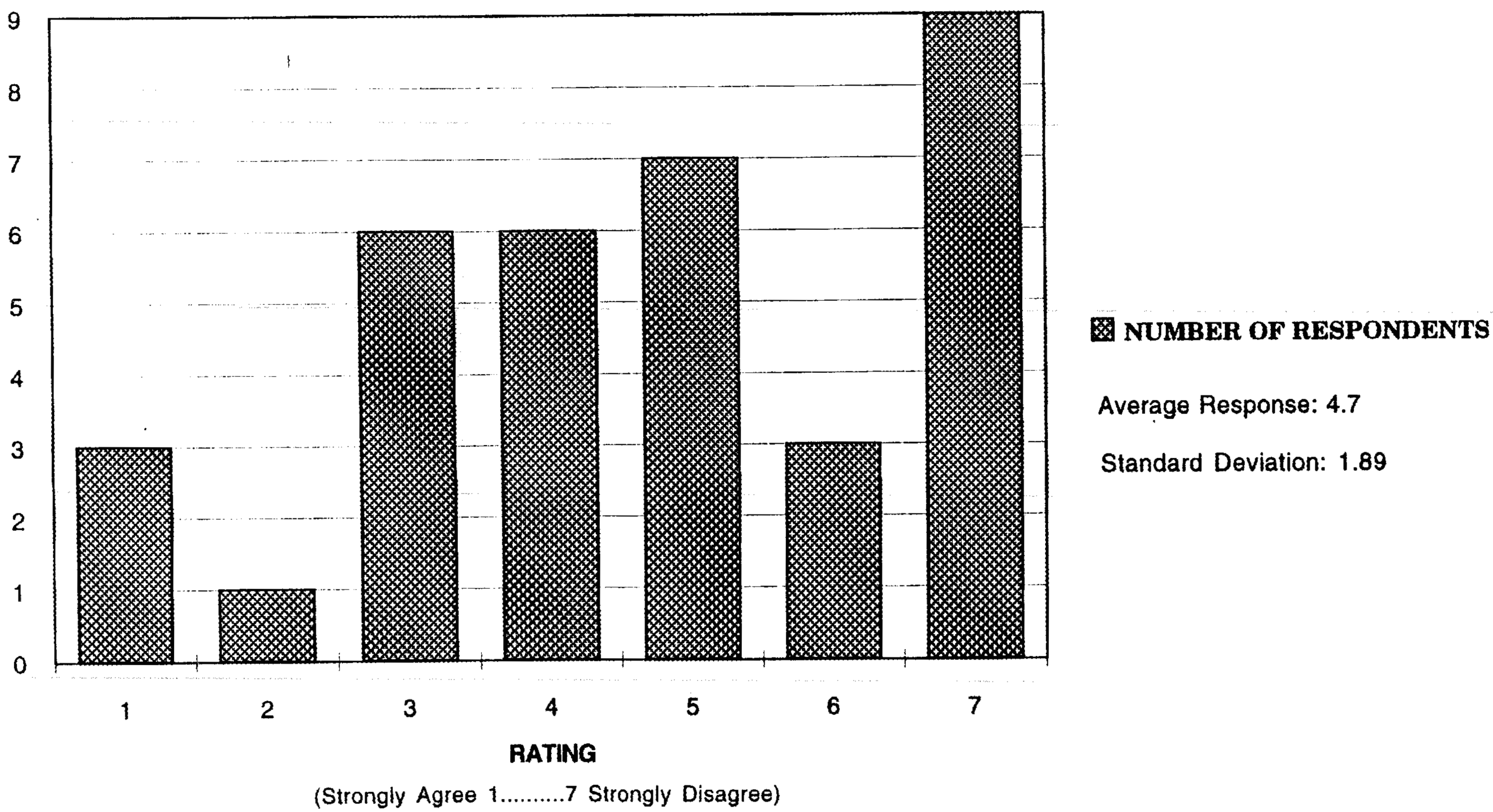
THE HAND CONTROLLER WAS EASIER TO USE THAN THE NORMAL MANUAL CONTROLS



Average Response: 2.7

Standard Deviation: 1.64

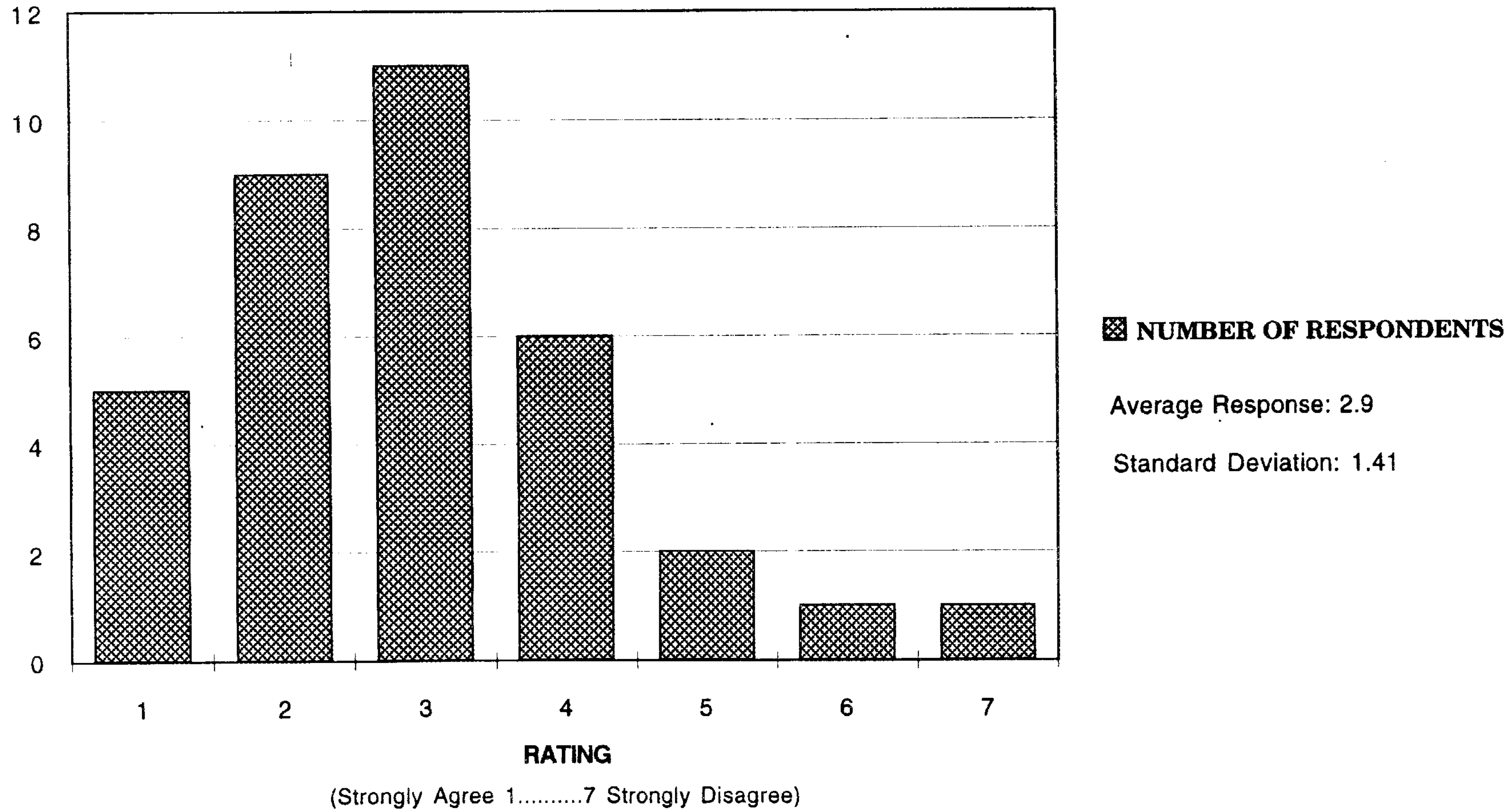
IT WAS HARDER TO DO THE TASK WITH THE REMOTE CONTROL SYSTEM THAN WITH A NORMAL SYSTEM



Average Response: 4.7

Standard Deviation: 1.89

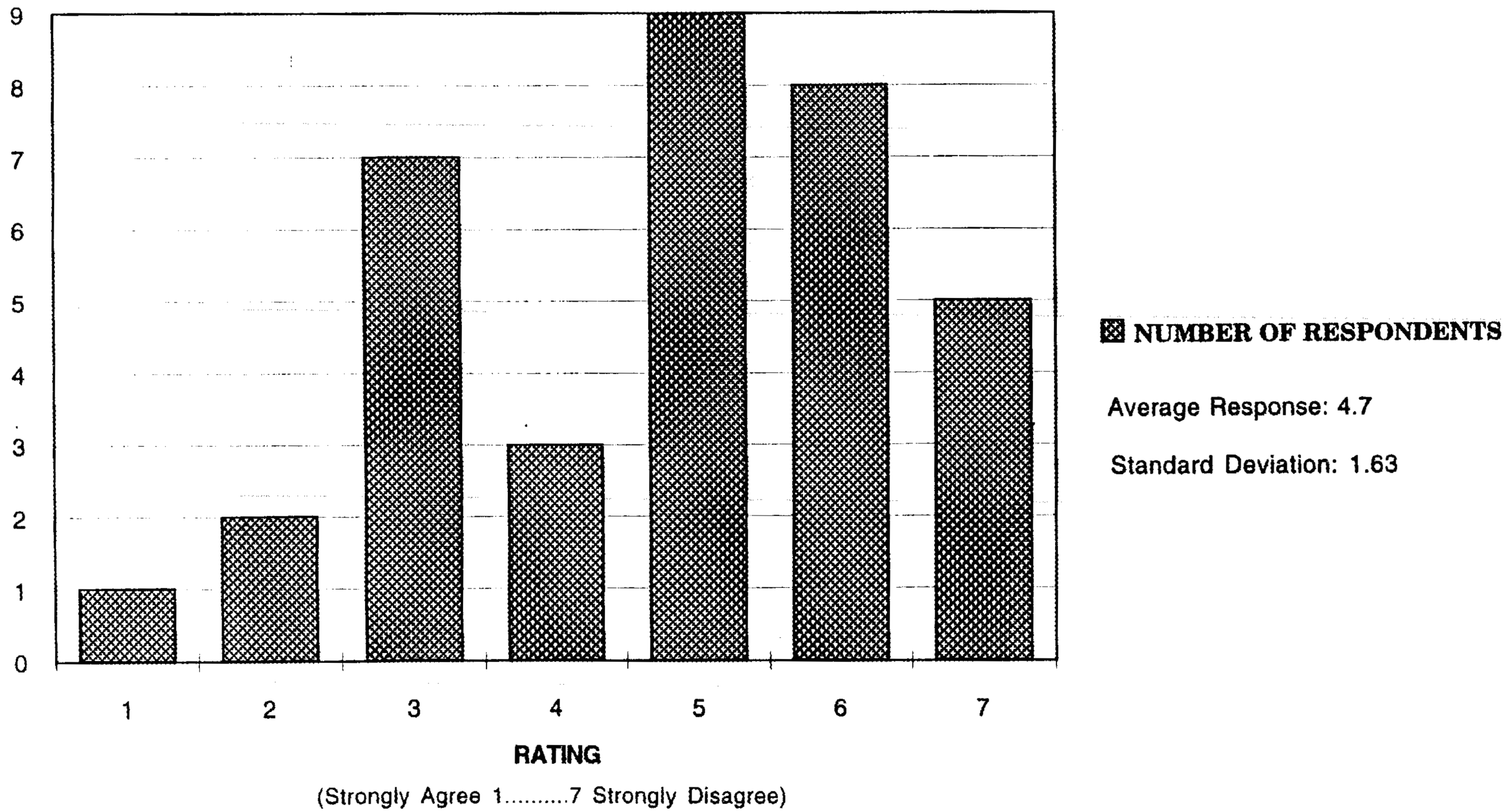
THE TVs AND SOUND SYSTEM REALLY MADE ME FEEL LIKE I WAS THERE WORKING AT THE REMOTE SITE



Average Response: 2.9

Standard Deviation: 1.41

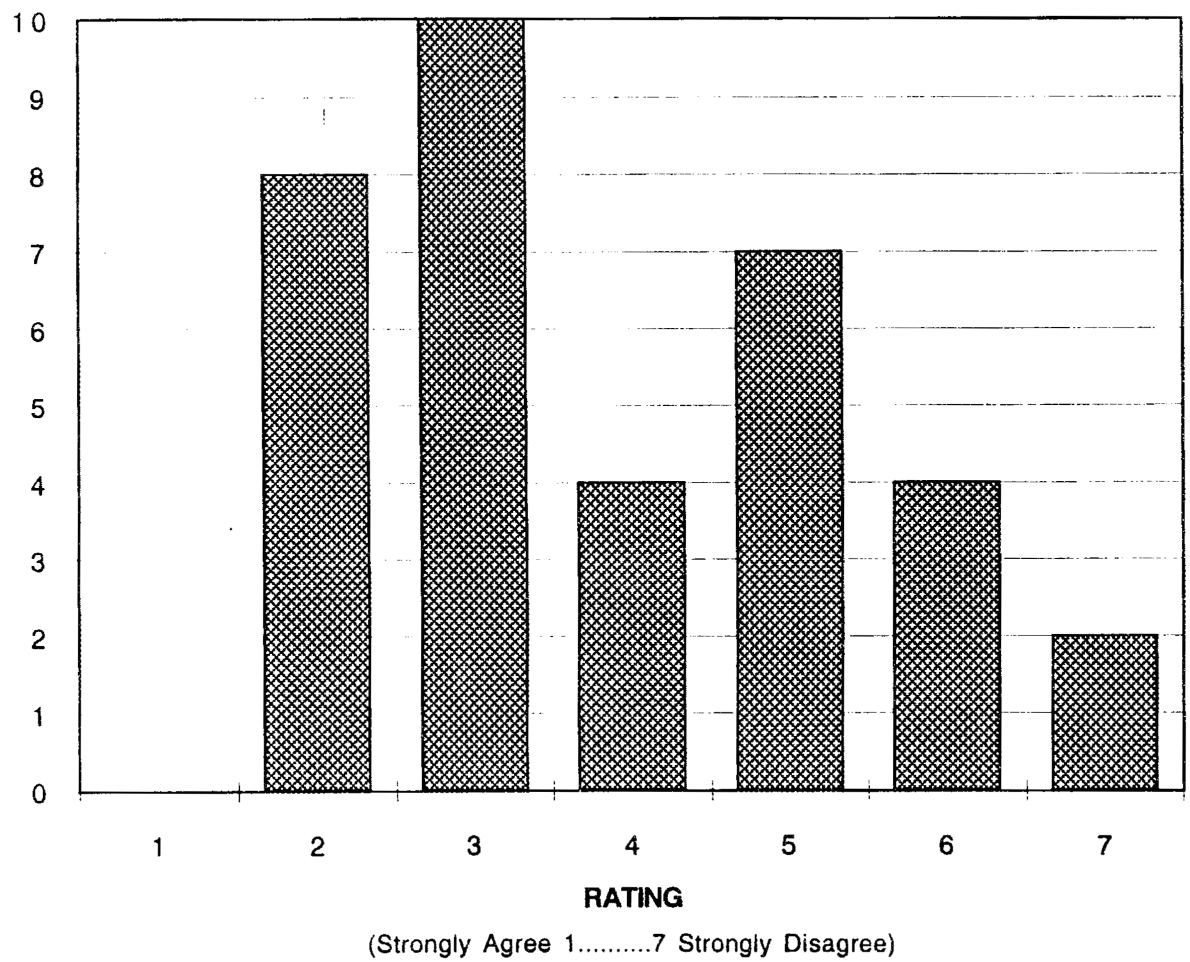
SOME DISPALYS (TEMPERATURE, TILT, JOINT POSITION, TORQUE, STATUS, ETC.) WERE NOT USEFUL



Average Response: 4.7

Standard Deviation: 1.63

THE TV MONITORS WERE THE BEST SIZE FOR THE WORK

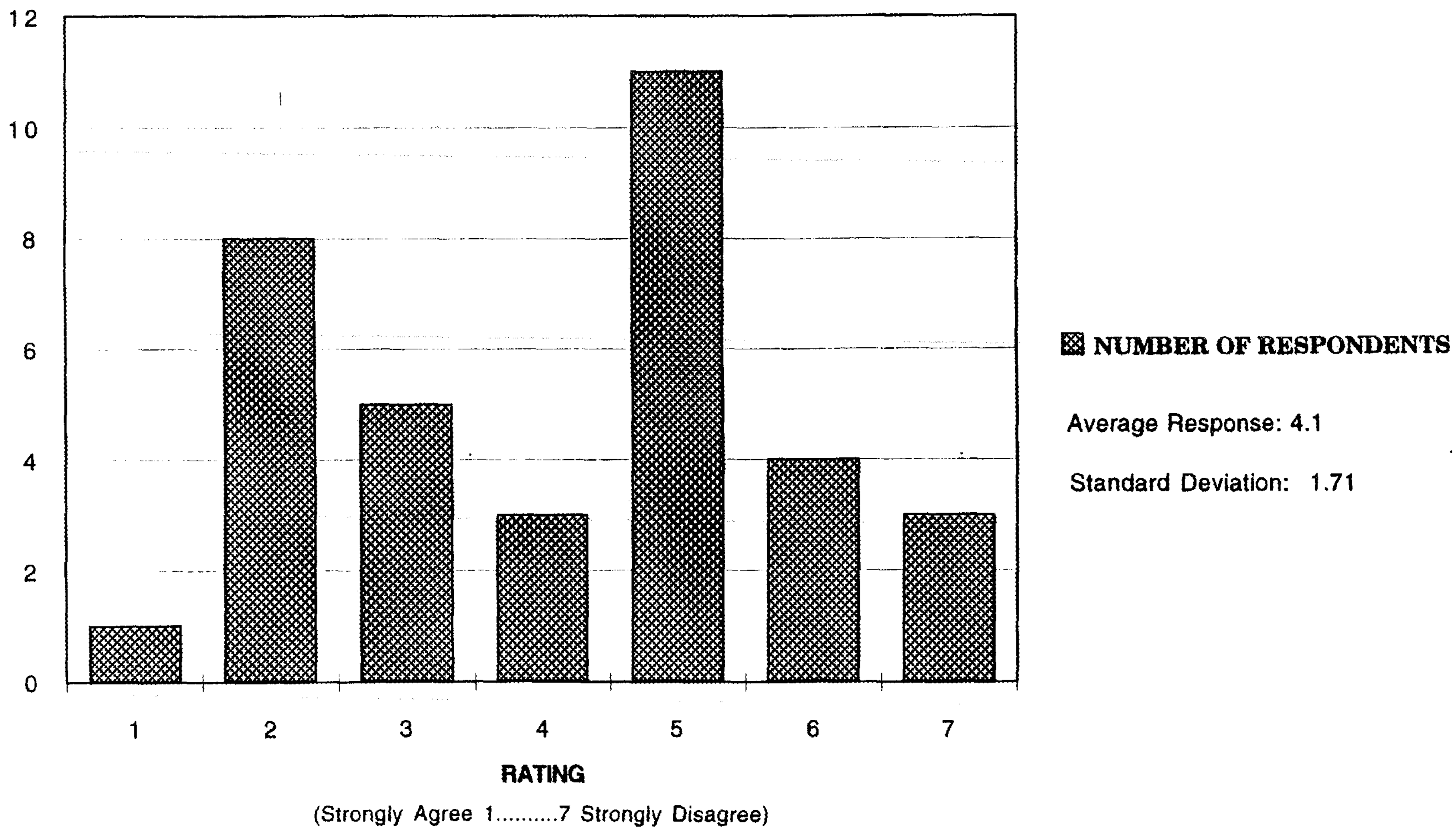


NUMBER OF RESPONDENTS

Average Response: 3.9

Standard Deviation: 1.56

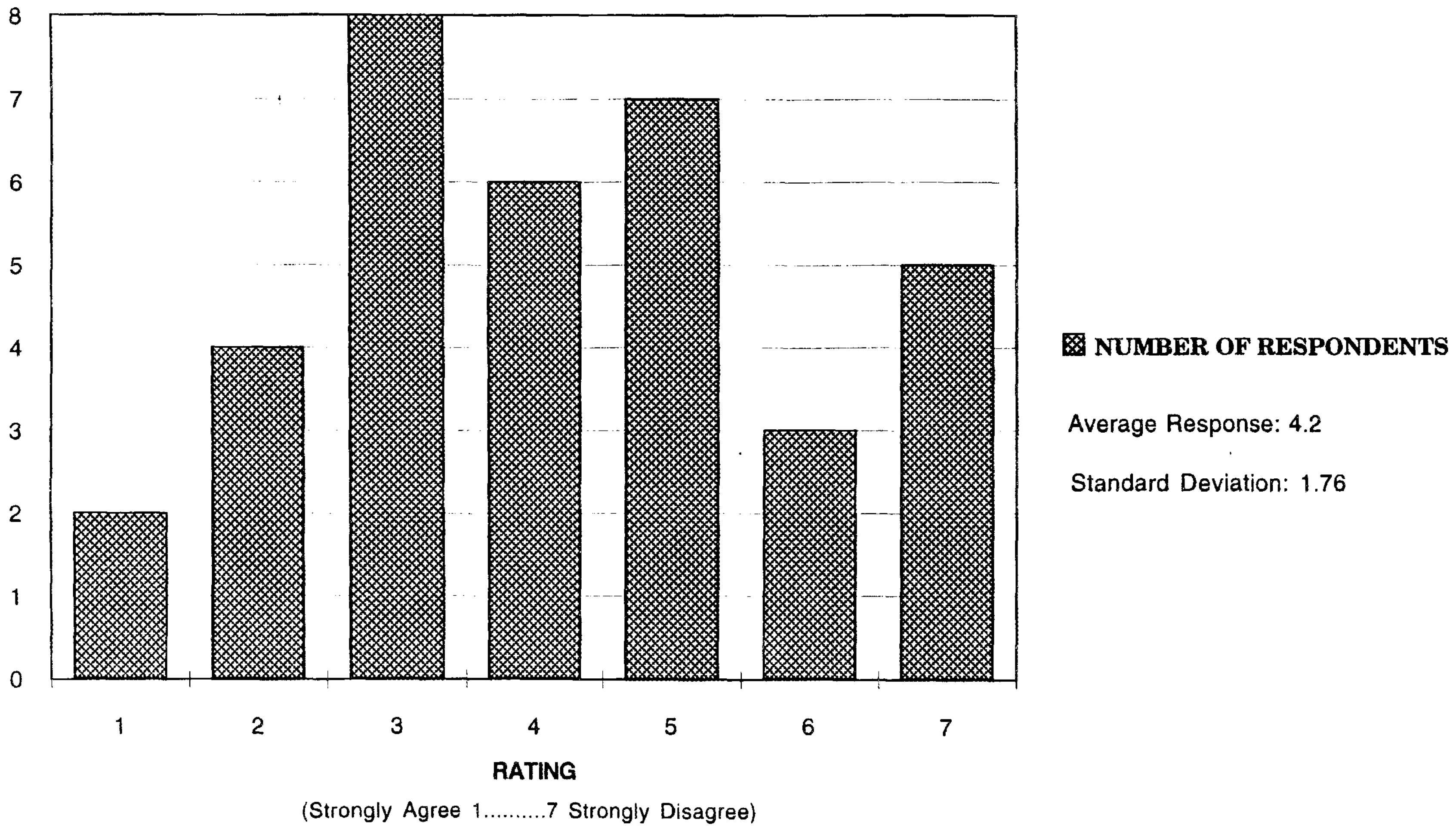
THE TV MONITORS WERE TOO SMALL



Average Response: 4.1

Standard Deviation: 1.71

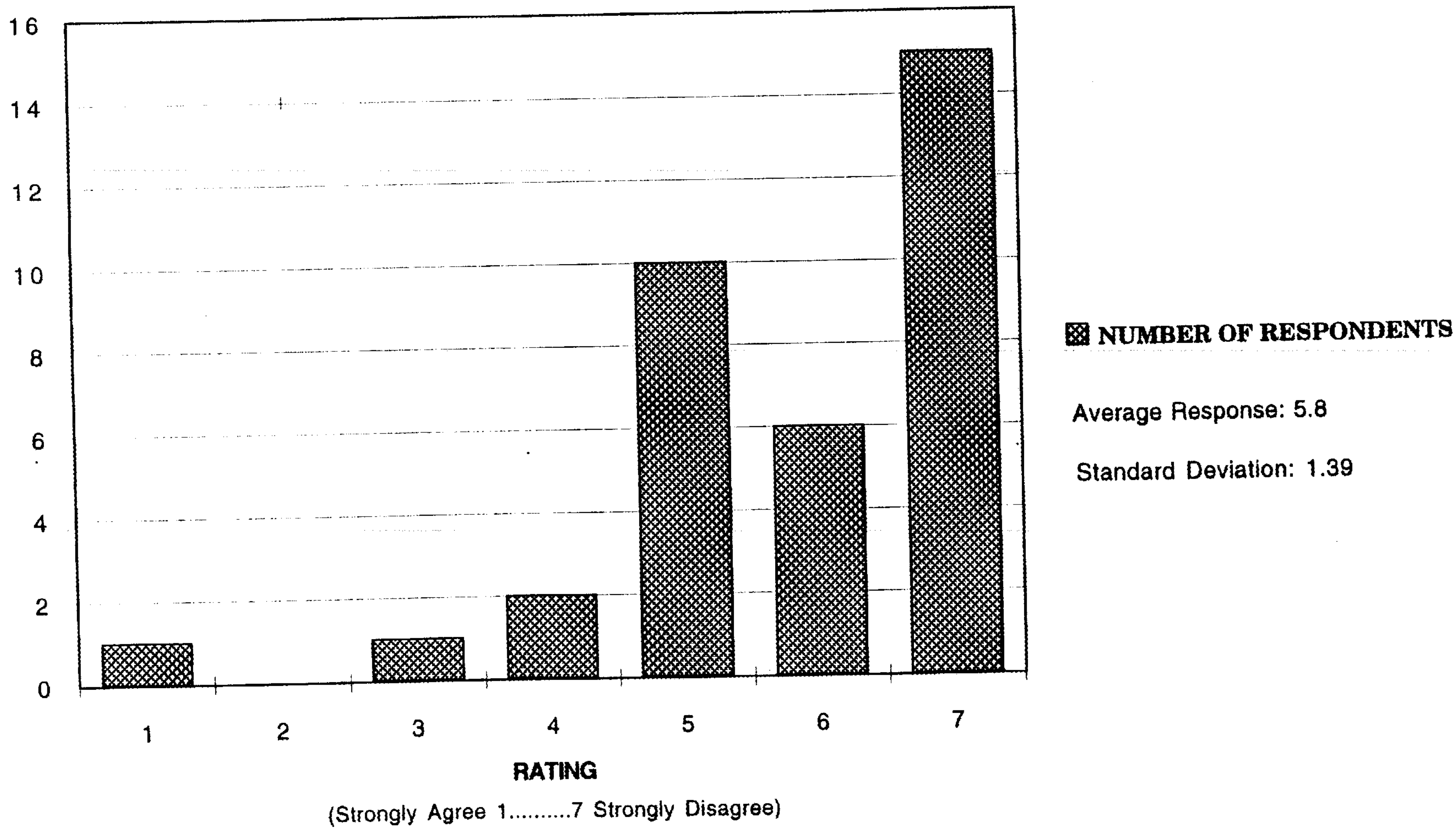
I COULDN'T HAVE DONE THE TASK WITHOUT THE ANIMATED BACK HOE DISPLAY



Average Response: 4.2

Standard Deviation: 1.76

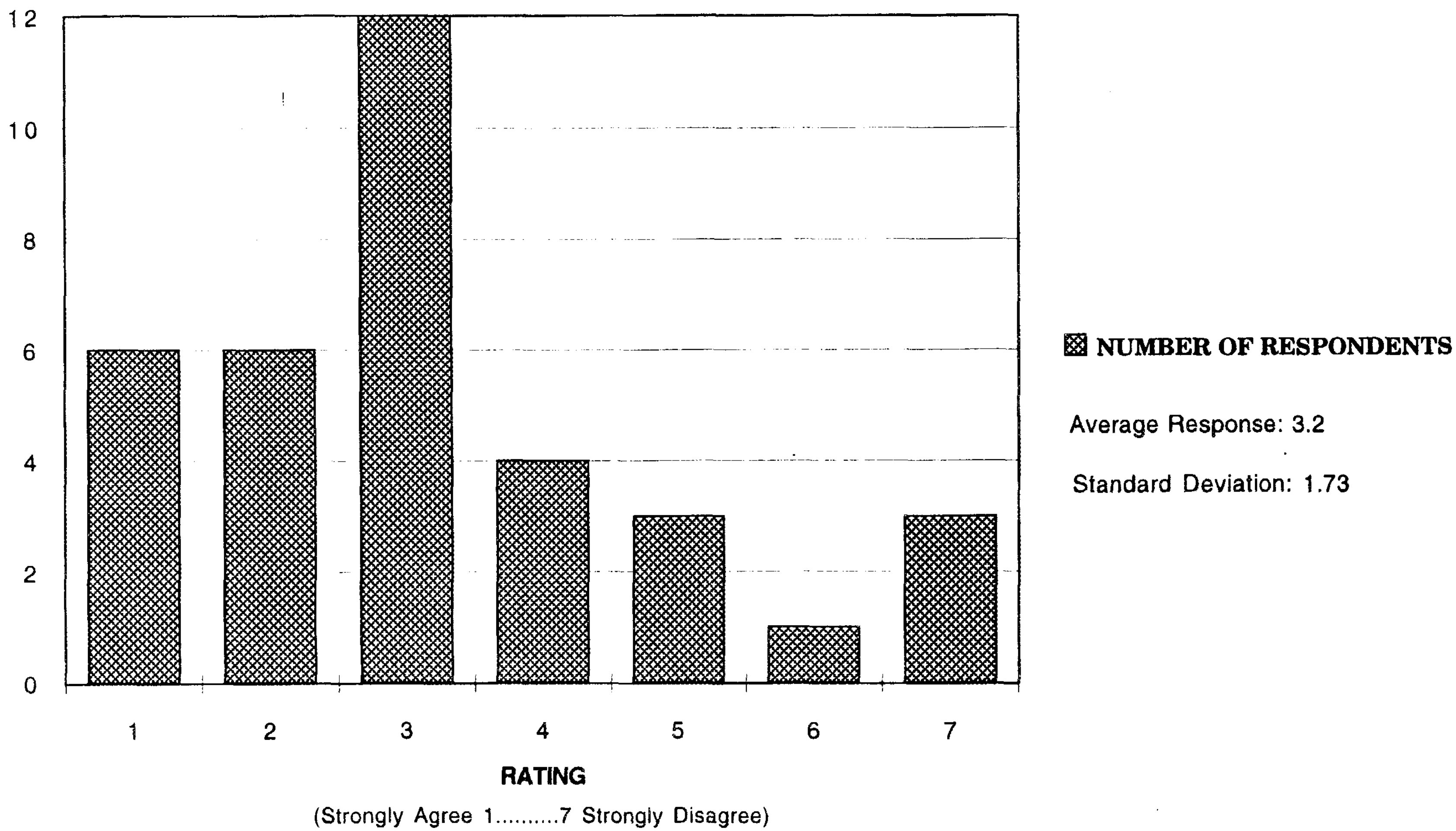
THE ANIMATED BACK HOE DISPLAY WAS NOT USEFUL DURING THE TASK



Average Response: 5.8

Standard Deviation: 1.39

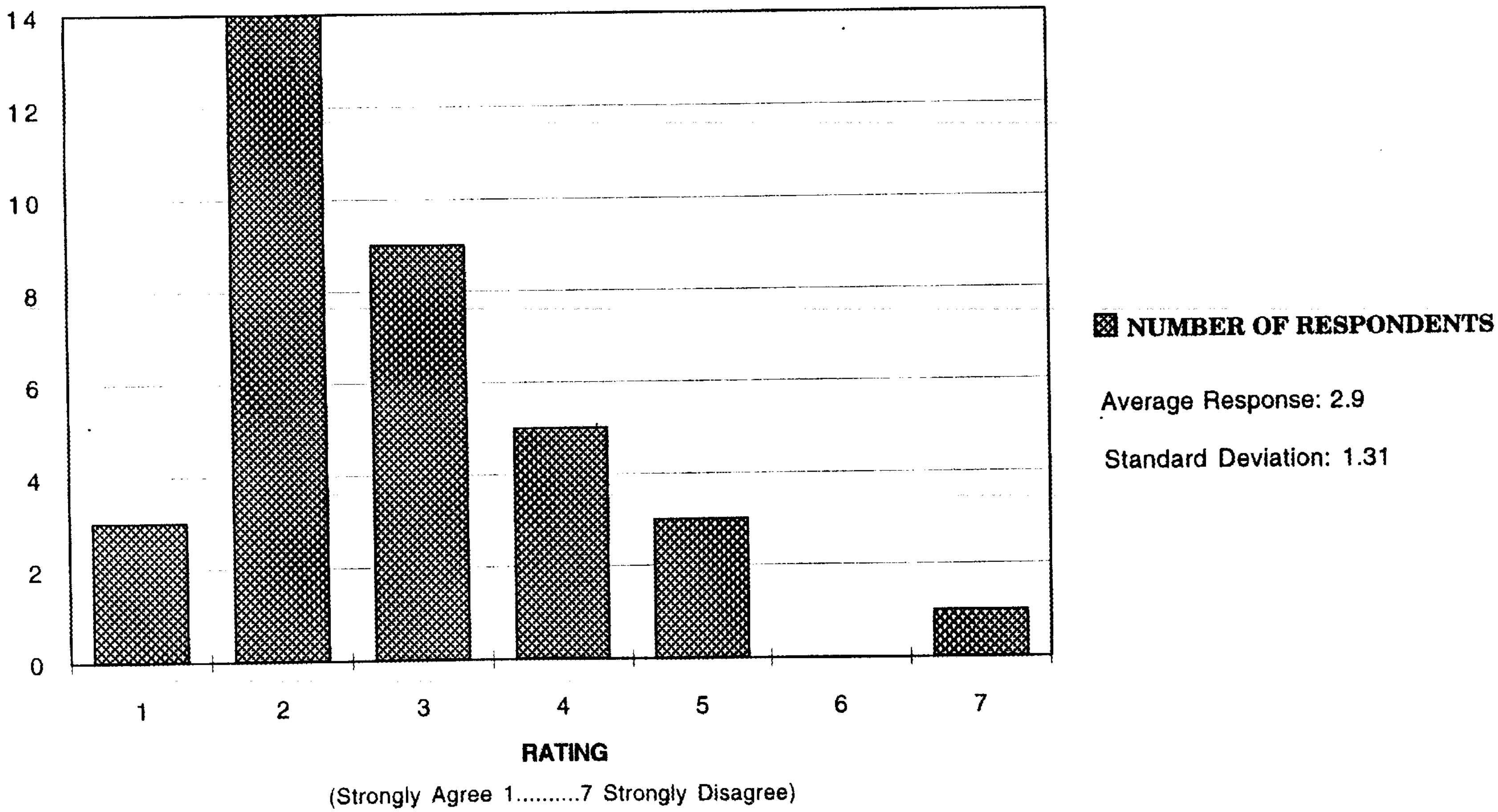
THE GRAPHIC INTERFACE GAVE ME ALL THE INFORMATION I NEEDED



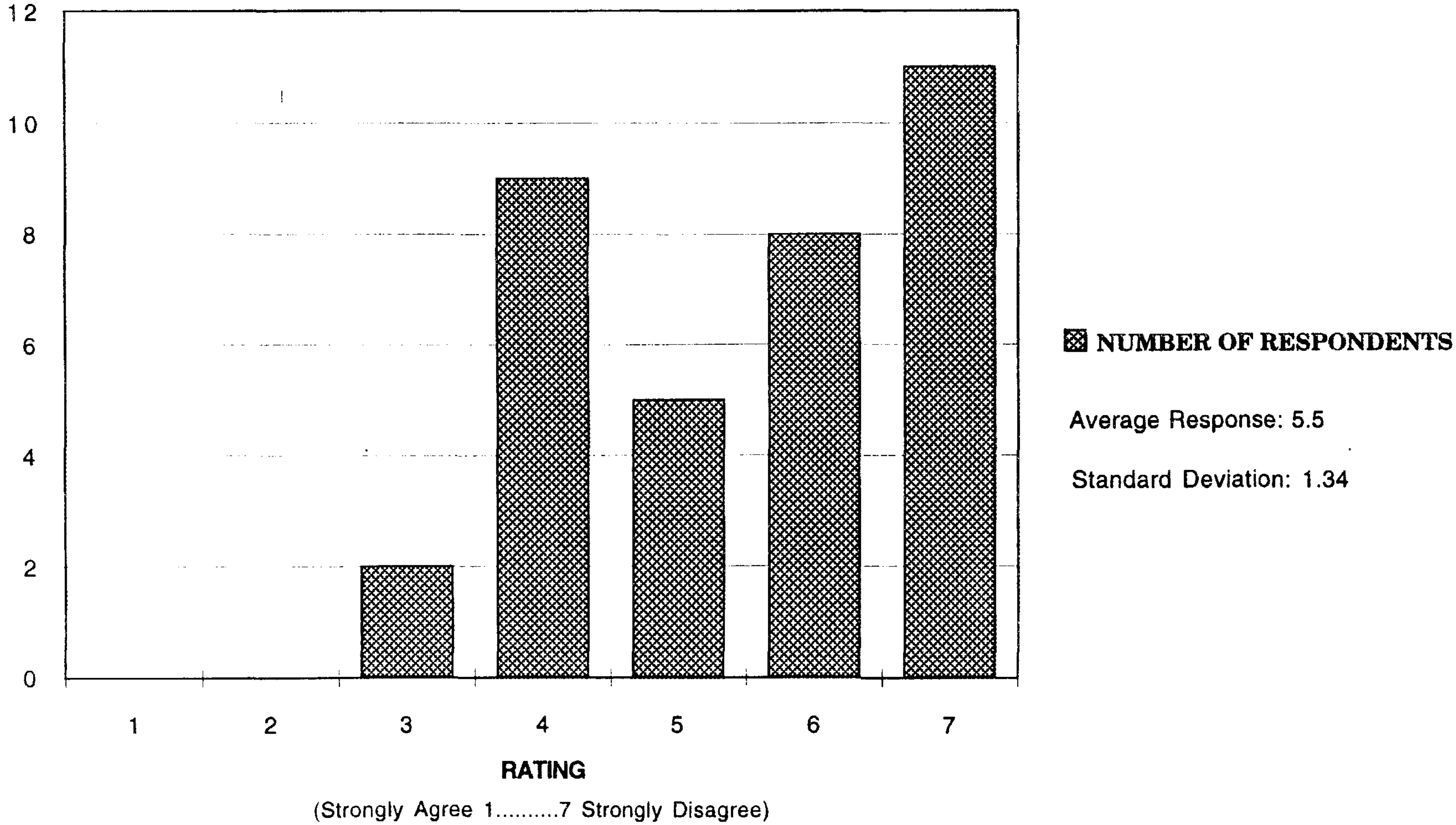
Average Response: 3.2

Standard Deviation: 1.73

THE CAMERAS ABOARD THE VEHICLE WERE IN THE BEST LOCATIONS TO DO THE WORK



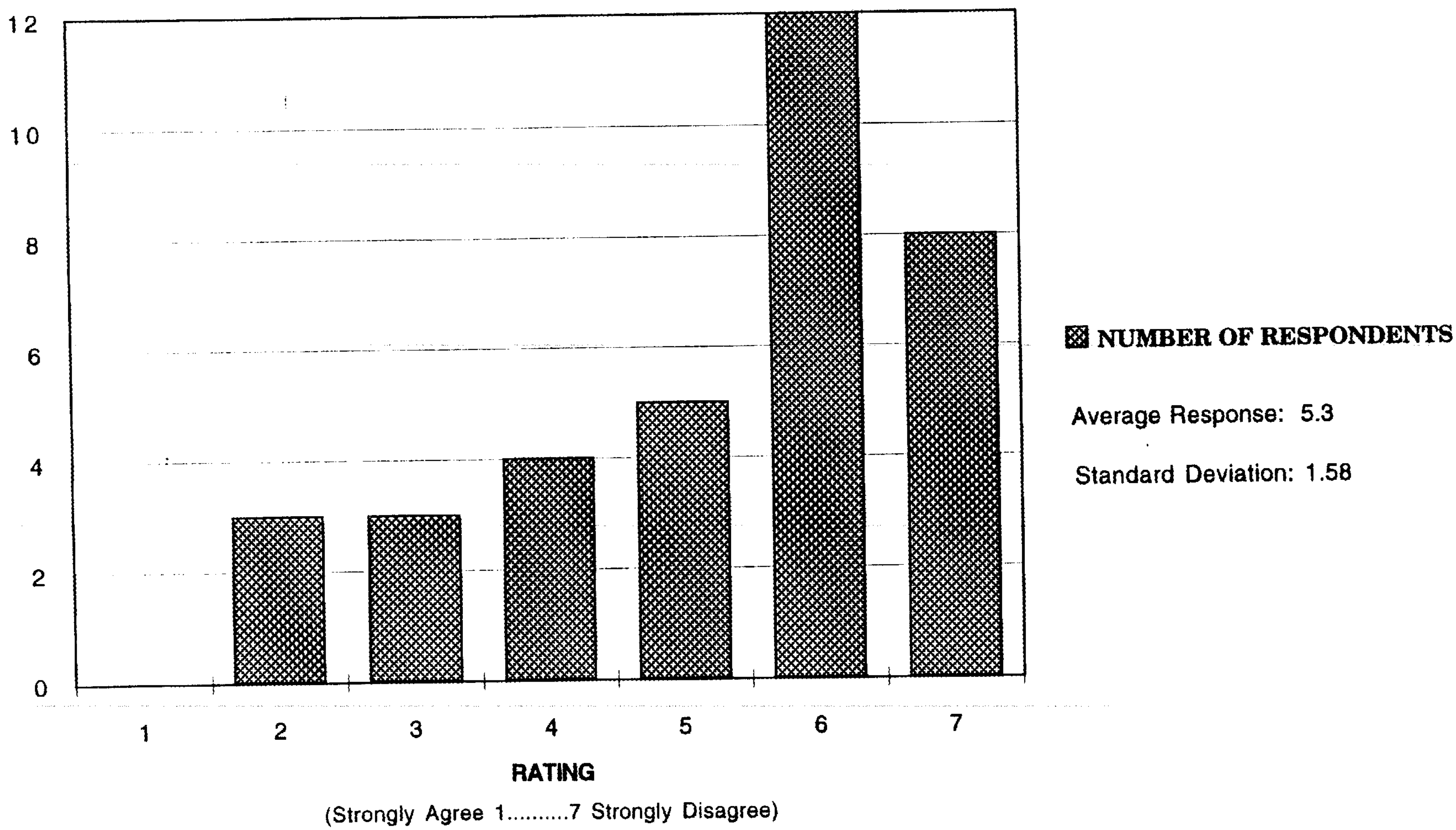
THE CAMERA CONTROLS WERE HARD OR CONFUSING TO USE



