1 of 2

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Digface Characterization Test Plan (Remote Testing)

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ABSTRACT

The objective of the Digface Characterization (DFC) Remote Testing project is to remotely deploy a sensor head (Mini-Lab) across a digface to determine if it can characterize the contents below the surface. The purpose of this project is to provide a robotics technology that allows removal of workers from hazards, increases speed of operations, and reduces life cycle costs compared to alternate methods and technologies. The Buried Waste Integrated Demonstration (BWID) is funding the demonstration, testing, and evaluation of DFC.

This document describes the test plan for the DFC remote deployment demonstration for the BWID. The purposes of the test plan are to establish test parameters so that the demonstration results are deemed useful and usable and perform the demonstration in a safe manner and within all regulatory requirements.

ACKNOWLEDGEMENT

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CONTENTS

ABSTRACT	iii
ACKNOWLEDGEMENT	v
ACRONYMS	xi
1. INTRODUCTION	1
1.1 DFC Technology Description and Background	1
1.2 Scope of Tests	4
1.3 Purpose and Objectives of Test	4
1.4 Technology Agreement	6
2. ORGANIZATION AND RESPONSIBILITIES	7
2.1 Organizational Responsibilities	7
2.2 Description of Organizations	7
2.2.1 Robotics Program	7
2.2.2 Buried Waste Integrated Demonstration Program	7
2.3 Personnel Support	7
2.4 Testing Responsibilities	8
2.5 Qualifications and Training Required	9
3. DESCRIPTION OF TESTS	10
3.1 System Tests	10
3.2 Uncertainty Analyses	11
3.3 Contingency Plan	12
4. SEQUENCE OF ACTIVITIES	13
5. SAMPLING AND DATA	14
6. DOCUMENT CONTROL	15

6.1 Data Management	15
6.1.1 BWID Requirements	15
6.1.2 Project File	15
6.1.3 Description of Data	16
6.1.4 Video Production	16
6.1.5 Data Reporting	16
6.2 Test Plan Changes	16
6.3 Other Documents	17
7. ANALYTICAL METHODS	18
8. DATA REDUCTION, VALIDATION, AND VERIFICATION	19
8.1 Data Reduction	19
8.2 Data Validation/Verification	19
9. QUALITY ASSURANCE	20
9.1 Data Quality Objectives	20
9.2 Test Objectives	20
9.3 Internal Quality Control Checks	22
9.4 Performance and System Audits	22
9.5 Corrective Action	23
10. EQUIPMENT AND INSTRUMENTS	24
11. SUPPLIES AND UTILITIES	25
12. HEALTH AND SAFETY	26
12.1 Hazard Analysis	26
12.2 Employee Training	26
12.3 Protective Equipment	26
12.4 Emergency Response Plan	26
13. RESIDUALS MANAGEMENT	28

14. REGULATORY REQUIREMENTS	29
14.1 National Environmental Policy Act	29
15. REFERENCES	30
Appendix A—Information on Mini-Lab	A-1
Appendix B—Engineering Test Sequences	B-1
Appendix C—Instrumentation Data Sheets	C-1

FIGURES

1. The gantry crane, with a Schilling arm, will be used to deploy the DFC sensors	4
2. Diagram showing the soil box for the robotics gantry crane demonstration	6
3. Sequence of testing activities	16

ACRONYMS

BWID	Buried Waste Integration Demonstration
BWRP	Buried Waste Robotics Program
LFC	Digface Characterization
DOE	U. S. Department of Energy
DQO	Data quality objectives
INEL	Idaho National Engineering Laboratory
IRC	Idaho Research Center
NBRC	North Boulevard Robotics Center
NEPA	National Environmental Policy Act
PM	Project manager
QA	Quality Assurance
SNL	Sandia National Laboratories

Digface Characterization Test Plan (Remote Testing)

1. INTRODUCTION

Characterization provides information that is necessary to determine which remedial action is best suited for a particular waste site. Characterization of all U. S. Department of Energy (DOE) sites with buried hazardous and/or radioactive waste is necessary to provide information to aid in the cleanup and restoration of the environment at these sites. Digface Characterization (DFC) provides several essential advantages over current manual characterization:

- It improves safety by removing workers from potentially hazardous waste sites (before and during removal of soil overburden).
- It decreases time for characterization by allowing for the simultaneous use of multiple sensors rather than one sensor at a time.
- It decreases costs by supporting rapid characterization of waste sites with multiple sensors
- It increases the locational precision and accuracy of where the contents are beneath the soil.

This section provides an introduction to the test plan. Section 1.1 discusses the technology and provides background information. Section 1.2 addresses the scope of the test. Section 1.3 gives the purpose of the test and the test objectives. Section 1.4 identifies the technology agreement with Buried Waste Integrated Demonstration (BWID).

1.1 DFC Technology Description and Background

The DFC prototypical deployment system consists of an array of remotely controlled geophysical, radiological, and chemical sensors packaged in a sensor head; a gantry crane with a Schilling arm for deployment of the sensor package; Mini-Lab for data acquisition, storage, reduction, and display; and a control station. Sensors being deployed by the crane include (a) a metal detector, (b) magnetometers, (c) a chemical detector, and (d) a gamma radiation detector. The sensor head was developed to be a platform for deploying a variety of sensors that may be interchanged for specific applications.

The gantry crane is a 3-ton unit that includes three axes of motion. The first axis (referred to as the x-axis) provides approximately 30 ft of linear travel distance. The second axis (referred to as the y-axis) is the trolley, exhibiting approximately 9-ft of movement. The third axis of motion (referred to as the z-axis) is the mast assembly, which has approximately 40 in. of vertical motion.

The gantry system is an industry available unit that has been modified to allow for remote operations. The mast assembly was designed and fabricated at the INEL, then interfaced with the crane at the crane manufacturer's facility. The crane has variable speed capability in each of the three-axes of motion. The x- and y-axes are designed for speeds of 0 to 30 ft/minute. The z-axis has

capability of 0 to 80 in./minute. Each axis is provided with closed loop position feedback by the implementation of incremental encoders.

Mounted to the mast assembly is a six axes hydraulic servo-controlled manipulator system. The manipulator system provides for the deployment of end effectors (tools) of various configurations and uses. Examples of some of these tools are a plasma arc cutting torch, mechanical cutting equipment (saws), and sensor packages (for hazardous material characterization). Each of the six axes on the manipulator also includes closed loop position feedback. Mounted in the manipulator wrist is a six axis force/torque sensor that provides for controlling the amount of force that the arm may apply. The force levels are adjustable at the operator station between 0 and 750 lb.

Closed circuit television cameras are mounted around the room to provide real-time viewing for operations personnel during system operations. The camera pan/tilt units are controlled by the system to automatically follow the movements of the manipulator end effector.

The gantry, manipulator, and camera pan/tilt units are controlled by a 16-axis controller that interfaces the system with the operations person(s) and provides supervisory control to the system. The controller also includes real-time simulation graphics capability, which allows the operator to visualize operations through the simulation. Operations may be performed in any of three modes. Modes 1 and 2 will be used most frequently for the unstructured environments that are anticipated. The three modes are

1. *Teleoperated*—The operator, using available control interfaces (joy sticks, a computer mouse, spaceball, and Schilling master control device), manually operates the system.
2. *Telerobotic*—The operator teaches paths to the system via the previously mentioned interfaces, manipulates and combines paths, stores them to file, and replays them as needed.
3. *Robotics*—The operator programs (using C or another appropriate computer language) the controller and replays the program as needed.

The system is supported by a sophisticated simulation graphics workstation. The workstation, built by Silicon Graphics, Inc., provides the capability of system simulation modeling. Motions performed within each operating mode can be seen as they happen on 3-D simulations of the work cell. A drawback to the simulation is that the system does not automatically update changes to the workcell. Currently, these require manual updating of the models. Automatic updating is being investigated.

The system is controlled and data are collected at a control station, which is housed in a room adjacent to the crane in the North Boulevard Robotics Center (NBRC). The system is shown in Figure 1.

Sandia National Laboratories (SNL) has developed a miniaturized in situ characterization laboratory, called Mini-Lab. Mini-Lab consists of a flexible software and hardware architecture for the acquisition, display, interpretation, and archival of sensor data.

Figure 1. The gantry crane, with a Schilling arm, will be used to deploy the DFC sensors. The crane system is located at the NBRC.

Mini-Lab consists of three main parts: (1) remote sensor package, (2) data acquisition and interface electronics, and (3) computer base station. The computer base station (SUN Microsystems Sparc 10 workstation) is attached to an Ethernet that ties the robotic controller. This communications interface allows the system components to exchange data and system commands with each other. Because of this interface, Mini-Lab can tell the robot controller what to do. Mini-Lab also positions and time-stamps data. Appendix A provides more information on Mini-Lab.

1.2 Scope of Tests

DFC is being developed to provide remote characterization of waste forms during remediation of a buried waste site. A DFC prototypical deployment system will be demonstrated, tested, and evaluated for the BWID Program at the NBRC, located at the Idaho National Engineering Laboratory (INEL). This test plan addresses testing of the gantry crane and Schilling arm (prototypical deployment system), Mini-Lab, as well as the deployment of the sensor package using the crane. The *Test Plan for Digface Characterization Performance Testing*¹ covers testing of the sensor package without the use of the crane.

A nonmetallic box has been developed that will contain soil and simulated buried waste configurations that may be encountered during characterization/remediation efforts on buried waste at various DOE sites. This box has been designed to fit beneath the gantry crane. Its function will be to house various physical, chemical, and radiological targets for the demonstrations. During the tests, the sensors that are being deployed by the gantry system will be passed over the waste box at a variety of speeds and at varying heights from the targets. From the data collected during these passes, the effectiveness of the delivery process, sensing elements, and data acquisition and data reduction systems will be determined. A pictorial of the soil box is shown in Figure 2.

1.3 Purpose and Objectives of Test

The purpose of this project is to demonstrate remote delivery of multiple geophysical sensors to a buried waste site, obtain data, and display data at the control station. The overall product will include test data on the control system, data display package (Mini-Lab), crane, and sensor deployment capabilities of the crane. The sensor package is being tested separately in a field test environment under *Test Plan for Digface Characterization Performance Testing*¹.

The DFC gantry system is (for these tests) comprised of the three-axis gantry, Schilling manipulator, camera pan/tilt units, system controller, and Mini-Lab. The test objectives are

- *Demonstrate and measure the accuracy of instrument placement by the DFC gantry system*—The overall system will be tested to determine the degree of positional accuracy obtainable using this deployment system. These tests will include the placement of sensors by the gantry, manipulator, and combined placement by both devices. Tests will be repeated several times for statistical purposes.
- *Determine the time required to perform a digface survey*—The system will be subjected to testing that will determine the amount of time required to setup and run an operation and

Figure 2. Diagram showing the soil box for the robotics gantry crane.

the required personnel and equipment that are needed to perform the operation. The effectiveness of data collection and interpretation utilizing these methods will be addressed.

- *Demonstrate and measure the ability to detect and locate radioactive and hazardous chemical hot spots*—This test will deploy a gamma and gas specific sensors over the digface to locate materials that have been strategically located within the waste box. The tests will be run at varying speeds and distances from the digface to generate optimum data. The tests will be repeated several times for statistical purposes. Both of these sensors are mounted in the sensor head that is a part of Mini-Lab.
- *Demonstrate and measure the ability to detect and locate metal objects buried in the digface*—A 5-gal can will be placed in the soil box for use with the metal detector and magnetometer. Soil will be removed between tests to obtain a data base of sensing strength versus soil depth. The tests will be run at varying speeds and distances from the digface to generate optimum data. The tests will be repeated several times for statistical purposes. Both of these sensors are mounted in the sensor head that is a part of Mini-Lab.
- *Demonstrate the capability and measure the accuracy of the automatic camera tracking system*—This test will investigate how well the camera pan/tilt units (which are servo-controlled by the system controller) will follow the end effector of the Schilling manipulator as it is moved around within the work space.
- *Assess and measure system availability*—A log of system operations will be maintained. System/component failures will be logged, and the cost and time required to repair these faults will be recorded. From the data collected, a figure for system availability will be stated.
- *Determine and measure the terrain following capabilities of the Schilling arm with Mini-Lab sensors attached*—To obtain data that are representative of the environment, the system will deploy the sensor package over the terrain in the soil box at specified standoff distances. This will be accomplished by the installation of ultrasonic sensors to the Mini-Lab sensor head. The ultrasonic sensor head is coupled with the Schilling controller and provides for terrain following at constant distances above the terrain.
- *Evaluate the control system to determine needed human factor improvements*—This test will provide qualitative feedback from operations personnel relative to the "user friendliness" of the system. This test is found in Appendix B.

1.4 Technology Agreement

DFC is being developed through the BWID Program and the Buried Waste Robotics Program (BWRP). The BWID Program and BWRPs are funding the demonstration, testing, and evaluation of DFC remote deployment under Technical Task Plans #ID-1320-03 and AL-2132-02.

2. ORGANIZATION AND RESPONSIBILITIES

2.1 Organizational Responsibilities

The DFC project manager (PM) has overall responsibilities for the project. Engineering, Geosciences, and other required support personnel receive direction from the project manager through approved work packages.

2.2 Description of Organizations

The DFC project is funded primarily by the BWID Program. The program is supported by the Robotics Technology Development Program and EG&G Idaho, Inc. Geosciences personnel. A description of the BWID Program and support groups is provided below.

2.2.1 Robotics Program

Participants from both the INEL and SNL provide support for digface characterization. SNL is the lead laboratory for developing and providing the Mini-Lab, and the INEL is the lead laboratory for upgrading the crane and performing the demonstration.

2.2.2 Buried Waste Integrated Demonstration Program

The mission of the BWID Program is to demonstrate and evaluate technologies that are potentially faster, better, cheaper, and/or safer for restoring buried waste sites. BWID provided funding for this demonstration, test, and evaluation to show the capabilities of a remotely controlled system to safely characterize buried wastes.

BWID is supported by various functional organizations within EG&G Idaho, Inc. In particular, Geosciences personnel support the BWID DFC project in specifying and testing of the sensor head package.¹ In addition, Geosciences is supporting the testing of the sensors using the gantry crane and Schilling arm. Data reduction and interpretation of data will be provided by Geosciences personnel.

2.3 Personnel Support

This section covers personnel support for the tests at the NBRC. At the INEL, a BWID DFC PM will have the overall responsibility in decision making during the demonstration. If a safety concern arises, the DFC PM and safety engineer will decide how to solve the problem or terminate testing. If the DFC tests at the INEL take longer than planned, the PM will have the authority to delay or defer testing as necessary to balance overall project objectives.

Equipment operators will be supplied by the INEL BWRP. Their main responsibilities will be to operate the equipment from the control station and monitor the data displays.

The Idaho Research Center (IRC) emergency response team will be responsible for responding to any emergencies related or unrelated to the DFC tests at the NBRC. The INEL DFC Robotics demonstration PM will be responsible for ensuring that all of the appropriate tests are conducted in

accordance with the procedures identified in this test plan. The PM will also coordinate activities to ensure that data logbooks are completed and stored properly, test changes, and photography and video production. The INEL DFC PM will coordinate any activities associated with maintenance of the gantry crane, Schilling arm, and control station.

The SNL Robotics PM will coordinate any activities associated with maintenance of Mini-Lab. The SNL Robotics PM will also be responsible for evaluating the data received during start-up of the DFC testing to verify that no obvious problems in the system have been incurred during set-up.

The main personnel supporting this task are listed below.

George Schneider	DOE-ID	DOE ID DFC PM
Aran Armstrong	DOE-ID	BWID Oversight
Kevin Kostelnik	INEL	BWID Integrated Demonstration Coordinator
Richard Callow	INEL	BWID DFC PM
Reva Hyde	INEL	Robotics PM
Kevin Croft	INEL	DFC Robotics Demonstration PM
Scott Allen	INEL	Robotics support
Nick Josten	INEL	Geosciences support
John Feddema	SNL	Robotics PM
Peter Boissiere	SNL	Robotics support

2.4 Testing Responsibilities

The responsibilities of the personnel involved in the testing of DFC are listed below.

- SNL test responsibilities—The manager at SNL is responsible for the following test:
 - Installation of Mini-Lab in accordance with the objectives specified in Section 1.3 in the NBRC environment.
- INEL test responsibilities—The program responsibilities are
 - Determine the precision and accuracy in locating waste
 - Assess the ability to detect and locate radioactive and hazardous chemical hot spots
 - Assess the response time and cost to characterize the simulated waste (time per area and cost per area)
 - Assess system availability
 - Determine the terrain following capabilities of the system
 - Evaluate the control system
 - Evaluate the camera system

- Evaluate the gantry crane
- Evaluate the Schilling arm
- Coordinate audits
- Media interfaces (through BWID)

The Geosciences responsibilities are

- Evaluate the sensors
- Evaluate the data and results
- Evaluate Mini-Lab.
- Data interpretation and evaluation—Interpretation and evaluation of the data taken during testing will be the responsibility of the personnel most familiar with the equipment, as listed below. Data interpretation will be explained and discussed in the Technology Evaluation Report.
 - Sensors (Geosciences)
 - Mini-Lab (SNL)
 - Gantry crane (Robotics Program)
 - Schilling arm (Robotics Program).

2.5 Qualifications and Training Required

All personnel operating equipment will be properly trained. This includes Incidental Crane Operating Training (Hoisting/Rigging) and control system vendor training.

Persons handling radioactive and/or chemical sources shall be properly trained and certified for that function.

3. DESCRIPTION OF TESTS

Tests on the DFC prototypical deployment system will be performed at the NBRC. The testing will focus on seven separate efforts. These efforts will be to test the geophysical sensors, determine gantry speed capability, determine gantry repeatability, investigate manipulator speed capability and repeatability, and evaluate the Mini-Lab. The tests are designed to run independently of other testing, and therefore, no specific order is required. Tests will be repeated as necessary to acquire meaningful data. General descriptions of each test are given below; test procedures are included in Appendix B. Test results will be provided in a technology evaluation report.

3.1 System Tests

All testing of the DFC prototypical deployment system will support system test objectives. Test procedures are included in Appendix B. The DFC gantry tests, including data reduction and conclusions, shall address the system test objectives as listed below:

- Determine the precision and accuracy of instrument placement by the DFC gantry system

This test will determine the ability of the robotics system to effectively deploy the Mini-Lab sensor package and acquire data that are sufficient to determine waste location. Target materials will be strategically placed in the soil box to support the testing. A 5-gal container will be placed inside for use with the metal detector and magnetometer. Soil will be removed between tests to obtain a data base of sensing strength versus soil depth. A volatile organic compound [nonhazardous and National Environmental Policy Act (NEPA) approved] will be strategically placed into the waste box to be used with the specific gas sensor, and a gamma source will be strategically located in the waste box to be used with the gamma sensor.

- Assess the ability to detect and locate radioactive and hazardous chemical hot spots

The system's ability to detect and locate any radioactive and/or hazardous chemical hot spots will be determined by putting retrievable chemical and radioactive sources down the tubes located in the box containing the simulated buried waste. The DFC prototypical deployment system would then survey the box containing the simulated waste. The system's performance in meeting this objective depends on the chemical sensor, radiation detector, gantry crane, Schilling arm, data communications, and control system.

- Assess the response time to characterize the simulated waste

To assess the time to characterize the simulated waste, an average time to survey the specified area will be calculated from multiple surveys. The speed the crane travels will be documented. To assess the cost to characterize an area of this size, several items will be considered, including but not limited to operating costs, maintenance costs, capital costs, and remedial action costs.

- Assess the system availability

The most important result of this test is to provide useful information so that this system can be evaluated for use as a part of a remedial alternative. The input to Environmental Restoration will be the Technology Evaluation Report. Environmental Restoration will also have access to BWID's data base that will house all project information. Section 6.1.1 discusses what information will be inserted into the BWID data base. This project is in its infancy and is planned for continued funding and development improvements in subsequent fiscal years. Therefore, the Technology Evaluation Report will document the status of digface characterization as of this fiscal year, give results for the current system, and provide suggestions for improvements.

- Determine the terrain following capabilities of the system

The ability of the control system to deploy the manipulator over the digface and using the ultrasonic sensors to provide for constant distance following of the terrain will be the focus of this test.

- Evaluate the control system to determine needed human factor improvements

This will be a cursory evaluation to examine the "friendliness" of the system operating interfaces. This procedure is outlined in Appendix B.

- Adequacy of the automatic tracking capability

This test will investigate how well the camera pan/tilt units will follow the end effector of the Schilling arm as it is moved around within the workspace.

- Evaluate the ability to detect and locate metal objects buried in the digface

A 5-gal can will be placed in the soil box for use with the metal detector and magnetometer. Soil will be removed between tests to obtain a data base of sensing strength versus soil depth. The tests will be run at varying speeds and distances from the digface to generate optimum data. The tests will be repeated several times for statistical purposes. Both of these sensors are mounted in the sensor head that is part of Mini-Lab.

3.2 Uncertainty Analyses

Uncertainty analyses will be performed for measurements and tests relating to the DFC prototypical deployment system tests requested by BWID. Results will be documented in the Technology Evaluation Report.

Two quantitative performance characteristics of a measurement system are precision and accuracy, and these both will be determined, either experimentally or by engineering judgment. They will be given for systems that affect any of the system test objectives discussed in Section 3.1. Precision and accuracy parameters will be developed for the system.

The precision and accuracy of the measurement system will be estimated from test measurements, and both a best estimate and a 95% confidence interval will be given for precision and accuracy. In the event that a particular test is invalid for some reason or the data are lost, best engineering judgement will be used to determine precision and accuracy of the system. This will be documented in the final report.

3.3 Contingency Plan

Tests will be discontinued in the event of adverse conditions that seriously affect testing (e.g., spills and fires), an equipment failure or an accident or emergency at the testing site. The INEL DFC Robotics Demonstration PM and the BWID DFC PM will evaluate the situation to determine the most appropriate method to meet the test objectives. In the event that testing deviates from this test plan, the test procedures will be "red-lined" in the field and initialled by the INEL DFC Robotics Demonstration PM and the BWID DFC PM and copies of these altered procedures will be provided to BWID within 2 weeks and will become a lifetime quality record.

4. SEQUENCE OF ACTIVITIES

The sequence of activities for the remote testing portion of the DFC experiments is not critical. Each test is designed to run independently of all other tests. The chart shown in Figure 3 lists all the test to be performed.

Figure 3. Testing activities.

5. SAMPLING AND DATA

The data obtained from operation of the Mini-Lab system will be collected into a data base, archived on tape, and copied for long-term storage for BWID. The data will be scrutinized by professional personnel who are familiar with the instruments and data acquisition equipment, qualified to interpret data of this nature. In addition, the Mini-Lab system provides the capability of providing output in forms that have already undergone a certain degree of data reduction and interpretation. Sampling and data acquisition will be as defined in the testing procedures found in Appendix B.

The gantry system is an industry available unit that has been modified to allow for remote operations. The mast assembly was designed and fabricated at the INEL, then interfaced with the crane at the crane manufacturer's facility. The crane has variable speed capability in each of the three-axes of motion. The x- and y-axes are designed for speeds of 0 to 30 ft/minute. The z-axis has

6. DOCUMENT CONTROL

EG&G Idaho procedures for document control will be followed for this project.

6.1 Data Management

6.1.1 BWID Requirements

Data will be managed in the manner that best protects the credibility of the data and is in compliance with the BWID Project Management Plan. In addition, the project shall comply to the following BWID data management policy:

1. Management of electronic data

- a. The project shall define the format, acquire the data, back up the data, control the configuration of the data, technically document the data, generate processed data, and archive the data.
- b. The project shall submit to BWID a copy of all configuration controlled data (raw and processed) and appropriate technical documentation acquired during the course of the demonstration testing. Project shall submit complete copies of final configuration controlled raw and processed data with appropriate technical documentation to BWID with the final report.

2. Management of reports

- a. The project shall draft reports, obtain and incorporate review comments, obtain approvals, archive, and control the configuration of data via a project Technology Demonstration File.
- b. Copies of all draft reports shall be submitted to BWID. Copies of all final reports shall be submitted to BWID with an electronic copy.

3. Management of logbooks

- a. Data shall be recorded in logbooks in accordance with EG&G Idaho guidelines.
- b. All logbook entries shall be photocopied at the end of each week of the demonstration, with copies delivered to BWID.

6.1.2 Project File

The project shall establish a project file that complies with all the requirements of the BWID program. The project file shall be a repository of all hard copy data (e.g., letters, reports, and engineering analysis) and electronic copy, original, and backup (e.g., data and processing software) information. The file shall have an index to configuration control file contents and facilitate locating

items in the file. Originals shall not be released but dated copies will be available to anyone. At the end of the testing, all data records from the project file will be scanned into the BWID data base.

6.1.3 Description of Data

Data contained in the project file will include the Technical Task Plan, authorized work packages, any change control document requests, and other administrative documentation. In addition, the project file will contain engineering drawing, analysis, and technical communication information. Vendor information that applies to the project will be contained in the file.