Average Response: 5.5

Standard Deviation: 1.34

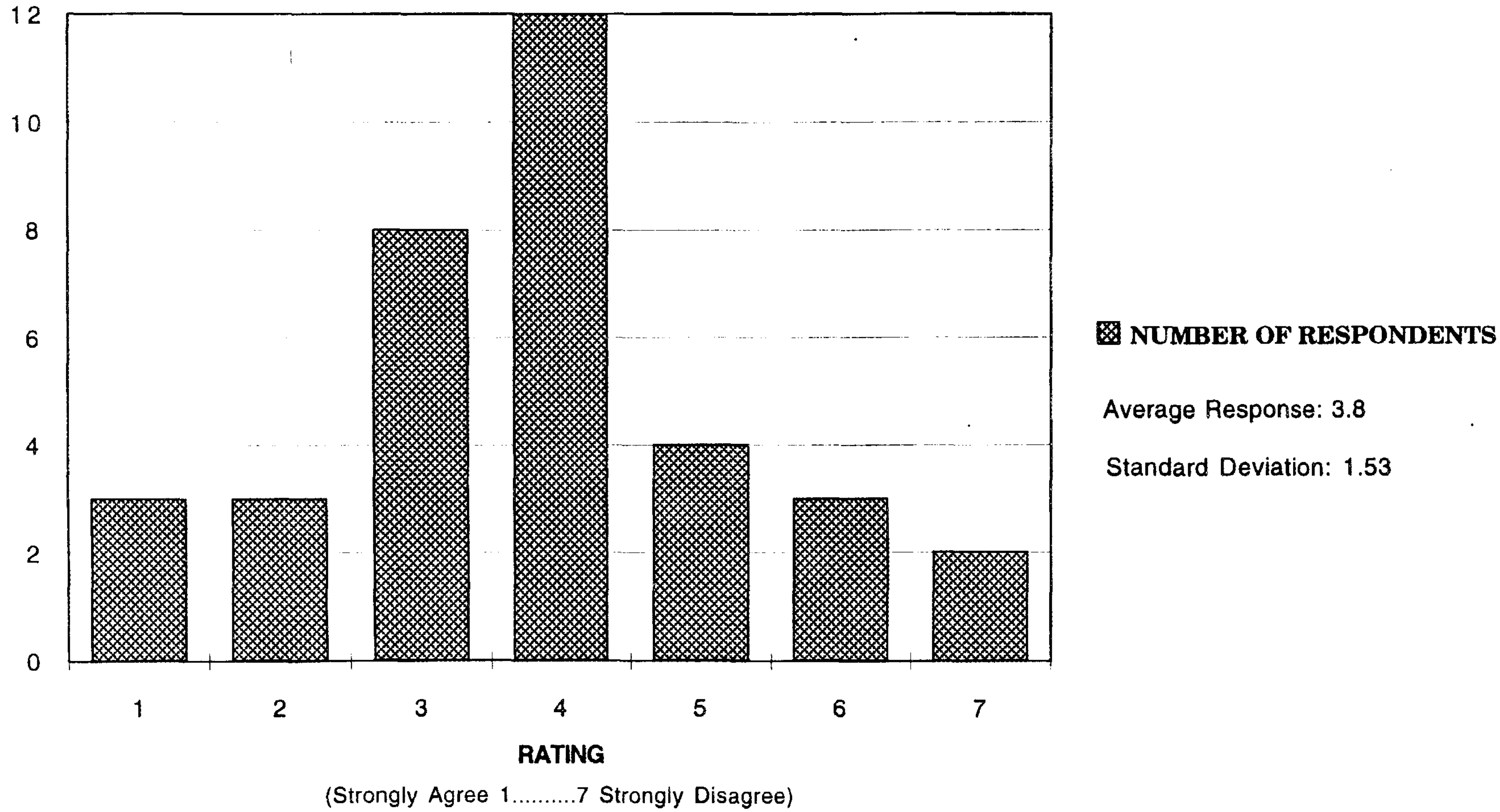
THE TV PICTURE QUALITY WASN'T GOOD ENOUGH TO DO THE JOB WELL



Average Response: 5.3

Standard Deviation: 1.58

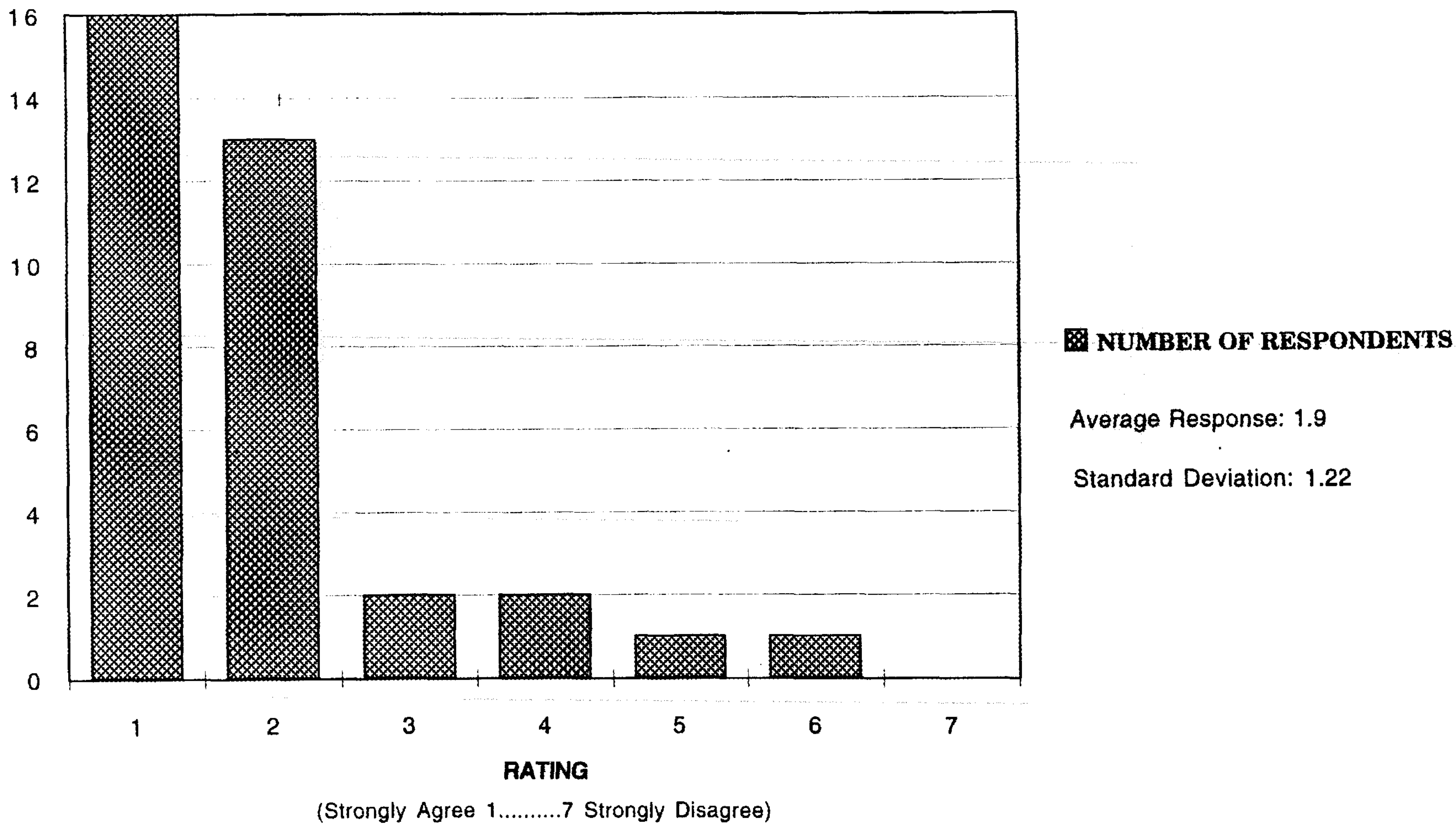
WHEN I WAS DOING THE TASK I FELT LIKE I WAS REALLY OUT THERE ON THE EXCAVATOR



Average Response: 3.8

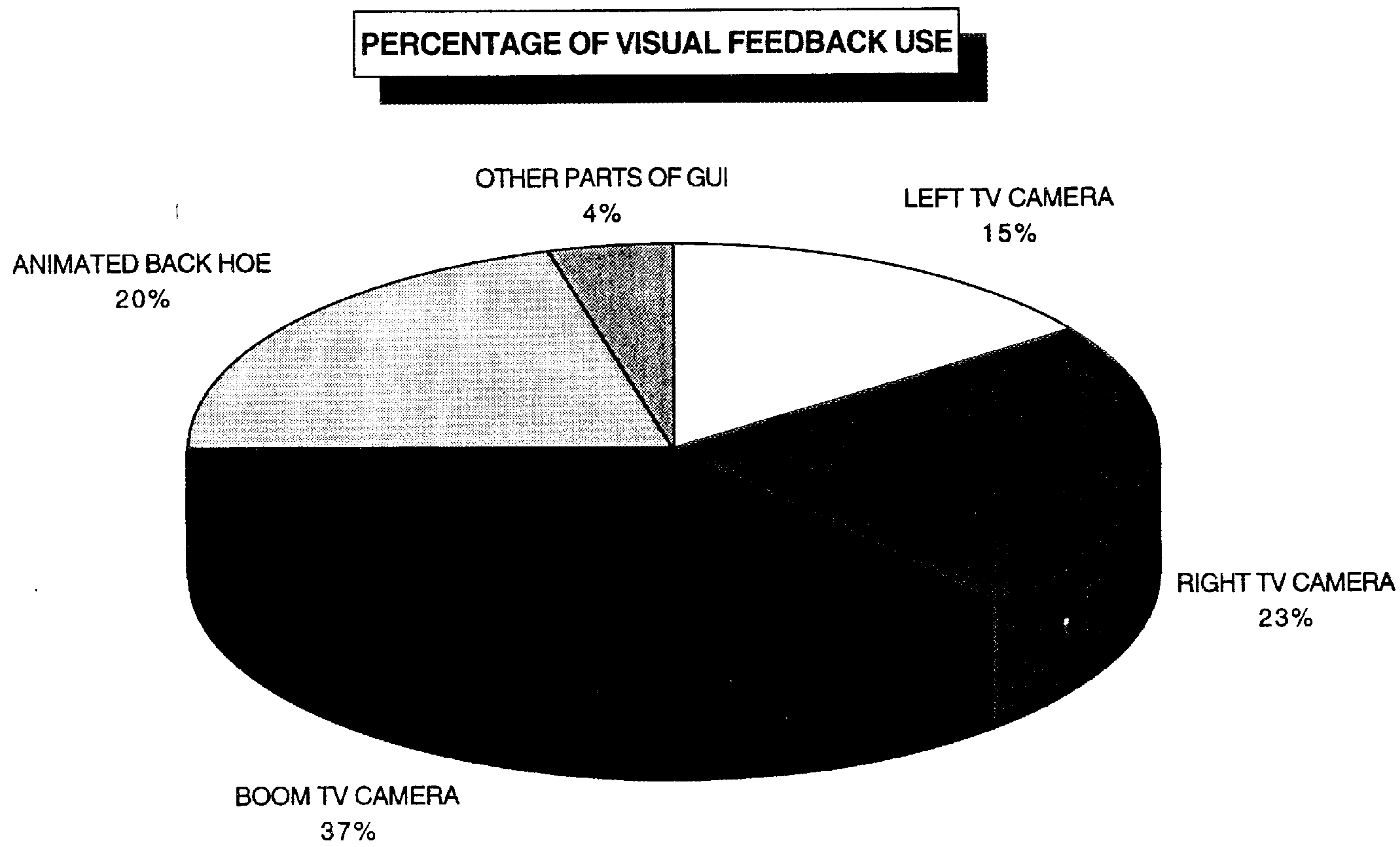
Standard Deviation: 1.53

THE SOUND FROM THE REMOTE AREA WAS IMPORTANT DURING THE TASK



Average Response: 1.9

Standard Deviation: 1.22



NOTE: PIE CHART SHOWS AVERAGE RESPONSE OF 32 EVALUATION PARTICIPANTS

APPENDIX D
SUMMARY OF OPERATOR COMMENTS

SUMMARY OF COMMENTS

RESPONSE NUMBER	COMMENTS
1	Recommend software enhancement. Full auto/semi-automatic bucket angle assist operations. Controls bucket angle automatically as a function of: % arm extensions; torque limits at joints;depth if cut selects. Auto/semi-auto status reporting and corrective action. Brings up system alert status on screen if system variable goes out of limits. Such limits would be: hydraulic pressure, fuel/engine status, tilt angle, load balance between bucket lift and vehicle tilt.
2	I think it will work.
3	None.
4	The joystick needs to have stronger springs. The system needs to be operable in an NBC environment and during darkness. The SEE sound is <u>very</u> important. Controls are easy to understand and use. Ensure the systems is maintainable on the battlefield.
5	The cameras don't allow for the sound of engine, the tilt of the vehicle, proper depth perception for fine control digging or maneuvering. Can the front bucket be raised to push vehicle forward for digging trenches?
6	Fairly simple, easy to use and understand.
7	Overall the remote operation went rather smoothly. It helps to have logged many hours manually before the remote operation. The only problem with the system which could result is the inexperience with the capabilities of the SEE Vehicle. I was really impressed with its operation.
8	None.

9 None.

10 The computer controls take more coordination than the lever of the machine. Once the controls are mastered, it shouldn't be a problem. The computer representation of the backhoe was beneficial in positioning the boom.

11 Camera should be placed higher to give a better view of the arm and surrounding area. The smaller camera should be larger, too much tunnel vision.

12 The cameras give a sense of tunnel vision and the TV monitor seemed to small. If one camera could be mounted high enough to view the vehicle and area of digging, it would make it easier.

13 Move microphone closer to bucket. Add lights. Adjust cameras.

14 Easily manipulated system. Sustained coordinated use seemed to work like a real SEE. (The simultaneous use of all controls for precise digging.)

15 It was difficult to get smooth action when moving from left to right. Possible use of a wide angle camera lens.

16 System will be of little use in most cases if the ability to drive the SEE remotely is not utilized. More depth perception should be placed into the system.

17 For Army use, a remote ability to lift/lower front bucket would greatly enhance the digging ability of the backhoe.

18 If fiber optics are used, an extra roll should be standard issue. If the original roll is damaged during a tactical situation, replacement would be almost impossible. For deeply buried ordnance, we need the ability to move the SEE and use the bucket loader to dig access routes into the excavation.

19 Hydraulics need to be stronger and smoother, I should be able to overload the system if needed, alarms did not allow this. The cameras were great!
I would incorporate a center on/off switch for the cameras.

20 Moving the backhoe left and right was too stiff and jumpy. I think that you should be able to move it easier and smoother, without so much resistance.

21 R&D should continue. I think it is a excellent system.

22 Cleanse monitors, would be easier to identify items on screen. LCD monitors lack a little in depth perception.

23 None.

24 None.

25 None.

26 The instrument gauges should have the normal operating ranges on the meter (green color). Operating the SEE remotely was the same as operating the SEE manually.

27 A soldier that plays video games would find this remote easier to use than I have.

28 None.

29 The computer controls are easier to use than the actual controls.

30 I was very skeptical at first but after operating the system I really like it. I hope it continues to work and is fielded soon.

31 Opening and closing the dipper was slow, giving a false sense of inoperability. With enough practice it should prove to be a very useful system.

32 None.

33 None.

34 None.

35 None.

APPENDIX E
SCHEMATIC DESIGN DRAWING INDEX

SMALL EMPLACEMENT EXCAVATOR DRAWING INDEX

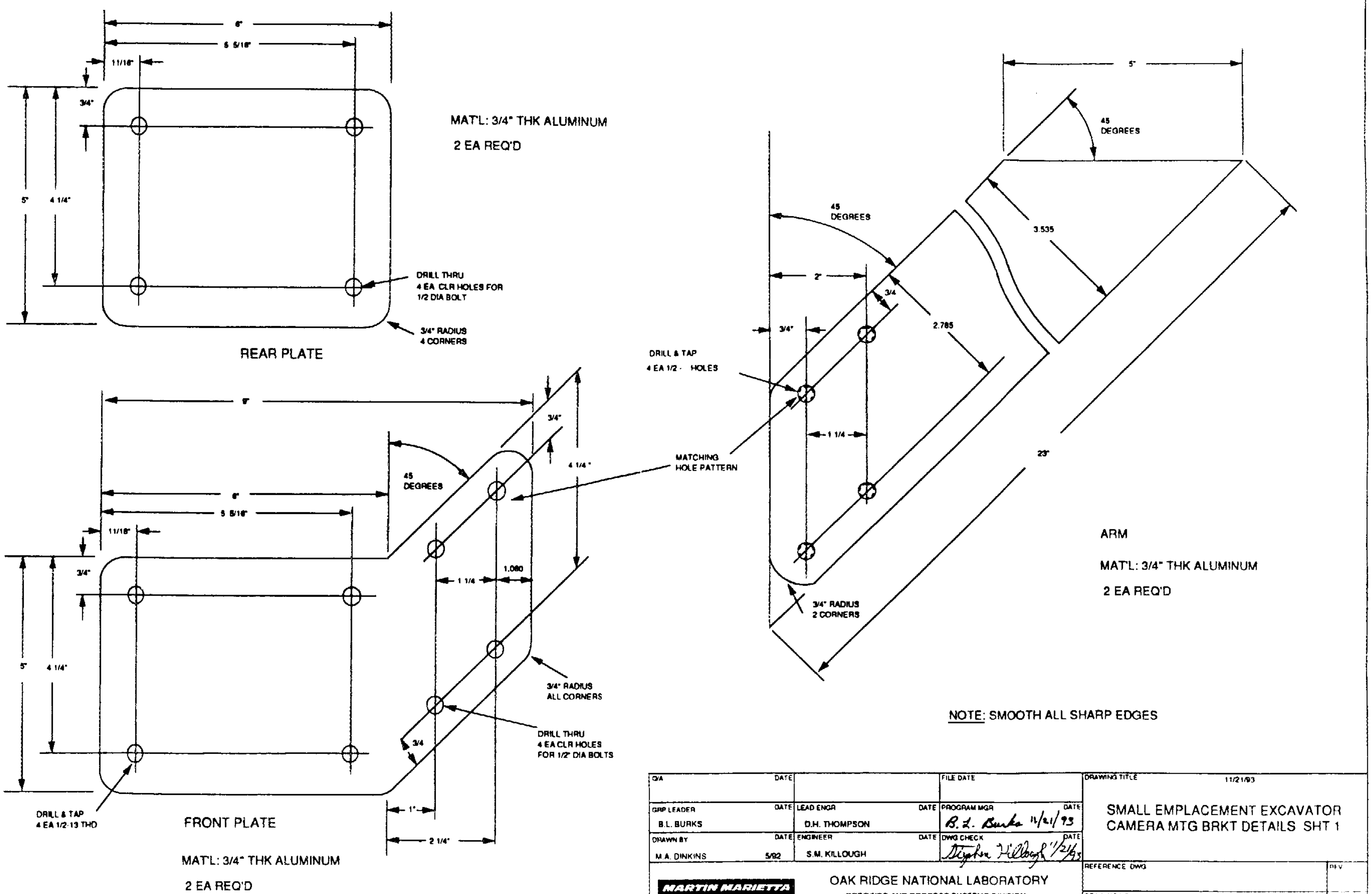
SEE-1	Camera Mtg Bracket Details Sht 1	
SEE-2	Camera Mtg Bracket Details Sht 2	
SEE-3	Camera Mtg Bracket Weldments & Assembly	
SEE-4	Video Camera & Lens Control Wiring Diagram	
SEE-5	Pan & Tilt Control Wiring Diagram	
SEE-6	Backhoe Joystick Control Wiring Diagram	
SEE-7	Alternator Support Bracket Details Sheet 1	
SEE-7	Atternaror Support Bracket Details Sheet 2	
SEE-7	Alternator Support Bracket Weldments Sheet 3	
SEE-8	Computer System Power Wiring Diagram	
SEE-9	Compact Backhoe Encoder Assembly	STAINLESS STEEL DESIGN
SEE-10	Compact Backhoe Encoder Details Sht 1	STAINLESS STEEL DESIGN
SEE-11	Compact Backhoe Encoder Details Sht 2	STAINLESS STEEL DESIGN
SEE-12	Compact Backhoe Encoder Details Sht 3	STAINLESS STEEL DESIGN
SEE-13	Compact Backhoe Encoder Details Sht 4	STAINLESS STEEL DESIGN
SEE-14	Compact Backhoe Encoder Details Sht 5	STAINLESS STEEL DESIGN
SEE-15	Compact Backhoe Encoder Details Sht 6	STAINLESS STEEL DESIGN
SEE-16	Compact Backhoe Encoder Assembly	ALUMINUM DESIGN
SEE-17	Compact Backhoe Encoder Details Sht 1	ALUMINUM DESIGN
SEE-18	Compact Backhoe Encoder Details Sht 2	ALUMINUM DESIGN
SEE-19	Compact Backhoe Encoder Details Sht 3	ALUMINUM DESIGN
SEE-20	Compact Backhoe Encoder Details Sht 4	ALUMINUM DESIGN
SEE-21	Compact Backhoe Encoder Details Sht 5	ALUMINUM DESIGN
SEE-22	Compact Backhoe Encoder Detals Sht 6	ALUMINUM DESIGN
SEE-23	VME DC Power Board Wiring Diagram	
SEE-24	Solenoid Valve Drives & Temperature Ckt	
SEE-25	Rev-up, Bucket, & Safety Valve Wiring Diagram	
SEE-26	Time-Out Timer Schematic Diagram	
SEE-27	A/D Input Cable Wiring Diagram	
SEE-28	Hydraulic Drive Signal Cable Wiring Diagram	
SEE-29	Resolver Cable Wiring Diagram	
SEE-30	Pressure Transducer Cable Wiring Diagram	
SEE-31	Backhoe Operator Control Box Wiring Diagram	
SEE-32	Backhoe Operator Control Box Metalphoto Labels	
SEE-33	VME Cabinet Air Cond Mtg Brackets Details & Assy	
SEE-34	VME Cabinet Mtg Brackets Details & Assembly	
SEE-35	VME Computer Cabinet Instrument Chassis Details	
SEE-36	VME Computer Cabinet Ass'y & Component Mtg Brkt Details	
SEE-37	Remote Drive Hyd Cntrl Valve Mtg Brkt Details	
SEE-38	Frontend Loader Control Component Mtg Plate Details	

Q/A / DATE		FILE DATE	DRAWING TITLE: 11/23/93 SMALL EMPLACEMENT EXCAVATOR DRAWING INDEX
GRP LEADER: B.L.BURKS / DATE	LEAD ENGR: D.H. THOMPSON / DATE	PROGRAM MGR: B.L. Burks / DATE 11/23/93	
DRAWN BY: M.A. DINKINS / DATE 5/92	ENGINEER: S.M. KILLOUGH / DATE	DWG CHECK: Stephen Killough / DATE 11/23/93	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG / REV DRAWING NO.: DWG INDEX Sht-1 / REV R0

SMALL EMPLACEMENT EXCAVATOR DRAWING INDEX

SEE-39 Remote Emergency Shutdown Safety Ckt Wiring Diagram
SEE-40 Bucket Encoder Mtg Bracket & Positioning Arm Details
SEE-41 Backhoe Boom Camera Housing Details
SEE-42 Front Hydraulic Electric Drive Wiring Diagram
SEE-43 Camera Video Switching Circuit Wiring Diagram
SEE-44 VME Computer Connector Layout & ID
SEE-45 GPS To VME Interconnecting Cable Wiring Diagram
SEE-46 Remote Driving Cntrl Box Piping & Wiring Diagram
SEE-47 Vehicle & Base Station Overall Block Diagram
SEE-48 Remote Driving Control Box To Computer Cable Wiring Diagram
SEE-49 Pneumatic & Video Switching Circuit Wiring Diagram
SEE-50 Pneumatic Shifter Indicator Circuit Wiring Diagram
SEE-51 Tilt Sensor Circuit Wiring Diagram
SEE-52 Engine Monitoring Sensors Wiring Diagram

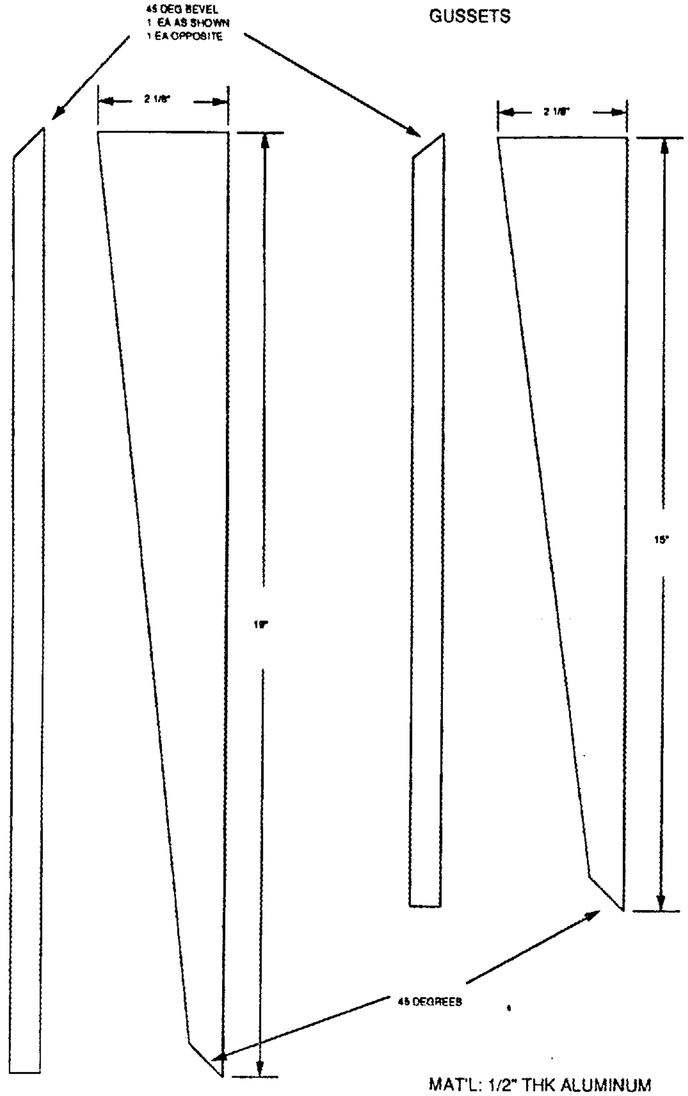
Q/A	DATE		FILE DATE	DRAWING TITLE 11/23/93
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON DATE	PROGRAM MGR B. L. Burks DATE 11/23/93	SMALL EMPLACEMENT EXCAVATOR DRAWING INDEX
DRAWN BY M.A. DINKINS	DATE 6/93	ENGINEER S.M. KILLOUGH DATE	DWG CHECK Stephen Killough DATE 11/23/93	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.		OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG — REV DRAWING NO. DWG INDEX Sht-2 — REV RØ



NOTE: SMOOTH ALL SHARP EDGES

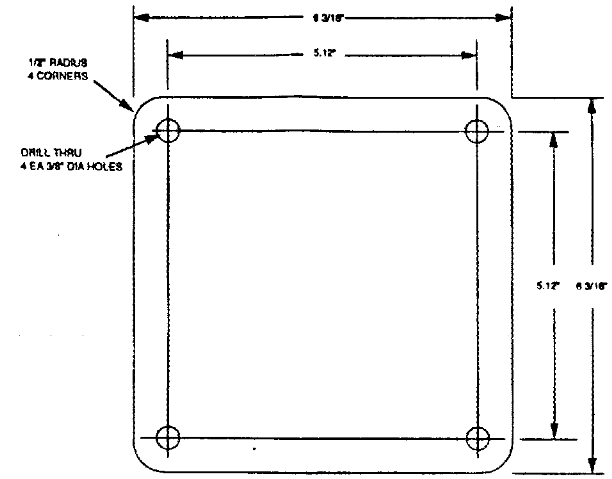
Q/A	DATE		FILE DATE	DRAWING TITLE 11/21/93
GRP LEADER B.L. BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B. L. Burks 11/21/93	SMALL EMPLACEMENT EXCAVATOR CAMERA MTG BRKT DETAILS SHT 1
DRAWN BY M.A. DINKINS	5/92	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 11/21/93	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC		OAK RIDGE NATIONAL LABORATORY — ROBOTICS AND PROCESS SYSTEMS DIVISION — Oak Ridge, Tennessee		REFERENCE DWG / DRAWING NO SEE-1 / REV RC

GUSSETS



MAT'L: 1/2" THK ALUMINUM
2 EA REQ'D

MAT'L: 1/2" THK ALUMINUM
2 EA REQ'D



BASE

NOTE: SMOOTH ALL SHARP EDGES

MAT'L: 1/2" THK ALUMINUM
2 EA REQ'D

QA DATE
FILE DATE
DRAWING TITLE 11/21/93

GRP LEADER B.L. BURKS DATE
LEAD ENGR D.H. THOMPSON DATE
PROGRAM MGR B. L. Burks 11/21/93 DATE

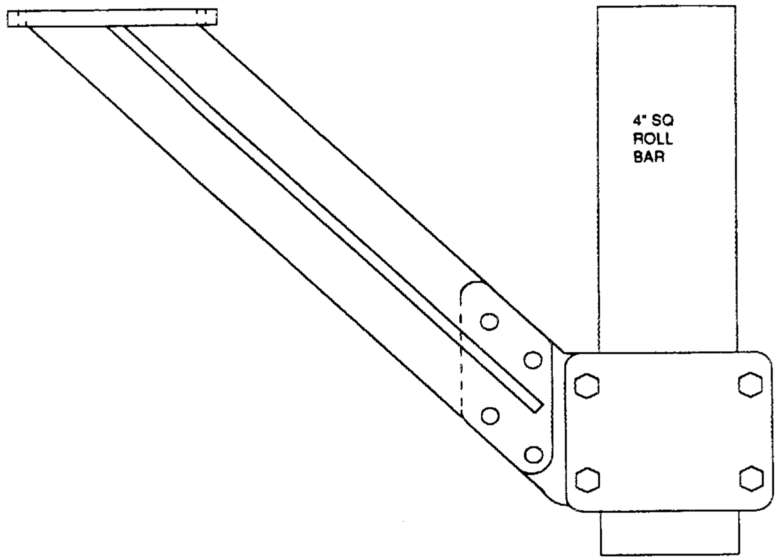
DRAWN BY M.A. DINKINS 5/92 DATE
ENGINEER S.M. KILLOUGH DATE
DWG CHECK Stephen Killough 11/21/93 DATE

SMALL EMPLACEMENT EXCAVATOR
CAMERA MTG BRKT DETAILS SHT 2

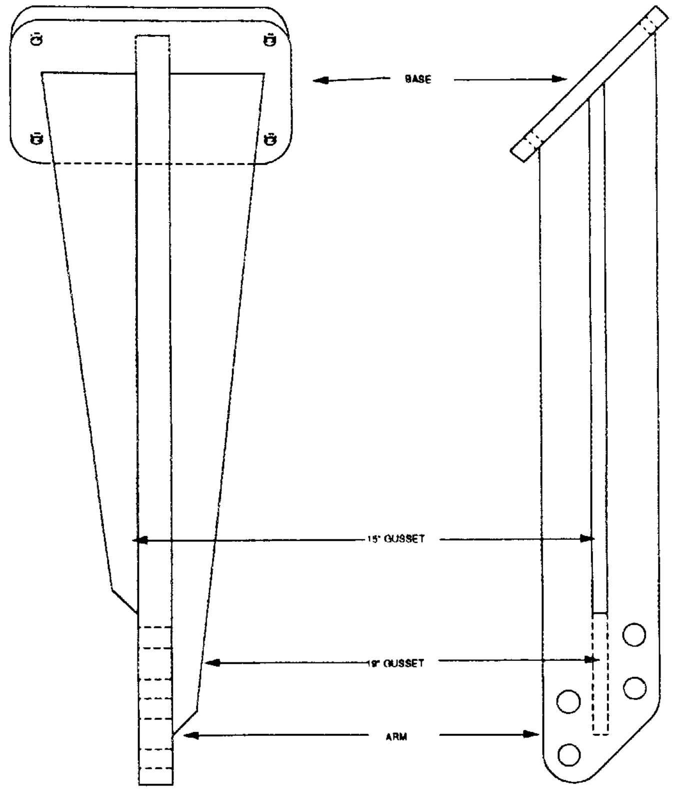
MARTIN MARIETTA
MARTIN MARIETTA ENERGY SYSTEMS, INC

OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG
REV
DRAWING NO
SEE 2
REV

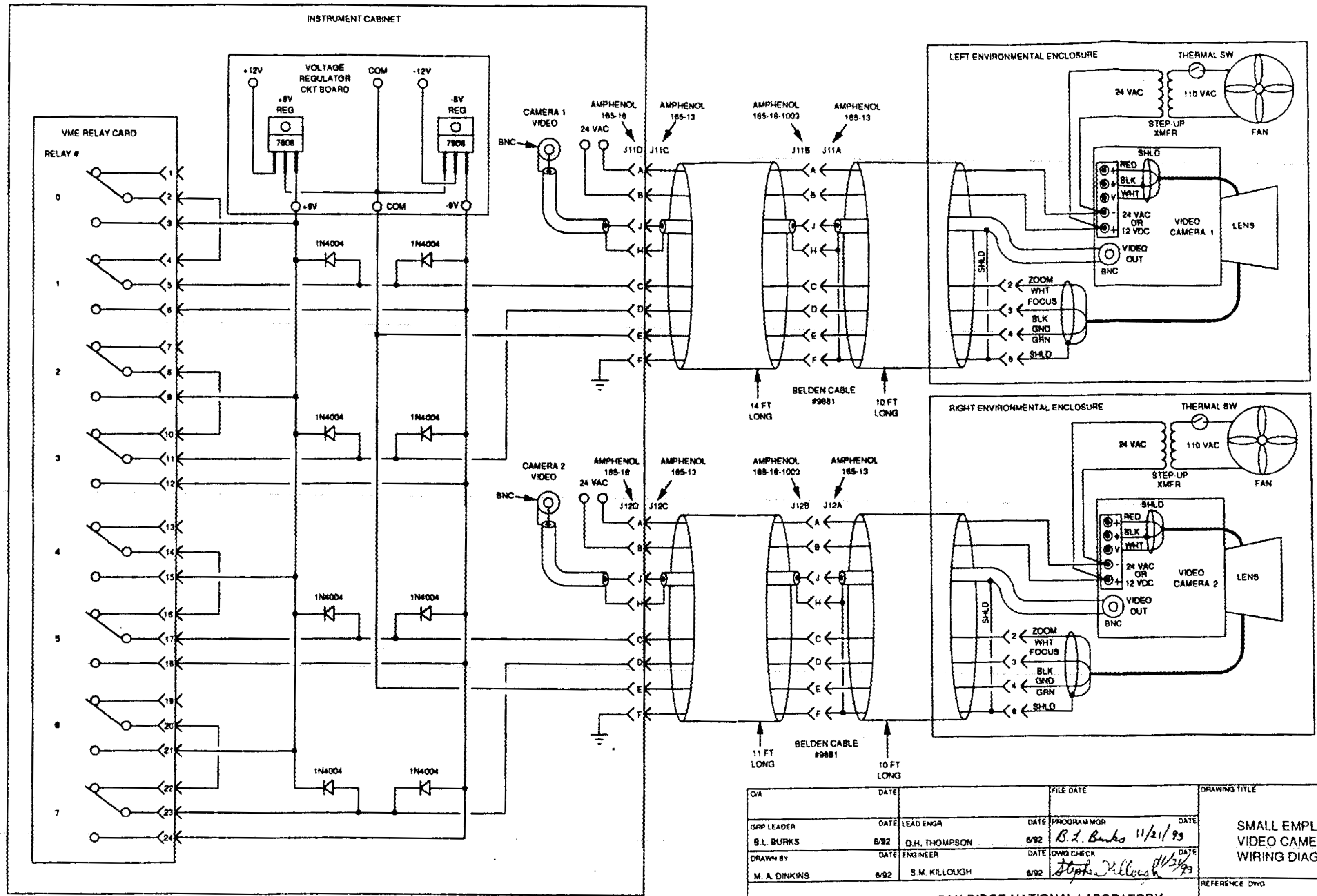


ASSEMBLY



WELD 1 EA AS SHOWN
1 EA IN WITH GUSSETS ON OPPOSITE SIDES

Q/A	DATE		FILE DATE	DRAWING TITLE 11/21/93
GRP LEADER B.L. BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B. L. Burks 11/24/93	SMALL EMPLACEMENT EXCAVATOR CAMERA MTG BRKT WELDMENTS & ASSEMBLY
DRAWN BY M.A. DINKINS	5/92	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 11/21/93	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC		OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG / REV DRAWING NO SEE-3 / REV