6.1.4 Video Production

A video will be taken of the DFC demonstration at the NBRC. The purpose of the video is to document the demonstration as well as serve as a means of communicating information on the robotics tests to the media and public.

6.1.5 Data Reporting

To ensure that the demonstration results are reported to interested parties, the following two methods of data reporting will be used.

1. Technology Evaluation Report—The data generated by the demonstration as well as information on the planning and conductance of tests will be assembled and documented in a Technology Evaluation Report. The Technology Evaluation Report will summarize the tests, test results, and lessons learned and will provide recommendations for further development.
2. Publications—Information on the demonstrations and results will be submitted for publication to the Waste Management '94 Conference and other waste management or environmental restoration related journals, conferences, and meetings.

6.2 Test Plan Changes

Change requests to this plan may be initiated by any person participating in demonstration, test, and evaluation activities but must be approved by the DFC Robotics Demonstration PM. There will be two levels of changes as follows.

Level one changes are modifications to the configuration of this plan that will nullify previously performed verification and validation efforts. Simply stated, such a change would raise uncertainty about whether or not the same test results would be achieved if the test were repeated. Level one change requests must be clearly documented. The documentation must specify the reasons for the change, current condition, proposed condition following the change, explanation of the increased benefits versus increased costs, and secondary changes that will be necessary as a result of the primary change. Level one change requests will be reviewed and approved by the DFC Robotics Demonstration PM. The reviews and approvals will be clearly documented. Level one changes will require revalidation of the system for testing. Implementation of level one changes and revalidation of the system for testing will be under the direction of the DFC Robotics Demonstration PM.

Level two changes are those changes to the configuration of this plan that will *not* nullify the verification and validation achieved during testing. Simply stated, such a change would *not* raise uncertainty about whether or not the same test results would be achieved if the test were repeated. Level two changes shall be clearly documented in the daily logbook and reviewed, approved, and implemented according to the appropriate operating procedures and test plan. Level two changes will not require revalidation of the system before the continuation of testing.

In the event that testing deviates from this test plan, the test procedures will be "red-lined" in the field and initialled by the INEL DFC Robotics Demonstration PM, and copies of these altered procedures will be provided to BWID within 2 weeks and will become a lifetime quality record.

6.3 Other Documents

Logbooks will be controlled in accordance with EG&G Idaho procedures. All logbook entries shall be photocopied at the end of each week of the demonstration and copies delivered to BWID.

7. ANALYTICAL METHODS

Data reduction algorithms are described in detail in the applicable Mini-Lab user's manual.

8. DATA REDUCTION, VALIDATION, AND VERIFICATION

8.1 Data Reduction

Mini-Lab displays analysis of sensor data within seconds of its acquisition. The system not only provides real-time display of in situ sensor data, but it also archives and recalls data from previous sensor scans. The real-time data interpretation provided by Mini-Lab will be compared with data from both the preprocessed data and the known location of the objects in the box containing simulated waste. This work will be accomplished by individuals qualified to perform this function.

8.2 Data Validation/Verification

Geosciences personnel will evaluate DFC test data real-time using their experience and knowledge to verify that the test and acquired data are credible. Test results or data that are not credible will be considered a test failure, and an engineering evaluation will be made to decide if the test will be repeated, modified, or the test failure simply documented and the next test started. Data will not be accepted if they were not taken in accordance with the established procedures.

9. QUALITY ASSURANCE

9.1 Data Quality Objectives

Data will be obtained with the best available instrumentation within the stated budget of the project. Instrumentation will be calibrated as necessary and operated within the stated calibration range for the instrument.

The data quality objectives (DQOs) include reviews by the DFC PM, project engineer, SNL personnel, and Geosciences personnel to verify that data are within required specifications. Tests will run to meet quality level B requirements, and will comply to the requirements of Quality Program Plan, QPP-377.

The following discussion of the detailed DQO includes a restatement of the test objective, the DQO for that test objective, and a statement of the uncertainty for the measurements to be taken to meet the DQO with a short discussion of how each uncertainty specification was developed.

The tests will be divided into two categories: (1) system test objectives and (2) component test objectives. The overall product will include test data on the control system, data display package (Mini-Lab), crane, and sensor deployment capabilities of the crane. The sensor package is being tested separately, in a field test environment, under *Test Plan for Digface Characterization Performance Testing*.¹

9.2 Test Objectives

The DFC gantry system, is (for these tests) comprised of the three-axis gantry, Schilling Titan 7F manipulator, camera pan/tilt units, system controller, and Mini-Lab. The system tests will have the following system test objectives:

- Test Objective—*Demonstrate and measure the accuracy of instrument placement by the DFC gantry system.* The overall system will be tested to determine the degree of positional accuracy obtainable using this deployment system. These tests will include the placement of sensors by the gantry, manipulator, and combined placement by both devices. Tests will be repeated several times for statistical purposes.

Data Quality Objective—*Determine with a 95% confidence that the system is repeatable within +/- 1 in.*

Uncertainty— *+/- 1/4 in.* The uncertainty is derived from the calibration of the measurement instruments and the methods use for reading those instruments.

- Test Objective—*Determine the time to perform a digface survey.* The system will be subjected to testing that will determine the amount of time required to setup and run an operation and the required personnel and equipment that are needed to perform the operation. The effectiveness of data collection and interpretation utilizing these methods will be addressed.

Data Quality Objective—*Determine with a 95% confidence the time to survey a given amount of surface area.*

Uncertainty— ± 30 seconds. This uncertainty is derived using engineering judgment.

- Test Objective—*Demonstrate and measure the ability to detect and locate metal objects buried in the simulated digface.* This test will determine the sensor package's ability to locate buried metal objects in the digface. A 5-gal can will be placed inside the digface for use with the metal detector and magnetometer.

Data Quality Objective—*Determine with a 95% confidence the location of buried metal objects within ± 6 in.*

Uncertainty— ± 1 in. This uncertainty is derived from the accuracy of the instrumentation, their calibration, and the positioning equipment.

- Test Objective—*Demonstrate and measure the ability to detect and locate radioactive and hazardous chemical hot spots.* This test will deploy gamma and gas specific sensors over the digface to locate materials that have been strategically located within the waste box. The tests will be run at varying speeds and distances from the digface to generate optimum data. The tests will be repeated several times for statistical purposes. Both of these sensors are mounted in the sensor head that is a part of Mini-Lab.

Data Quality Objective—*Determine with a 95% confidence the location of buried materials, chemical and radioactive hot spots within ± 6 in.*

Uncertainty— ± 1 in. This uncertainty is derived from the accuracy of the instrumentation, their calibration, and the positioning equipment.

- Test Objective—*Demonstrate the capability and measure the accuracy of the automatic camera tracking system.* This test will investigate how well the camera pan/tilt units (which are servo-controlled by the system controller) will follow the end effector of the Schilling manipulator as it is moved around within the work space.

Data Quality Objective—*Determine with a 95% confidence the accuracy of the automatic camera tracking system to follow the end effector of the Schilling arm.* Success will be to keep the end effector in the center of the monitor picture ± 3 in. (1/4 of the monitor's screen width).

Uncertainty— ± 1 in. This uncertainty is derived from engineering judgment.

- Test Objective—*Assess and measure system availability.* A log of system operations will be maintained. System/component failures will be logged, and the cost and time required to repair these faults will be recorded. From the data collected, a figure for system availability will be stated.

Data Quality Objective—*Determine with a 95% confidence that the system availability is 99%.*

Uncertainty— $\pm 50\%$ This uncertainty is derived from engineering judgment. The uncertainty is extremely high due the short duration of the test time and that only one system will be tested. One system is not a representative sample, and life testing would require months of continuous operation.

- **Test Objective—***Determine terrain following capabilities of the Shilling arm with Mini-Lab sensors attached.* To obtain data that are representative of the environment, the system will deploy the sensor package over the terrain in the soil box at specified standoff distances. This will be accomplished by installing ultrasonic sensors to the Mini-Lab sensor head. The ultrasonic sensor head is coupled with the Schilling controller and provides for terrain following at specified distances off of the terrain.

Data Quality Objective—*Determine with a 95% confidence that the sensor head can be controlled to maintain a constant height ± 1 in. above the terrain during a survey.*

Uncertainty— ± 1 in. This uncertainty is derived from engineering judgment and the error involved in taking measurements.

- **Test Objective—***Evaluate the control system to determine needed human factor improvements.* This test will provide qualitative feedback from operations personnel relative to the "user friendliness" of the system. This test is found in Appendix B.

Data Quality Objective—No confidence level will be provided. The data taken will be of a subjective nature. However, the ease of operation of the system will be evaluated and reported on.

Uncertainty—Not applicable.

9.3 Internal Quality Control Checks

Internal quality control checks will be performed during and after testing. These include the INEL DFC Robotics Demonstration PM responsible for the tests reviewing completeness and accuracy of the logbooks, executing performance and system audits (see Section 9.4), and checking to ensure that the established procedures are being followed.

9.4 Performance and System Audits

Performance audits are conducted to quantitatively evaluate the output of a measurement system. System audits are conducted to qualitatively evaluate the operational details of a quality assurance (QA) program. These audits will be conducted internally.

A performance audit will be conducted by a QA engineer at the time of the demonstration at the NBRC. This audit will involve developing a checklist of critical operations and determining whether the operation was completed satisfactorily. Section 9.5 discusses corrective action.

A system audit to verify that the instrument(s) are operating within expected parameters will be done before and after the NBRC demonstration by the respective operations personnel. This information will be documented in logbooks. In addition, a post system audit will be performed to determine how well the data correlates to known data for the simulated waste box.

9.5 Corrective Action

If it is determined that the data being taken will not meet the test objectives because of an equipment malfunction or other reasons, the criteria to continue the demonstration will be based on the following:

1. If the BWID DFC PM and the INEL DFC Robotics Demonstration PM can establish and implement a corrective action using the existing procedure and without compromising the test objectives, or drastically affecting either cost or schedule, then they may implement the corrective action
2. If the corrective action determined by the DFC PM and INEL Robotics Demonstration PM does compromise the test objectives, changes the existing procedures, or drastically affects cost or schedule, then the DFC PM, Robotics Demonstration PM, and QA engineer must approve of the plan before implementation.

10. EQUIPMENT AND INSTRUMENTS

To the greatest extent possible, all instruments and equipment will be calibrated with approved calibration procedures. Before all tests, the responsible test engineer will ensure all equipment requiring calibration is within their calibration dates. Specific details (including range, accuracy, tolerance requirements, calibration procedures, a preventative maintenance schedule, and a list of critical spare parts) on all the test equipment and instrumentation is given in the manufacturer's data sheets found in Appendix C. All equipment will be locked up at night and on days it will not be required inside the NBRC.

11. SUPPLIES AND UTILITIES

This section addresses the supplies, utilities, and facilities that will be required to demonstrate DFC at the NBRC.

Utilities are conveniently available and will supply electricity for the control systems and data collection and transfer equipment. Fire extinguishers and the IRC emergency response team will also be available during the demonstration in case of fire or release of hazardous material (hydraulic fluid spill).

Office space, water, and lavatory facilities are provided in the NBRC.

12. HEALTH AND SAFETY

This section addresses the health and safety issues for the demonstration. All work performed at the NBRC must be reviewed and approved by the Facility Health and Safety Representative and documented in Safe Work Permits. All work will be performed in full compliance with all of the health and safety requirements for the BWID project as spelled out in the BWID Project Management Plan.

12.1 Hazard Analysis

The demonstration will be performed on clean, simulated waste. A chemical and radiation source will be used in the tubes in the simulated waste box under very controlled conditions. Safety is the highest priority for operations at DOE facilities, and risks to workers must be removed to the greatest extent possible. Providing operators with the ability to control the equipment at a safe distance from the waste is the most reliable method of protecting them from the hazards mentioned above. The remotely controlled crane, then, involves less risk than conventional manned equipment and is a safer method of hazardous/radioactive waste characterization. Since safety is increased by developing remote technologies, and the demonstration will involve only very limited risk, regulatory and public acceptance of DFC is expected.

The hazard classification determined for the DFC demonstration is "routinely accepted by the public."^a

12.2 Employee Training

All personnel operating equipment will be properly trained. This includes Incidental Crane Operating Training (Hoisting/Rigging) and control system vendor training. All personnel involved in the demonstrations (other than short-term visitors who must be escorted by a qualified person at all times) must have up-to-date blue card training before receiving access to the NBRC and crane area.