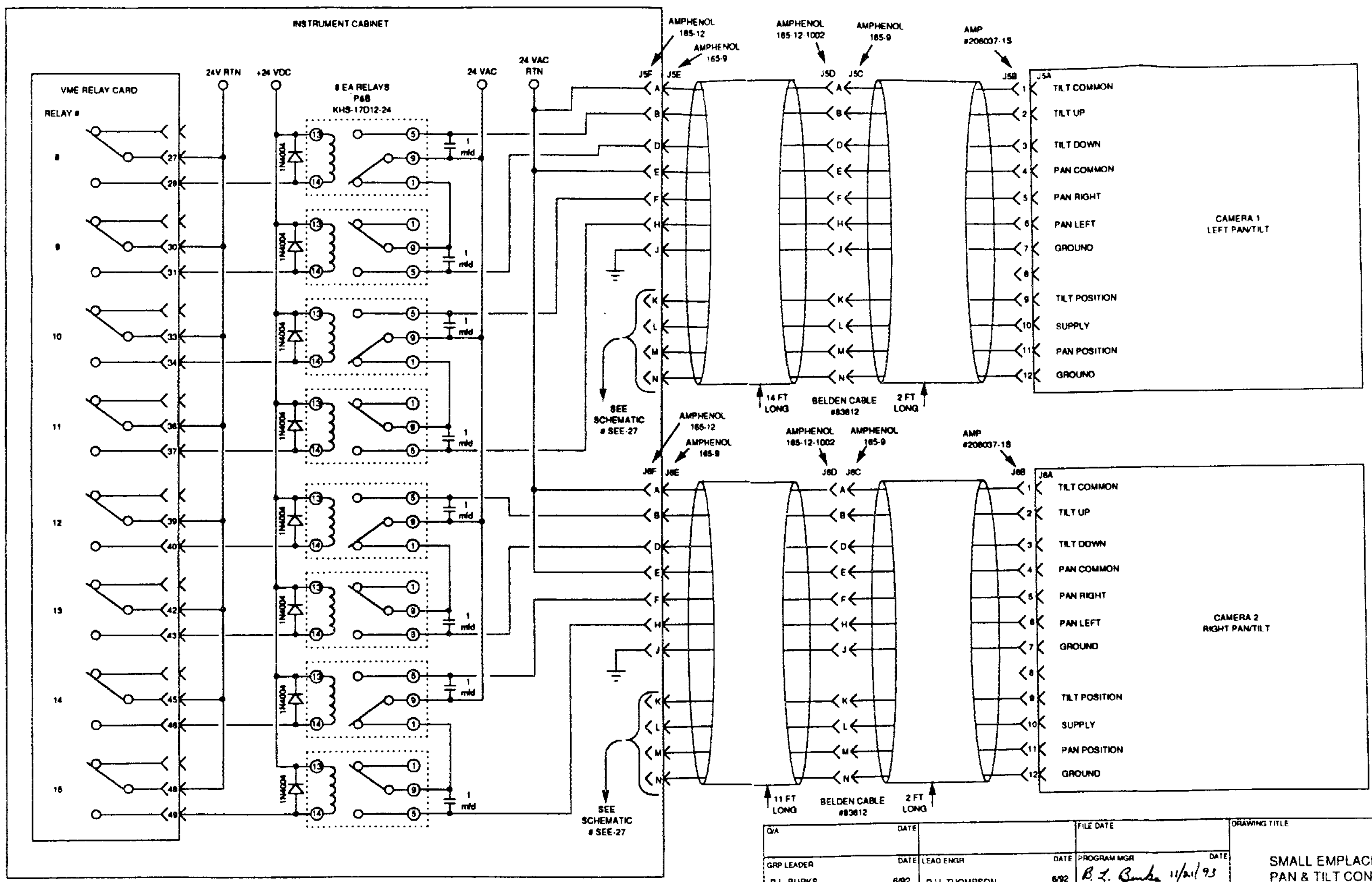


Q/A	DATE		DATE	FILE DATE		DRAWING TITLE 11/21/93
GRP LEADER B.L. BURKS	6/92	LEAD ENGR O.H. THOMPSON	6/92	PROGRAM MGR B.L. Burks 11/21/93	DATE	SMALL EMPLACEMENT EXCAVATOR VIDEO CAMERA & LENS CONTROL WIRING DIAGRAM
DRAWN BY M. A. DINKINS	6/92	ENGINEER S.M. KILLOUGH	6/92	DWG CHECK Steph Killough 11/23/93	DATE	

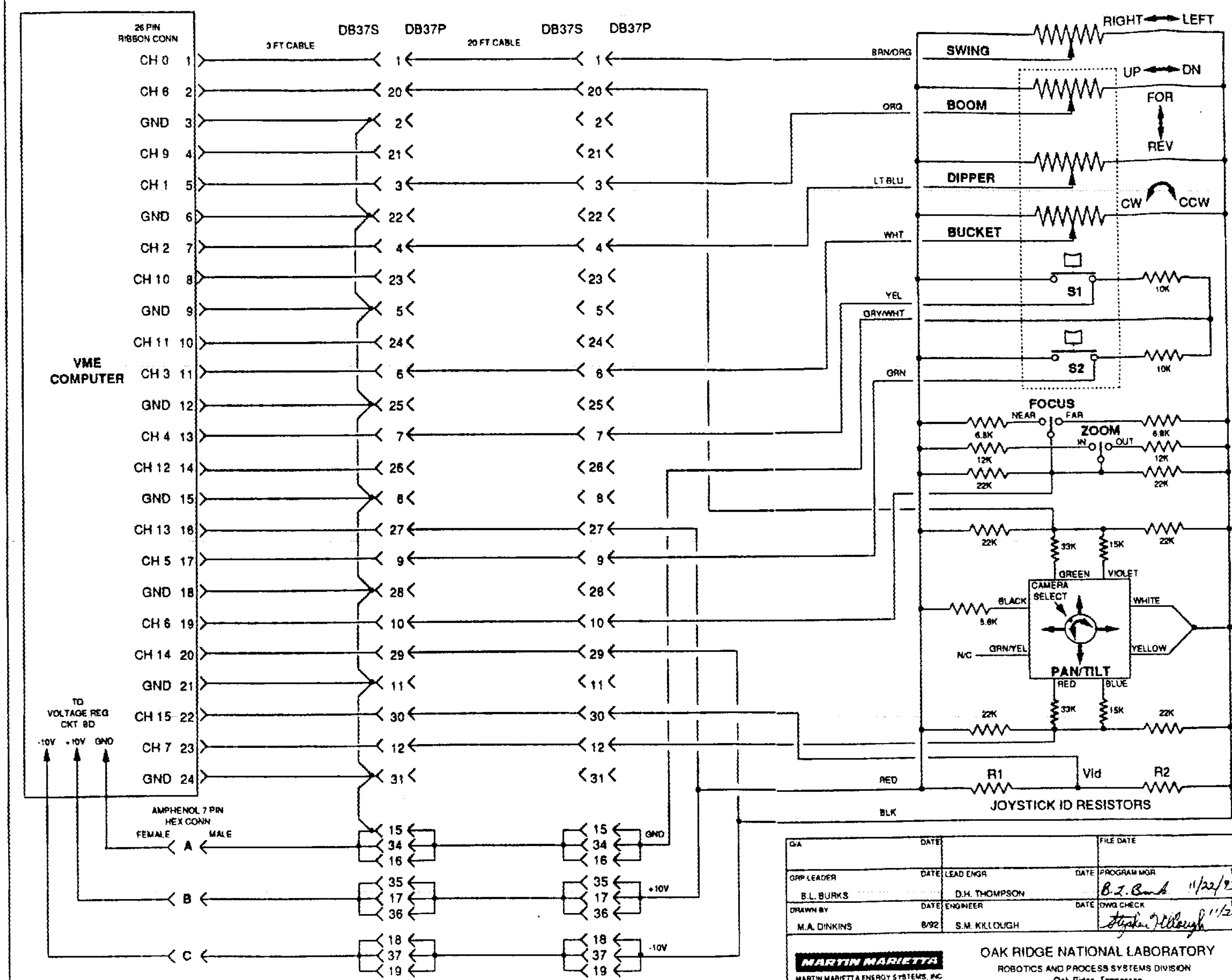
MARTIN MARIETTA
MARTIN MARIETTA ENERGY SYSTEMS, INC

OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG | REV
DRAWING NO SEE-4 | REV



Q/A — DATE		FILE DATE	DRAWING TITLE 11/21/93
GRP LEADER — DATE: B.L. BURKS 6/92	LEAD ENGR — DATE: D.H. THOMPSON 6/92	PROGRAM MGR — DATE: B. L. Burks 11/21/93	SMALL EMPLACEMENT EXCAVATOR PAN & TILT CONTROL WIRING DIAGRAM
DRAWN BY — DATE: M. A. DINKINS 6/92	ENGINEER — DATE: S.M. KILLOUGH 6/92	DWG CHECK — DATE: Stephen Killough 11/21/93	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY — ROBOTICS AND PROCESS SYSTEMS DIVISION — Oak Ridge, Tennessee		REFERENCE DWG — REV; DRAWING NO SEE-5 — REV RCl



JOYSTICK ID RESISTOR TABLE			
TYPE	Vid	R1	R2
-	+10.0V	-	-
15	+8.75V	1K	15K
14	+7.50V	2K	14K
13	+6.25V	3K	13K
12	+5.00V	4K	12K
11	+3.75V	5K	11K
10	+2.50V	6K	10K
9	+1.25V	7K	9K
8	0.00V	10K	10K
7	-1.25V	9K	7K
6	-2.50V	10K	6K
5	-3.75V	11K	5K
4	-5.00V	12K	4K
3	-6.25V	13K	3K
2	-7.50V	14K	2K
1	-8.75V	15K	1K
-	-10.0V	-	-

QA	DATE		FILE DATE
GRP LEADER B.L. BURKS	DATE	LEAD ENGR D.H. THOMPSON	DATE PROGRAM MGR B.L. Burks 11/22/93
DRAWN BY M.A. DINKINS	DATE 8/92	ENGINEER S.M. KILLOUGH	DATE DWG CHECK Stephen Killough 11/22/93

DRAWING TITLE 11/22/93

SMALL EMPLACEMENT EXCAVATOR BACKHOE JOYSTICK CONTROL WIRING DIAGRAM

MARTIN MARIETTA
MARTIN MARIETTA ENERGY SYSTEMS, INC

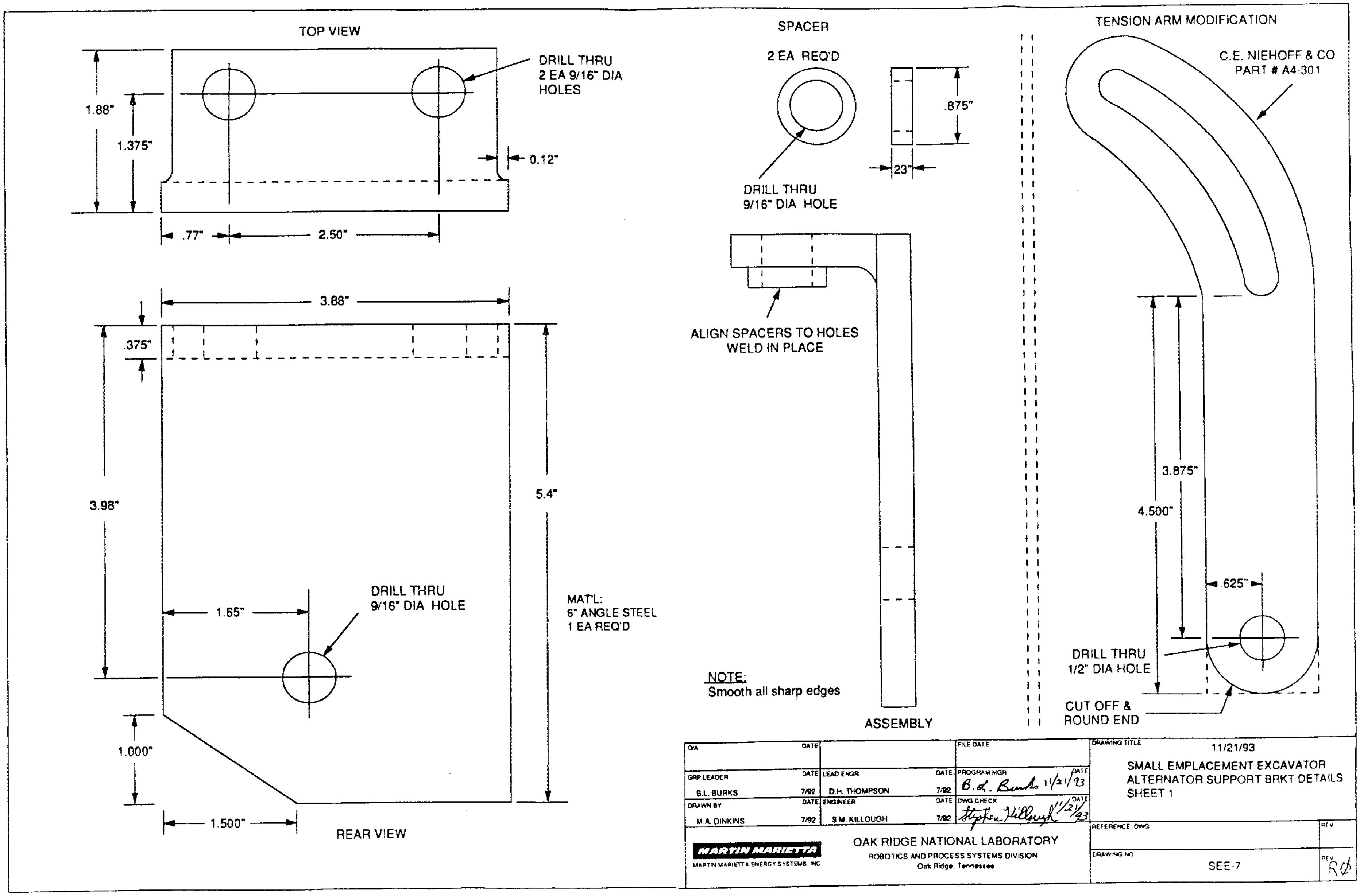
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG

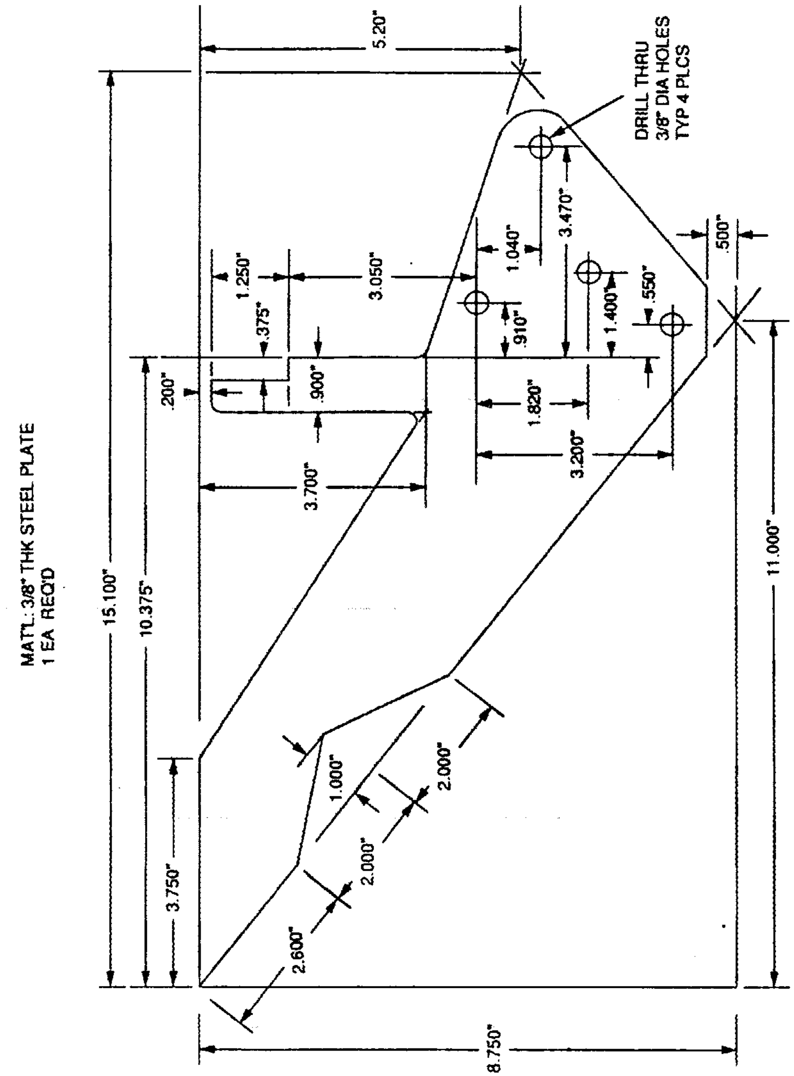
REV

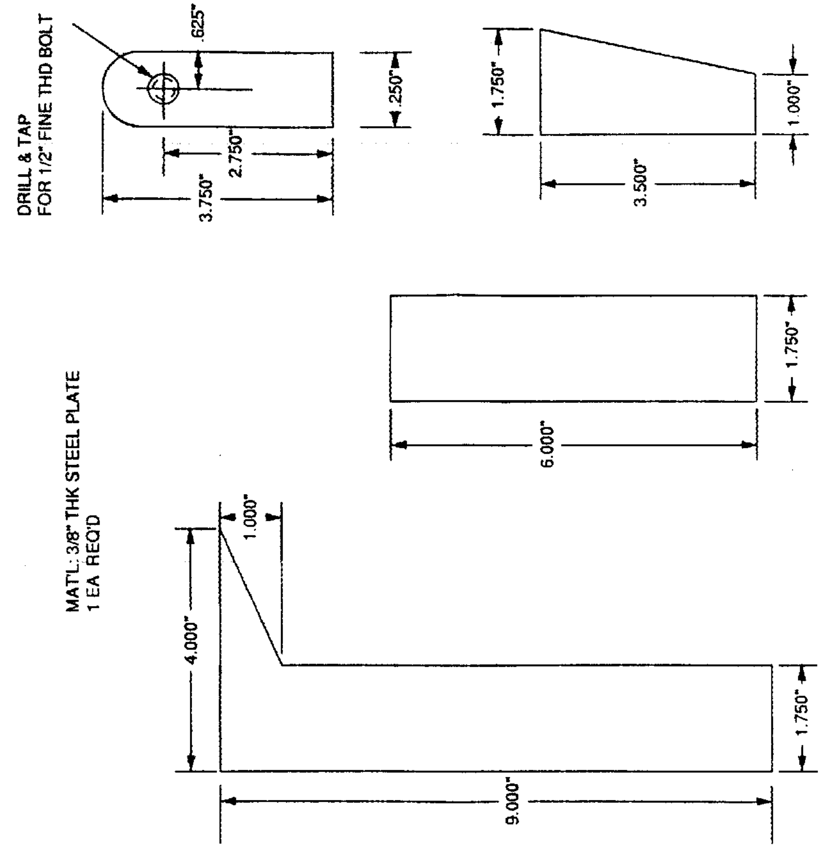
DRAWING NO SEE-6

REV Rd



TOP VIEW
DRILL THRU
2 EA 9/16" DIA
HOLES
1.88"
1.375"
0.12"
.77"
2.50"
3.88"
.375"
3.98"
5.4"
DRILL THRU
9/16" DIA HOLE
1.65"
MAT'L:
6" ANGLE STEEL
1 EA REQ'D
1.000"
1.500"
REAR VIEW
SPACER
2 EA REQ'D
.875"
.23"
DRILL THRU
9/16" DIA HOLE
ALIGN SPACERS TO HOLES
WELD IN PLACE
NOTE:
Smooth all sharp edges
ASSEMBLY
TENSION ARM MODIFICATION
C.E. NIEHOFF & CO
PART # A4-301
3.875"
4.500"
.625"
DRILL THRU
1/2" DIA HOLE
CUT OFF &
ROUND END
Q/A DATE
FILE DATE
DRAWING TITLE
11/21/93
SMALL EMPLACEMENT EXCAVATOR
ALTERNATOR SUPPORT BRKT DETAILS
SHEET 1
GRP LEADER DATE
B.L. BURKS 7/92
LEAD ENGR DATE
D.H. THOMPSON 7/92
PROGRAM MGR DATE
B. L. Burks 11/21/93
DRAWN BY DATE
M.A. DINKINS 7/92
ENGINEER DATE
S.M. KILLOUGH 7/92
DWG CHECK DATE
Stephen Killough 11/21/93
REFERENCE DWG
REV
MARTIN MARIETTA
MARTIN MARIETTA ENERGY SYSTEMS, INC
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee
DRAWING NO
SEE-7
REV
R0





SCALE = 2:1

QA	DATE		FILE DATE	DRAWING TITLE
GRP LEADER: B.L. BURKS	7/92	LEAD ENGR: D.H. THOMPSON 7/92	PROGRAM MGR: B. L. Burks 11/21/93	11/21/93 SMALL EMPLACEMENT EXCAVATOR ALTERNATOR SUPPORT BRKT DETAILS SHEET 2
DRAWN BY: M.A. DINKINS	7/92	ENGINEER: S.M. KILLOUGH 7/92	DWG CHECK: Stephen Killough 11/21/93	

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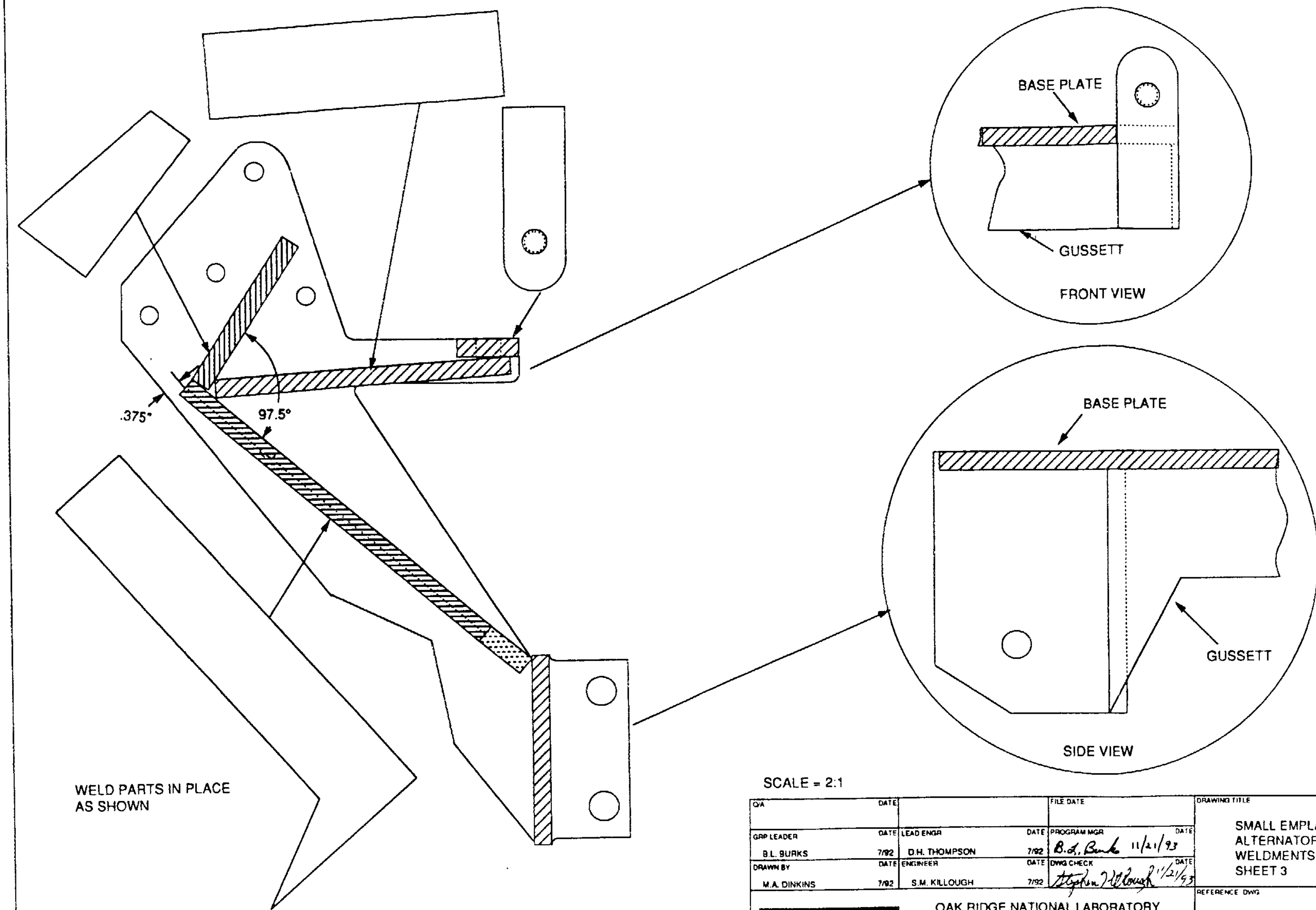
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

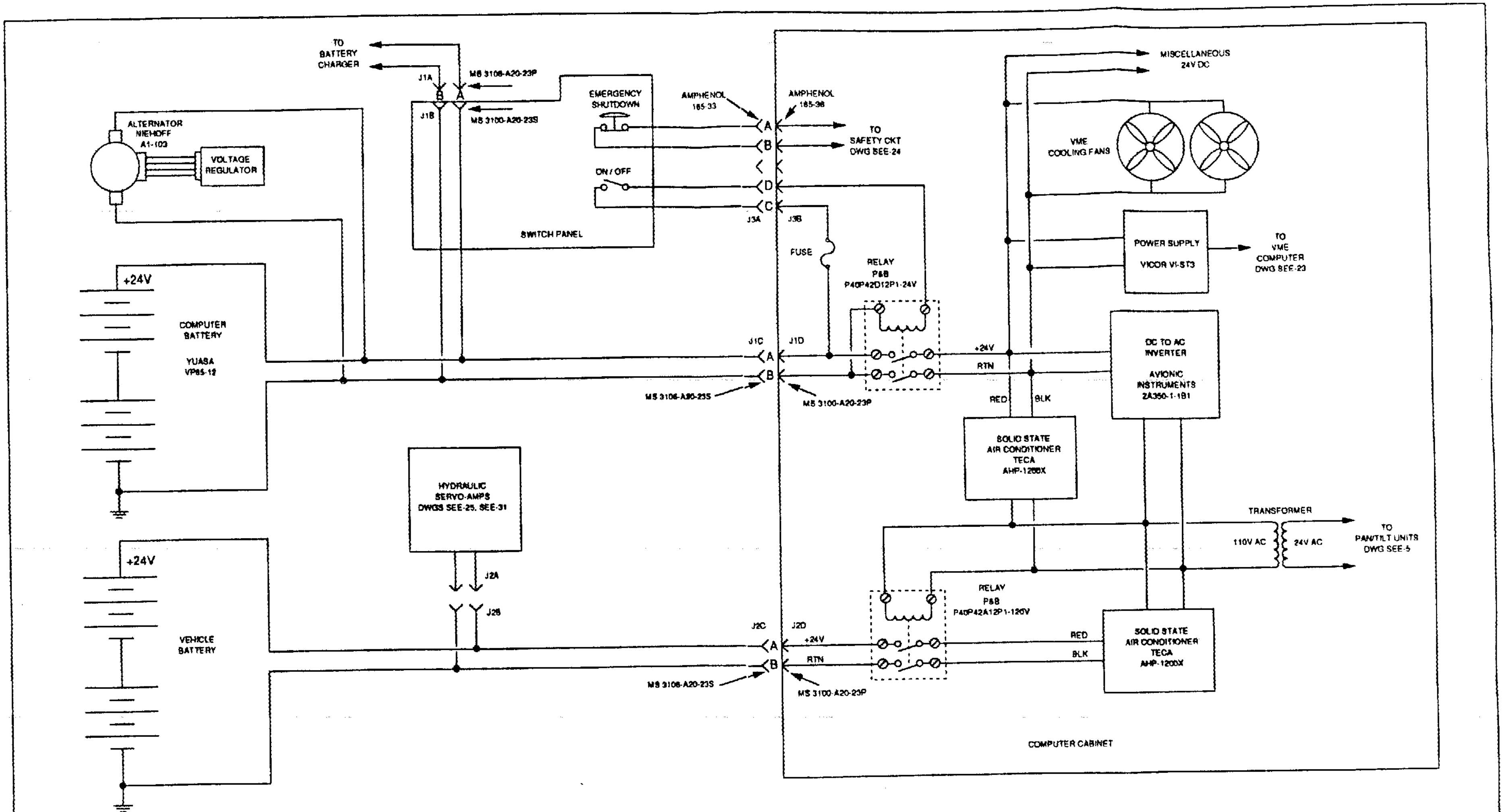
REFERENCE DWG | REV

DRAWING NO: SEE-7 | REV: RØ

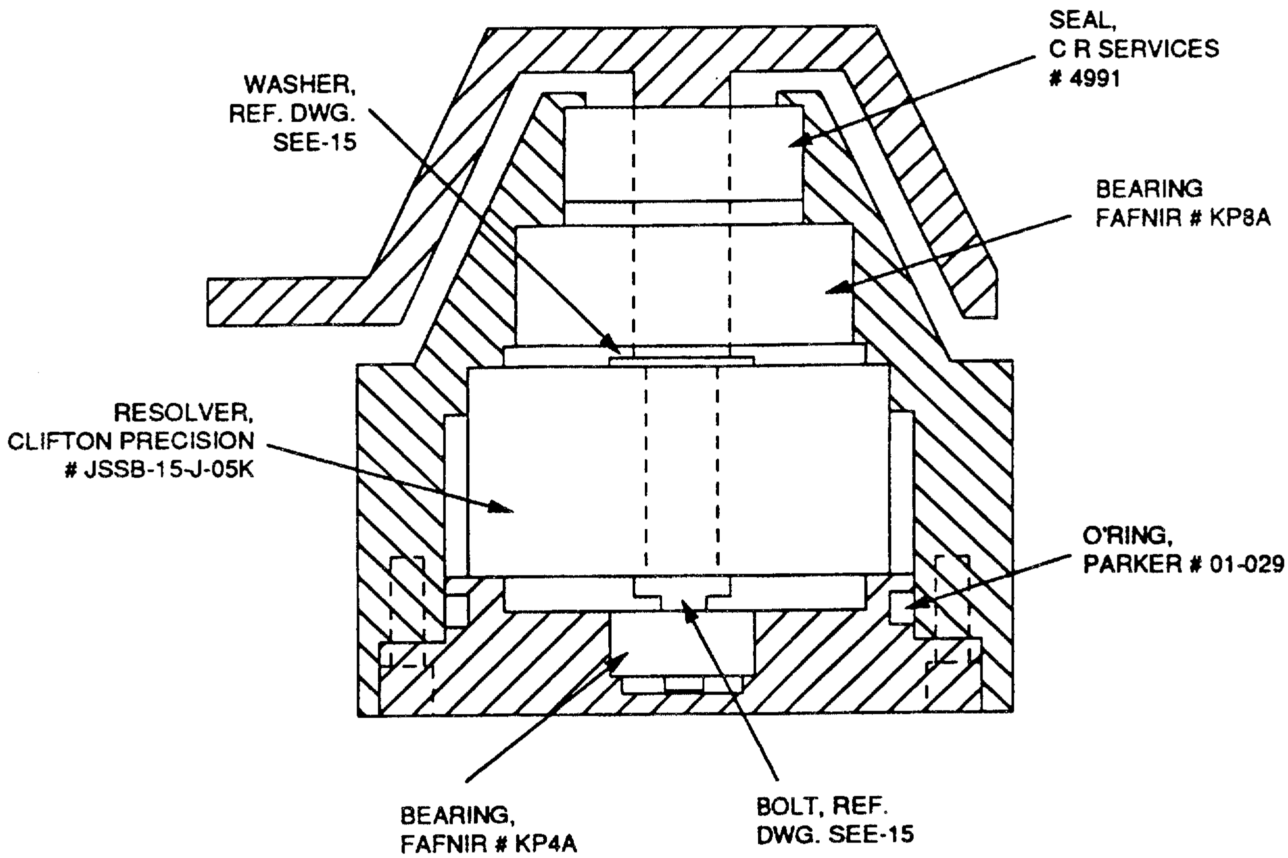


SCALE = 2:1

Q/A	DATE		FILE DATE	DRAWING TITLE
GRP LEADER B.L. BURKS	7/92	LEAD ENGR D.H. THOMPSON 7/92	PROGRAM MGR B.L. Burks 11/21/93	11/21/93 SMALL EMPLACEMENT EXCAVATOR ALTERNATOR SUPPORT BRKT WELDMENTS SHEET 3
DRAWN BY M.A. DINKINS	7/92	ENGINEER S.M. KILLOUGH 7/92	DWG CHECK Stephen M Killough 11/21/93	REFERENCE DWG / REV
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC		OAK RIDGE NATIONAL LABORATORY — ROBOTICS AND PROCESS SYSTEMS DIVISION — Oak Ridge, Tennessee		DRAWING NO SEE-7 — REV RC



Q/A	DATE		FILE DATE	DRAWING TITLE 11/21/93 SMALL EMPLACEMENT EXCAVATOR COMPUTER SYSTEM POWER WIRING DIAGRAM
GRP LEADER B.L. BURKS	DATE 7/92	LEAD ENGR D.H. THOMPSON 7/92	PROGRAM MGR B. L. Burks 11/21/93	
DRAWN BY M.A. DINKINS	DATE 7/92	ENGINEER S.M. KILLOUGH 7/92	DWG CHECK Stephen Killough 11/21/93	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC		OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG — REV DRAWING NO SEE-8 — REV RØ



NOTE:
1. ASSEMBLY DRAWING, NOT TO SCALE.
2. MATERIAL TO MACHINE PARTS IS STAINLESS STEEL.
3. REF. DWGS. SEE-10 THRU SEE-15.