12.3 Protective Equipment

Specific protective equipment will be as specified in the testing procedures and in the Safe Work Permits. The INEL will provide hard hats and safety glasses, where needed (in the crane area). Safety shoes may be required for those entering the crane area but will not be available at the NBRC.

12.4 Emergency Response Plan

The tests will be conducted at the NBRC. The IRC emergency team will be alerted to the demonstrations and will be available in case of an accident. In the event of an emergency, the NBRC

a. R. Peatross, "Tentative Hazard Classification for Demonstration of Digface Characterization, June 1993.

Emergency Response Plan would be followed. In the event of a spill (such as hydraulic fluid), the NBRC spill plan will be followed.^b

b. Letter from Doug Ardry to Ron Hilker, "ERAD In-Town Facility Spill Control Plan," DEA-10-93.

13. RESIDUALS MANAGEMENT

This section addresses residuals management. For the NBRC demonstration of DFC, a radioactive source and a nonhazardous chemical (^{217}Cs and ethanol) will be used to demonstrate the radiation detector and chemical sensor on the sensor head. The radiation source is used for equipment calibration at the INEL and will be returned to storage after use. A radioactive source custodian will supply the source to the NBRC, accompany it at all times, and will be responsible for its return. The nonhazardous chemical used for the chemical sensor will be disposed of properly in a landfill after the demonstration.

The simulated waste box will be stored at the NBRC for future tests of this system as well as other systems.

14. REGULATORY REQUIREMENTS

This section addresses regulatory requirements for the DFC demonstration. Since the demonstration will be performed at on simulated waste and not on actual waste the only regulatory requirement that needs to be complied with is NEPA.

14.1 National Environmental Policy Act

The environmental impact from this demonstration will be minimal. Characterizing the simulated waste will result only in short-term noise. The crane and noise effects are negligible. The simulated waste in the test box is nonhazardous and nonradioactive and will not have a significant impact on the environment.

An environmental checklist was submitted to BWID for these activities. For these demonstrations, BWID prepared a categorical exclusion that has been approved by DOE Idaho Operations Office.

15. REFERENCES

1. N. Josten and L. Roybal, *Test Plan for Digface Characterization Performance Testing*, EG&G Idaho, Inc., EGG-WTD-10766, May 1993.

Appendix A

Information on Mini-Lab

Mini-Lab

Miniaturized
In Situ Characterization
Laboratory

SANDIA NATIONAL LABORATORIES
Intelligent Systems and Robotics Center

Mini-Lab

Sandia National Laboratories has developed a miniaturized in situ characterization laboratory, called Mini-Lab, for on-site analysis of hazardous materials. The focus of the Mini-Lab project is not to invent the sensors and transducers needed for characterization, but to develop a flexible software and hardware architecture for the acquisition, display, interpretation, and archival of sensor data. By creating a robust framework that can accept off-the-shelf and custom sensors, characterization systems can be more rapidly and cost-effectively deployed. An operator can quickly reconfigure the system to incorporate new or different types of sensors as the application requires.

The Need:

Mini-Lab provides a faster, safer, and cheaper way of characterizing hazardous sites than present field sampling. The sensor package can be positioned by a variety of means including robotic or tele-operated arms, mobile vehicles, or the package may be positioned over a conveyor belt with hazardous materials. This in situ method of characterization removes the operator from the hazardous environment. Applications in which Mini-Lab would be beneficial include:

- Remediation of underground storage tanks and hazardous waste landfills,
- Mapping, surveillance and reconnaissance in space and other dangerous environments,
- Waste segregation for decommissioned production facilities, and
- An emergency response tool for nuclear accidents.

As an example, present field sampling for underground rad-waste storage tanks are expensive, time-consuming, and hazardous to human health. Core sampling, a common technique used in the characterization of waste tanks, can take up to six months and can cost more than \$300,000 per sample. Additionally, there is a real risk to human health because of the large number of people exposed to the waste during the removal, transportation, analysis, and disposal of the samples. This conventional process also generates additional waste because the handling devices and instrumentation that come into contact with the samples also become contaminated and must be properly disposed of. In contrast, using Mini-Lab, operators are able to remotely analyze the waste by in-tank mapping without the risk to human health and without generating waste. Although this may not completely eliminate the need for core sampling, it could dramatically reduce the number of samples that would otherwise be required.

Mini-Lab's in situ measurements have the additional benefits of providing a much faster turnaround time than off-site lab analysis. The data can be analyzed as they are being acquired so that if additional data is required, real-time decisions can be made to repeat a sensor pass over a site or take additional readings.

The Architecture:

Mini-Lab consists of three main parts:

(1) the remote sensor package, (2) the data acquisition and interface electronics, and (3) the computer base station. These parts are described below:

(1) Mini-Lab's remote sensor package is a small, lightweight, low power module that can be positioned under robotic or tele-operated control. This module is made up of a decontaminable shell that houses the suite of chemical, radiological, and physical property sensors. The size of sensor package and type of sensors included depend on the site and application-specific needs. The design of the architecture was governed by the philosophy to make it as flexible as possible so that the users would have a "plug and play" system to quickly evaluate various sensors.

(2) The data acquisition and interface electronics hardware is needed to support the sensor package. This specially designed circuitry was developed to reduce the signal noise present when communicating with

Mini-Lab Interchange Capabilities

remotely deployed sensors in harsh environments. The design also reduces the total number of data lines connecting the base station with the sensor package, because additional wiring (or RF communication equipment in the case of mobile vehicles) reduces the reliability, increases the complexity for cable routing, and adds additional weight to the deployment system. The interface module for Mini-Lab consists of high bandwidth analog-to-digital converters, a multiplexer, and a synchronous serial communication board. The functionality of this module is being incorporated into an Application Specific Integrated Circuit (ASIC) to ensure reliable, low power operation in a compact package. The final version will be constructed using radiation-hardened microelectronics capable of surviving in severe radiation environments.

(3) The computer base station is responsible for acquiring, combining, interpreting, displaying, and archiving a wide range of sensor data. The menu-driven operator interface was designed to be a highly visual, easy-to-use system that an operator can quickly understand and control. Software routines create accurate and reliable statistical analysis of sensor data within seconds of its acquisition. The computer base station provides a visual, real-time display of in situ sensor data as well as the capability to archive and recall data from previous sensor scans. The base station also contains a library of routines that add to the flexibility and speed of characterization by allowing the operator to quickly change the sensor configuration and reuse hardware and software needed for the acquisition, interpretation, display, and archival of data. Graphical programming is used for configuring the system and

Representative Screen

includes transparent volumetric rendering to aid in the viewing of complex, three-dimensional data. This design is flexible enough so that the same base station can be reused for many different types of waste characterization applications.

As an example of Mini-Lab's data combination and display features, the image above shows a representative screen that can be generated. The picture shows a black and white image from a TV camera with a color overlay from another sensor such as infrared (IR) camera. By having a color overlay from the IR camera on the TV image, the operator can clearly see the intensity of temperature differences and, more importantly, exactly where these "hot spots" occur. This feature would also be valuable in remediation of waste sites for segregating different radioactive, toxic, or explosive

materials from other nonhazardous waste. A dramatic cost reduction can be realized by segregating waste streams because of the high cost associated with the disposal of mixed hazardous waste. The representative screen above also shows the menu-driven control window and a warning screen that alerts and directs the operator in case of emergencies. To assist the operator in keeping track of the location of the remote sensor package, a special window inset in the lower, left side of the screen shows the location of the sensor package and/or robotic vehicle on a blueprint of the building layout. The base computer can automatically compute the movement of the sensor package, calculate its position in the building coordinate frame and display it to the operator.

Unique Features:

Mini-Lab provides features that enhance and improve the characterization effort:

- **Faster:** Automated generation of site maps detailing the location of chemical, radiological, and physical constituents in real-time.
- **Safer:** Early warning system: ability to detect and react to hazardous conditions prompted by data collection and interpretation system.
- **Cheaper:** Less expensive than traditional sampling techniques and dramatic reduction in new waste generated.
- **Better:** Provides higher resolution data for more accurate characterization by performing repeated scans in areas of interest.

Current status:

During FY91, Sandia National Laboratories developed and demonstrated the first generation Mini-Lab for in situ waste characterization of chemical and radiological constituents. This first laboratory prototype contains eight sensors: a gas chromatograph, gamma spectrometer, and broadband gamma, oxygen, hydrogen, temperature, pressure, and humidity sensors. The resulting sensing system was scanned over a mockup of a waste storage tank by a gantry style robot. While the robot arm scanned the sensing package over the waste, a distributed computing system acquired sensor data, correlated the data with the position of the robot, and produced maps of the chemical

and radiological contents of the mockup tank in real-time.

During FY92, Sandia worked on improvements to the Mini-Lab. Based on perceived DOE site needs, additional sensors were integrated into the system. Sandia incorporated a miniaturized penetrometer capable of measuring viscous properties of sludge-type materials. Also, a Sandia developed sensor for measuring volatile organic compounds was added along with improved humidity and hydrogen sensors. A capacitive based proximity sensor was added to guide the robot a fixed distance away from the waste surface.

For FY93, plans are to integrate prototypes of Mini-Lab into a variety of other projects including remediation efforts for buried waste sites, inspection and inventory of radioactive storage vaults, and an exploration tool for a planetary rover.

The Department of Energy is remediating its sites around the country which are environmentally contaminated. Currently, waste site characterization is extremely time-consuming and expensive. Mini-Lab represents an advanced technology solution that will make the characterization of hazardous waste sites proceed faster, safer, and cheaper than conventional methods. Mini-Lab was developed by DOE's Office of Technology Development as part of the Robotics Technology Development Program. This work is being performed at Sandia by the staff in the Intelligent Systems and Robotics Center. For more information, contact:

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Sandia
National
Laboratories

Department of Energy

Appendix B

Engineering Test Sequences

CONTENTS

B-1. GEOPHYSICAL SENSOR TESTS	B-5
B-1.1 References	B-5
B-1.2 General	B-5
B-1.3 Materials and Equipment	B-5
B-1.4 Specific Precautions	B-5
B-1.5 Prerequisites	B-6
B-1.6 Procedure	B-6
B-2. SYSTEM SPEED CAPABILITY	B-9
B-2.1 References	B-9
B-2.2 General	B-9
B-2.3 Materials and Equipment	B-9
B-2.4 Specific Precautions	B-9
B-2.5 Prerequisites	B-10
B-2.6 Procedure	B-10
B-3. GANTRY REPEATABILITY	B-11
B-3.1 References	B-11
B-3.2 General	B-11
B-3.3 Materials and Equipment	B-11
B-3.4 Specific Precautions	B-12
B-3.5 Prerequisites	B-12
B-3.6 Procedure	B-12
B-4. MANIPULATOR SPEED CAPABILITY	B-13
B-4.1 References	B-13
B-4.2 General	B-13
B-4.3 Materials and Equipment	B-13
B-4.4 Specific Precautions	B-14
B-4.5 Prerequisites	B-14
B-4.6 Procedure	B-14
B-5. MANIPULATOR REPEATABILITY	B-16
B-5.1 References	B-16
B-5.2 General	B-16
B-5.3 Materials and Equipment	B-16
B-5.4 Specific Precautions	B-17
B-5.5 Prerequisites	B-17
B-5.6 Procedure	B-18

B-6. MINI-LAB INVESTIGATIONS	B-19
B-6.1 References	B-19
B-6.2 General	B-19
B-6.3 Materials and Equipment	B-19
B-6.4 Specific Precautions	B-19
B-6.5 Prerequisites	B-19
B-6.6 Procedure	B-20
B-7. HUMAN FACTORS EVALUATION OF THE CONTROL SYSTEM	B-20
B-6.1 References	B-20
B-6.2 General	B-21
B-6.3 Materials and Equipment	B-22
B-6.4 Specific Precautions	B-22
B-6.5 Prerequisites	B-22
B-6.6 Procedure	B-22

B-1. GEOPHYSICAL SENSOR TESTS

B-1.1 References

None.

B-1.2 General

The purpose of this test sequence is to evaluate the geophysical sensors that are mounted on the crane to determine their capability to indicate the presence of hazardous materials buried in the digface. Vendor data sheets for the sensors used in this test are shown in Appendix C.

1. The tests will evaluate the following performance factors:

A series of tests to evaluate these factors is outlined below. Tests will be performed at the North Boulevard Robotics Center (NBRC); however, it is intended that most of the basic operating characteristics of the geophysical sensors will be defined and documented before the test/demonstration. This will permit activities at the NBRC to be focused on deploying the sensors and on collecting the site-specific survey data needed to evaluate the ability to detect and map (locate) the simulated wastes.

B-1.3 Materials and Equipment

The following materials and equipment will be required to perform the tests outlined above and described below.

- 1 lab notebook
- Gantry crane
- Schilling arm
- Mini-Lab

B-1.4 Specific Precautions

The operation of the geophysical sensors on the crane present no direct risks to personnel or equipment and require no particular precautions during tests or other activities. However, precautions will be taken to eliminate the minor risks that are associated with the operation of the large equipment such as the crane. It will be standard operating procedure to ensure that crane movement is not initiated until all nearby personnel are in a safe position and are aware of the planned maneuvers.

B-1.5 Prerequisites

Perform pretest briefings before the initiation of testing sequences, as required by the testing engineer. These briefings will outline the scope and objectives of the tests and review the procedures.

Step 1. Personnel Qualifications

It is expected that these tests will be performed by engineers and scientists who are familiar with the crane and the geophysical sensors. The operation of the geophysical sensors during the tests, processing of the recorded test data, analysis of the data, and evaluation of the performance of the sensors and their platform (crane) will be by the Buried Waste Robotics Program and EG&G Idaho, Inc. Geosciences.

Step 2. Facilities/Utilities

No utilities other than normal 115-V AC power are needed when the crane is operated by means of the controller. All crane tests will be performed at the NBRC.

B-1.6 Procedure

Step 1. Preliminary actions. These preliminary actions shall be performed to guarantee the proper test set up and that all equipment and the test area is ready and functional. The performance of these actions will be noted in the logbook. Before operating the crane and its sensors for test purposes, the following preliminary actions will be taken:

Step 1.1 Verify that all pertinent mechanical and electrical mountings and connections are secure.

Step 1.2 Verify that the required electrical power supply voltages are present.

Step 1.3 Verify that the video cameras and displays are operational.

Step 1.4 Verify that the Emergency Stops are functional.

Step 1.5 Ensure that the test area is clear of other equipment that could damage the crane and/or sensors or be damaged by it.

Step 1.6 Ensure that the test area is clear of nonessential personnel and that nearby personnel are cognizant of the crane's operation and safety precautions associated with it.

Step 2. Evaluate the effects of terrain following on the sensors. Data will be collected every 6 in.

- Step 2.1 Perform a test using a camera to evaluate terrain following without any sensors attached. The video will be considered the data, but 1-in. lines behind the terrain should indicate the crane's ability to follow the terrain.
- Step 2.2 Attach the sensor head to the arm. The only sensor that needs to be "on" is the volatile organic compound (VOC) sensor.
- Step 2.3 Move the arm with the sensor head horizontally over the simulated waste box, i.e., at a constant height. Repeat this step so that it is performed twice.
- Step 2.4 Move the arm so that the sensors follow the terrain with a 6-in. offset. Repeat this step so that it is performed twice.
- Step 2.5 Move the arm so that the sensors follow the terrain with a 3-in. offset. Repeat this step so that it is performed twice.
- Step 2.6 Move the arm such that the sensors follow the terrain with a 1-in. offset (if the results of Step 2.1 indicate that this is a safe distance for the equipment). If this is not a safe distance, redline this procedure to indicate at what distance (as close as possible while maintaining safety) the test was performed. Repeat this step so that it is performed twice.
- Step 2.7 Evaluate the results from Steps 2.4–2.6 to determine the furthest offset distance that gives sufficient results. Move the crane so that the sensors follow the terrain at this offset at four different speeds. Each speed should be repeated so that two separate measurements are taken. The first speed will consist of moving the crane to each data collection point (every 6 in.), stopping the crane, and then collecting the data. The other speeds will vary but will all be continuous. The speeds to be tested are 25, 50, 75, and 100% of maximum speed.
- Step 3. Evaluate the interference of the crane on the sensors.
- Step 3.1 Remove dirt from the simulated waste box so that the dirt is level and 3 ft deep.
- Step 3.2 The following sensors should be attached to the sensor head and mounted on the arm: electromagnetometer (EM), VOC, and gamma-ray.
- Step 3.3 At a distance of 6 in. above the dirt, take data in an x-y grid of 6 × 6 in. in a serpentine manner.
- Step 3.4 Change the sensor head so that the magnetometer is the only sensor "on." Data should be taken in the same 6 × 6-in. grid as Step 3.3.
- Step 3.5 Remove 6 in. of dirt depth from the simulated waste box.

- Step 3.6 Still using the magnetometer, take data 6 in. above the dirt level in the same manner as Step 3.3.
 - Step 3.7 Change the sensor head so that the EM, VOC, and gamma-ray sensors are "on." Take data 6 in. above the dirt level in the same manner as Step 3.3.
 - Step 3.8 Remove 6 in. of dirt depth from the simulated waste box.
 - Step 3.9 Still using the EM, VOC, and gamma-ray sensors, take data 6 in. above the dirt level in the same manner as Step 3.3.
 - Step 3.10 Evaluate the gamma-ray sensor data results based on 25, 50, 75, and 100% maximum speed capability of the system.
 - Step 3.11 Change the sensor head so that the magnetometer is the only sensor "on." Take data 6 in. above the dirt level in the same manner as Step 3.3.
- Step 4. Evaluate the sensor head for electromagnetic interference.
- Step 4.1 The sensor head should be changed so that the magnetometer and EM are "on."
 - Step 4.2 Fix the Schilling arm, but allow that crane to move. Take data on a 1 × 1-ft grid in the crane envelope. The closest the sensor head should get to the floor is 3 in.
 - Step 4.3 Fix the crane, but allow the Shilling arm to move. Take data on a 1 × 1-ft grid in the arm envelope. The closest the sensor head should get to the floor is 3 in.
 - Step 4.4 Based on the results of Steps 4.2 and 4.3, predict what the crane and arm interference will be at five random locations within the crane/arm operational envelope.
 - Step 4.5 At the five separate locations of Step 4.4, in the crane and arm envelope, take measurements in a 3 × 3 × 3-ft grid. The pitch of the Schilling arm should be varied.
 - Step 4.5 Evaluate the recorded sensor data for the effects of EM interference.

B-2. SYSTEM SPEED CAPABILITY

B-2.1 References

None.

B-2.2 General

The purpose of this test is to assess the operating speed range of the gantry system. To understand the ability of the system to deploy sensors and equipment at varying rates (based on the particular device being deployed), knowledge of the variable speed capability of the system is required.

The overall objective of the study is to perform testing to be able to generate a system speed curve that defines the boundaries of speed capability for the equipment. Specific objectives of the study will be to determine (axis-by-axis) the speed capability of the gantry system.

B-2.3 Materials and Equipment

The following materials and equipment will be required to perform the tests outlined above and described below.

- 1 lab notebook
- Predesigned data tables for data collection
- 2 black pens
- Stop watch
- Tape measure (25 ft)
- Gantry system
- 1 equipment operator
- 1 person for obtaining measurements
- 1 person for recording measurements
- 1 video recording system for recording of tests.

B-2.4 Specific Precautions

During testing, access to the operational envelope of the gantry will be physically restricted by labeled barriers. **ACCESS TO THE RESTRICTED AREA WILL NOT BE PERMITTED WITHOUT FIRST SECURING THE SYSTEM ELECTRONIC POWER SUPPLIES.**

B-2.5 Prerequisites

Perform pretest briefings before the initiation of testing sequences as required by the testing engineer. These briefings will outline the scope and objectives of the tests and review the procedures.

B-2.6 Procedure

The following provides the procedures for determining the variable speed capability of the gantry system. Anytime one of the steps refers to recording data, an entry to the logbook will be made.

- Step 1. Collect all materials, procedures, and equipment required to perform the testing. Notify personnel and perform pretest briefings.
- Step 2. For each of the three axes of motion on the gantry (x, y, and z), determine the middle travel range which occupies 60% of the operating length for that axis. Legibly and permanently mark each stationary extreme (leaving 20% on each end of travel). This 20% on either end will allow for achieving constant speed for the test measurements.
- Step 3. Install indicating devices (pointers, arrows, etc.) at the midpoint of each translating axis of motion to provide indication for the timekeeper when the travel extremes have been met.
- Step 4. The following tests will be run to determine the speed rangeability of the gantry x-axis:

X-axis: From home position, run the x-axis at the following speed increments (percent of full speed) and time and record the movement between points established in Step 3 above:

25%, 50%, 75%, 100%

Repeat each incremental test five times.
- Step 5. The following tests will be run to determine the speed rangeability of the gantry y-axis:

Y-axis: Repeat the procedure of Step 4, for the y-axis.
- Step 6. The following tests will be run to determine the speed rangeability of the gantry z-axis.

Z-axis: Repeat the procedure of Step 4, for the z-axis.

- Step 7. Average the data collected for each axis of motion and plot independent curves (distance versus time) on a graph within the logbook.

B-3. GANTRY REPEATABILITY

B-3.1 References

None.

B-3.2 General

The purpose of this test is to assess the repeatability of the gantry system. To understand the ability of the system to deploy sensors and equipment, determination of the systems ability to repeat positioning is very important.

The overall objective of the study is to perform gantry testing to be able to generate repeatability data for each axis of motion. This information will reinforce confidence that the locational information being gathered, during the experiments, is sufficient to accurately characterize the area being scrutinized.

Specific objectives of the test will be to perform repeatability tests for each axis of motion of the gantry. The tests will be performed independently of each other and tabulated in the logbook.

B-3.3 Materials and Equipment

The following materials and equipment will be required to perform the tests outlined above and described below.

- 1 lab notebook
- Predesigned data tables for data collection
- 2 black pens
- 2 Dial indicator, 3-in. (spring loaded)
- Various clamps (up to 4-in.)
- 1 roll duct tape
- 1 target plate
- Tape measure (25 ft)
- Gantry system
- 1 equipment operator

- 1 person for obtaining measurements
- 1 person for recording measurements
- 1 video recording system for recording of tests.

B-3.4 Specific Precautions

During testing, access to the operational envelope of the gantry will be physically restricted by labeled barriers. **ACCESS TO THE RESTRICTED AREA WILL NOT BE PERMITTED WITHOUT FIRST SECURING THE SYSTEM ELECTRONIC POWER SUPPLIES.**

B-3.5 Prerequisites

Perform pretest briefings before the initiation of testing sequences, as required by the testing engineer. These briefings will outline the scope and objectives of the tests and review the procedures.

B-3.6 Procedure

The following tests will determine the repeatability of each axis of the gantry system. The testing will be performed for each individual axis of motion (x, y, and z). Anytime a step indicates recording of data, entries will be made into the logbook.

- Step 1. Collect all materials, procedures, and equipment required to perform the testing. Notify personnel and perform pretest briefings.
- Step 2. For each of the three axes of motion on the gantry (x, y, and z), determine the "HOME" position and permanently mark on both the stationary and translating member of that axis such that when the axis is at "HOME" the two marks line up.
- Step 3. The following tests will be run to determine the repeatability of the gantry x-axis.

X-axis: Install the dial indicators on the x-axis at locations where they will not become damaged, but yet be able to engage strategically placed targets at "HOME" and along the axis of concern.

Establish a dial gage target at the following locations, perform five repeated tests on each target, before moving to the next target. Record the axis, location, and measured deviations for both "HOME" and the location being tested:

Target locations 25%, 50%, 75%, 100% of maximum travel.

- Step 4. The following tests will be run to determine the repeatability of the gantry y-axis.

Y-axis: Repeat the procedure of Step 3 for the y-axis.

Step 5. The following tests will be run to determine the repeatability of the gantry z-axis.

Z-axis: Repeat the procedure of Step 3, for the z-axis.

Step 7. Plot the data as a function of deviation versus distance for each test and axis performed, on a graph within the logbook.

B-4. MANIPULATOR SPEED CAPABILITY

B-4.1 References

None.

B-4.2 General

The purpose of this test is to envelope the operating speed capability of the Schilling Titan 7F manipulator. Information obtained from this test will assist in determining the overall capabilities of the gantry system.

The overall objective of the study is to perform manipulator testing to be able to generate operating speed data for the manipulator. By determination of manipulator speed capability, system limitations may be identified.

Specific objectives of the test will be to perform speed (velocity) tests for two major axes of the system. The axes to be tested are rotation about the base (joint 1, approximately 270 degrees) and vertical lift (joint 2). The tests will be performed independently of each other and tabulated in the logbook.

B-4.3 Materials and Equipment

The following materials and equipment will be required to perform the tests outlined above and described below.

- 1 lab notebook
- Predesigned data tables for data collection
- 2 black pens
- 1 target plate
- Tape measure (25 ft)
- Stop watch (1/100 second resolution)
- Gantry system

- 1 equipment operator
- 1 person for obtaining measurements
- 1 person for recording measurements
- 1 video recording system for recording of tests
- 1 closed circuit television camera and monitor
- 1 camera tripod.