Q/A	DATE			FILE DATE		DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS	DATE 10/92	LEAD ENGR D. H. THOMPSON	DATE 10/92	PROGRAM MGR B. L. Burks	DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY	DATE 10/92	ENGINEER S. M. KILLOUGH	DATE 10/92	DWG CHECK Stephen Killough	DATE 12/9/93	

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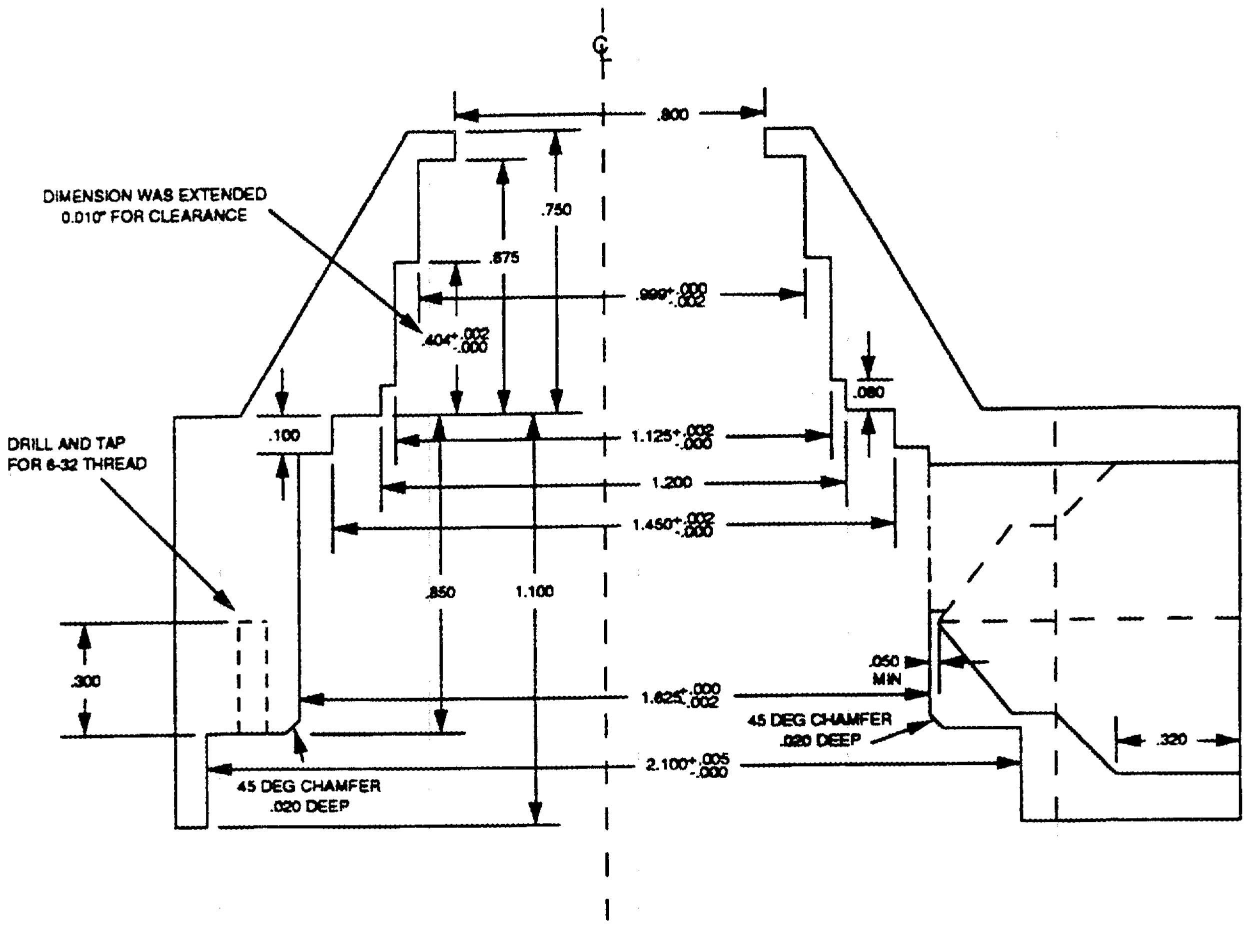
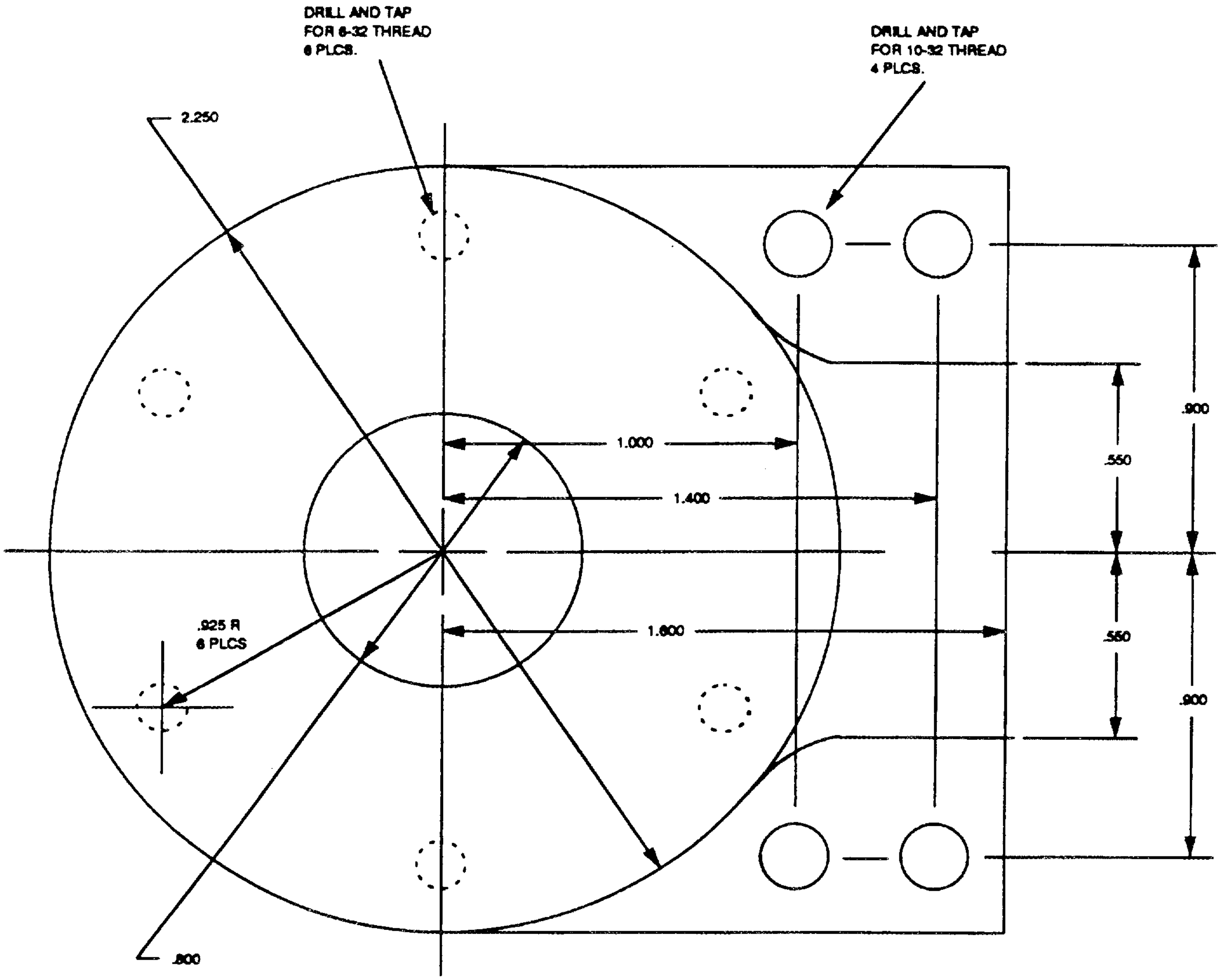
Oak Ridge, Tennessee

REFERENCE DWG	REV
DRAWING NO. SEE-9	REV R0



NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-9.

Q/A	DATE		FILE DATE	DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS	DATE 10/92	LEAD ENGR D. H. THOMPSON DATE 10/92	PROGRAM MGR B. L. Burks DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY	DATE 10/92	ENGINEER S. M. KILLOUGH DATE 10/92	DWG CHECK Stephen Killough DATE 12/9/93	
MARTIN MARIETTA ENERGY SYSTEMS, INC.		OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG / REV
				DRAWING NO. SEE-10 REV RØ



NOTES:

1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-9.

Q/A	DATE			FILE DATE		DRAWING TITLE
GRP LEADER B. L. BURKS	DATE 10/92	LEAD ENGR D. H. THOMPSON	DATE 10/92	PROGRAM MGR B. L. Burks	DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY	DATE 10/92	ENGINEER S. M. KILLOUGH	DATE 10/92	DWG CHECK Stephen Killough	DATE 12/9/93	

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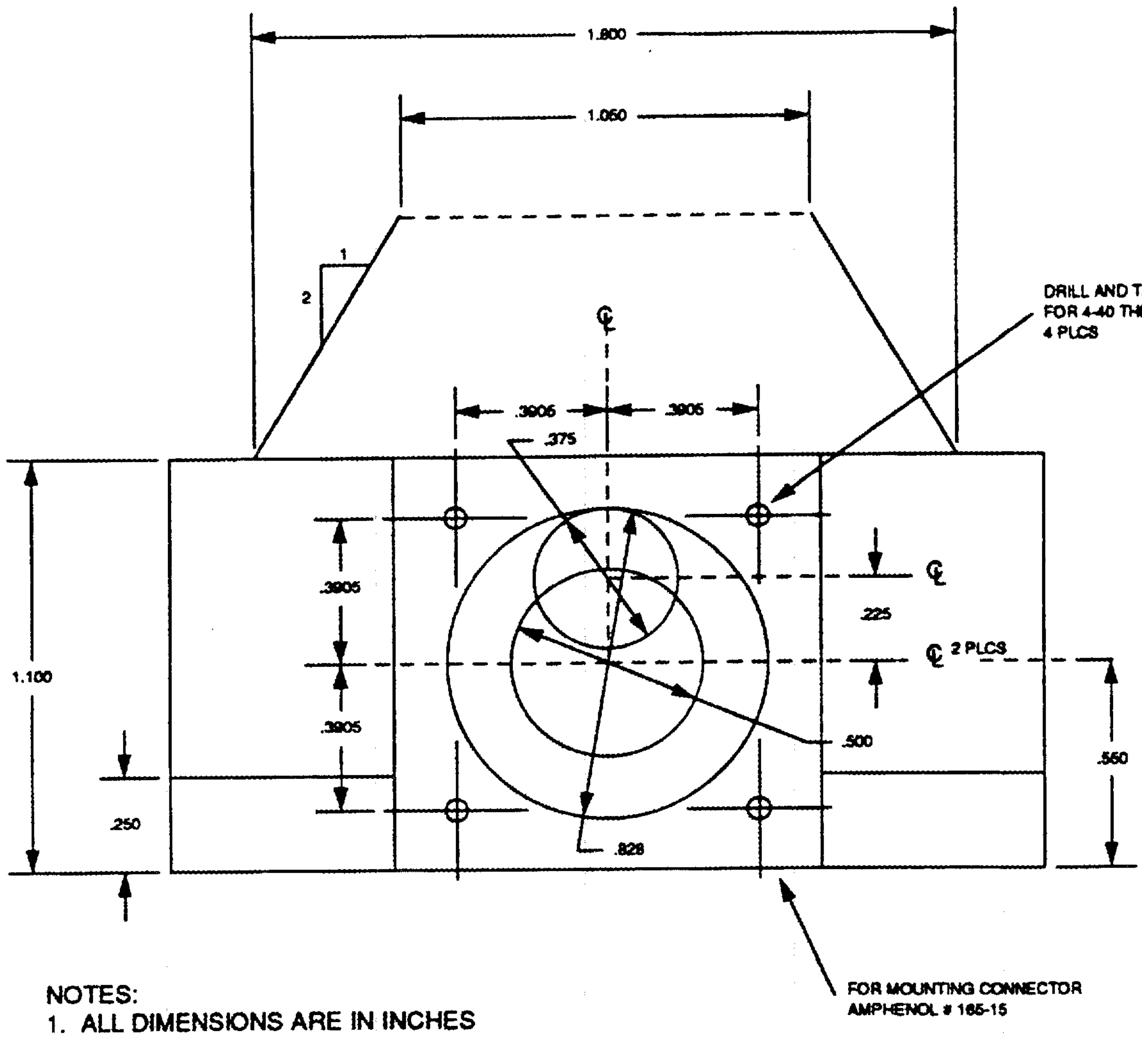
Oak Ridge, Tennessee

REFERENCE DWG | REV

DRAWING NO. SEE-11 | REV R∅

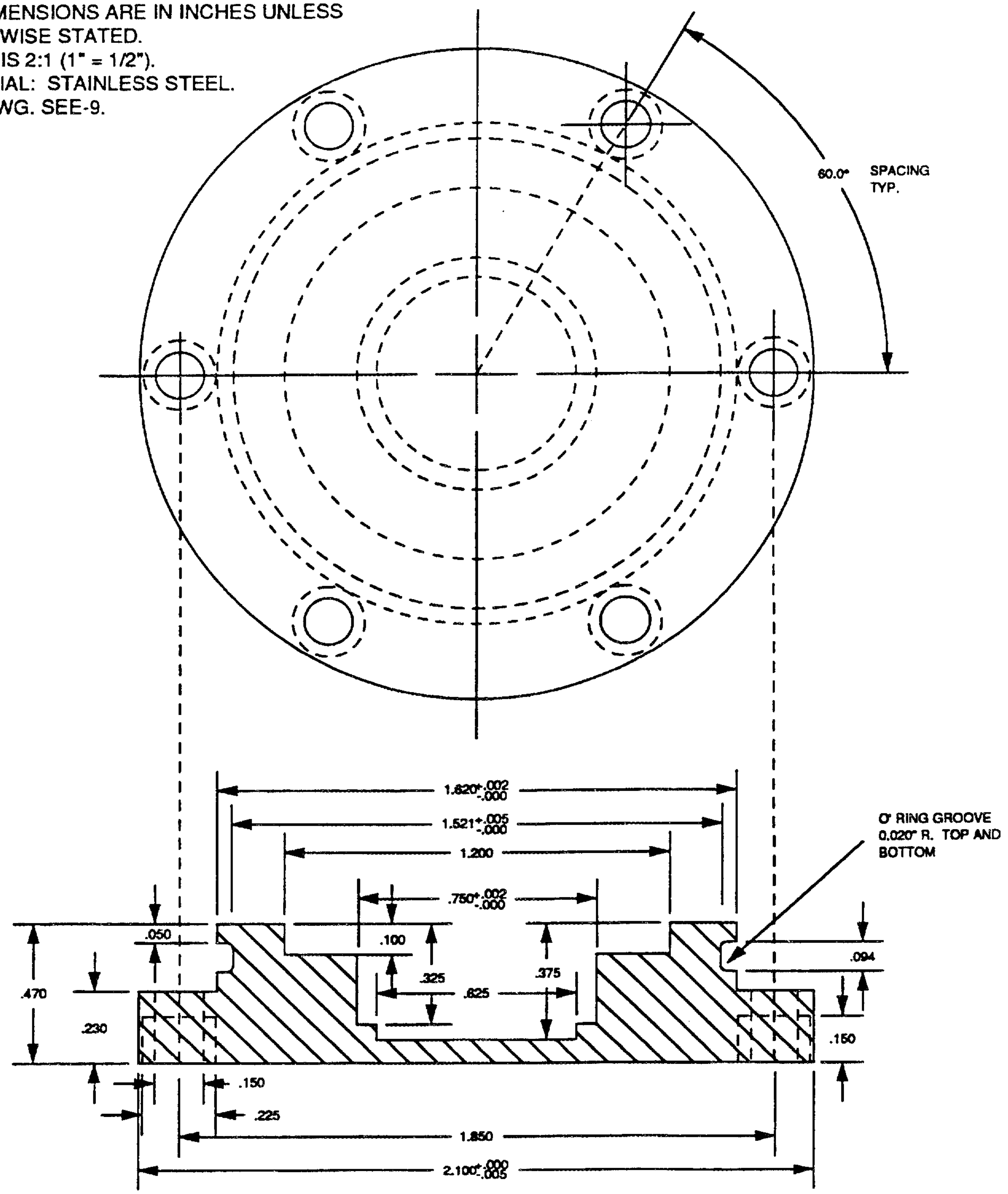


NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAILESS STEEL.
4. REF. DWG. SEE-9.

Q/A — DATE		FILE DATE	DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS — DATE 10/92	LEAD ENGR D. H. THOMPSON — DATE 10/92	PROGRAM MGR B. L. Burks — DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY — DATE 10/92	ENGINEER S. M. KILLOUGH — DATE 10/92	DWG CHECK Stephen Killough — DATE 12/9/93	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG — REV
			DRAWING NO. SEE-12 — REV RØ

BOTTOM PLATE

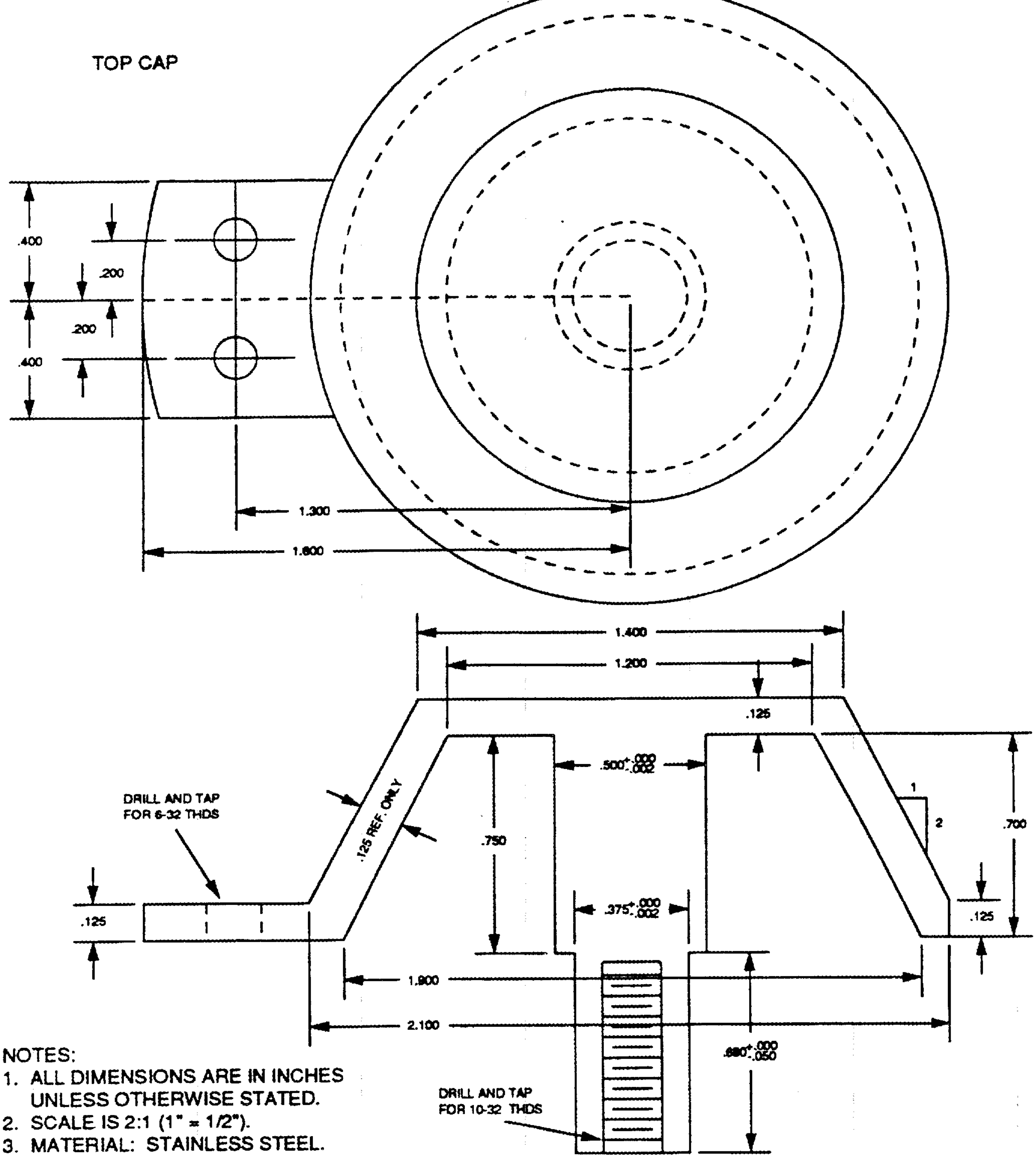
NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-9.



Q/A DATE		FILE DATE	DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS DATE 10/92	LEAD ENGR D. H. THOMPSON DATE 10/92	PROGRAM MGR B. L. Burks DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY DATE 10/92	ENGINEER S. M. KILLOUGH DATE 10/92	DWG CHECK Stephen Killough DATE 12/9/93	

MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee	REFERENCE DWG	REV
		DRAWING NO. SEE-13	REV RØ

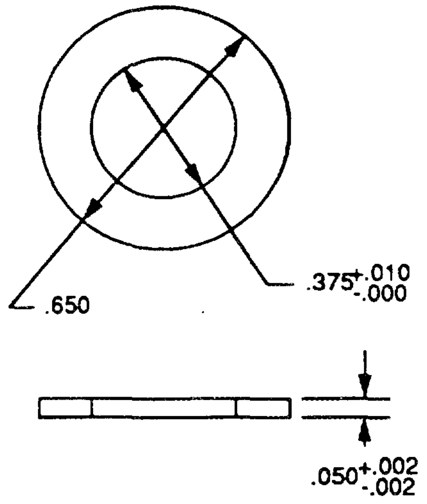
TOP CAP



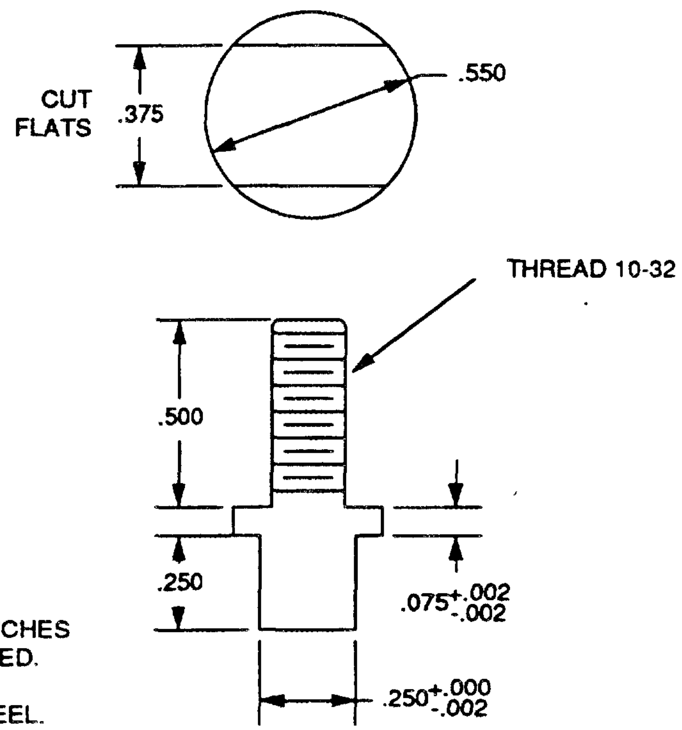
NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-9.

Q/A — DATE		FILE DATE	DRAWING TITLE: 12/9/93
GRP LEADER: B. L. BURKS — DATE: 10/92	LEAD ENGR: D. H. THOMPSON — DATE: 10/92	PROGRAM MGR: B. L. Burks — DATE: 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY: R. D. BRADLEY — DATE: 10/92	ENGINEER: S. M. KILLOUGH — DATE: 10/92	DWG CHECK: Stephen Killough — DATE: 12/9/93	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG — REV
			DRAWING NO. SEE-14 — REV R0

WASHER BETWEEN
TOP BEARING AND
THE RESOLVER



BOTTOM BEARING
SHAFT



NOTES:

1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-9.

Q/A	DATE			FILE DATE		DRAWING TITLE: 12/9/93
GRP LEADER: B. L. BURKS	DATE: 10/92	LEAD ENGR: D. H. THOMPSON	DATE: 10/92	PROGRAM MGR: B. L. Burks	DATE: 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY: R. D. BRADLEY	DATE: 10/92	ENGINEER: S. M. KILLOUGH	DATE: 10/92	DWG CHECK: Stephen Killough	DATE: 12/9/93	

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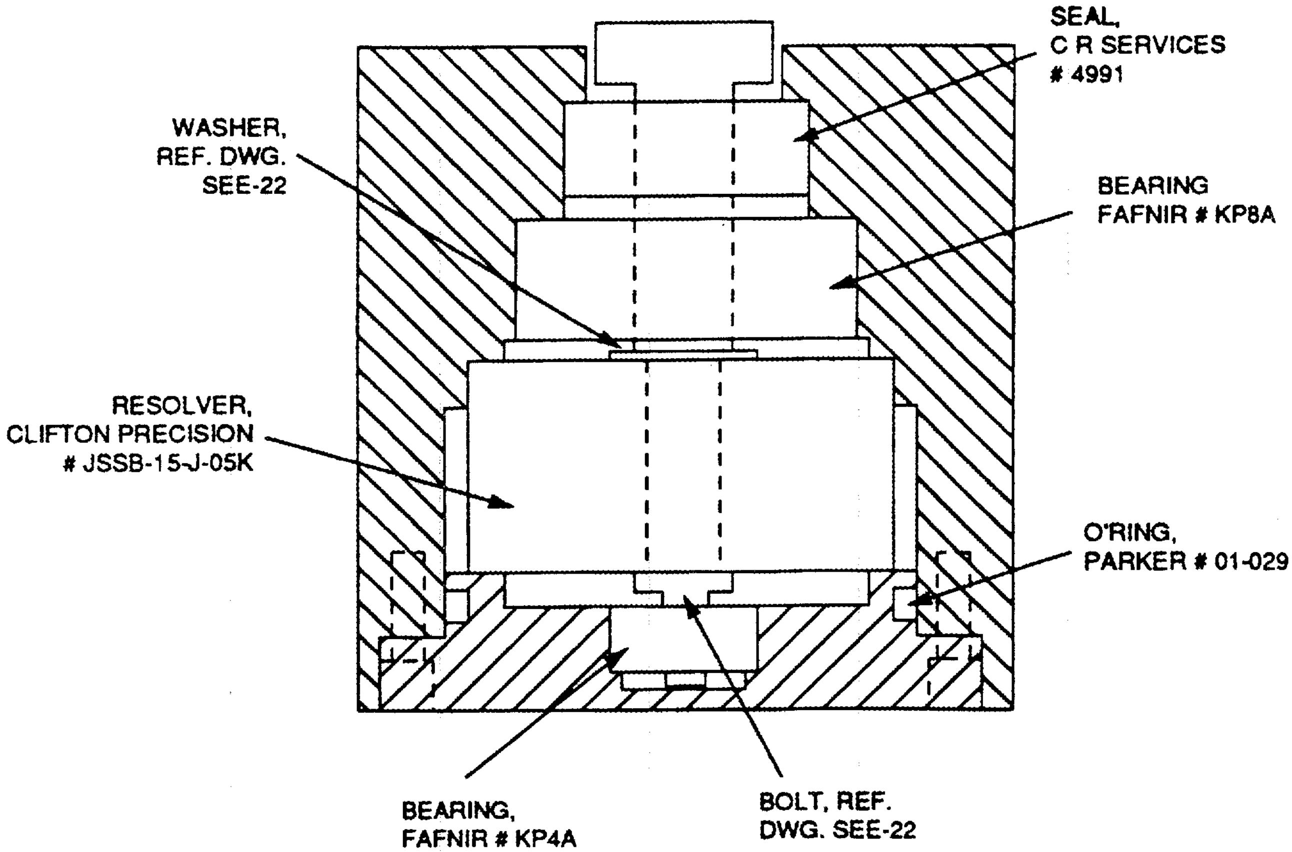
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG | REV

DRAWING NO. SEE-15 | REV RØ



NOTES:
1. ASSEMBLY DRAWING, NOT TO SCALE.
2 HARD COAT ANNOIZE ALUMINUM PARTS BLACK
3. REF. DWGS. SEE-17 THRU SEE-22.

Q/A / DATE		FILE DATE	DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS / DATE 10/92	LEAD ENGR D. H. THOMPSON / DATE 10/92	PROGRAM MGR B. L. Burks / DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY / DATE 10/92	ENGINEER S. M. KILLOUGH / DATE 10/92	DWG CHECK Stephen Killough / DATE 12/9/93	

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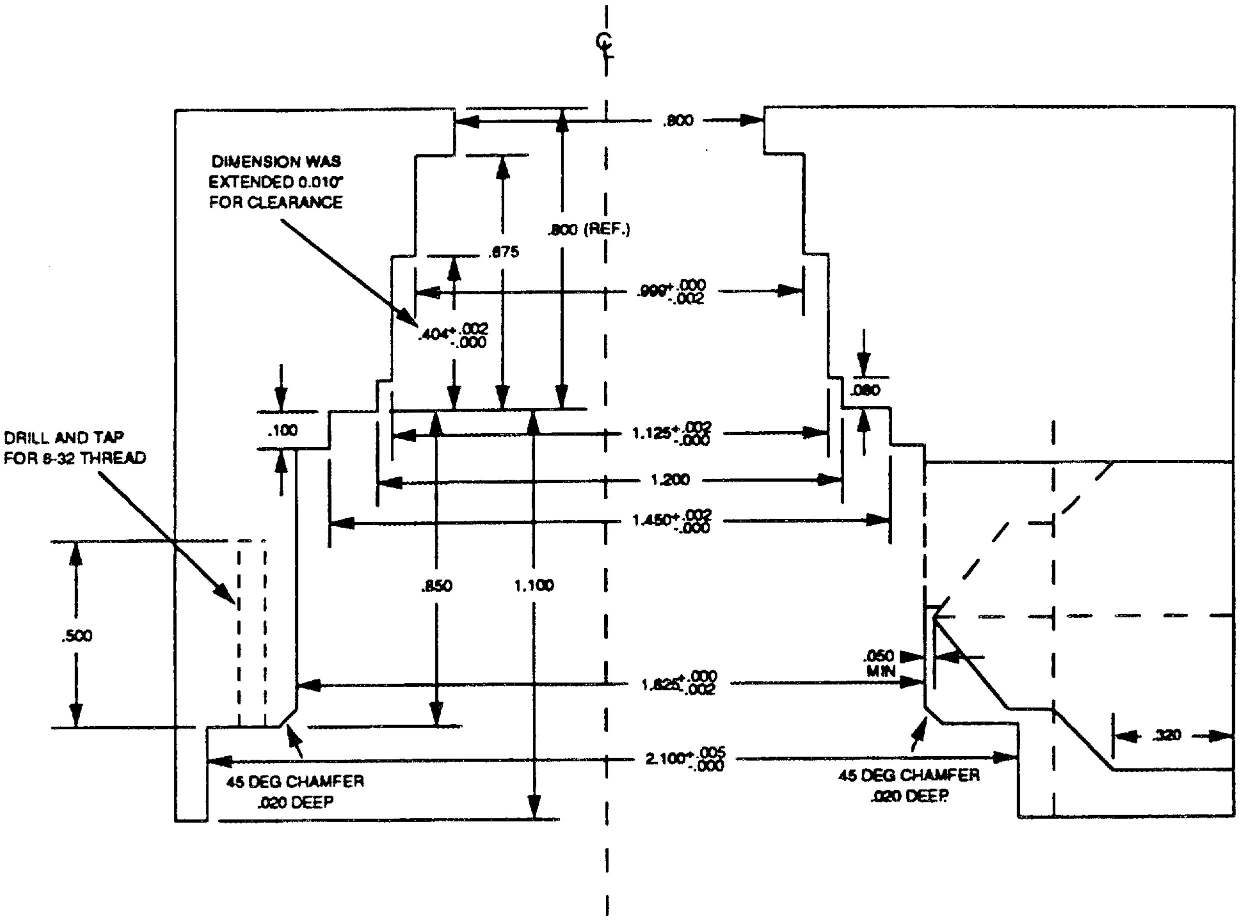
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG	REV
DRAWING NO. SEE-16	REV R0



NOTES:

1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1"1/2").
3. MATERIAL: ALUMINUM.
4. REF. DWG. SEE-16.

Q/A — DATE		FILE DATE	DRAWING TITLE: 12/9/93
GRP LEADER: B. L. BURKS — DATE 10/92	LEAD ENGR: D. H. THOMPSON — DATE 10/92	PROGRAM MGR: B. L. Burks — DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY: R. D. BRADLEY — DATE 10/92	ENGINEER: S. M. KILLOUGH — DATE 10/92	DWG CHECK: Stephen Killough — DATE 12/9/93	

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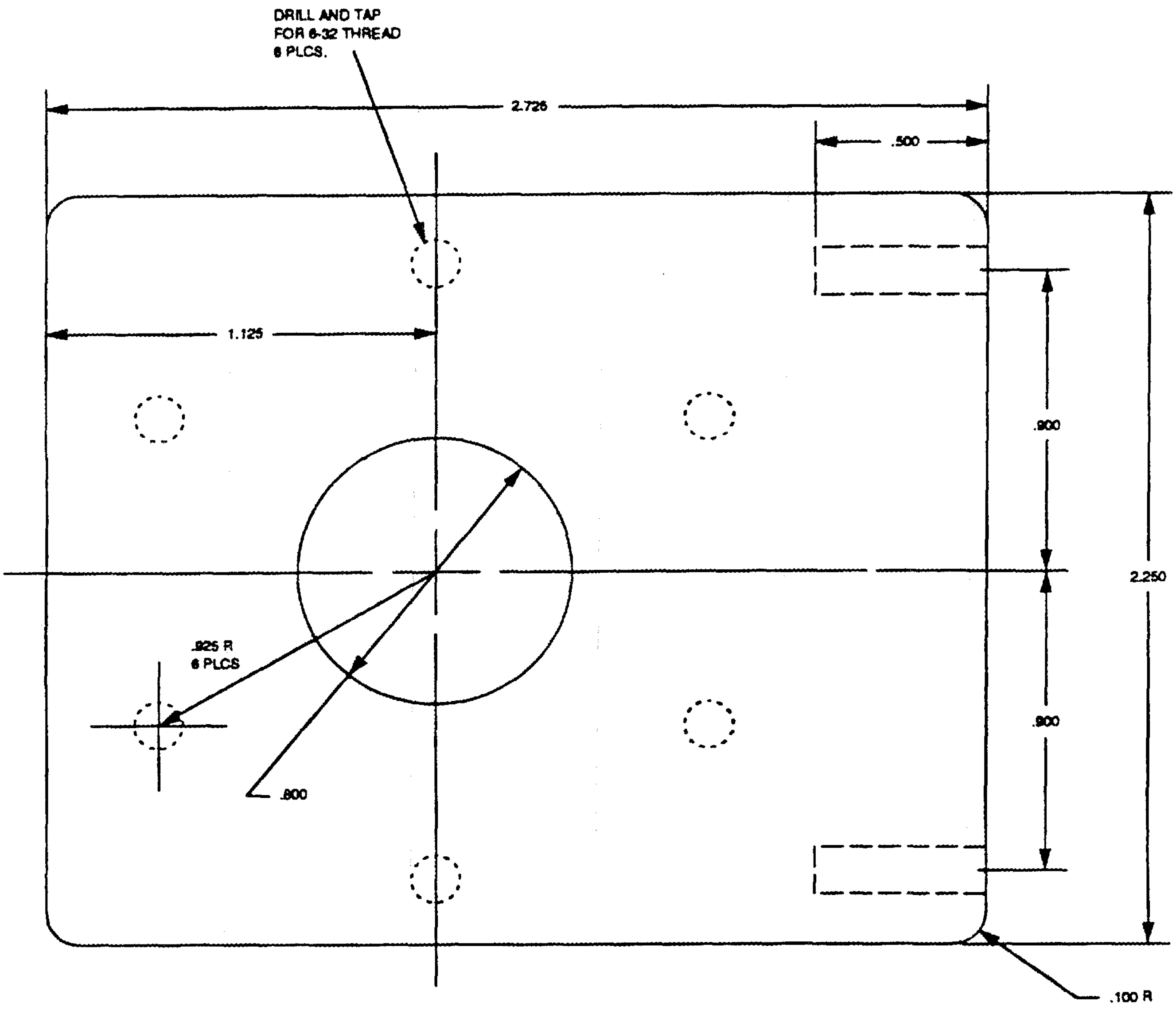
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG	REV
DRAWING NO. SEE-17	REV R0



NOTES:

1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: ALUMINUM.
4. REF. DWG. SEE-16.

Q/A — DATE		FILE DATE	DRAWING TITLE: 12/9/93
GRP LEADER: B. L. BURKS — DATE 10/92	LEAD ENGR: D. H. THOMPSON — DATE 10/92	PROGRAM MGR: B. L. Burks — DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY: R. D. BRADLEY — DATE 10/92	ENGINEER: S. M. KILLOUGH — DATE 10/92	DWG CHECK: Stephen Killough — DATE 12/9/93	

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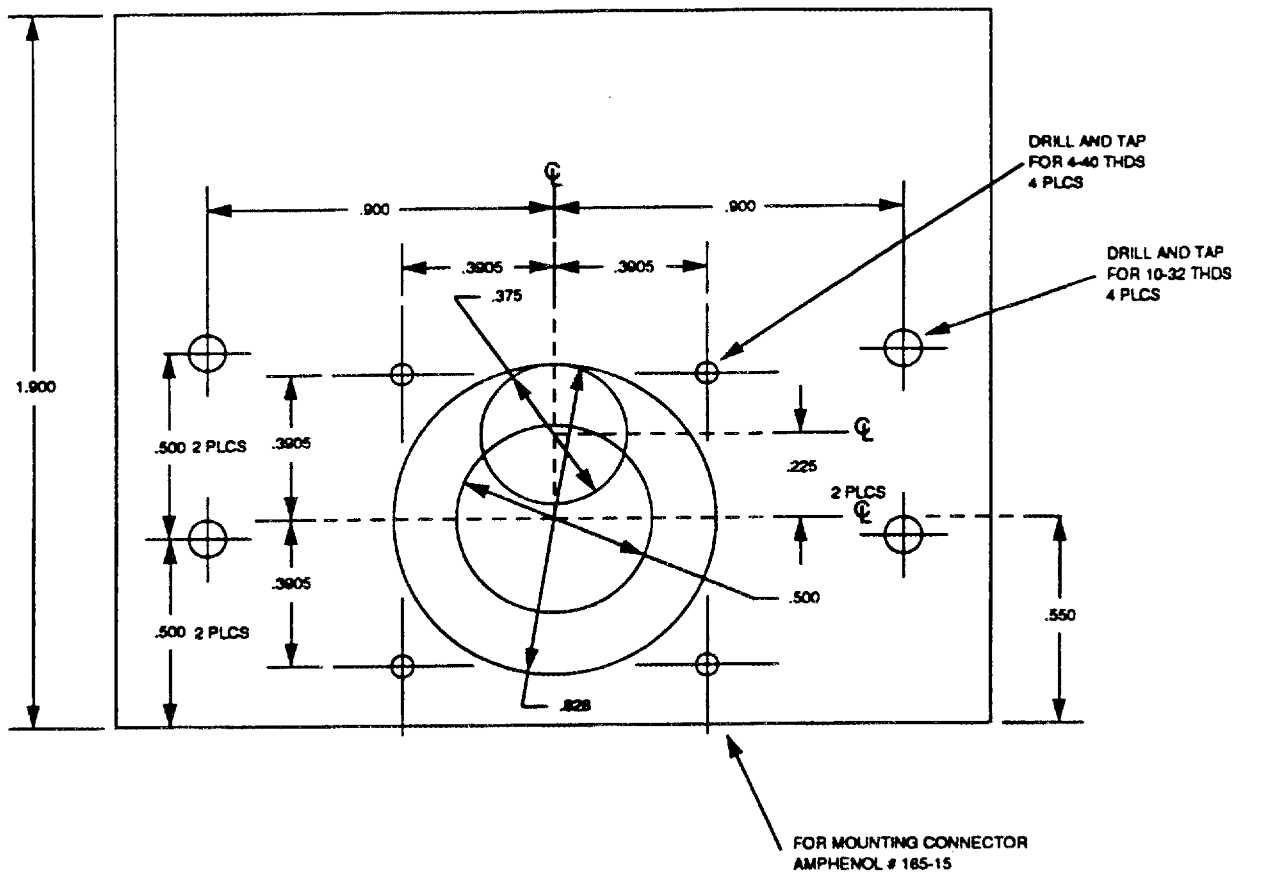
OAK RIDGE NATIONAL LABORATORY

ROBOTICS AND PROCESS SYSTEMS DIVISION

Oak Ridge, Tennessee

REFERENCE DWG — REV

DRAWING NO. SEE-18 — REV R0



NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: ALUMINUM.
4. REF. DWG. SEE-16.

Q/A DATE		FILE DATE	DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS DATE 10/92	LEAD ENGR D. H. THOMPSON DATE 10/92	PROGRAM MGR B. L. Burks DATE 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY DATE 10/92	ENGINEER S. M. KILLOUGH DATE 10/92	DWG CHECK Stephen Killough DATE 12/9/93	

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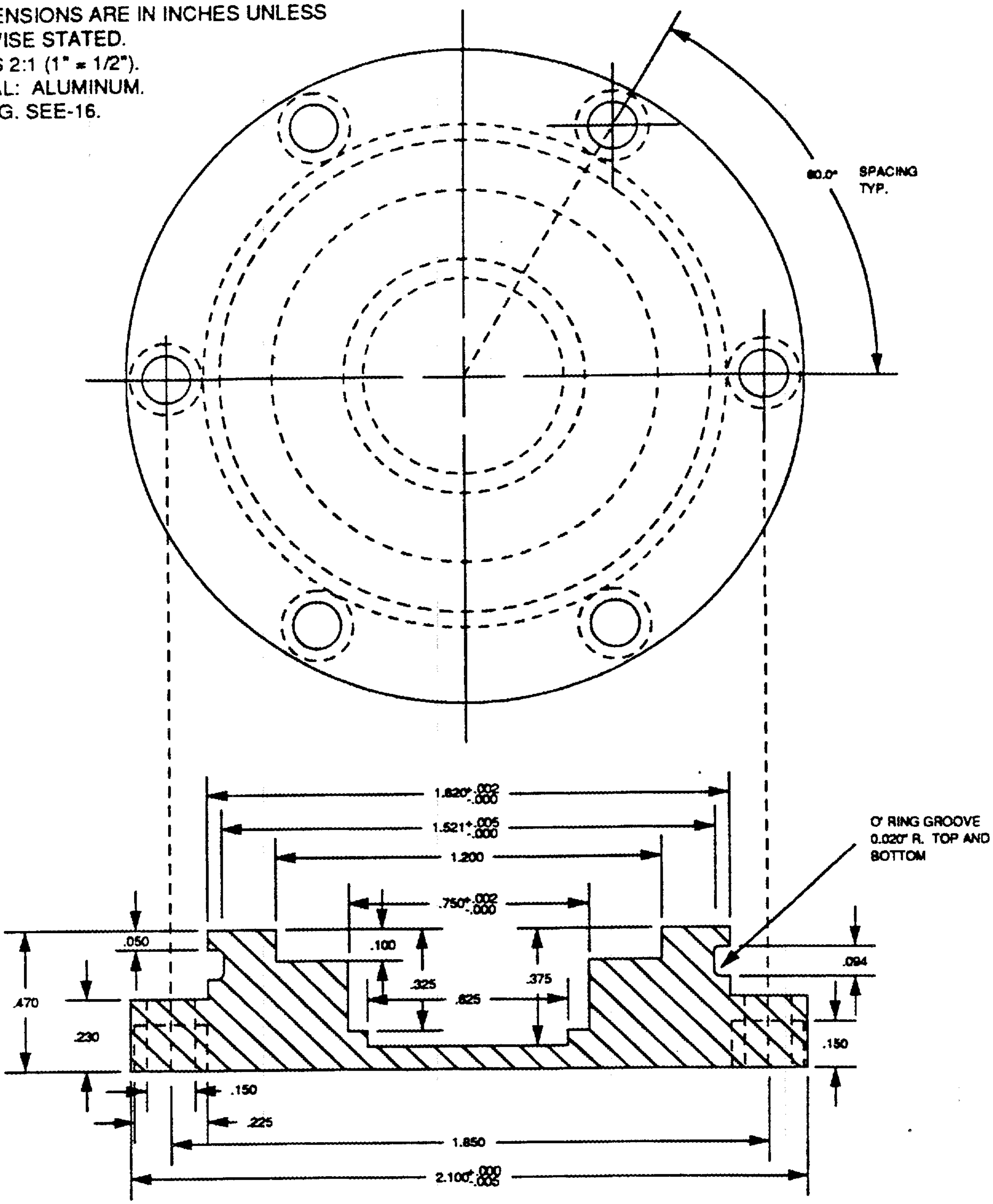
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG	REV
DRAWING NO. SEE-19	REV RØ

BOTTOM PLATE

NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: ALUMINUM.
4. REF. DWG. SEE-16.



Q/A	DATE		FILE DATE	DRAWING TITLE 12/9/93
GRP LEADER B. L. BURKS	DATE 10/92	LEAD ENGR D. H. THOMPSON 10/92	PROGRAM MGR B. L. Burks 12/9/93	COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
DRAWN BY R. D. BRADLEY	DATE 10/92	ENGINEER S. M. KILLOUGH 10/92	DWG CHECK Stephen Killough 12/9/93	

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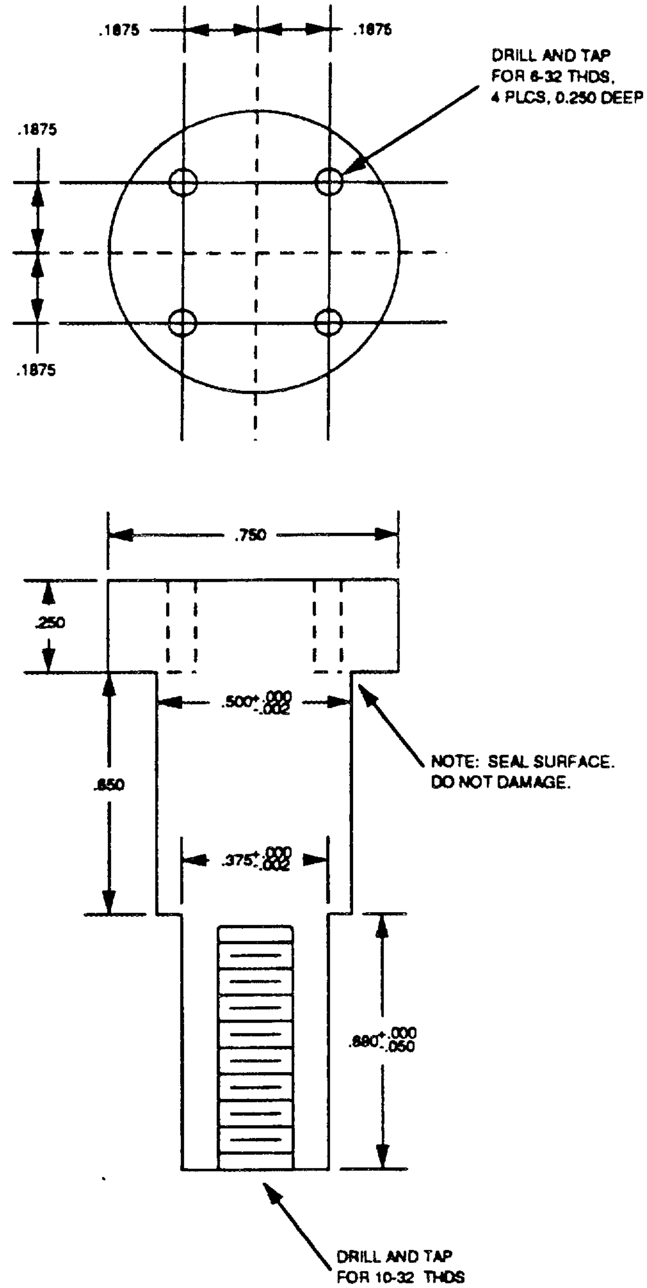
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG | REV

DRAWING NO. SEE-20 | REV RØ

SHAFT



NOTES:
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-16.

Q/A	DATE			FILE DATE		DRAWING TITLE 12/9/93 COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
GRP LEADER B. L. BURKS	DATE 10/92	LEAD ENGR D. H. THOMPSON	DATE 10/92	PROGRAM MGR B. L. Burks	DATE 12/9/93	
DRAWN BY R. D. BRADLEY	DATE 10/92	ENGINEER S. M. KILLOUGH	DATE 10/92	DWG CHECK Stephen Killough	DATE 12/9/93	

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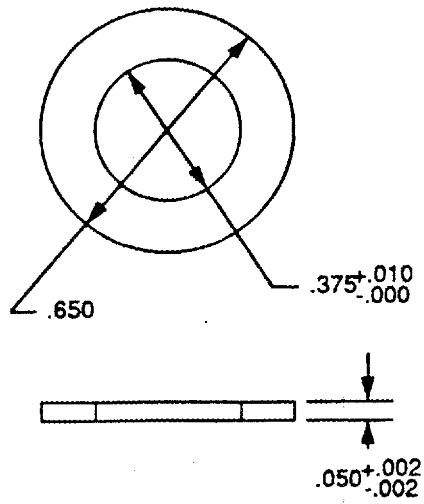
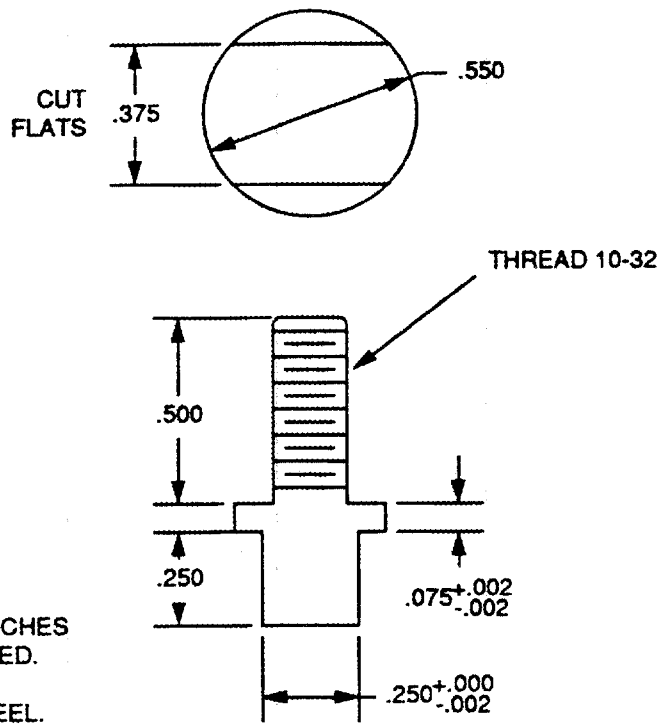
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

REFERENCE DWG	REV
DRAWING NO. SEE-21	REV RØ

STAINLESS STEEL WASHER BETWEEN TOP BEARING AND THE RESOLVER



BOTTOM BEARING SHAFT

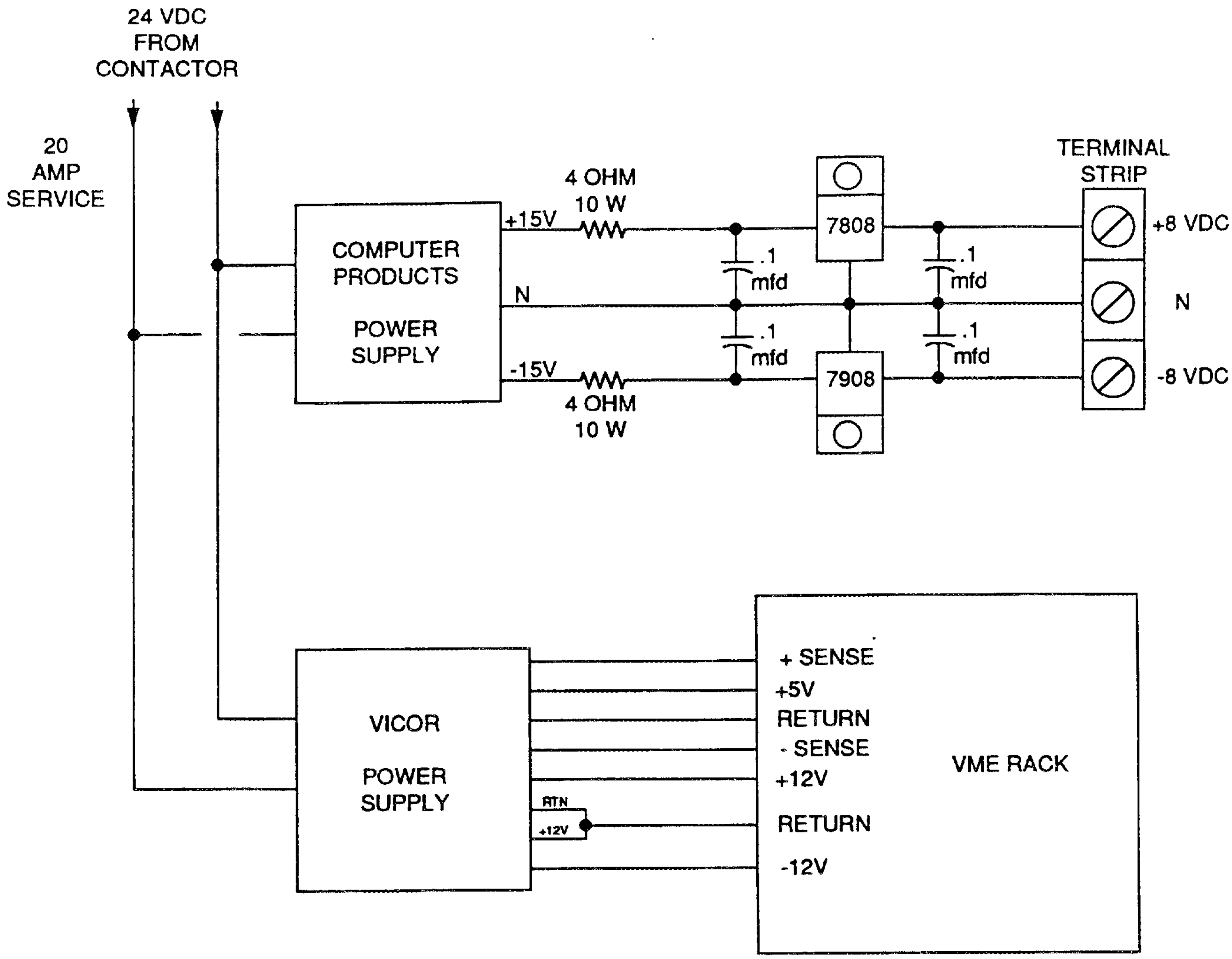


NOTES:

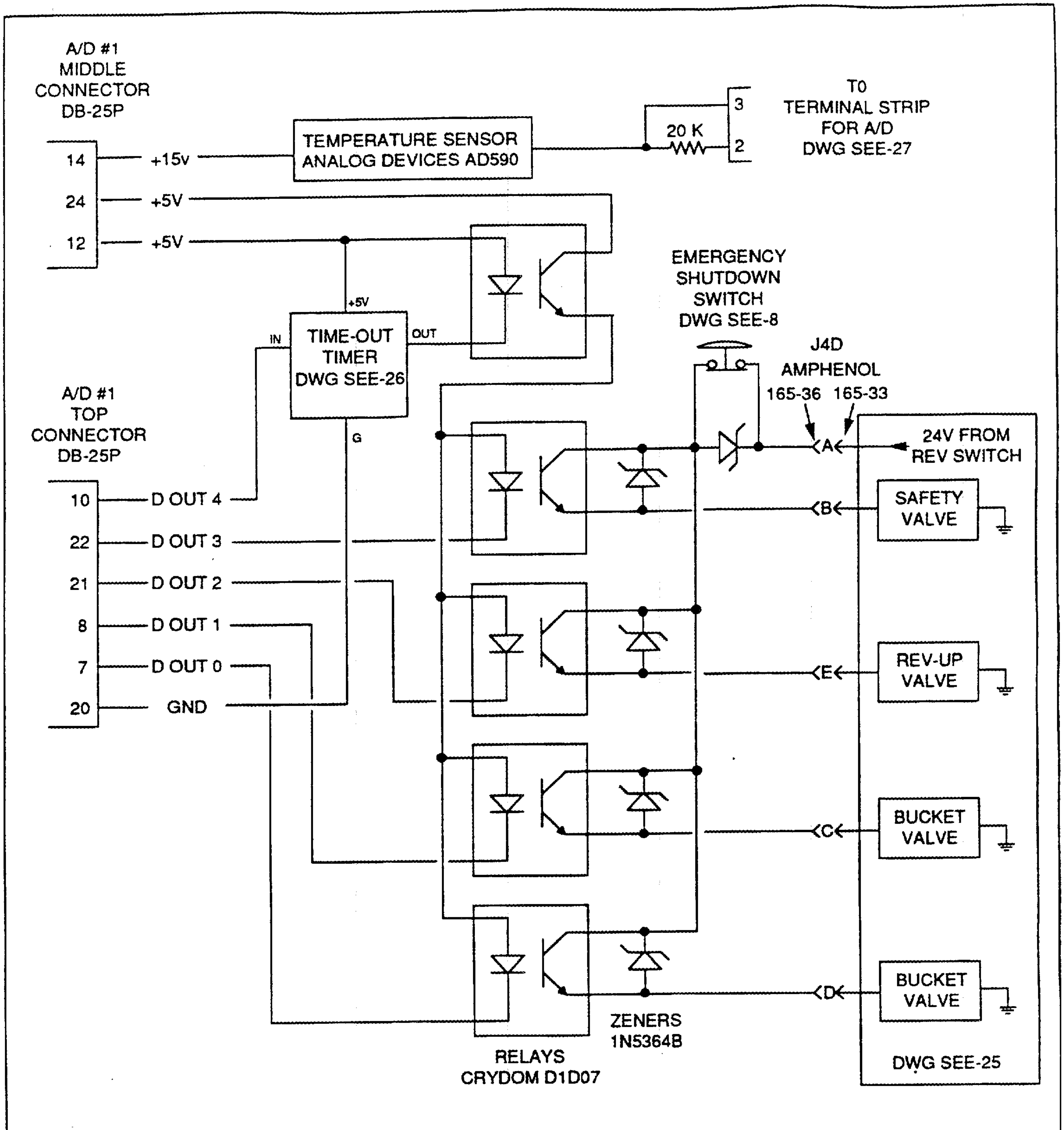
1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE STATED.
2. SCALE IS 2:1 (1" = 1/2").
3. MATERIAL: STAINLESS STEEL.
4. REF. DWG. SEE-16

Q/A — DATE		FILE DATE	DRAWING TITLE: 12/9/93 COMPACT BACKHOE ENCODER FOR THE SMALL EMPLACEMENT EXCAVATOR
GRP LEADER: B. L. BURKS — DATE 10/92	LEAD ENGR: D. H. THOMPSON — DATE 10/92	PROGRAM MGR: B. L. Burks — DATE 12/9/93	
DRAWN BY: R. D. BRADLEY — DATE 10/92	ENGINEER: S. M. KILLOUGH — DATE 10/92	DWG CHECK: Stephen Killough — DATE 12/9/93	

MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee	REFERENCE DWG	REV
		DRAWING NO. SEE-22	REV R0



Q/A	DATE	FILE DATE	DRAWING TITLE 11/21/93
GRP LEADER B.L.BURKS	DATE / LEAD ENGR D.H. THOMPSON	DATE / PROGRAM MGR B.L. Burks 11/21/93	SMALL EMPLACEMENT EXCAVATOR VME DC POWER BOARD WIRING DIAGRAM
DRAWN BY M.A. DINKINS 5/92	DATE / ENGINEER S.M. KILLOUGH	DATE / DWG CHECK Stephen Killough 11/21/93	DATE
MARTIN MARIETTA / MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY / ROBOTICS AND PROCESS SYSTEMS DIVISION / Oak Ridge, Tennessee		REFERENCE DWG / REV
			DRAWING NO. SEE-23 / REV R0



Q/A DATE		FILE DATE	DRAWING TITLE 11/21/93
GRP LEADER DATE B.L.BURKS	LEAD ENGR DATE D.H. THOMPSON	PROGRAM MGR DATE B.L. Burks 11/21/93	SMALL EMPLACEMENT EXCAVATOR SOLENOID VALVE DRIVERS AND TEMPERATURE CIRCUIT WIRING DIAGRAM
DRAWN BY DATE M.A. DINKINS 5/92	ENGINEER DATE S.M. KILLOUGH	DWG CHECK DATE Stephen Killough 11/21/93	

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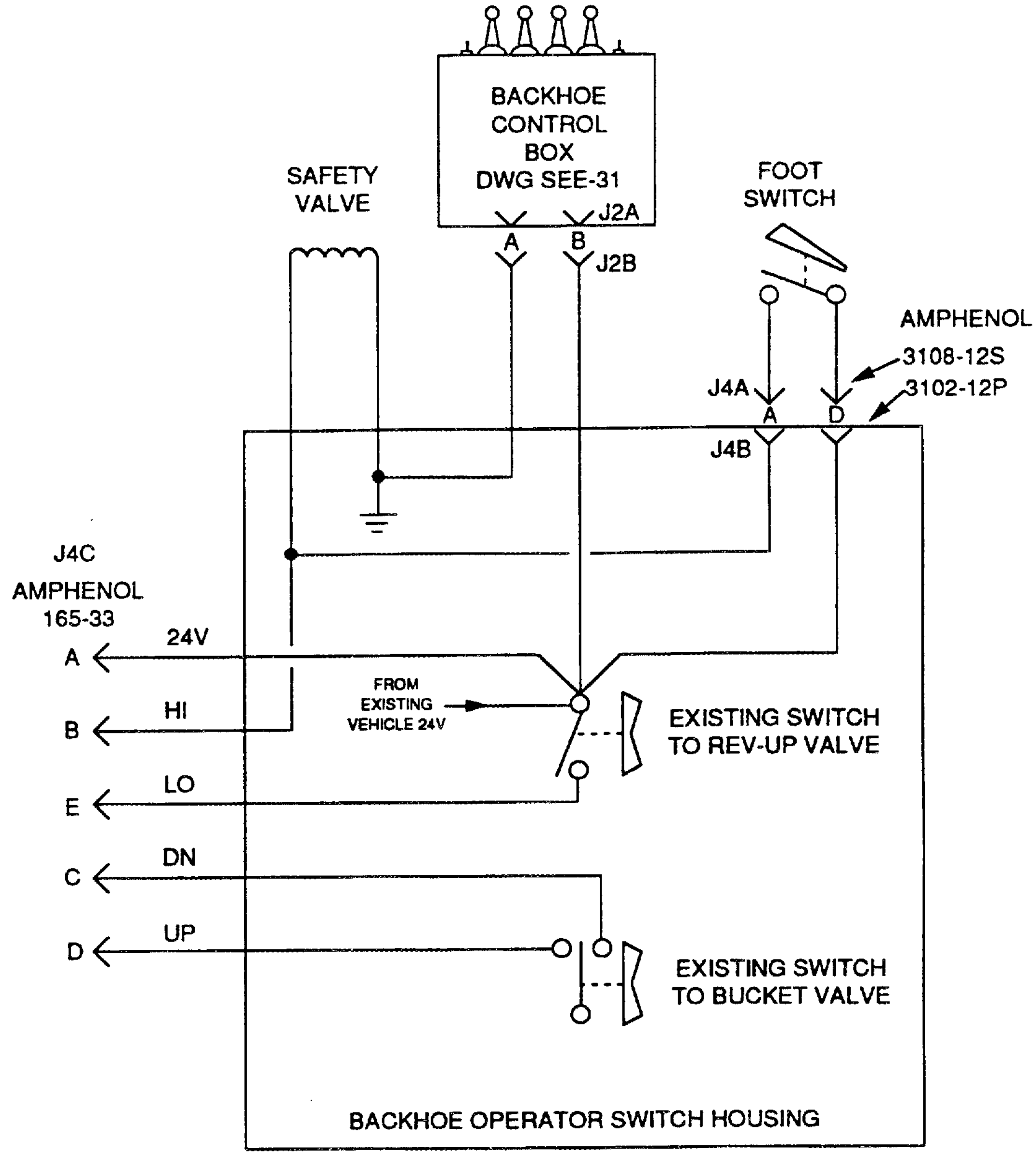
REFERENCE DWG | REV

DRAWING NO. SEE-24 | REV RØ



Q/A	DATE		FILE DATE	DRAWING TITLE 11/21/93
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B.L. Burks 11/21/93	SMALL EMPLACEMENT EXCAVATOR REV-UP, BUCKET, & SAFETY VALVE WIRING DIAGRAM
DRAWN BY M.A. DINKINS	DATE 5/92	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 11/21/93	

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ROBOTICS AND PROCESS SYSTEMS DIVISION
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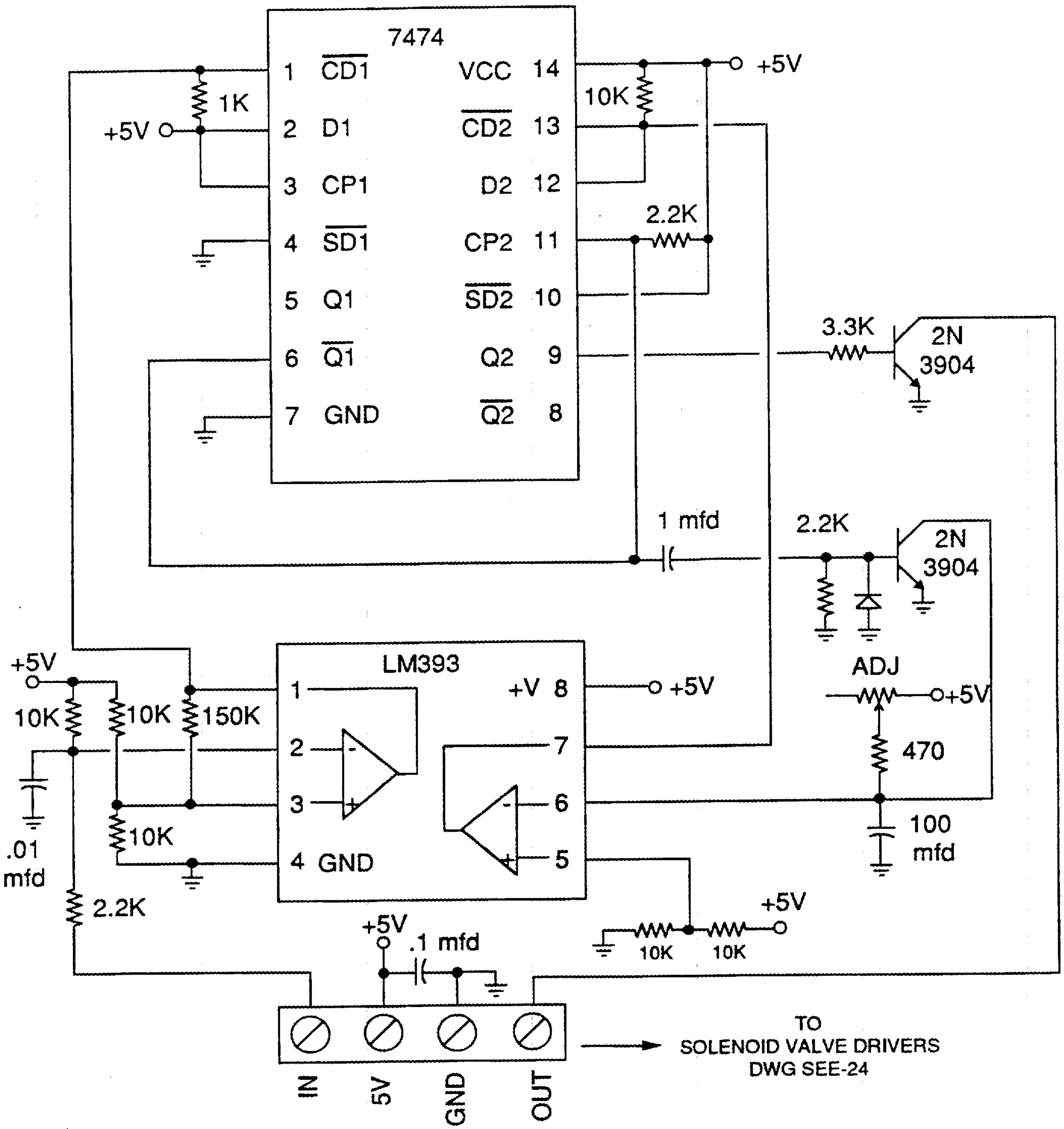
REFERENCE DWG	REV
DRAWING NO. SEE-25	REV RØ



Q/A	DATE		FILE DATE	DRAWING TITLE
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B. L. Burks 11/21/93	11/21/93 SMALL EMPLACEMENT EXCAVATOR TIME-OUT TIMER SCHEMATIC DIAGRAM
DRAWN BY M.A. DINKINS	DATE 5/92	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 11/21/93	

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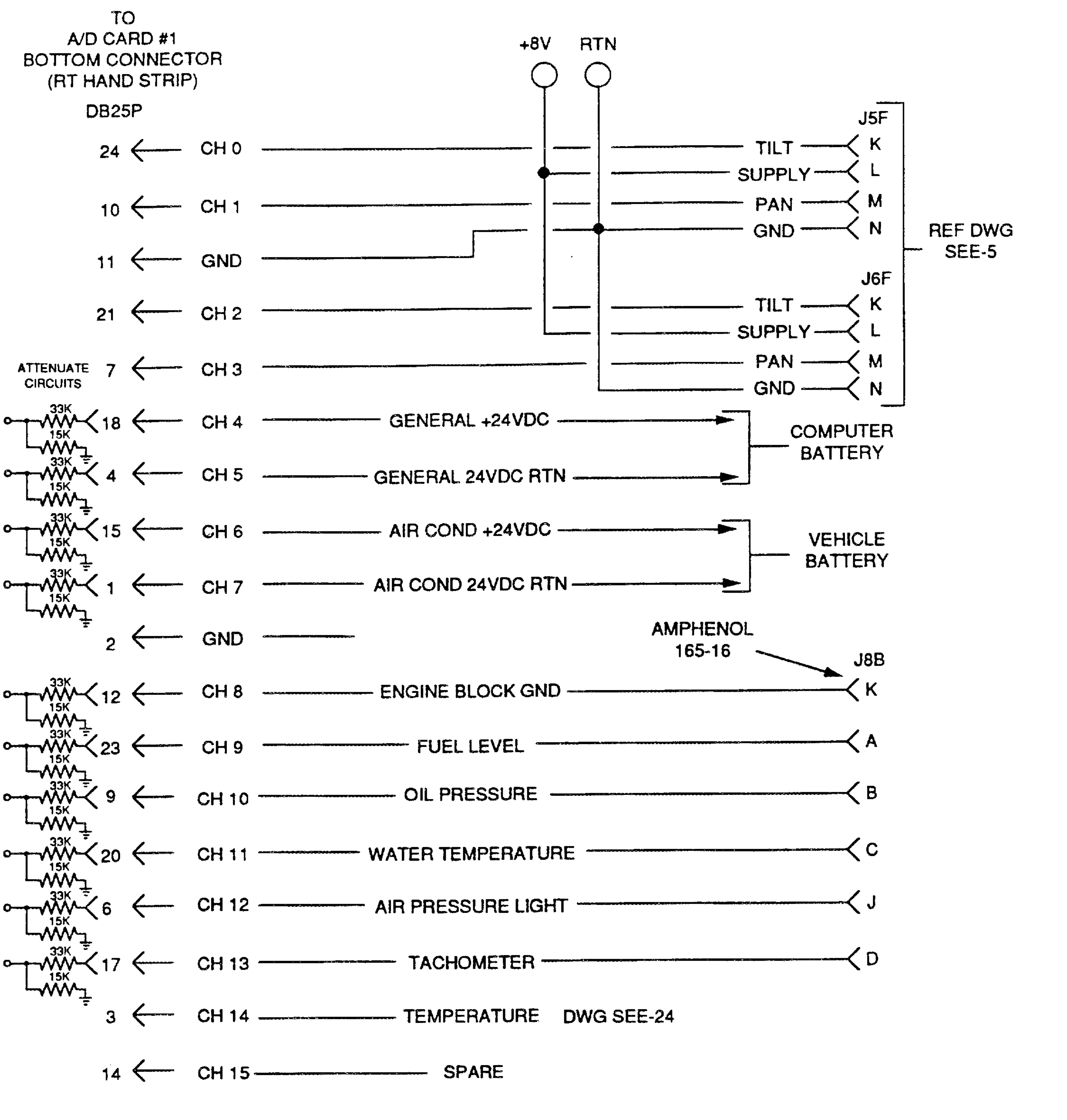
REFERENCE DWG	REV
DRAWING NO. SEE-26	REV R0



Q/A DATE

FILE DATE

DRAWING TITLE 11/21/93

GRP LEADER B.L.BURKS DATE

LEAD ENGR D.H. THOMPSON DATE

PROGRAM MGR B.L. Burks 11/21/93 DATE

SMALL EMPLACEMENT EXCAVATOR
A / D INPUT CABLE WIRING DIAGRAM

DRAWN BY M.A. DINKINS DATE 5/92

ENGINEER S.M. KILLOUGH DATE

DWG CHECK Stephen Killough 11/21/93 DATE

REFERENCE DWG

REV

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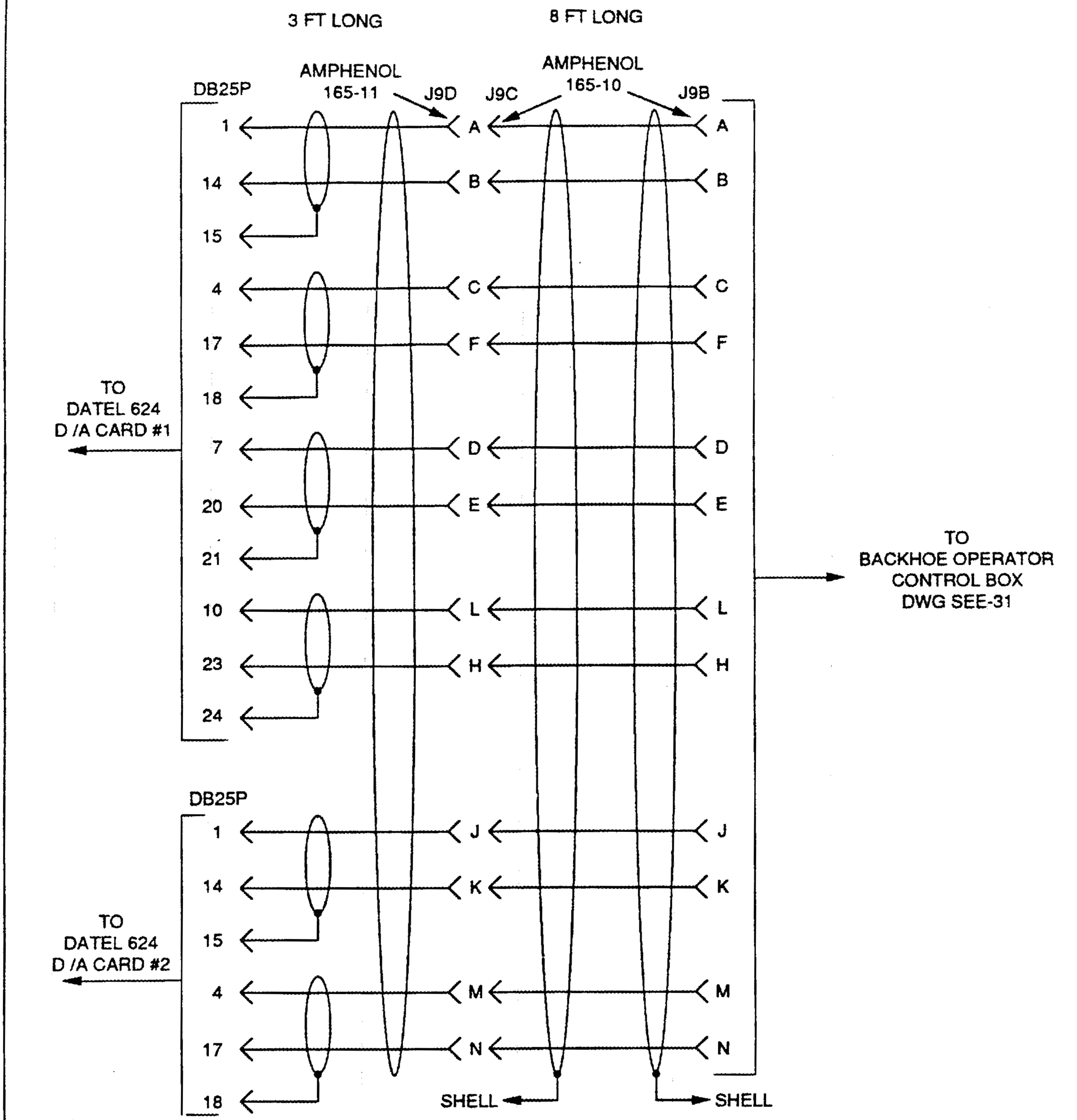
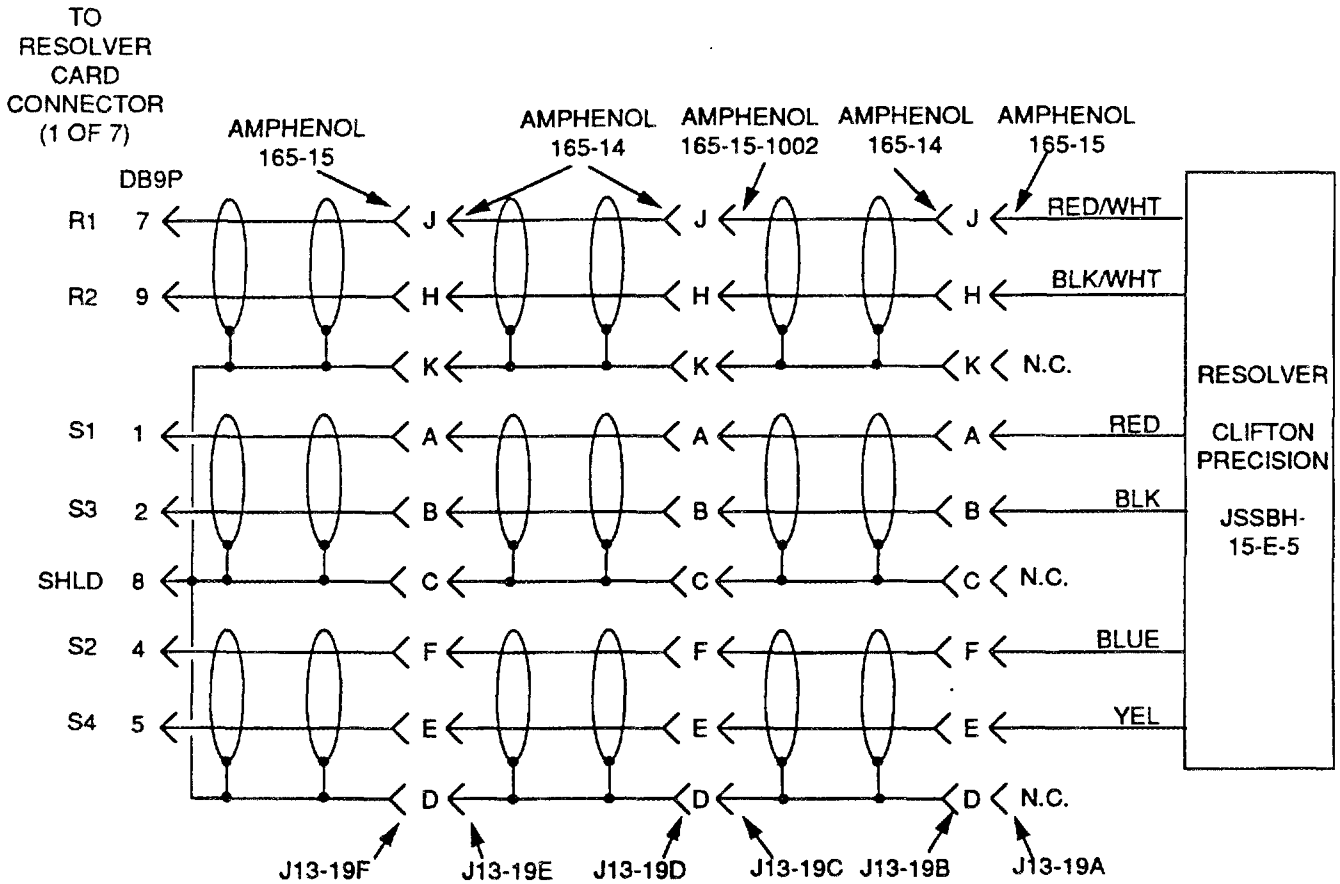
Oak Ridge, Tennessee