B-4.4 Specific Precautions

During testing, access to the operational envelope of the gantry will be physically restricted by labeled barriers. **ACCESS TO THE RESTRICTED AREA WILL NOT BE PERMITTED WITHOUT FIRST SECURING THE SYSTEM ELECTRONIC POWER SUPPLIES.**

B-4.5 Prerequisites

Perform pretest briefings before the initiation of testing sequences as required by the testing engineer. These briefings will outline the scope and objectives of the tests and review the procedures.

B-4.6 Procedure

The following will determine the speed capability of the two manipulator axes being tested. The testing will be performed for each individual axis of motion. Anytime a step indicates recording of data, entries will be made into the logbook.

- Step 1. Collect all materials, procedures, and equipment required to perform the testing. Notify personnel and perform pretest briefings.
- Step 2. Extend the manipulator to its full length, to the right extreme position of the base (joint 1), and full down (joint 2). For the two axes being considered establish a "HOME" position and permanently mark on both the stationary and translating member of that axis so that when the axis is at "HOME," the two marks line up.
- Step 3. The following tests will be run to determine the speed of the base rotation axis (joint 1) of the manipulator:

Joint 1: At a distance of 180 degrees opposite from home position, place a line on the stationary member of joint 1. Place the closed circuit television camera on a tripod and position out of the operating range of the manipulator so that the view of the stationary mark on joint 1 will have an unobstructed view during testing. Focus the camera so that the mark is very obvious.

Set the manipulator control for joint 1 to 5% of maximum speed, using the teach capability of the system, teach the "home" position as the starting point for the path.

Manually rotate the system around to the stationary mark, line up the two marks and teach this point as the "stop" point.

Return to "home" and replay the path. Correct as required.

- Step 4. The following tests will be run to determine the speed capability of joint 1 at speeds of 25%, 50%, 75%, and 100% of maximum:

25%: Set the manipulator control to 25% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

50%: Set the manipulator control to 50% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

75%: Set the manipulator control to 75% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

100%: Set the manipulator control to 100% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

- Step 5. The following tests will be run to determine the speed of the shoulder joint (joint 2) axis of the manipulator:

Joint 1: At a distance of 90 degrees opposite (up) from home position, place a line on the stationary member of joint 2. Place the closed circuit television camera on a tripod and position out of the operating range of the manipulator so that the view of the stationary mark on joint 2 will have an unobstructed view during testing. Focus the camera so that the mark is very obvious.

Set the manipulator control for joint 2 to 5% of maximum speed, using the teach capability of the system, teach the "home" position as the starting point for the path.

Manually rotate the system up to the stationary mark, line up the two marks, and teach this point as the "stop" point.

Return to "home" and replay the path. Correct as required.

- Step 6. The following tests will be run to determine the speed capability of joint 2 at speeds of 25%, 50%, 75%, and 100% of maximum:

25%: Set the manipulator control to 25% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

50%: Set the manipulator control to 50% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

75%: Set the manipulator control to 75% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

100%: Set the manipulator control to 100% of maximum speed. As the path is replayed, start the stop watch and stop the watch at the end of travel. Record the data in the logbook. Repeat the procedure 5 times. Reset the system to "home."

Step 7. Plot the data as a function of time versus angle (distance) for each test and axis performed, on a graph within the logbook.

B-5. MANIPULATOR REPEATABILITY

B-5.1 References

None.

B-5.2 General

The purpose of this test is to assess the repeatability of the manipulator system. To understand the ability of the system to deploy sensors and equipment, determination of the systems ability to repeat positioning is very important.

The overall objective of the test is to be able to generate repeatability data for the manipulator system. This information will reinforce confidence that the locational information being gathered, during the experiments, is sufficient to accurately characterize the area being scrutinized.

Specific objectives of the test will be to perform repeatability tests for several points within the envelope of the manipulator. The tests will be performed independently of each other and tabulated in the logbook.

B-5.3 Materials and Equipment

The following materials and equipment will be required to perform the tests outlined above and described below.

- 1 lab notebook

- Predesigned data tables for data collection
- 2 black pens
- 3 Dial indicator, 3-in. (spring loaded)
- Various clamps (up to 4-in.)
- 1 roll duct tape
- 1 target plate
- Tape measure (25 ft)
- Gantry system with Titan manipulator
- 1 equipment operator
- 1 person for obtaining measurements
- 1 person for recording measurements
- 1 video recording system for recording of tests
- 1 pointing rod (.5 in. diameter).

B-5.4 Specific Precautions

During testing, access to the operational envelope of the gantry will be physically restricted by labeled barriers. **ACCESS TO THE RESTRICTED AREA WILL *NOT* BE PERMITTED WITHOUT FIRST SECURING THE SYSTEM ELECTRONIC POWER SUPPLIES.**

B-5.5 Prerequisites

Perform pretest briefings before the initiation of testing sequences as required by the testing engineer. These briefings will outline the scope and objectives of the tests and review the procedures.

Position the gantry crane such that the z-mast is in the center of travel of the y-axis. The gantry will remain stationary during this testing sequence. Power to the crane motors is to be turned off and the switch locked out.

Position the manipulator arm so that it is fully extended and that all subsequent points measured will be in a region that is outside of the manipulators ability to reach.

Setup a table with x, y, and z coordinates and use the dial indicators as the axes. Establish and mark a datum (0,0,0) for x, y, and z. Make allowance for +/- 1-in. variance in each axis and the ability to measure this variance using the dial indicators. Note that this device is intended to measure variations from an established point, not to identify the system relative to the world model.

B-5.6 Procedure

The following tests will provide an indication of the repeatability of the Schilling Titan manipulator system. The testing will be performed for several points within the working envelope of the manipulator. Anytime a step indicates recording of data, entries will be made into the logbook.

- Step 1. Collect all materials, procedures, and equipment required to perform the testing. Notify personnel and perform pretest briefings. Install the pointer rod into the manipulator jaws and secure with a bolt through the jaws.
- Step 2. For each of point tested a reference point will be established and using the teach function of the manipulator will be taught. The manipulator will then be randomly moved from that point and instructed to repeat the position of that point. The deviation from the reference point will then be measured using the three-axis table and dial indicators.

Point 1: Position the manipulator at a point in the far left extreme quadrant of the operating envelope at a vertical position of approximately 5 ft off the floor. Freeze the arm in this position. Teach this point to the control system, and using the prebuilt x, y, z table, establish the 0,0,0 reference point (about 1.5-in. of the 3-in. travel for the dial indicators) for the pointer that is held in the jaws.

Test: Move the manipulator from point 1 and move the arm around its operating envelope (cycling all of its joints). Replay point 1 and freeze the joints when the manipulator has returned to the point. Using the x, y, z table, measure the variation of position from the reference point and record the data in the logbook. Repeat this test three times.

Point 2: Position the manipulator at a point in middle quadrant of the operating envelope at a vertical position of approximately 5 ft off the floor. Freeze the arm in this position. Teach this point to the control system and using the prebuilt x, y, z table, establish the 0,0,0 reference point (about 1.5-in. of the 3-in. travel for the dial indicators) for the pointer that is held in the jaws.

Test: Move the manipulator from point 2 and move the arm around its operating envelope (cycling all of its joints). Replay point 2 and freeze the joints when the manipulator has returned to the point. Using the x, y, z table, measure the variation of position from the reference point and record the data in the logbook. Repeat this test three times.

Point 3: Position the manipulator at a point in the extreme right quadrant of the operating envelope at a vertical position of approximately 5 ft off the floor. Freeze

the arm in this position. Teach this point to the control system and using the prebuilt x, y, z table, establish the 0,0,0 reference point (about 1.5-in. of the 3-in. travel for the dial indicators) for the pointer that is held in the jaws.

Test: Move the manipulator from point 3 and move the arm around its operating envelope (cycling all of its joints). Replay point 3 and freeze the joints when the manipulator has returned to the point. Using the x, y, z table, measure the variation of position from the reference point and record the data in the logbook. Repeat this test three times.

- Step 3. Compile the data obtained from the tests and average the deviations obtained for the x-axis, y-axis, and z-axis.

B-6. MINI-LAB INVESTIGATIONS

B-6.1 References

See Appendix A of this document for a description of Mini-Lab.

B-6.2 General

The purpose of this investigation is to qualitatively assess the overall performance of Mini-Lab. The system will be evaluated for accuracy and resolution of data and its ability to classify, identify, and characterize waste materials in the digface mockup.

The overall objective of the test is to determine if the implementation of robotics controls (Mini-Lab), for the purpose of characterization will provide better data than could be obtained by existing manual methods.

B-6.3 Materials and Equipment

Actual reference data regarding the type, concentration, and placement of simulated hazardous materials within the mockup.

Characterization data obtained during the course of the system test.

B-6.4 Specific Precautions

None.

B-6.5 Prerequisites

All characterization testing has been completed, the data collected, and the reference data available for evaluation.

B-6.6 Procedure

- Step 1. Provide a written evaluation of the accuracy and resolution of data provided by the Mini-Lab system as compared with conventional methods of obtaining the same information.
- Step 2. Provide a written evaluation of the systems ability to classify, identify, and characterize waste materials as compared with the methods currently used (and based on the known materials in the mockup).
- Step 3. Provide a written evaluation of the systems availability. This will include (but not be limited to) system problems, failures, time to repair, data lost, etc.
- Step 4. Provide a written evaluation of the useability of the system graphics as compared to the situation without their presence.
- Step 5. Provide written suggestions relative to system improvements that may be incorporated to enhance the usage and value of the system.

B-7. HUMAN FACTORS EVALUATION OF THE CONTROL SYSTEM

B-7.1 References

- 1. O. D. Duncan and M. Stenbeck, "Are Likert Scales Unidimensional?" *Social Science Research*, Vol. 16, 1987, pp. 247-259.
- 2. G. E. Cooper and R. P. Harper, *The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities*, National Aeronautic and Space Administration, Ames Research Center, Moffett Field, California, NASA Report TN-D-5153, April 1969.
- 3. G. B. Reid, C. A. Shingledecker, and F. T. Eggemeier, "Application of Conjoint Measurement to Workload Scale Development," *Proceedings of the Human Factors Society 25th Annual Meeting*, 1981.
- 4. S. G. Hart and L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research, *Human Mental Workload*, Hancock and Meshkati (eds.), Elsevier Science Publishers, B. V., 1988, pp. 139-183.
- 5. M. S. Sanders and E. J. McCormick, *Human Factors in Engineering and Design*, McGraw-Hill Book Company, 1987, pp. 51-53.
- 6. Casali and W. W. Wierwille, "On the Measurement of Pilot Workload: A Comparison of Assessment Techniques Addressing Sensitivity and Intrusion Issues," *Ergonomics*, Vol. 27(10), 1984.

B-7.2 General

The purpose of this test sequence is to assess the usability of the control systems operator interface by performing a cursory human factors evaluation.

This evaluation can be divided into three objectives. The first objective is to assess the usability of the control station. This includes evaluating operator control over crane speed, operator control over position of crane, ease of operation, quality of viewing screens, performance of control devices, and usefulness of graphics. The second objective is to identify factors that may affect performance. The third objective is to identify any deficiencies.

The step by step procedures are given later in this test sequence. Data will be determined valid by the test administrator. If the procedures are deviated from, the test administrator will red line this procedure to reflect those changes.

Where possible, quantitative data will be recorded; however, qualitative data regarding the subject's thoughts on the system such as operator satisfaction will also be collected. Qualitative data will be measured using a subjective scale. Techniques for quantifying subjective judgements have been developed in the field of psychometrics. Psychometric techniques are subjective measurement methods and have been used to subjectively measure a person's perceptions of mental workload and quality, and other applications. These are two types of psychometric techniques: ranking and rating. Ranking is a method in which a list is ordered from lowest to highest or from highest to lowest. Rating is a method used to obtain some type of classifiable quantity. There are several types of rating scales, including (1) global or straight point scales such as bipolar and Likert scales¹; (2) global-guided or scales that use network of questions that guide the evaluator to a point on a straight point scale such as the Cooper-Harper scale²; (3) multidimensional global-guided or scales that break down the subject into more detailed subparts and rate the subparts, such as the Subjective Workload Assessment Technique³ or Task Load Index⁴; and (4) multidimensional global-guided or scales the break down the subject into subparts and rate those subparts using a global-guided scale. The scale to be used for measuring operator satisfaction will be a global-guided scale. This scale used a flowchart to help structure the evaluation process. By doing this, the technique allows for a ten point scale, which is more reliable than the traditional global five or seven point scale. Because human beings typically can only distinguish between seven +/- two things,⁵ the method uses a flowchart that only requires humans to distinguish between two or three things at a time but for several episodes—making it a ten point scale. The scale is quick, easy to use, and requires minimal training. This technique has been proven to be sensitive, reliable, and valid.⁶ The global-guided scale is shown in Figure B-1.