DRAWING NO. SEE-27

REV RØ



Q/A — DATE		FILE DATE	DRAWING TITLE 11/21/93 SMALL EMPLACEMENT EXCAVATOR HYDRAULIC DRIVE SIGNAL CABLE WIRING DIAGRAM
GRP LEADER B.L.BURKS — DATE	LEAD ENGR D.H. THOMPSON — DATE	PROGRAM MGR B. L. Burks 11/21/93 — DATE	
DRAWN BY M.A. DINKINS — DATE 5/92	ENGINEER S.M. KILLOUGH — DATE	DWG CHECK Stephen Killough 11/21/93 — DATE	REFERENCE DWG — REV
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		DRAWING NO. SEE-28 — REV R0



4 EA CABLES
3 FT LONG

4 EA CABLES
8 FT LONG

1 EA CABLE 6 FT LONG
1 EA CABLE 8 FT LONG
1 EA CABLE 16 FT LONG
1 EA CABLE 21 FT LONG

USE ALPHA #6073 CABLE

Q/A DATE		FILE DATE	DRAWING TITLE: 11/21/93 SMALL EMPLACEMENT EXCAVATOR RESOLVER CABLES WIRING DIAGRAM
GRP LEADER DATE B.L.BURKS	LEAD ENGR DATE D.H. THOMPSON	PROGRAM MGR DATE B.L. Burks 11/21/93	
DRAWN BY DATE M.A. DINKINS 5/92	ENGINEER DATE S.M. KILLOUGH	DWG CHECK DATE Stephen Killough 11/21/93	

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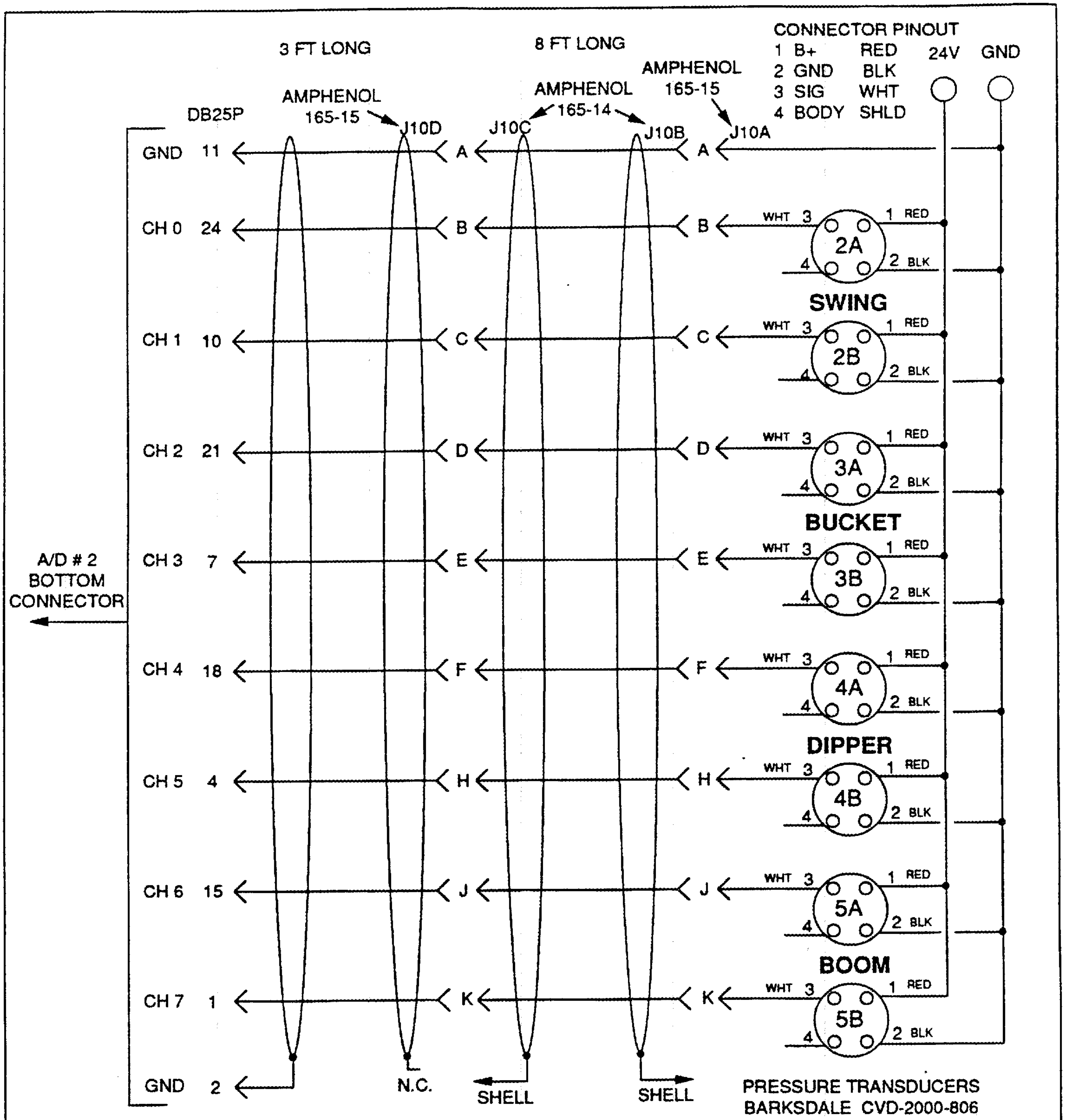
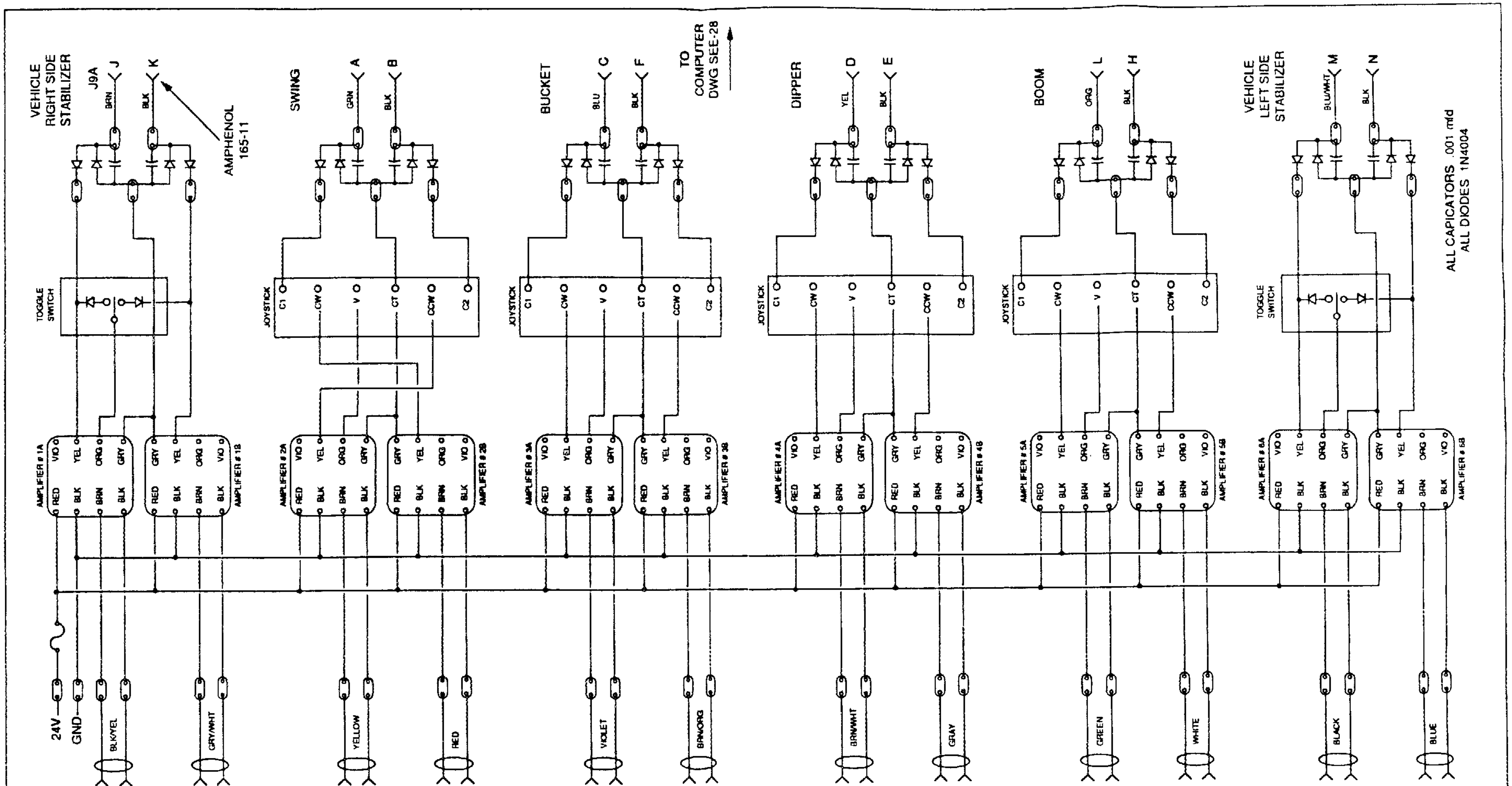
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

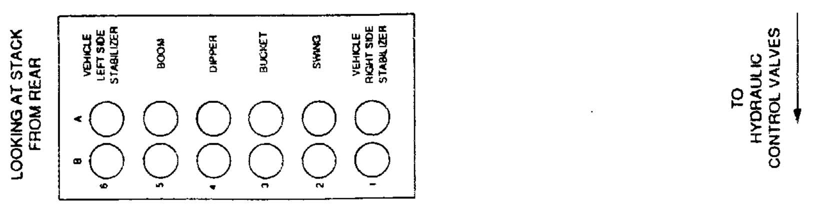
REFERENCE DWG — REV

DRAWING NO. SEE-29 — REV R0

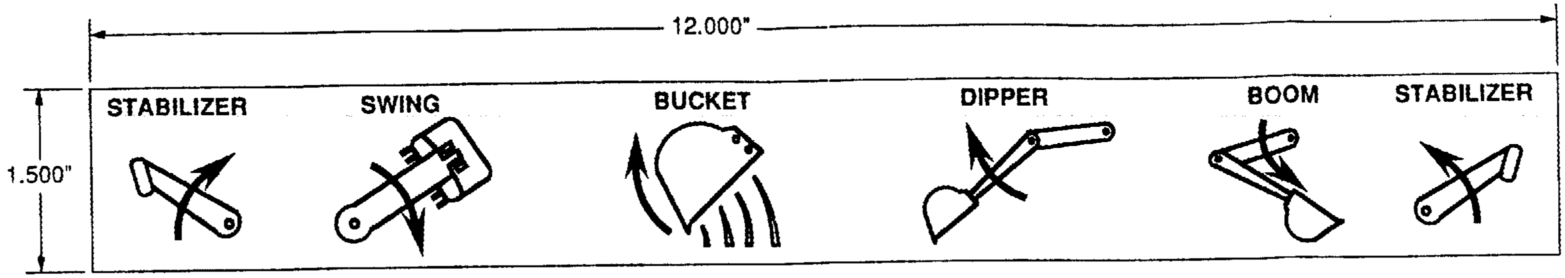


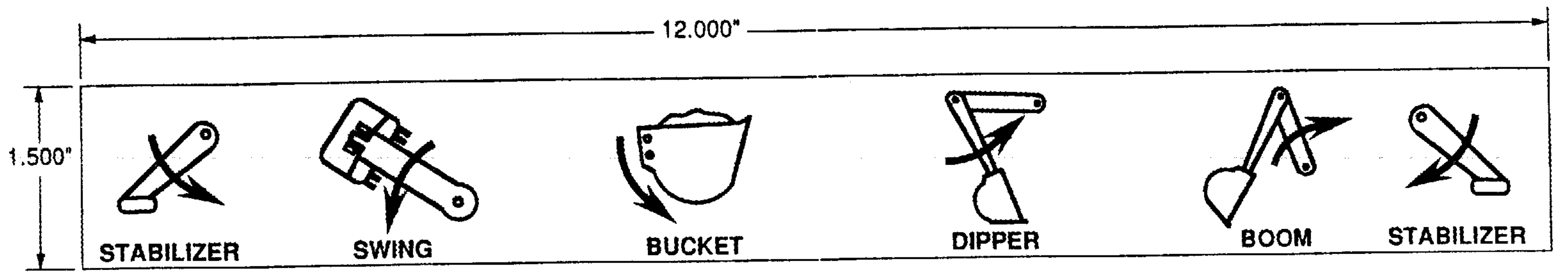
Q/A DATE		FILE DATE	DRAWING TITLE 11/12/93
GRP LEADER B.L.BURKS DATE	LEAD ENGR D.H. THOMPSON DATE	PROGRAM MGR B. L. Burks 11/12/93 DATE	SMALL EMPLACEMENT EXCAVATOR PRESSURE TRANSDUCER CABLE WIRING DIAGRAM
DRAWN BY M.A. DINKINS DATE 5/92	ENGINEER S.M. KILLOUGH DATE	DWG CHECK Stephen Killough 11/12/93 DATE	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG — REV
			DRAWING NO. SEE-30 — REV R∅



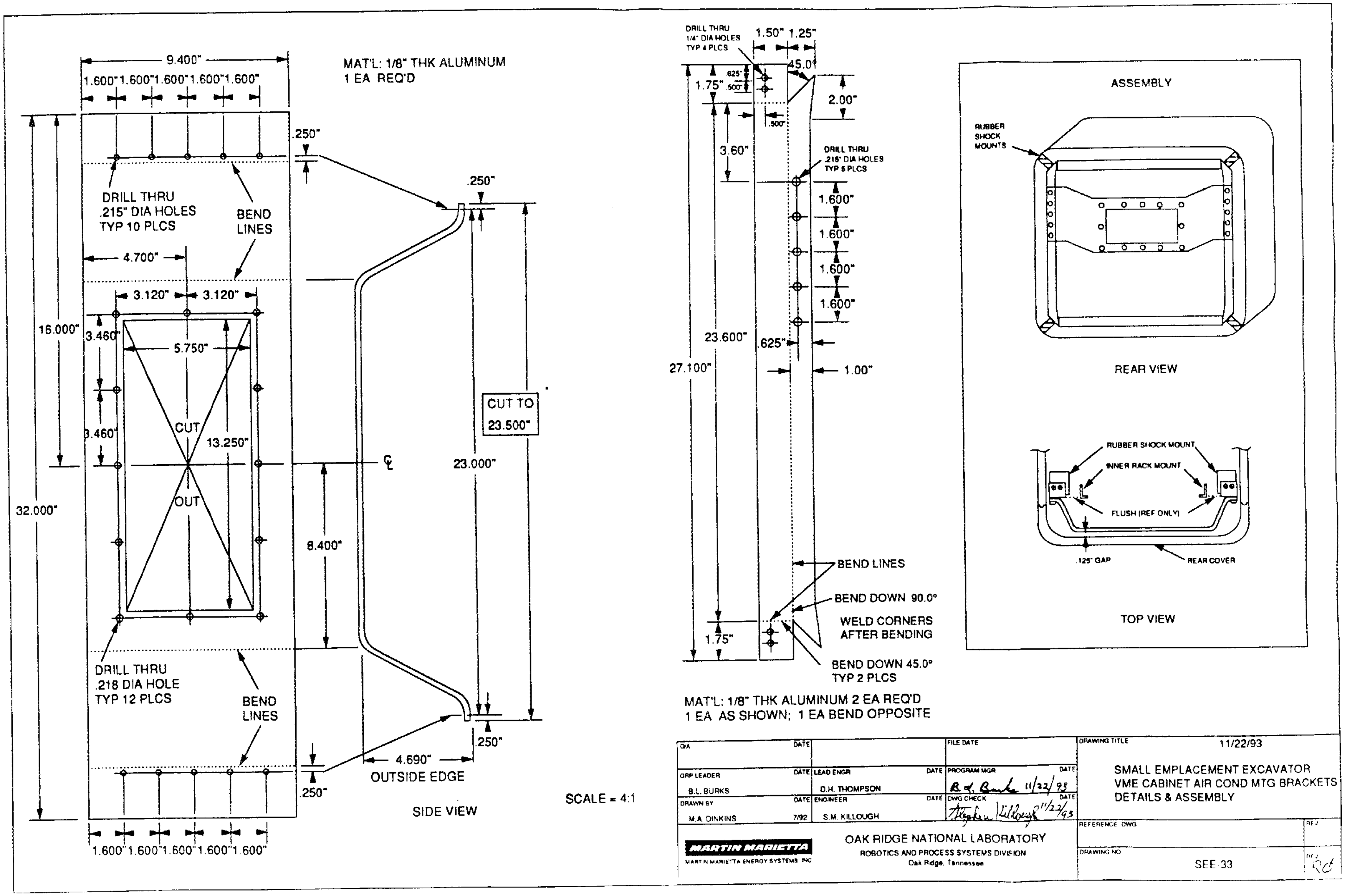


Q/A — DATE		FILE DATE	DRAWING TITLE 11/22/93
GRP LEADER B.L. BURKS — DATE	LEAD ENGR D.H. THOMPSON — DATE	PROGRAM MGR B. L. Burks 11/22/93	SMALL EMPLACEMENT EXCAVATOR BACKHOE OPERATOR CONTROL BOX WIRING DIAGRAM
DRAWN BY M.A. DINKINS — DATE	ENGINEER S.M. KILLOUGH — DATE 8/92	DWG CHECK Stephen Killough 11/22/93	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG SEE-28 — REV
			DRAWING NO SEE-31 — REV

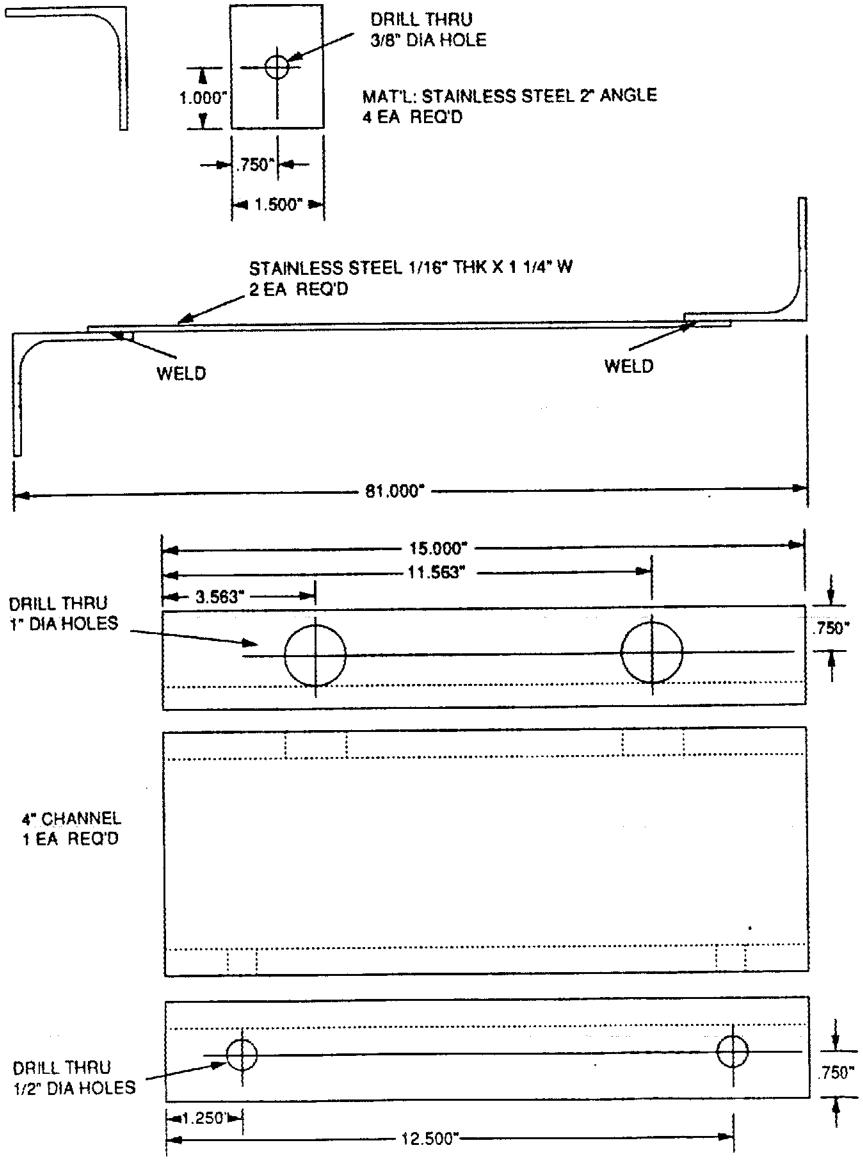


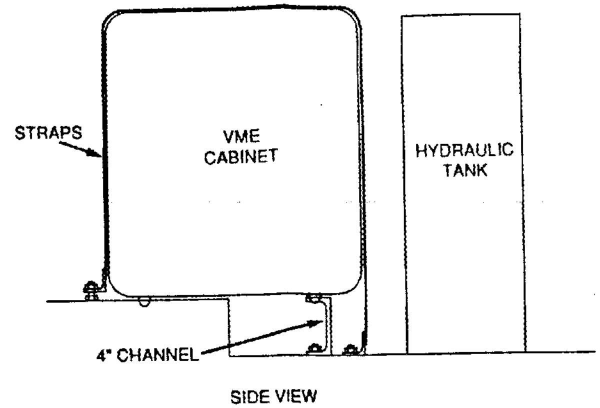


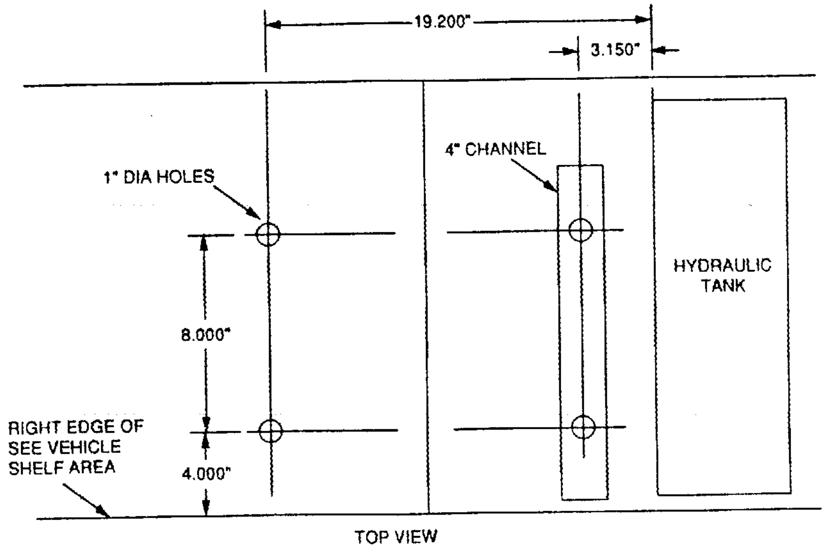
QA / DATE		FILE DATE	DRAWING TITLE 11/22/93
GRP LEADER B.L. BURKS / DATE	LEAD ENGR D.H. THOMPSON / DATE	PROGRAM MGR B. L. Burks 11/22/93 / DATE	SMALL EMPLACEMENT EXCAVATOR BACKHOE OPERATOR CONTROL BOX METALPHOTO LABELING
DRAWN BY M.A. DINKINS / DATE 1/93	ENGINEER S.M. KILLOUGH / DATE	DWG CHECK Stephen Killough 11/22/93 / DATE	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG / REV DRAWING NO SEE-32 / REV R0



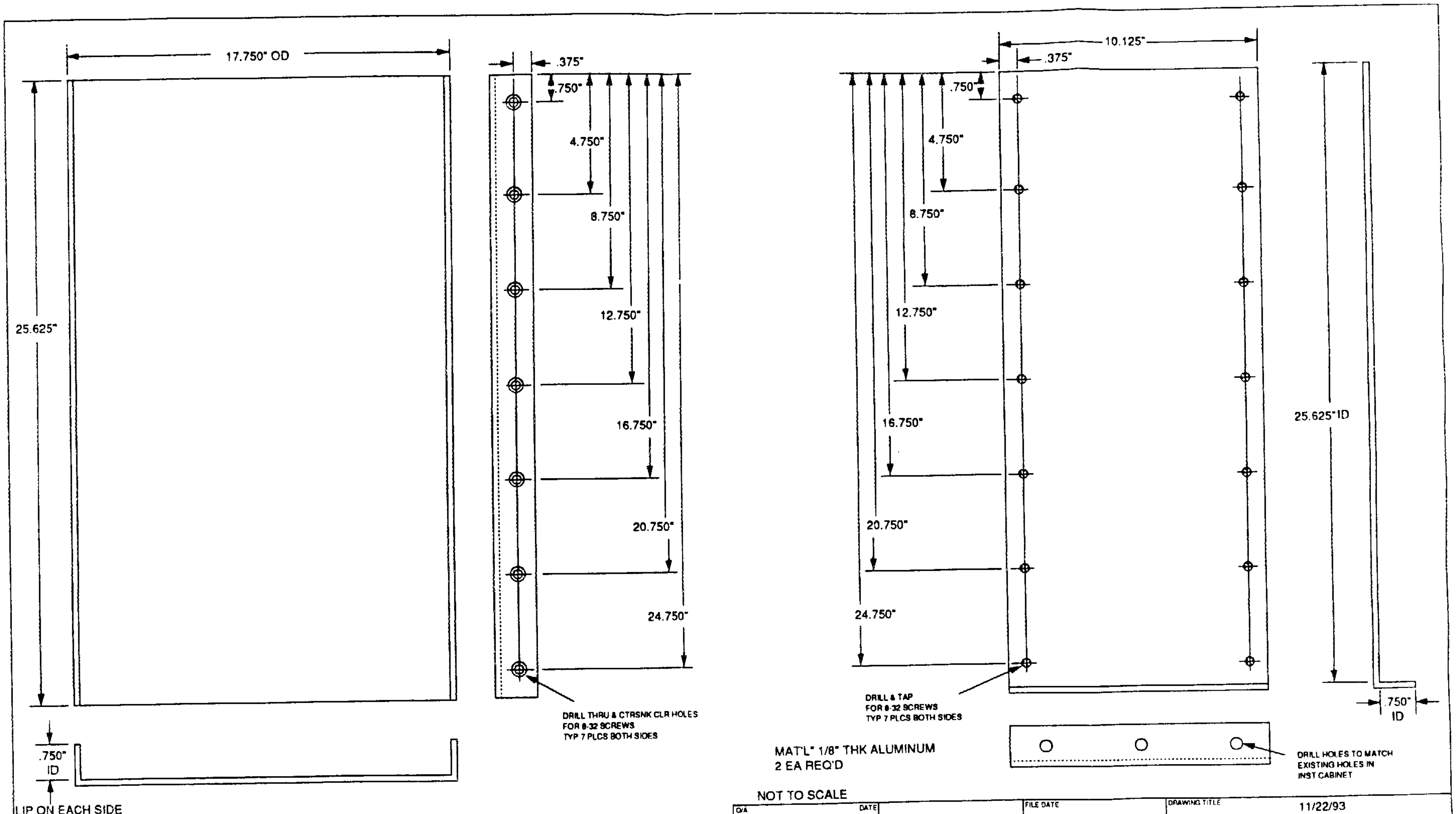
9.400"
1.600" 1.600" 1.600" 1.600" 1.600"
MAT'L: 1/8" THK ALUMINUM
1 EA REQ'D
.250"
DRILL THRU
.215" DIA HOLES
TYP 10 PLCS
BEND LINES
4.700"
3.120" 3.120"
16.000"
3.460"
5.750"
3.460"
CUT
13.250"
OUT
32.000"
8.400"
23.000"
CUT TO
23.500"
DRILL THRU
.218 DIA HOLE
TYP 12 PLCS
BEND LINES
4.690"
OUTSIDE EDGE
SIDE VIEW
1.600" 1.600" 1.600" 1.600" 1.600"
SCALE = 4:1
DRILL THRU
1/4" DIA HOLES
TYP 4 PLCS
1.50" 1.25"
45.0°
.625"
.500"
1.75"
2.00"
.500"
3.60"
DRILL THRU
.215" DIA HOLES
TYP 5 PLCS
1.600"
1.600"
1.600"
1.600"
23.600"
.625"
27.100"
1.00"
BEND LINES
BEND DOWN 90.0°
WELD CORNERS
AFTER BENDING
1.75"
BEND DOWN 45.0°
TYP 2 PLCS
MAT'L: 1/8" THK ALUMINUM 2 EA REQ'D
1 EA AS SHOWN; 1 EA BEND OPPOSITE
ASSEMBLY
RUBBER SHOCK MOUNTS
REAR VIEW
RUBBER SHOCK MOUNT
INNER RACK MOUNT
FLUSH (REF ONLY)
.125" GAP
REAR COVER
TOP VIEW
QA
GRP LEADER B.L. BURKS
DRAWN BY M.A. DINKINS 7/92
LEAD ENGR D.H. THOMPSON
ENGINEER S.M. KILLOUGH
FILE DATE
PROGRAM MGR 11/22/93
DWG CHECK 11/22/93
DRAWING TITLE 11/22/93
SMALL EMPLACEMENT EXCAVATOR
VME CABINET AIR COND MTG BRACKETS
DETAILS & ASSEMBLY
REFERENCE DWG
DRAWING NO SEE-33
MARTIN MARIETTA
MARTIN MARIETTA ENERGY SYSTEMS, INC
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee







QA / DATE		FILE DATE	DRAWING TITLE 11/22/93
GRP LEADER B.L. BURKS / DATE	LEAD ENGR D.H. THOMPSON / DATE	PROGRAM MGR B.L. Burks 11/22/93 / DATE	SMALL EMPLACEMENT EXCAVATOR VME CABINET MTG BRACKETS DETAILS AND ASSEMBLY
DRAWN BY M.A. DINKINS / DATE 7/92	ENGINEER S.M. KILLOUGH / DATE	DWG CHECK Stephen Killough 11/23/93 / DATE	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC	OAK RIDGE NATIONAL LABORATORY — ROBOTICS AND PROCESS SYSTEMS DIVISION — Oak Ridge, Tennessee		REFERENCE DWG / REV — DRAWING NO SEE-34 / REV RØ



MAT'L: 1/8" THK ALUMINUM
2 EA REQ'D

NOT TO SCALE

Q/A DATE
GRP LEADER DATE B.L. BURKS
DRAWN BY DATE M.A. DINKINS 2/93
LEAD ENGR DATE D.H. THOMPSON
ENGINEER DATE S.M. KILLOUGH
FILE DATE
PROGRAM MGR DATE [signature] 11/22/93
DWG CHECK DATE [signature] 11/22/93

DRAWING TITLE 11/22/93
SMALL EMPLACEMENT EXCAVATOR
VME COMPUTER CABINET INST CHASSIS
DETAILS

REFERENCE DWG
REV
DRAWING NO SEE-35

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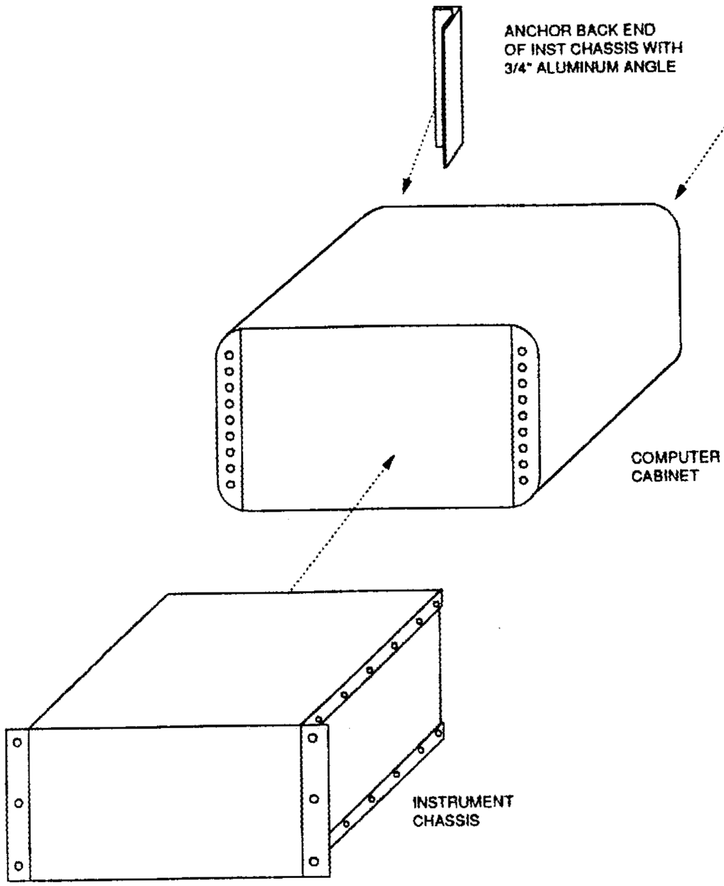
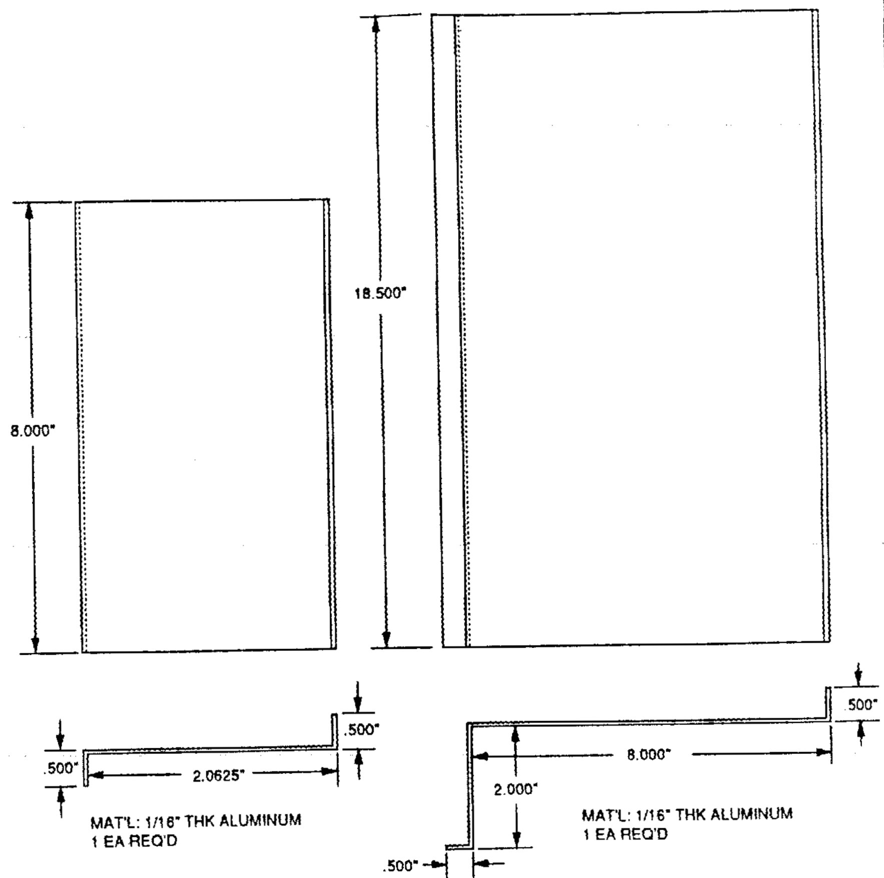
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee

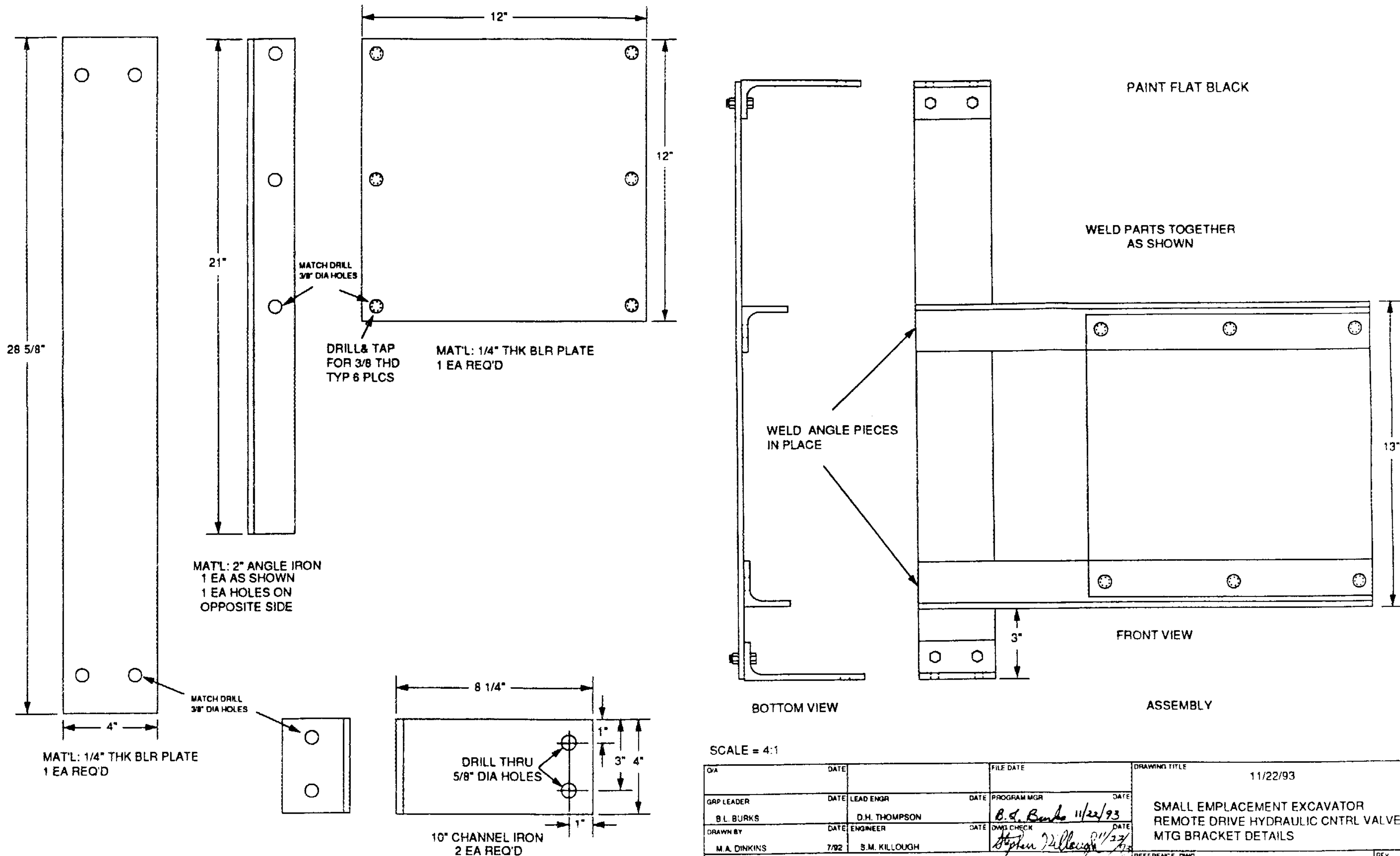


ASSEMBLY



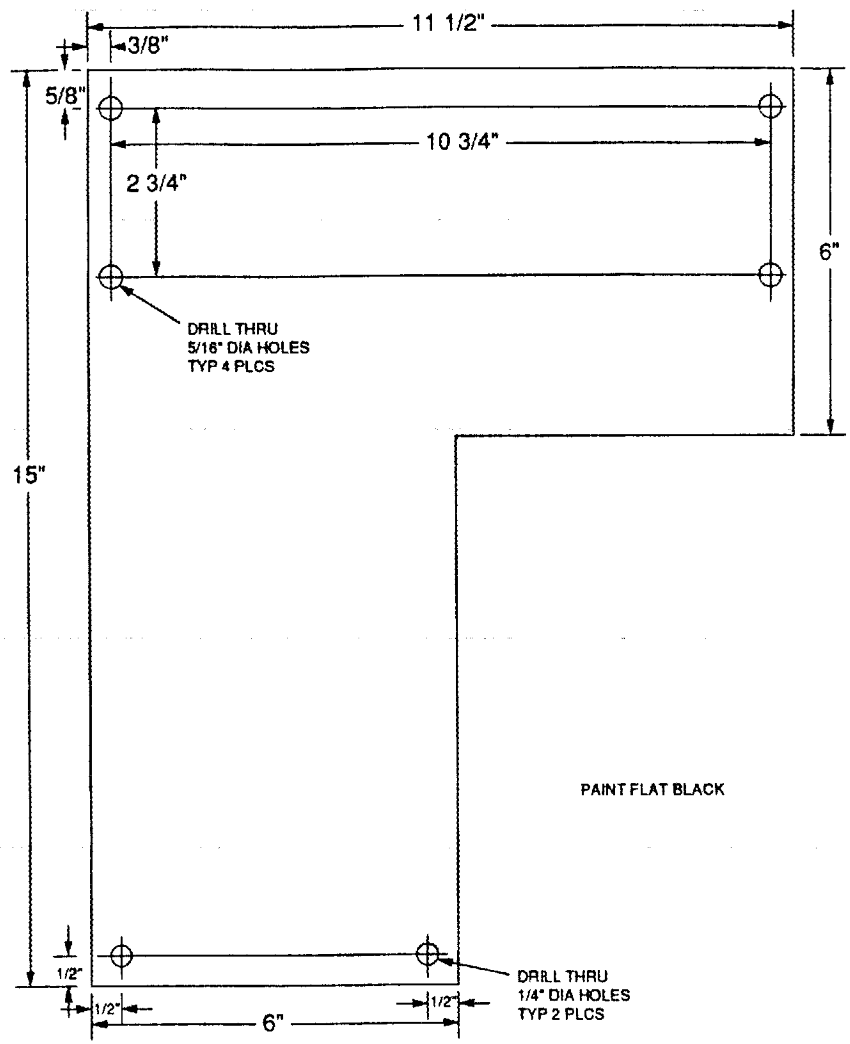
NOT TO SCALE

Q/A / DATE		FILE DATE	DRAWING TITLE: 11/22/93 SMALL EMPLACEMENT EXCAVATOR VME COMPUTER CABINET ASSY & COMPONENT MTG BRACKET DETAILS
GRP LEADER: B.L. BURKS / DATE	LEAD ENGR: D.H. THOMPSON / DATE	PROGRAM MGR: B.L. Burks 11/22/93 / DATE	
DRAWN BY: M.A. DINKINS / DATE: 2/93	ENGINEER: S.M. KILLOUGH / DATE	DWG CHECK: Stephen Killough 11/22/93 / DATE	REFERENCE DWG / REV
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		DRAWING NO: SEE-36 / REV: 0



SCALE = 4:1

Q/A — DATE		FILE DATE	DRAWING TITLE: 11/22/93
GRP LEADER: B.L. BURKS — DATE	LEAD ENGR: D.H. THOMPSON — DATE	PROGRAM MGR: B.L. Burks 11/22/93 — DATE	SMALL EMPLACEMENT EXCAVATOR REMOTE DRIVE HYDRAULIC CNTRL VALVE MTG BRACKET DETAILS
DRAWN BY: M.A. DINKINS — DATE 7/92	ENGINEER: S.M. KILLOUGH — DATE	DWG CHECK: Stephen Killough 11/22/93 — DATE	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC	OAK RIDGE NATIONAL LABORATORY — ROBOTICS AND PROCESS SYSTEMS DIVISION — Oak Ridge, Tennessee		REFERENCE DWG — REV; DRAWING NO: SEE 37 — REV

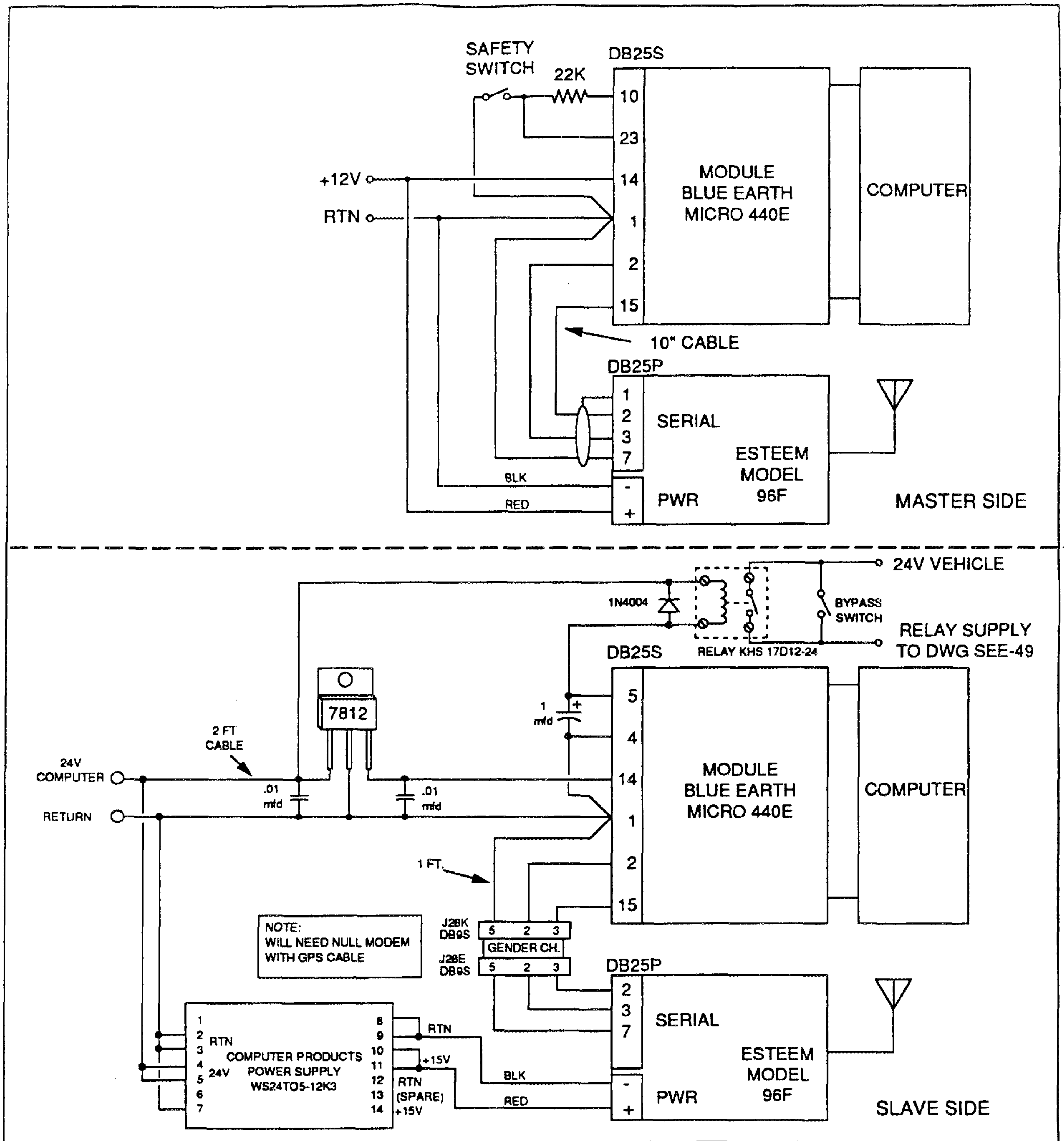


PAINT FLAT BLACK

MAT'L: 1/4" THK BOILER PLATE
1 EA REQ'D

SCALE = 2:1

Q/A / DATE		FILE DATE	DRAWING TITLE 11/22/93 SMALL EMPLACEMENT EXCAVATOR FRONT END LOADER CONTROL COMPONENT MTG PLATE DETAILS
GRP LEADER B.L. BURKS / DATE	LEAD ENGR D.H. THOMPSON / DATE	PROGRAM MGR B. L. Burks 11/22/93	
DRAWN BY M.A. DINKINS / DATE 3/93	ENGINEER S.M. KILLOUGH / DATE	DWG CHECK Stephen M. Killough 11/22/93	
MARTIN MARIETTA / MARTIN MARIETTA ENERGY SYSTEMS, INC	OAK RIDGE NATIONAL LABORATORY / ROBOTICS AND PROCESS SYSTEMS DIVISION / Oak Ridge, Tennessee		REFERENCE DWG / REV; DRAWING NO SEE-38 / REV 00



Q/A	DATE		FILE DATE	DRAWING TITLE 11/18/93
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B. L. Burks 11/18/93	SMALL EMPLACEMENT EXCAVATOR REMOTE EMERGENCY SHUTDOWN SAFETY CIRCUIT WIRING DIAGRAM
DRAWN BY M.A. DINKINS	DATE 6/93	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 11/18/93	

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OAK RIDGE NATIONAL LABORATORY

ROBOTICS AND PROCESS SYSTEMS DIVISION

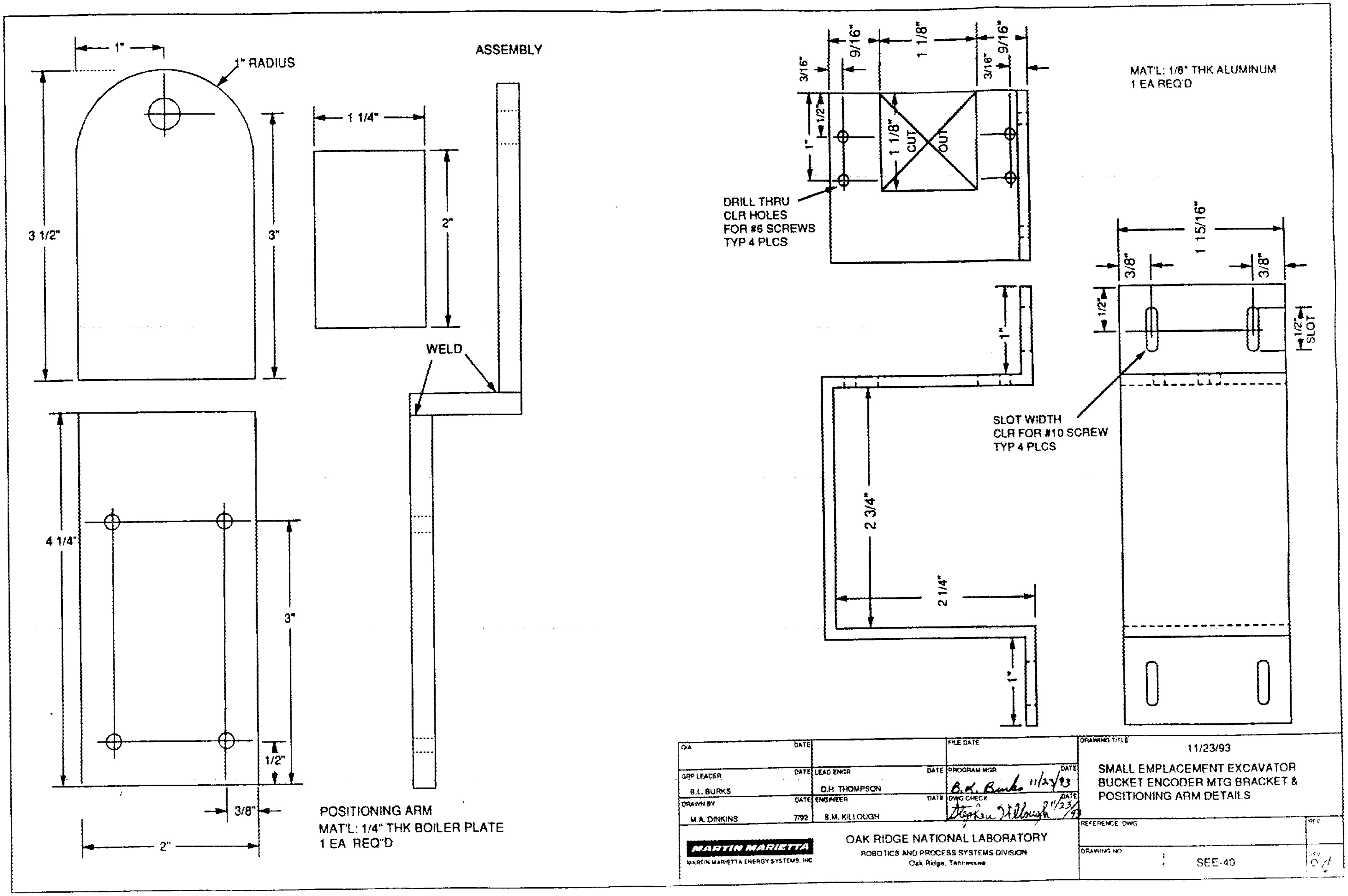
Oak Ridge, Tennessee

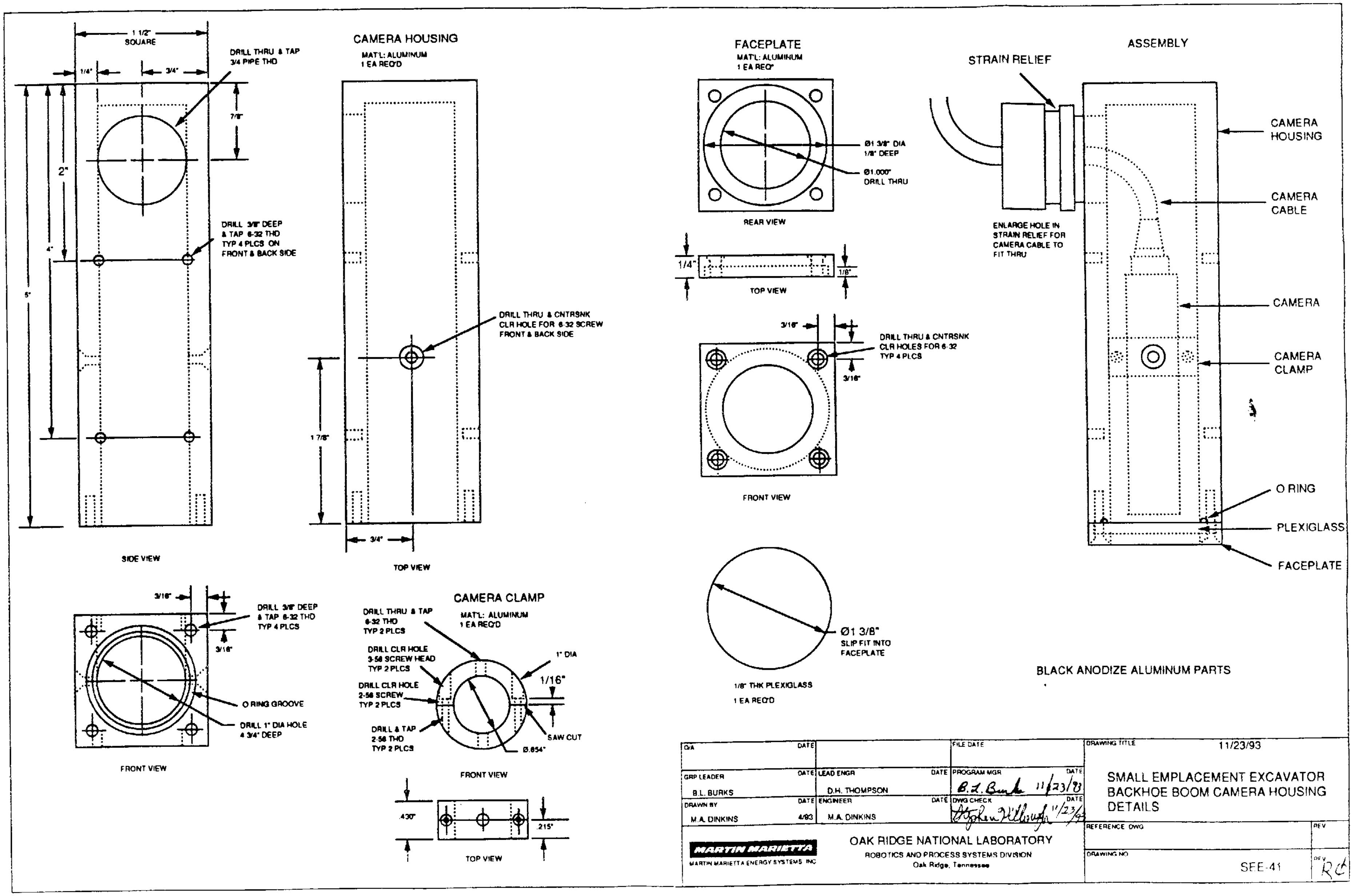
REFERENCE DWG

REV

DRAWING NO. SEE-39

REV RØ


1"
1" RADIUS
3 1/2"
3"
ASSEMBLY
1 1/4"
2"
WELD
4 1/4"
3"
1/2"
3/8"
2"
POSITIONING ARM
MAT'L: 1/4" THK BOILER PLATE
1 EA REQ'D
9/16"
1 1/8"
9/16"
3/16"
3/16"
1/2"
1"
1 1/8"
CUT
OUT
DRILL THRU
CLR HOLES
FOR #6 SCREWS
TYP 4 PLCS
MAT'L: 1/8" THK ALUMINUM
1 EA REQ'D
1 15/16"
3/8"
3/8"
1/2"
1/2" SLOT
1"
SLOT WIDTH
CLR FOR #10 SCREW
TYP 4 PLCS
2 3/4"
2 1/4"
1"
GRP LEADER B.L. BURKS
DRAWN BY M.A. DINKINS 7/92
LEAD ENGR D.H. THOMPSON
ENGINEER S.M. KILLOUGH
PROGRAM MGR 11/23/93
DWG CHECK 11/23/93
DRAWING TITLE 11/23/93
SMALL EMPLACEMENT EXCAVATOR
BUCKET ENCODER MTG BRACKET &
POSITIONING ARM DETAILS
MARTIN MARIETTA
MARTIN MARIETTA ENERGY SYSTEMS, INC.
OAK RIDGE NATIONAL LABORATORY
ROBOTICS AND PROCESS SYSTEMS DIVISION
Oak Ridge, Tennessee
DRAWING NO SEE-40


1 1/2" SQUARE
1/4"
3/4"
DRILL THRU & TAP 3/4 PIPE THD
7/8"
2"
4"
5"
DRILL 3/8" DEEP & TAP 6-32 THD TYP 4 PLCS ON FRONT & BACK SIDE
SIDE VIEW
CAMERA HOUSING
MAT'L: ALUMINUM
1 EA REQ'D
DRILL THRU & CNTRSNK CLR HOLE FOR 6-32 SCREW FRONT & BACK SIDE
1 7/8"
3/4"
TOP VIEW
3/16"
DRILL 3/8" DEEP & TAP 6-32 THD TYP 4 PLCS
3/16"
O RING GROOVE
DRILL 1" DIA HOLE 4 3/4" DEEP
FRONT VIEW
CAMERA CLAMP
MAT'L: ALUMINUM
1 EA REQ'D
DRILL THRU & TAP 6-32 THD TYP 2 PLCS
DRILL CLR HOLE 3-56 SCREW HEAD TYP 2 PLCS
DRILL CLR HOLE 2-56 SCREW TYP 2 PLCS
DRILL & TAP 2-56 THD TYP 2 PLCS
1" DIA
1/16"
SAW CUT
Ø.854"
FRONT VIEW
.430"
.215"
TOP VIEW
FACEPLATE
MAT'L: ALUMINUM
1 EA REQ'
Ø1 3/8" DIA 1/8" DEEP
Ø1.000" DRILL THRU
REAR VIEW
1/4"
1/8"
TOP VIEW
3/16"
DRILL THRU & CNTRSNK CLR HOLES FOR 6-32 TYP 4 PLCS
3/16"
FRONT VIEW
Ø1 3/8"
SLIP FIT INTO FACEPLATE
1/8" THK PLEXIGLASS
1 EA REQ'D
ASSEMBLY
STRAIN RELIEF
CAMERA HOUSING
CAMERA CABLE
ENLARGE HOLE IN STRAIN RELIEF FOR CAMERA CABLE TO FIT THRU
CAMERA
CAMERA CLAMP
O RING
PLEXIGLASS
FACEPLATE
BLACK ANODIZE ALUMINUM PARTS
Q/A
DATE
FILE DATE
DRAWING TITLE
11/23/93
GRP LEADER
B.L. BURKS
LEAD ENGR
D.H. THOMPSON
PROGRAM MGR
11/23/93
DRAWN BY
M.A. DINKINS
4/93
ENGINEER
M.A. DINKINS
DWG CHECK
SMALL EMPLACEMENT EXCAVATOR
BACKHOE BOOM CAMERA HOUSING
DETAILS
REFERENCE DWG
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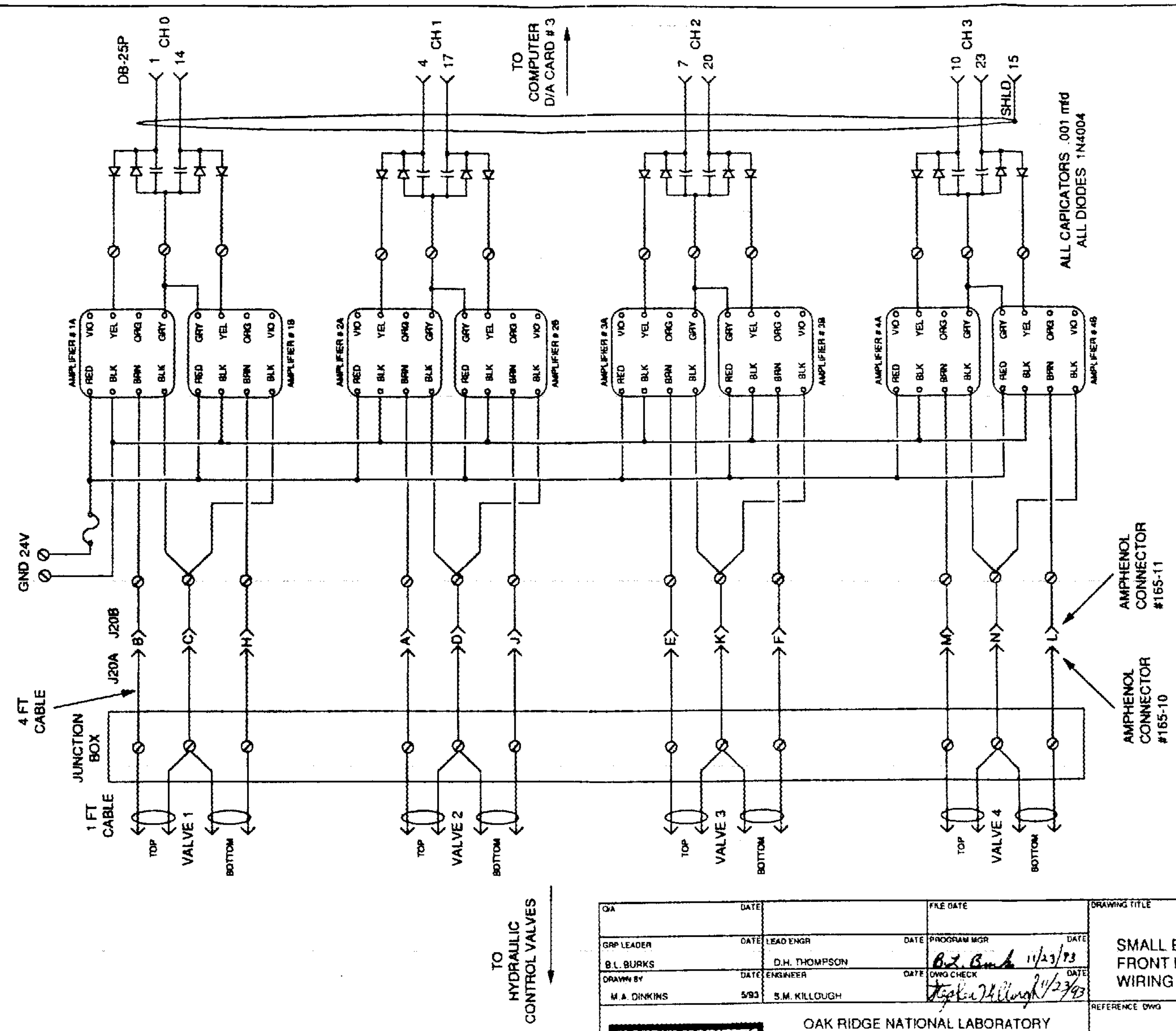

QA	DATE		FILE DATE	DRAWING TITLE
GRP LEADER B.L. BURKS	DATE	LEAD ENGR D.H. THOMPSON	DATE	PROGRAM MGR B.L. Burks 11/23/93	11/23/93 SMALL EMPLACEMENT EXCAVATOR FRONT HYDRAULIC ELECTRIC DRIVE WIRING DIAGRAM
DRAWN BY M.A. DINKINS	DATE 5/93	ENGINEER S.M. KILLOUGH	DATE	DWG CHECK Stephen Killough 11/23/93	

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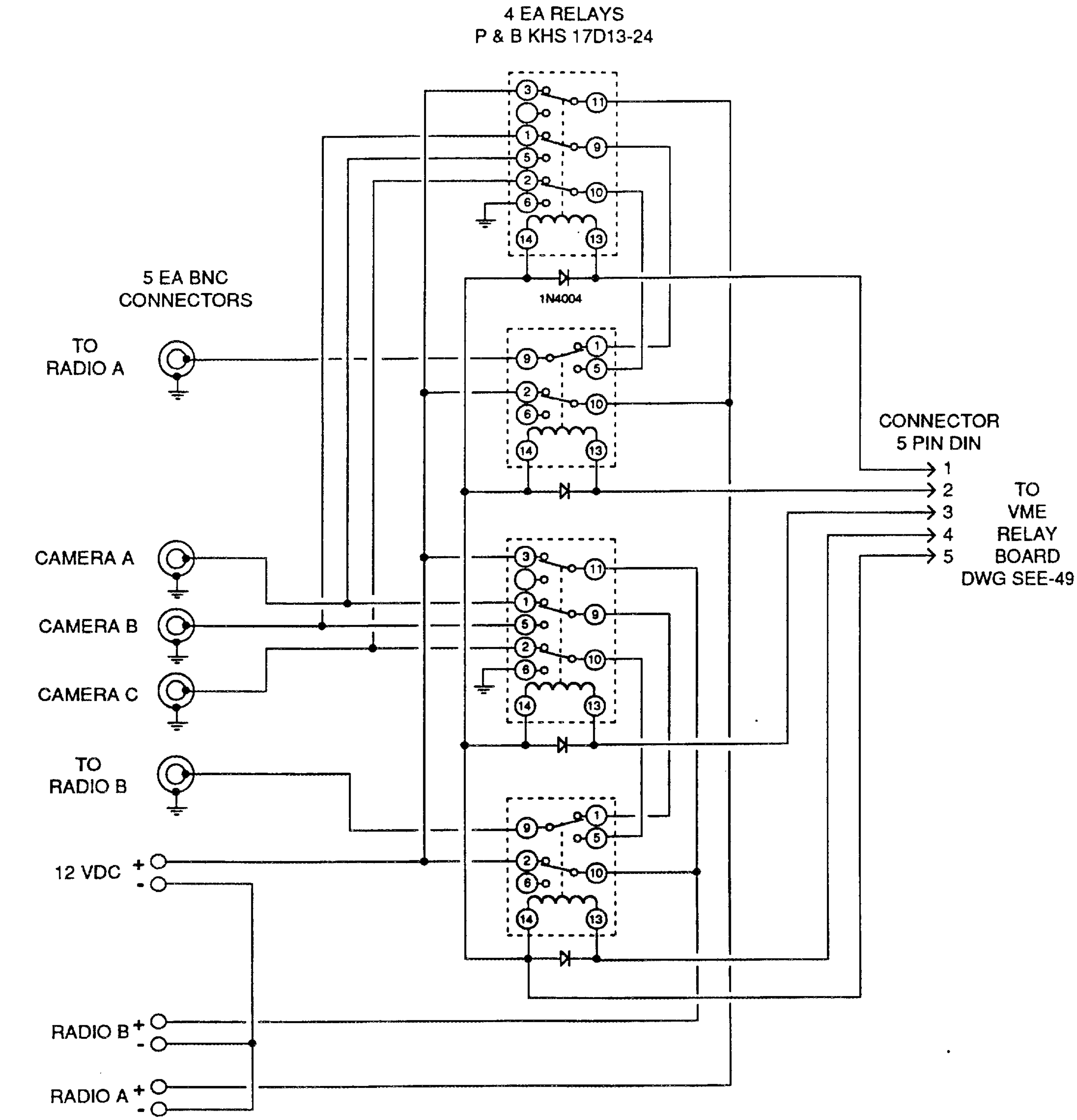

Q/A DATE		FILE DATE	DRAWING TITLE 11/23/93
GRP LEADER DATE B.L.BURKS	LEAD ENGR DATE D.H. THOMPSON	PROGRAM MGR DATE B. L. Burks 11/23/93	SMALL EMPLACEMENT EXCAVATOR CAMERA VIDEO SWITCHING CIRCUIT WIRING DIAGRAM
DRAWN BY DATE M.A. DINKINS 6/93	ENGINEER DATE S.M. KILLOUGH	DWG CHECK DATE Stephen Killough 11/23/93	

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SHIFT INDICATOR J27B	RESERVED	RESERVED	GPS J28G
PNEUMATIC CONTROLS J25D	RESERVED	RESERVED	THIRD CAMERA J26
VIDEO RADIO ANTENNA J21	VIDEO RADIO ANTENNA J22	MICRO PHONE J23	ARLAN ANTENNA J24
FRONT HYDRAULIC DRIVE J20B	RESOLVER 5 STEERING J17F	RESOLVER 6 FRONT LOADER J18F	RESOLVER 7 FRONT BUCKET J19F
RESOLVER 1 SWING J13F	RESOLVER 2 BOOM J14F	RESOLVER 3 DIPPER J15F	RESOLVER 4 BUCKET J16F
LEFT CAMERA J11D	LEFT PAN/TILT J5F	RIGHT CAMERA J12D	RIGHT PAN/TILT J6F
VEHICLE POWER J2D	ENGINE MONITOR J8B	PRESSURE TRANS DUCERS J10D	REAR HYDRAULIC DRIVE J9D
COMPUTER POWER J1D	PANEL SWITCH J3B	HYDRAULIC SAFETY J4D	FIBER OPTIC CABLE J7

Q/A	DATE		FILE DATE	DRAWING TITLE 11/23/93
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B. L. Burks 11/23/93	SMALL EMPLACEMENT EXCAVATOR VME COMPUTER CONNECTOR LAYOUT & ID
DRAWN BY M.A. DINKINS	DATE 6/93	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 11/23/93	

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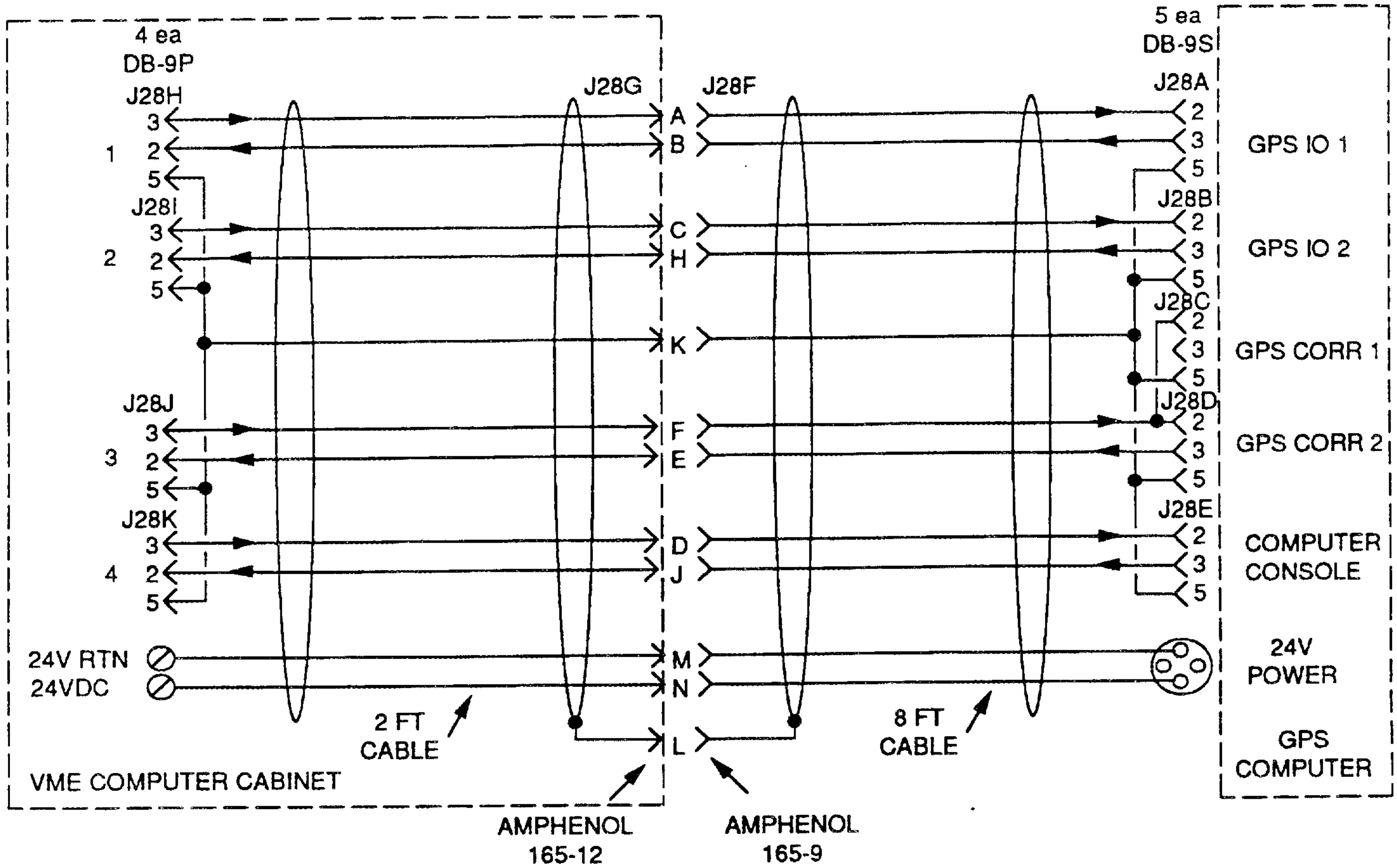

Q/A / DATE		FILE DATE	DRAWING TITLE 11/19/93
GRP LEADER / DATE: B.L.BURKS	LEAD ENGR / DATE: D.H. THOMPSON	PROGRAM MGR / DATE: B. L. Burks 11/19/93	SMALL EMPLACEMENT EXCAVATOR GPS TO VME INTERCONNECTING CABLE WIRING DIAGRAM
DRAWN BY / DATE: M.A. DINKINS 6/93	ENGINEER / DATE: S.M. KILLOUGH	DWG CHECK / DATE: Stephen Killough 11/19/93	