B-7.3 Materials and Equipment

The following materials and equipment will be required to perform the tests outlined above and described in detail below.

- 1 lab notebook
- 2 pens

- Watch (resolution of one second)
- Tape measure (25 ft)
- A system operator
- Digface characterization system.

B-7.4 Specific Precautions

No personnel shall be in the room with the crane while subjects are operating the equipment for this test.

B-7.5 Prerequisites

None.

B-7.6 Procedure

Following are the procedures for testing the control system for Digface Characterization. Any time that one of the steps refers to recording some data, it will be recorded in a logbook. Only one subject will be tested at a time.

Step 1. Assess the usability of the control station.

Step 1.1 Explain the control system and how it can be used to control the crane. This training session should last approximately 10 minutes. The contents of the training will be kept in the project file.

Step 1.2 Operator control over crane speed. The subjects will be asked to survey the simulated waste box in a precise, predetermined manner at four different speeds. The four speeds to be tested are 25, 50, 75, and 100% of maximum speed. At each speed the following data shall be recorded: (1) the actual speed the crane moved, (2) operator's thoughts on the controls and displays, (3) perceived level of control, and (4) perceived difficulty. The crane speed will be measured by timing the cranes movements over a specified length. The operators will be asked to verbalize their thoughts while operating the crane. The global-guided scale shown in Figure B-1 will be used to measure the operator's perceived level of control and perceived difficulty. These thoughts will be recorded in a logbook. The global-guided scale shown in Figure B-1 will be used to measure the operator's perceived level of control and perceived difficulty.

Figure B-1. Global-guided scale.

- Step 1.3 Operator control over position of crane. The subject will be asked to survey the simulated waste box in a precise way. The following information will be recorded: (1) time it takes the subject to perform this task, (2) number of errors, (3) operator's thoughts on the controls and displays, (4) perceived level of control, (5) perceived difficulty, and (6) accuracy of movements. Time will be measured using a stop watch and will be recorded to the nearest second. The number of errors will be determined subjectively by counting the number of times the operator must perform a corrective action. An example of this would be for the operator to have the arm move in the opposite direction than intended. The operators will be asked to verbalize their thoughts while operating the crane. The global-guided scale shown in Figure C-1 will be used to measure the operator's perceived level of control and perceived difficulty. These thoughts will be recorded in a logbook.
- Step 1.4 Ease of operation. The operators will be asked to perform the following: (1) leave the crane stationary, but move the arm; (2) leave the arm stationary, but move the crane; (3) move both the arm and crane simultaneously. The following will be recorded: (1) operator's thoughts on the controls and displays, (2) perceived level of control, and (3) perceived difficulty. The operators will be asked to verbalize their thoughts while operating the crane. The global-guided scale shown in Figure B-1 will be used to measure the operator's perceived level of control and perceived difficulty. These thoughts will be recorded in a logbook.
- Step 1.5 Quality of viewing screens. The operators will be asked their opinion on the quality of the viewing screens. Any suggestions will be recorded.
- Step 1.6 Performance of control devices. The operators will be asked their opinion on the performance of the controls. Any suggestions will be recorded.
- Step 2. Identify factors that may affect performance.
- Step 2.1 The human factors engineer will record information in a logbook based on judgement and results of the previous tests. Information to be considered includes: lighting, anthropometrics, noise, workload, alarms, environment, controls, displays, feedback, physical space and layout, and cameras.
- Step 3. Identify any deficiencies.
- Step 3.1 As a result of the previous tests, the human factors engineer shall record any system control deficiencies that affect the usability of the system. In addition, the safeguards against losing control, communication, or data will be recorded.

Appendix C

Instrumentation Data Sheets

Sandia National Laboratories

Albuquerque, New Mexico 87185

June 16, 1993

Kevin Croft
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

Dear Kevin:

→ (included at the end of this letter.)

In your June 1 letter, you requested some details about the Mini Lab sensor heads. John Feddema provided drawings of the size and layout of the main sensor head. In this letter, I will address the remaining questions including those mentioned in John's June 11 letter to you.

DC Power Supply: Mini Lab has several on board DC-DC converters that require a nominal 12 VDC input. The converters will operate over a fairly wide range (10-20 VDC). Due voltage drop in the lines, a supply capable of providing 15 VDC at 5 amps is required.

Cabling from VME to Schilling: Two twisted pairs of 22 AWG for data plus one pair of 16 AWG for power. If such a cable is not available, six pairs of 22 AWG could be substituted using two pairs for data and four pairs in parallel to provide power.

Magnetometer: The magnetometer has been received at Sandia. Our original concept of a long tubular sensor head resulted in a 30" long package to maintain sufficient separation between the sensor and the electronics. This length severely restricts the work envelope. Instead, the sensor will now consist of two parts. The sensor head will be a 4" diameter by 10" long cylinder containing the sensor coils only. The sensor electronics, signal conditioner and multiplexer will be in a similarly sized package permanently mounted to the tool rack near the base of the Schilling. This approach will not effect cable management for the sensor head since a single cable of similar size is required for either approach. The 5' cable provided on the mag sensor must be replaced with a 15' cable. The manufacturer said the effect of a longer cable is quite small and, if necessary, the sensor can be tuned at the factory to accommodate this length. The magnetometer will also be powered from the 15 VDC supply used for the main sensor head. I have enclosed a block diagram showing the cabling and power connetions required.

Connectors: Connectors to the sensor heads have not been chosen. A minimum of six pins is required and a military type (ITT Canon) connector will be used. Sandia will provide the connectors. They will be sent to INEL to be attached to the cabling.

Sensors: You requested specific information concerning the sensors and modifications for Mini Lab. Below, each of the five sensor types is discussed in detail.

Ultrasonic Proximity Sensors:

3 Sensors with a range of 2-24", resolution 0.005".

These are commercially available from:

Contaq Technologies
15 Main Street
Bristol, Vermont 05443

The sensors used are based on a Part Number: ISU-101-IS-HRD-EN2-PCB. The sensors are ordered with a close range adjustment alteration to reduce the minimum sensing distance from 6" to 2". In addition the usual 2" NPT stainless steel case is omitted. The sensors provide 4-20 mA analog output (the IS option), provide high resolution output (HRD), will operate in a sequential non-interfering mode (EN2), and are equipped with an RS-232 port used for programming the setpoints and range.

Metal Detector:

The coil is a commercial 6" coil Part Number 624-0263 manufactured by:

White's Electronics
Sweet Home, OR

The coil has been only slightly modified by removing the conductive case and replacing it by applying a conductive layer to the inside of the MiniLab case. The associated electronics are designed and built by Sandia. I have included a schematic. The sensitivity and resolution of the system has not yet been characterized.

Optical Pyrometer:

The surface temperature device is an infrared thermocouple from:

Exergen
1 Bridge Street
Newton, MA 02158

It is a model IRT/c .2 K-140-3 which provides a Type K thermocouple response of the temperature of the surface being viewed. The thermocouple has a 2% accuracy (compared to a Type K thermocouple) from 80 to 180 degrees F. The device is connected through cold junction compensation circuitry (Part Number CJ-K) from:

Omega Engineering
P.O. Box 2284
Stamford, CT 06906

This provides a signal that is a measure of absolute (rather than differential) temperature. The compensator is accurate to 1 degree F over an ambient range of 60 to 100 degrees F. The compensator has been modified to operate on 5 VDC rather than the 1.35 V battery that was originally supplied.

Dosimeter:

The dosimeter is Geiger counter available from:

Eberline Instrument Corp.
P. O. Box 2108
Santa Fe, NM 87504-2108

It is a Model E-120 with a HP-270 probe. It provides full scale ranges of 0.5 5 and 50 mR/hr. The counter has been modified to operate on 5 VDC instead of the original 3 volt battery. Also wires have been attached to obtain an analog voltage output proportional to dose rate.

Gas Sensor:

The gas sensor is a tin oxide semiconductor based sensor available from:

Figaro USA, Inc.
1000 Skokie Blvd. Suite 575
Wilmette, IL 60091

The circuitry will operate with a number of specific gas sensors by simply plugging in a different sensing module. We plan on using an organic solvent vapor sensor (TGS 822) for detecting ethanol vapor, but any of the sensors listed below could be used:

Gas	Threshold (approx.)	Part Number
Chlorofluorocarbons	100 ppm	TGS 831
Hydrogen Sulfide	5 ppm	TGS 825
Ammonia	30 ppm	TGS 824
Hydrogen	10 ppm	TGS 821
Combustible Gases	500 ppm	TGS 813
Organic Solvent Vapors	50 ppm	TGS 822

Other sensors are available with relatively short lead time.

I hope this has answered all current questions about Mini Lab. I would be happy to obtain further details on these sensors or discuss the above information. Please feel free to call me at (505)-845-9835.

Sincerely,

Barry Spletzer
Intelligent System Sensors and
Controls Department 1611

Copy to:

INEL Nick Josten
1611 J. T. Feddema
1661 P. T. Boissiere
1661 D. S. Horschel
1661 C. Q. Little
1611 Day File

Schematic of Mini Lab Layout

Title METAL DETECTOR @6.6KHz			
Size C	Number	Rev 1	
Date 4-15-93	Drawn by RLW		
Filename METAL S01	Sheet 1 of 1

Intelligent In Situ Characterization System (Mini-Lab)

John T. Feddema, 1611

C-9

Problem Statement

- **Before DOE's hazardous waste sites can be cleaned up, knowledge of physical, chemical, and radiological contents is needed to plan remediation and disposal processes.**
- **A single computing interface is needed between a robotic positioning system and a set of characterization sensors.**
 - **To create site maps.**
 - **To aid in data interpretation.**
 - **To document the characterization process.**
 - **To speed up the characterization process.**

Solution

Mini-Lab provides:

- A general software and hardware computing architecture for acquisition, graphical display, archival, and interpretation of sensor data.
- An interface between the characterization sensors and the robotic arm and/or vehicle.
- Automatic generation of site maps.
- Uniform menu-driven user interface for quickly connecting sensors.
- Common library of display and interpretation routines.
- Early warning and diagnostics routines.
- Complete audit trail recorded in database

Unique Capabilities of Mini-Lab

- **Acquires sensor data through a variety of interfaces: analog, serial, parallel, GISC, and video.**
- **Automatically stamps sensor data with time, date, and robot position stamp before saving to files.**
- **Displays both real-time and archived sensor data.**
- **Automatic warning when thresholds are exceeded.**
- **Menu-driven user interface allows rapid deployment of sensors (plug and play interface).**
- **Sensor configurations (type, channel, displays, etc) are saved for reuse and modification.**

Mini-Lab as an Intelligent Subsystem

Current Status of Mini-Lab

- **Uses VME system to collect sensor data and robot position.**
- **Remote sensor heads contain on-board A/D and multiplexing circuitry which acquire up to 32 channels of analog data.**
- **Menu-driven interface is written in XViews (runs under Sun OpenWindows).**
- **Graphical display is performed using PV-Wave software.**
- **Documentation is under development. Plan to have a stable release in late FY93.**

Sensors Incorporated Into Mini-Lab So Far:

- **Analog Devices**
(using remote 16 channel digitizer, MUX, and high speed synchronous serial communication)
 - + Sandia Hydrogen Gas Sensor
 - + Nyad Oxygen Gas Sensor
 - + National Semiconductor Temperature Sensor
 - + ICSensors Pressure Sensor
 - + Hy-Cal Humidity Sensor
 - + ARA penetrometer
 - Tip Force
 - Pore Pressure
 - Viscosity
 - + Sandia's Capacitive Based Proximity Sensor
- **Serial Devices**
 - + MTI Gas Chromatograph
 - + Contaq Ultrasonic Proximity Sensors
- **Parallel Devices**
 - + Canberra Gamma Spectrometer

Mini-Lab is Leveraging off of Commercial Software Products:

- **So Far:**
 - + **PV-WAVE for Data Display**
 - + **Xviews Windowing package for menus**
 - + **VxWork's Real-Time Operating System**
- **Investigating:**
 - + **National Instrument's LabViews**
 - + **DataViews**
 - + **Gensyn's G2**
 - + **Talarian's RTworks**
 - + **NRT's ESMART**
 - + **Advanced Visualization System (AVS)**

Computer Architecture for the Intelligent In Situ Characterization System

Sandia National Laboratories

Albuquerque, New Mexico 87185

August 16, 1993

Kevin Croft
Idaho National Engineering Laboratory
EG&G Idaho, Inc., Mail Stop 3740
P.O. Box 1625
1955 Fremont Ave.
Idaho Falls, ID 83415

Dear Kevin:

Enclosed are the spec sheets for the transducers in Mini Lab. My June 16 letter to you gives all the appropriate model numbers for the transducers. We briefly discussed calibration and output in engineering units while I was up there. In general, the transducer outputs are fed to an amplifier to increase the sensitivity. Because of this, the transducer response will not match the spec sheets. If you need to display engineering units, I would suggest that you perform a 1 or 2 point calibration of the transducers. This is straightforward for all sensors but the metal detector. I do not know of an appropriate engineering unit for the metal detector.