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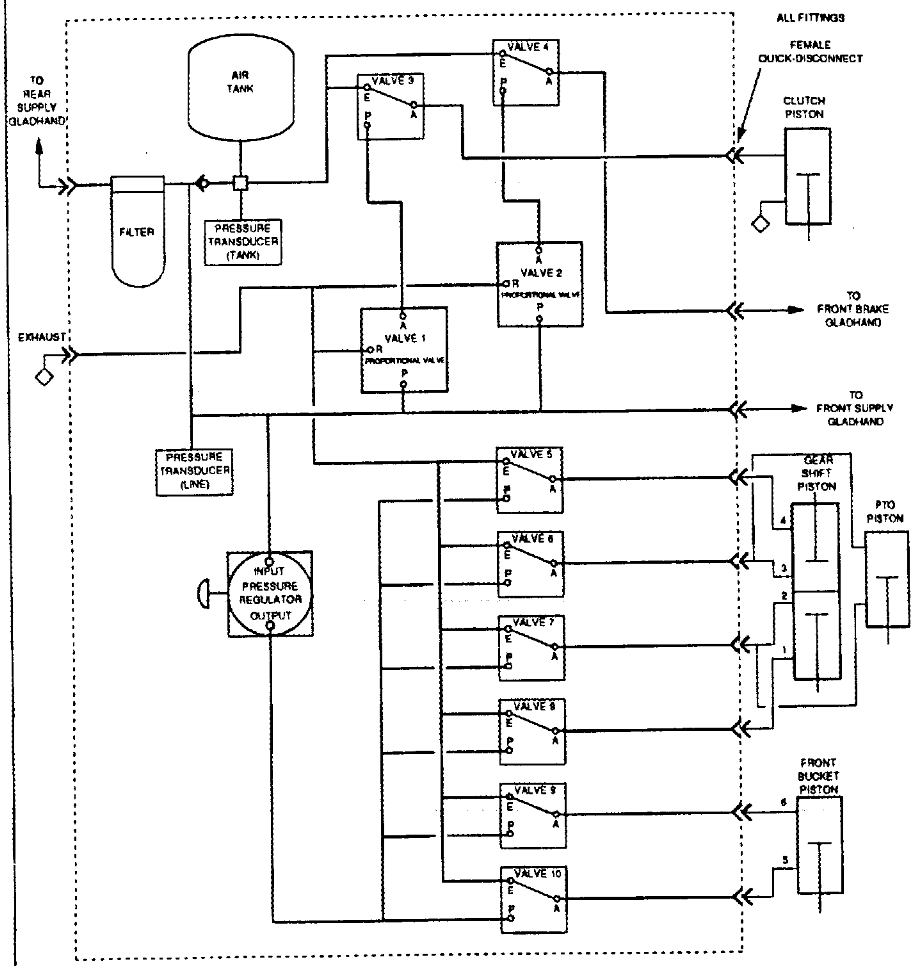
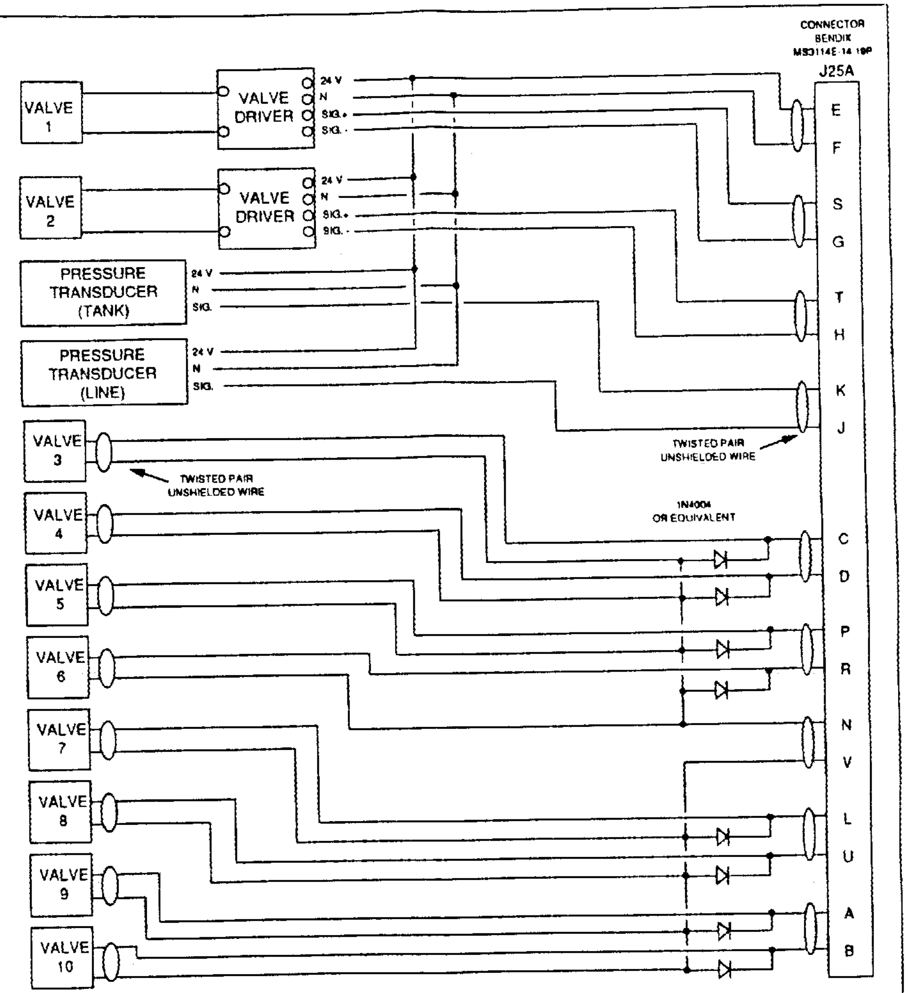
DRAWING NO. SEE-45	REV RØ



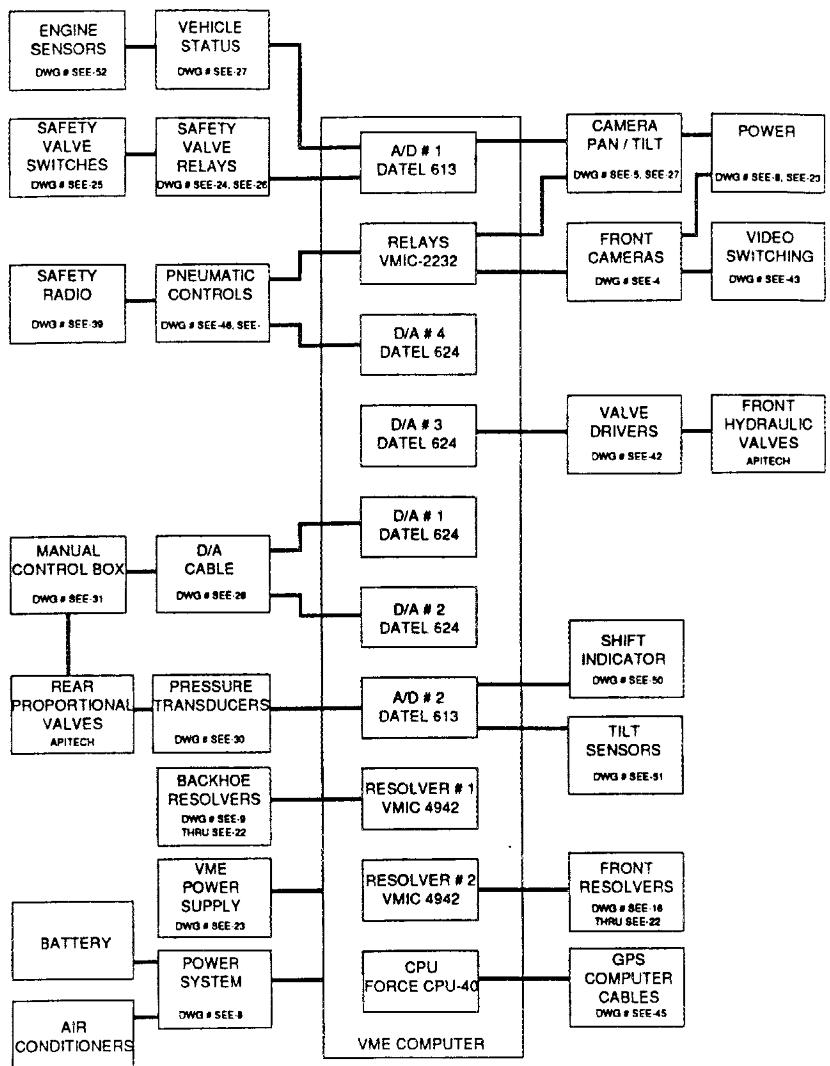
PNEUMATIC PIPING

AIR SUPPLY & EXHAUST-------3/8" PLASTIC TUBING
CONTROL VALVES-----------------1/8" PLASTIC TUBING

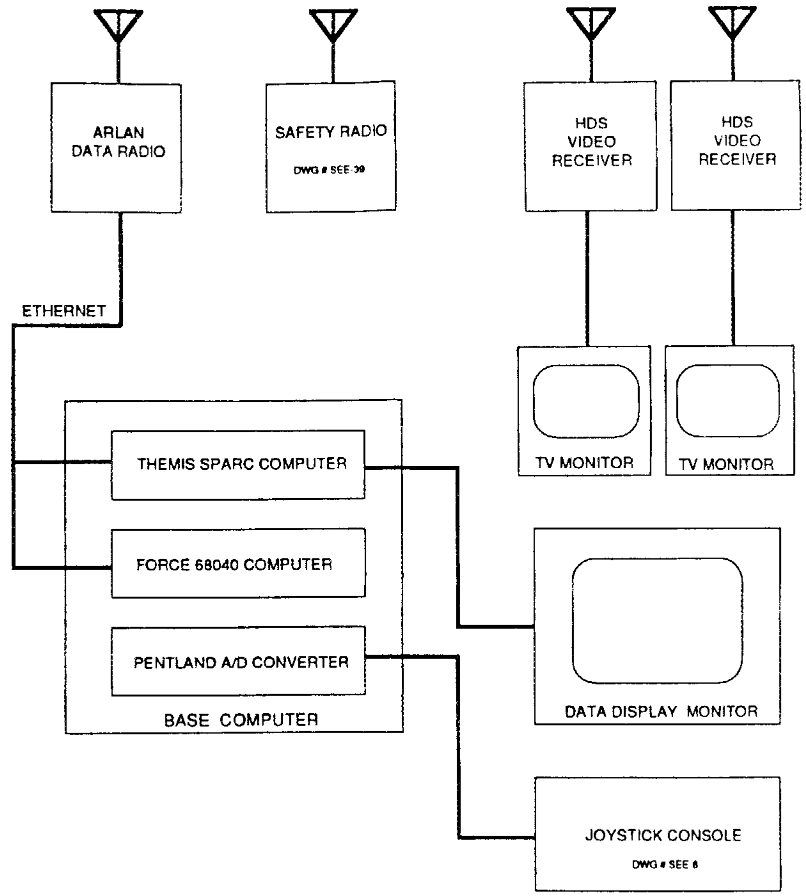


WIRING DIAGRAM

Q/A	DATE			FILE DATE	DRAWING TITLE 11/16/93
GRP LEADER B.L. BURKS	DATE	LEAD ENGR D.H. THOMPSON	DATE	PROGRAM MGR B. L. Burks 11/16/93	SMALL EMPLACEMENT EXCAVATOR REMOTE DRIVING CONTROL BOX PIPING & WIRING DIAGRAM
DRAWN BY M.A. DINKINS	DATE 11/93	ENGINEER S.M. KILLOUGH	DATE	DWG CHECK Stephen Killough 11/16/93	
MARTIN MARIETTA — MARTIN MARIETTA ENERGY SYSTEMS, INC		OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee			REFERENCE DWG — REV; DRAWING NO SEE-46 — REV Rd



VEHICLE OVERALL BLOCK DIAGRAM



BASE STATION OVERALL BLOCK DIAGRAM

QA DATE		FILE DATE	DRAWING TITLE 11/17/93
GRP LEADER B.L. BURKS DATE	LEAD ENGR D.H. THOMPSON DATE	PROGRAM MGR B.L. Burks 11/17/93 DATE	SMALL EMPLACEMENT EXCAVATOR VEHICLE & BASE STATION OVERALL BLOCK DIAGRAM
DRAWN BY M.A. DINKINS DATE 11/93	ENGINEER S.M. KILLOUGH DATE	DWG CHECK Stephen Killough 11/17/93 DATE	

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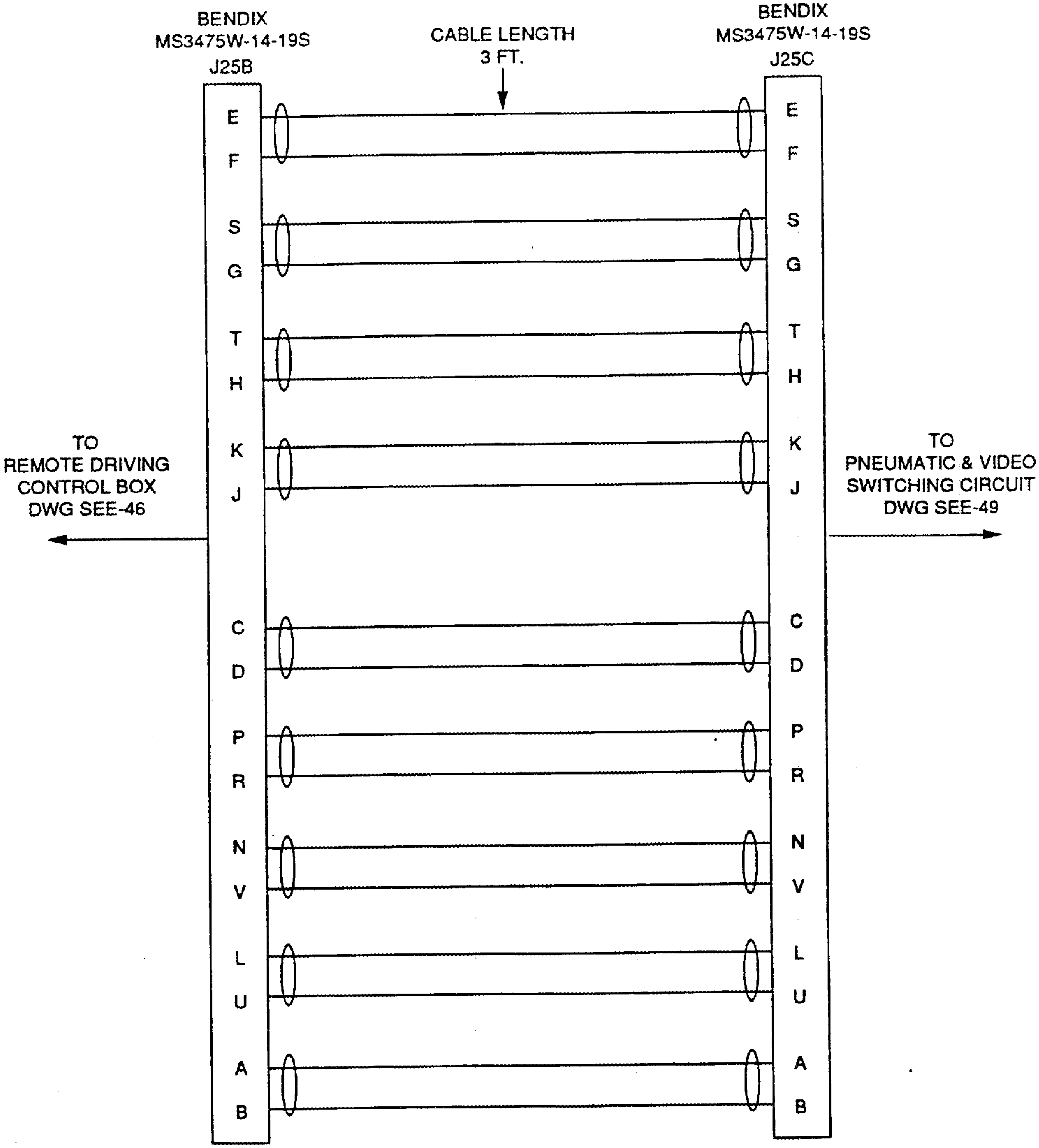

Q/A — DATE		FILE DATE	DRAWING TITLE: 11/19/93
GRP LEADER: B.L.BURKS — DATE	LEAD ENGR: D.H. THOMPSON — DATE	PROGRAM MGR: B. L. Burks 11/19/93 — DATE	SMALL EMPLACEMENT EXCAVATOR REMOTE DRIVING CNTRL BOX TO COMPUTER CABLE WIRING DIAGRAM
DRAWN BY: M.A. DINKINS — DATE: 11/93	ENGINEER: S.M. KILLOUGH — DATE	DWG CHECK: Stephen Killough 11/19/93 — DATE	REFERENCE DWG — REV

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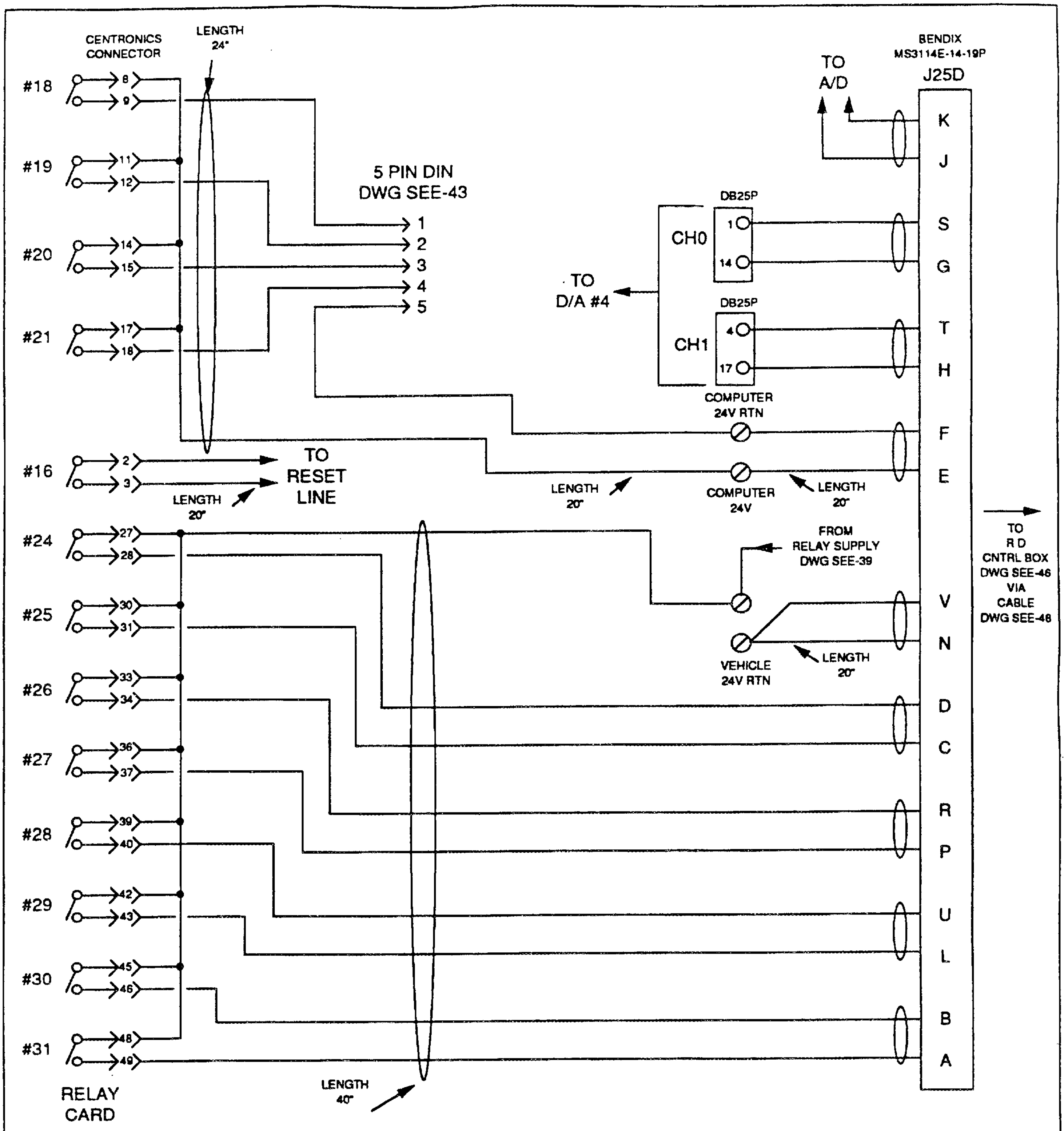

Q/A DATE		FILE DATE	DRAWING TITLE 11/19/93
GRP LEADER DATE B.L.BURKS	LEAD ENGR DATE D.H. THOMPSON	PROGRAM MGR DATE B. L. Burks 11/19/93	SMALL EMPLACEMENT EXCAVATOR PNEUMATIC & VIDEO SWITCHING CKT WIRING DIAGRAM
DRAWN BY DATE M.A. DINKINS 11/93	ENGINEER DATE S.M. KILLOUGH	DWG CHECK DATE Stephen Killough 11/19/93	

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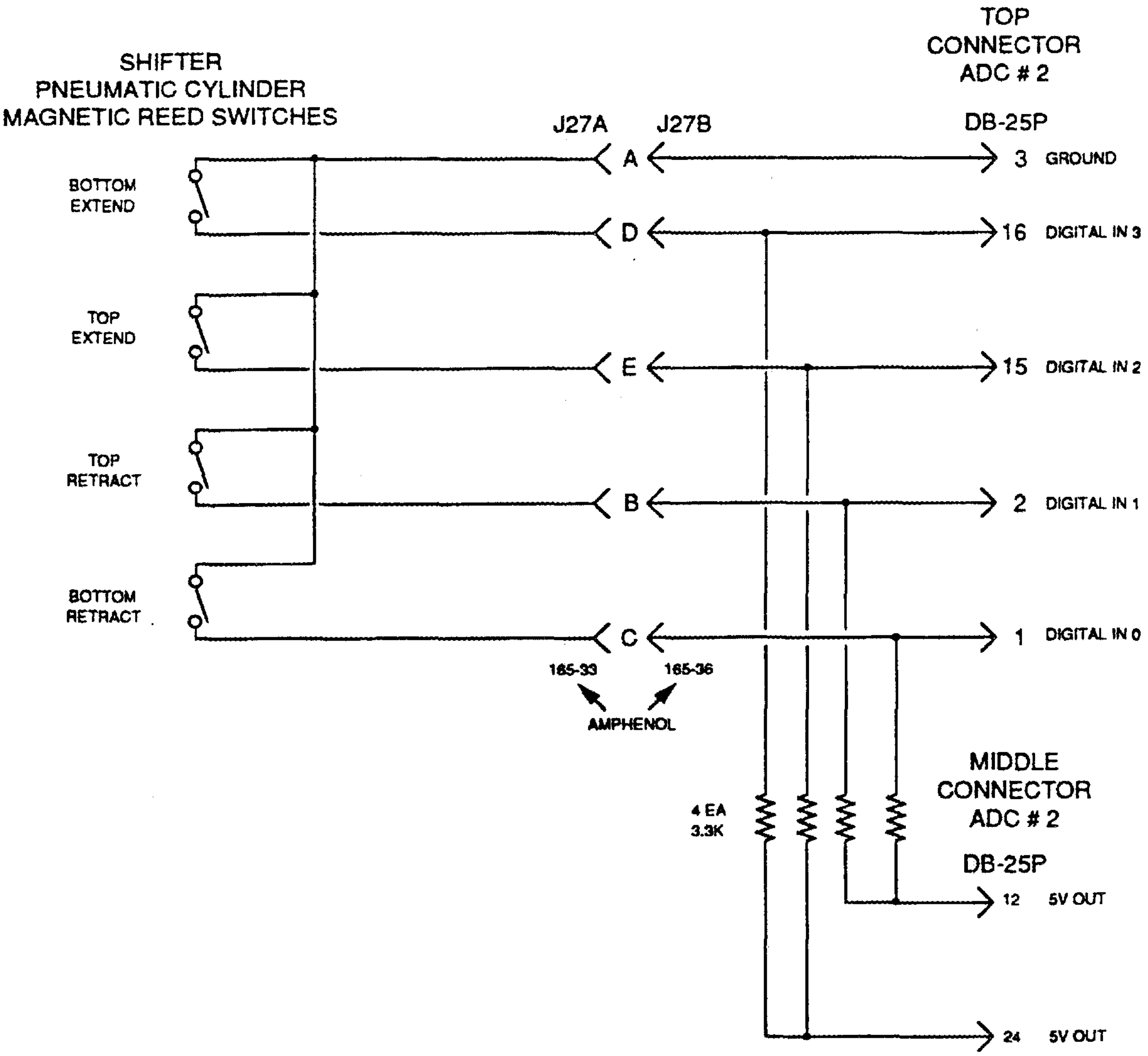
REFERENCE DWG	REV
DRAWING NO. SEE-49	REV R0



Q/A DATE		FILE DATE	DRAWING TITLE 12/7/93
GRP LEADER DATE B.L.BURKS	LEAD ENGR DATE D.H. THOMPSON	PROGRAM MGR DATE B. L. Burks 12/7/93	SMALL EMPLACEMENT EXCAVATOR PNEUMATIC SHIFTER INDICATOR CKT WIRING DIAGRAM
DRAWN BY DATE M.A. DINKINS 12/93	ENGINEER DATE S.M. KILLOUGH	DWG CHECK DATE Stephen Killough 12/7/93	
MARTIN MARIETTA MARTIN MARIETTA ENERGY SYSTEMS, INC.	OAK RIDGE NATIONAL LABORATORY ROBOTICS AND PROCESS SYSTEMS DIVISION Oak Ridge, Tennessee		REFERENCE DWG — REV
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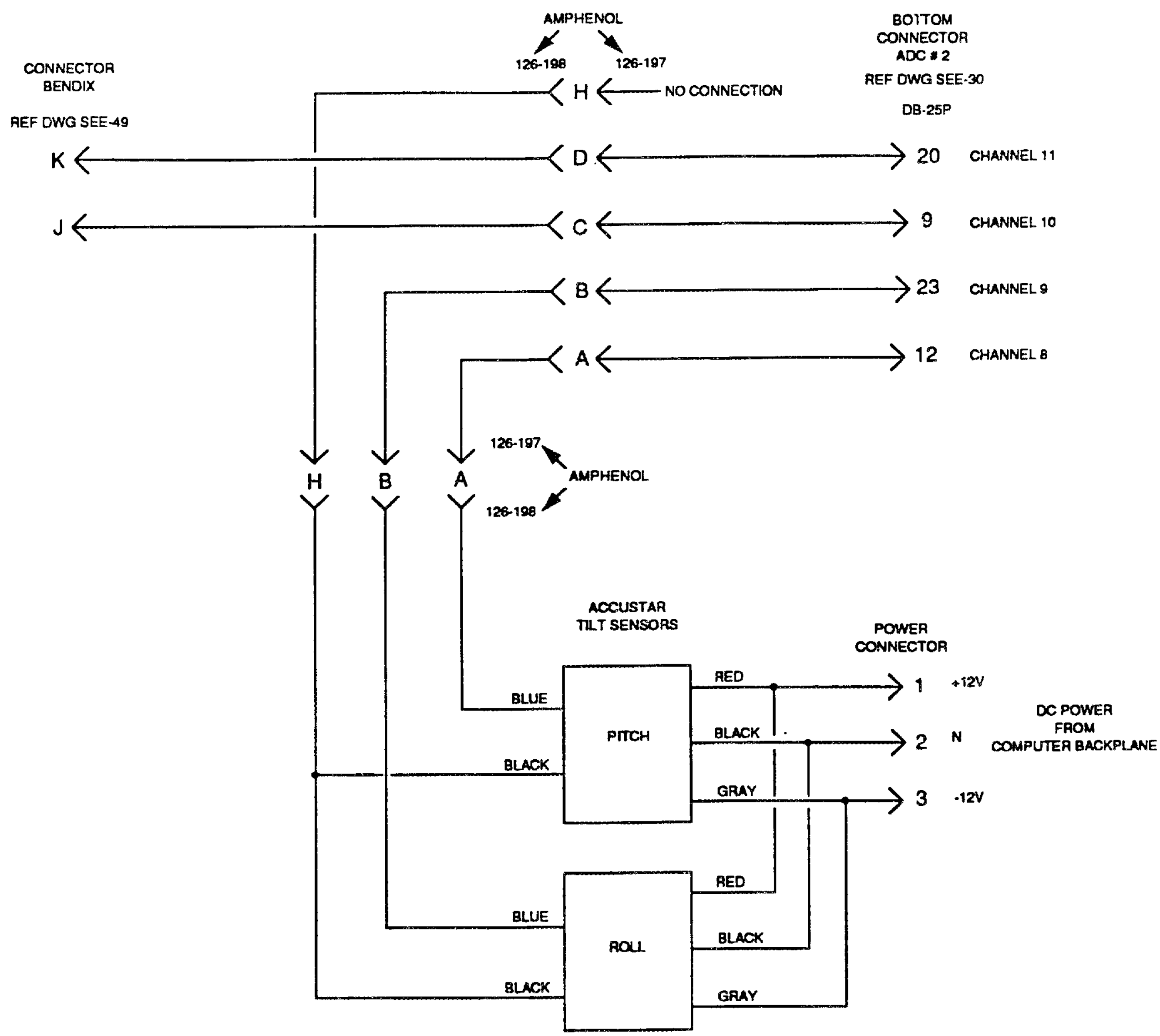

Q/A	DATE		FILE DATE	DRAWING TITLE 12/7/93
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON DATE	PROGRAM MGR B.L. Burks 12/7/93 DATE	SMALL EMPLACEMENT EXCAVATOR TILT SENSOR CIRCUIT WIRING DIAGRAM
DRAWN BY M.A. DINKINS	DATE 12/93	ENGINEER S.M. KILLOUGH DATE	DWG CHECK Stephen Killough 12/7/93 DATE	

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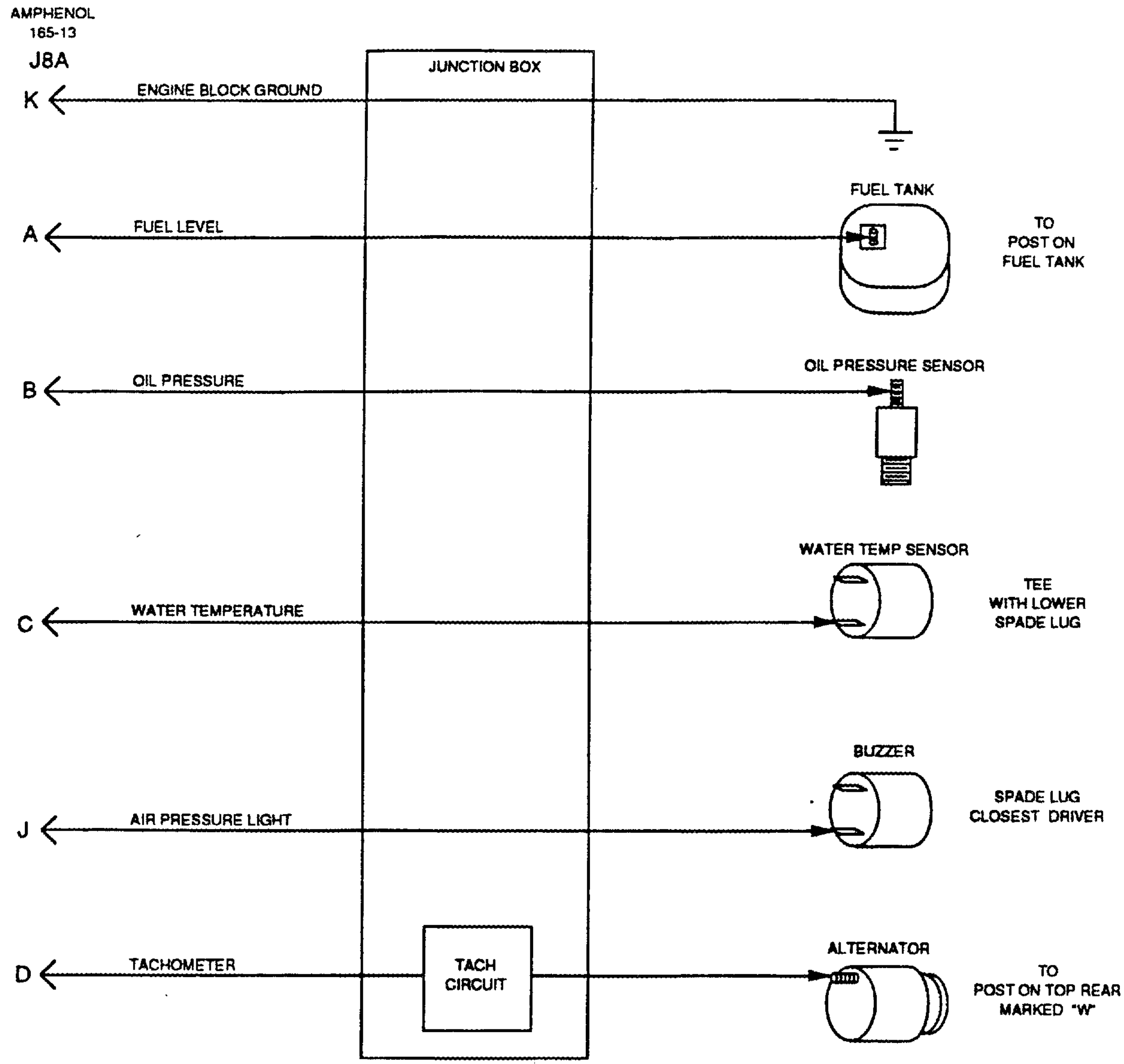

Q/A	DATE		FILE DATE	DRAWING TITLE
GRP LEADER B.L.BURKS	DATE	LEAD ENGR D.H. THOMPSON	PROGRAM MGR B. L. Burks 12/7/93	12/7/93 SMALL EMPLACEMENT EXCAVATOR ENGINE MONITORING SENSORS WIRING DIAGRAM
DRAWN BY M.A. DINKINS	DATE 12/93	ENGINEER S.M. KILLOUGH	DWG CHECK Stephen Killough 12/7/93	

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REFERENCE DWG	REV
DRAWING NO. SEE-52	REV R0

APPENDIX F
PARTS INVENTORY

PARTS INVENTORY

Notes:

1. Only the significant items are listed here. Many miscellaneous cables, switches, and connectors are identified in the schematics.

2. Most parts are commercial grade, although military grade versions (such as the VME cards) are available. Most connectors and cabinets are military grade.

3. The front hydraulics and pneumatics are used only for the remote driving.

4. Both radio and fiber optic communication systems are listed.

HYDRAULICS (REAR)

Device	Manufacturer	Model	Schematic#
Valve stack (six segment)	Apitech	VPO series	
Load holding valve (two)	Sun	CBCA-LHN-BCJ	
Servo amplifiers (twelve)	Apitech	MC3202-0111	SEE-31
Joysticks (four)	OEM Controls	MS4M7898	SEE-31
Joystick cabinet	Hoffman		
Safety valve	Sun	YREG-LAN-TL	SEE-25
Pressure transducers (eight)	Barksdale	CVD-2000-806	SEE-30
Filter	Donaldson	HPK04	

HYDRAULICS (FRONT)

Device	Manufacturer	Model	Schematic#
Valve stack (four segment)	Apitech	VP series	
Servo amplifiers (eight)	Apitech	MC3202-0111	SEE-42
Relief valves	Parker	XRD101S16S16-6T	
Hydraulic motor	Char-Lynn	Series M, 128-0132	
Filter	Donaldson	HPK03	

PNEUMATICS

Device	Manufacturer	Model	Schematic#
Shift cylinder (two)	PHD	AV2R	SEE-46
Clutch cylinder	SMC	NCQ7A250-300D	SEE-46
Proportional air valve (two)	SMC	NVEP3121-2-03	SEE-46
Solenoid air valve (eight)	SMC	NVS3135-0352D	SEE-46
Air filter	SMC	NAF400-N03B2	SEE-46
Equipment box	Hoffman		

CAMERAS

Device	Manufacturer	Model	Schematic#
TV cameras (two)	Vicon	VC2700-24	SEE-4
Zoom lenses (two)	Vicon	V8.5-51AC	SEE-4
Camera housings (two)	Vicon	VH8400H-17-HT	SEE-4
Pan/tilts (two)	Vicon	V330APT-P	SEE-5
Dipper camera	ELMO	MN-401E	SEE-41
Video radio (two Tx, two Rx)	HDS	T181, R181	SEE-47

VEHICLE COMPUTER

Device	Manufacturer	Model	Schematic#
VME rack	Mupac	120BC41-CA20/CL09	SEE-23
Fans	Schroff	10703-141	SEE-8
Computer board	Force	CPU-40	SEE-47
Analog to digital (two)	Datel	613	SEE-47
Resolver decoder (two)	VMIC	VMIVME-4942	SEE-47
Digital to analog (three)	Datel	624	SEE-47
Relay card	VMIC	VMIVME-2232	SEE-47
Tilt sensors	Sperry	Accustar	SEE-51
Power supply	Vicor	VI-ST3	SEE-8
Data radio	Telesystems	Arlan 620	
AC inverter	Avionic Instruction	2A350-1-1B1	SEE-8
Cabinet	Zero	955D21P12J2A21VB	
Solid state air condition (two)	TECA	AHP-1200X	SEE-8
Safety radio	Electronic Systems Technology	ESTEEM 96F	SEE-39
Safety computer	Blue Earth	Micro 440E	SEE-39
Resolvers (seven)	Clifton Precision	JSSB-15-J-05K	SEE-16
Resolver housings (seven)	(custom)		SEE-16,19
Video fiber optic (Tx) (four)	Optelecom	3253T	
Ethernet fiber optic	Cabletron	FOT-F14	
Alternator	C.E. Niehoff	A1-103	SEE-8
Batteries (two)	Yuasa	NP65-12	SEE-8

BASE STATION

Device	Manufacturer	Model	Schematic#
Cabinet	Zero	915S8P12J2A2B	
VME rack	Mupac	105BC41-LC05-LW05	
Workstation CPU	Themis	SPARC 2SE-16	SEE-47
Communication CPU	Force	CPU-40	SEE-47
Memory board	Matrix	MD-RAM	
Analog to digital	Pentland	MPV906	SEE-47
Power supply	Vicor	VI-ST3	
Disk drive	Micropolis	2210	
Computer LCD display	Sharp	LQ10DH11	
Video LCD display (two)	Sharp	LQ9RA03	
Video NTSC to RGB	Inline	IN1540	
Fiber optic cable	Optical Cable	B06-080C-W3SB/1UC/900	
Video fiber optic (Rx) (four)	Optelecom	3253R	
Ethernet fiber optic	Cabletron	COFOT-F1	
Ethernet data radio	Telesystems	Arlan 620	
Control levers	CH Products	Model 300 SJ	SEE-6

Appendix F

Schematics

INTERNAL DISTRIBUTION

1. G. A. Armstrong
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4. R. E. Barry
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6. B. E. Bernacki
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163. Clinton Bastin, Manager, LMR Reprocessing Projects, Division of Fuels and Reprocessing, Office of Facilities, Fuel Cycle, and Test Programs, NE-471, Department of Energy, Washington, DC 20545.

164. D. W. Bennett, Pacific Northwest Laboratories, P.O. Box 999, Richland, WA 99352.

165. M. S. Evans, Pacific Northwest Laboratories, P.O. Box 999, Richland, WA 99352.

166-216 P. Gibbons, Westinghouse Hanford Company, 2355 Stevens Drive, Building MO-414, Richland, WA 99352

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235. Office of Assistant Manager for Energy Research and Development, DOE Oak Ridge Field Office, P.O. Box 2008, Oak Ridge, TN 37831-6269

236-237. Office of Scientific and Technical Information, DOE Oak Ridge Field Office, P.O. Box 62, Oak Ridge, TN 37831.