I have a few comments on the current state of the sensors. The proximity transducers have been calibrated to read full output (4095 counts) at 2.5 inches and 20% of full count (819 counts) at 12 inches. The output will not change once outside of this range. They should not need further calibration. The pyrometer requires a battery for operation of the cold junction compensator due to a problem with common grounds. The battery has a life of 2000 hours. Unfortunately, the ON-OFF switch is accessible only by removing the Mini Lab cover. I have included a spare battery with this letter. The geiger counter is currently set on its most sensitive range. Range multipliers of 10X and 100X can be set using the knob on the dosimeter board. The is configured with the HP-270 probe with the cover open. For calibration purposes, the dosimeter provides full scale output when the range switch is placed in the "Battery" position. Because of the high amplifier gain, full scale output is well beyond the range of the multiplexer. The calibration equation of the gas sensor is given in the data sheet along with a typical response plot. Notice that the sensor response is highly nonlinear. The current Mini Lab software can not perform nonlinear function on the displayed data.

I hope this has provided the needed information. I would be happy to obtain further details on these sensors or discuss the above information. Please feel free to call me at (505)-845-9835.

Sincerely,

Barry Spletzer
Intelligent System Sensors and
Controls Department 1611

Copy to

INEL Nick Josten
1611 J. T. Feddema
1611 Day File

MODEL E-120/E-120E

SECTION I
GENERAL

A. PURPOSE AND DESCRIPTION

The Models E-120 and E-120E are small, lightweight geiger counters for the detection and measurement of gamma (also beta with E-120E) radiation. The E-120 is typically used with external hand probe Model HP-270 and the E-120E is typically used with external hand probe Model HP-190A. The models are identical except for the detector and meter face.

Two "D" size batteries power the instrument, and special circuitry is incorporated to conserve battery life.

The battery condition may be checked by a front panel control. The radiation intensity is read out on a large, easily read meter with a linear scale. Three switch-selected ranges give full scale sensitivities of 0.5, 5, and 50 mR/h (^{137}Cs) for the E-120 and 500, 5k and 50k counts per minute (cpm) for the E-120E. The response time of the meter is continuously adjustable, and the reading may be brought to zero at any time by the reset control.

A phone output is provided for the use of earphones, an Eberline Model SK-1 speaker, or for counting events with a scaler.

B. SPECIFICATIONS

The specifications listed are appropriate for the E-120/E-120E when used with the probe and cord listed.

1. Detector

	E-120 with Model HP-270 Probe	E-120E with Model HP-190A Probe
a. Geiger-Mueller Tube	30 mg/cm ² halogen quenched	Halogen quenched, thin window, 1.4 - 2.0 mg/cm ²
b. Sensitivity (^{137}Cs)	Approximately 1200 cpm per mR/h	Approximately 2500 cpm per mR/h
c. Energy Response	See Figure 1-3	N/A
d. Dead Time	Approximately 100 μs	Approximately 200 μs
e. Housing	Impact resistant plastic	Protective screen end cap
f. Environment	Weatherproof	Weatherproof
g. Cable	CA-1-36 (STANDARD)	CA-1-36 (STANDARD)
h. 2π Beta Efficiency with end cap removed	N/A	^{90}Sr : Approximately 35 percent ^{90}Y : Approximately 25 percent ^{137}Cs : Approximately 10 percent

2. Indicator

a. Visual

(1) Scale length: 2.37 inches (6 cm)

(2) Scale Marking:

E-120: Dual scales, 0 to 5 mR/h with 25 increments and 0-6k cpm with 30 increments.

E-120E: 0 to 5k cpm with 25 increments.

(3) Range: Switch controlled multipliers of X0.1,

X1 and X10, yielding 0.5, 5, or 50 mR/h (600, 6k or 60k cpm) for E-120, and 500, 5k, or 50k cpm for E-120E.

(4) Response Time: Continuously adjustable by RESPONSE control from 2 seconds to 10 seconds, measured to 90 percent of final reading.

(5) Linearity: Within ± 5 percent of full scale, typically ± 2 percent of F.S.

(6) Saturation: E-120 meter will remain pegged in

Manual Insert: MODEL HP-270 HAND PROBE

The standard Model HP-177C probe on this instrument has been replaced by the Model HP-270. The new HP-270 uses the same G-M tube and provides basically the same performance. The advantage of the HP-270 is an energy compensating shield built into the housing. This provides an energy response within $\pm 20\%$ from 40 KeV to at least 1.25 MeV (see graph below). Other specifications remain similar to the HP-177C.

Energy Response of HP-270 Hand Probe

eberline

REF. NO. 1059

P. O. Box 2108, Santa Fe, New Mexico 87501 (505) 471-3232 TWX: 910-985-0678

12/12/77

MODEL E-120/E-120E

^{137}Cs gamma fields up to at least 5 R/h when using a HP-270 probe. E-120E not specified.

(7) Battery Dependence: Calibration shifts less than 10 percent with battery voltage change from 3 to 2 V (new batteries to end point).

b. Aural:

(1) Connector: Miniature audio style.

(2) Signal: One pulse for each event counted. Negative 2.5 V capacitively coupled.

3. Power

a. Battery Complement: Two each "D" size batteries of any type with voltage between 1.0 and 1.6 V per battery.

b. Battery Life: Depends on battery type, age, and temperature. Nominal life with new batteries near room temperature is:

Type	Life
C-Zn	300 hours
Alkaline	500 hours
Ni-Cd	200 hours
(Single Charge)	

4. Environmental

a. Temperature: The instrument is operational from -40°F to $+140^{\circ}\text{F}$ (-40°C to $+60^{\circ}\text{C}$) with a typical temperature coefficient of -0.15 percent per $^{\circ}\text{F}$ (-0.27 percent per $^{\circ}\text{C}$). Maximum temperature coefficient -0.25 percent per $^{\circ}\text{F}$ (-0.45 percent per $^{\circ}\text{C}$).

The battery type used limits the low temperature performance because of terminal voltage decrease and internal impedance increase. For prolonged operation at low temperatures, the following criteria are suggested:

Battery Type	Usable to
C-Zn	0°F (-18°C)
Alkaline	-40°F (-40°C)
Ni-Cd	-40°F (-40°C)

5. Mechanical

a. Size

Height: $6\frac{1}{4}$ inches (16.5 cm)
Length: $6\frac{3}{4}$ inches (17.1 cm)
Width: $3\frac{3}{4}$ inches (8.6 cm)

b. Weight: With batteries: 3 pounds including probe (1.4 kg).

Figure 1-3. Typical Energy Response of E-120 with HP-270 Probe (10434-B4201)

2 of 2

|

MODEL E-120/E-120E

SECTION II
OPERATION

A. DESCRIPTION OF CONTROLS AND CONNECTORS

1. External (See Figure 2-1)

a. **Switch:** Five position rotary switch that turns instrument *OFF*, checks battery (*BATT*) condition and selects scale multipliers of X0.1, X1, X10. This number must be multiplied by the meter reading to obtain the proper field intensity.

b. **RESPONSE:** Controls response time of meter to the most desirable compromise between speed and fluctuation for the particular usage.

c. **RESET:** Discharges integrating capacitor, bringing meter reading to zero rapidly.

d. **PHONE:** Pulse output for use with earphone, speaker, or external scaler. Mating connector is Switchcraft #5501F.

e. **Detector Connector:** Connection to Hand Probe. BNC series coaxial.

2. Internal (See Figure 2-1)

a. **Calibration Controls:** One control for each range which individually calibrates that range to agree with the radiation field.

B. PREPARATION FOR USE

1. Inspection

The instrument should be checked for physical damage.

2. Connections

Connect the probe cable to the detector connector.

C. USING THE INSTRUMENT

1. Starting

Turn the switch to the *BATT* check position. The meter should indicate within the *BATT OK* area.

2. Operation Check

Place a check source in a repeatable position adjacent to the detector and move the switch to a range that gives an upscale reading. Note that the reading is sensitive to the position of the source. The reading may be recorded for future reference.

Push the *RESET* button and the reading should drop to zero rapidly, then climb back to source reading when the *RESET* is released. The *RESPONSE* may be adjusted to get the most desirable compromise between speed of response and meter fluctuation.

3. Interpretation of Indications

The meter reading must be multiplied by the scale factor to obtain the proper number. The fluctuation of the meter is normal and is caused by the random nature of radioactive decay.

On the E-120, either the mR/h or the cpm scale may be read. Prime calibration at the factory is mR/h using a ^{137}Cs source. The relation between the two scales is the average for the Geiger-Mueller tube used in the E-120 in a ^{137}Cs field. Thus, the cpm scale will be close to true frequency and may be used without recalibration. However, if cpm is to be used, and maximum accuracy is desired, the instrument should be recalibrated using a frequency standard.

The E-120E is calibrated to read true pulse frequency.

MODEL E-120/E-120E

SECTION III

THEORY OF OPERATION

A. GENERAL (See Figure 3-1)

The high voltage supply develops ~ 900 V, which is applied to the geiger tube, giving it the proper operating voltage. When radiation reacts in the geiger tube, negative pulses are generated. These pulses are coupled into the amplifier where they are amplified. They are then coupled to the trigger circuit where they are converted to standard size pulses of power. These standard pulses are applied to the meter driver which converts them to standard pulses of current, averages this current and drives the meter. Thus the meter deflection is proportional to the average rate of radiation at the geiger tube.

B. FUNCTIONAL THEORY (See Figures 3-1 and 6-1)

1. High Voltage Supply

The oscillator transistor Q1 drives T1 primary and gets its feedback from T1's red-orange winding. The voltage is stepped up by T1's secondary, rectified, filtered, and applied to V1. V1 regulates at 900 V. The current through V1 is sensed by Q2, amplified and used to control the current through Q3. The current through Q3 controls the bias level of the oscillator Q1. This tends to hold the current through V1 to a constant value, regardless of battery voltage. The result of this is that power is not wasted with new batteries and will still function with lower voltage batteries. This greatly extends battery life.

2. Amplifier

Q4 amplifies and inverts the negative input pulses from the detector. It is biased just into cut-off so its output is near 0 V. A pulse turns it on and the resulting positive output starts the trigger circuit.

3. Trigger

Integrated circuit A1 is connected to operate as a monostable multivibrator whose pulse width is controlled by the RC time constant between its pins 7 and 9. This time constant is established by the setting of S12 (scale selection) which selects a particular R and C. The calibration controls form the R for each scale, making the pulse width continuously adjustable for calibration.

When the trigger is initiated by the pulse from Q4, the output at pin 6 goes positive and holds until the predetermined time (RC) elapses.

4. Meter Driver

The driver Q5 is normally off so no current flows through M1. When the trigger is on, Q5 is turned on and current flows. The amount of current is determined by the voltage on the base of Q5 and the value of R15. The length of time that current flows is determined by the pulse width of the trigger. This (current times time) forms a certain charge which is transferred to C9 for each event counted. C9 discharges through M1, yielding a certain average current dependent on the rate of input pulses. Changing the pulse width of the trigger (i.e., changing scales or calibration pot setting) changes the average current for a given input pulse rate. This allows the meter to be calibrated to read in mR/H (or cpm) at the detector.

The response time of M1 is controlled by the RC time constant of C9 and R16, the response control. With R16 set to low resistance the time constant is fast, and at high resistance it is slow.

5. Phone Driver

Q6 amplifies and inverts the output pulse from the trigger, yielding a large amplitude negative going pulse which is capacitively coupled to the *PHONE* connector.

MODEL E-120/E-120E

Figure 3-1. System Block Diagram

MODEL E-120/E-120E

SECTION IV
MAINTENANCE

A. DISASSEMBLY AND REASSEMBLY

1. Batteries

The batteries are secured in holders on the etched board. Pull the batteries from the holders. Replace by sliding the batteries into holders, making certain they are centered and of the correct polarity. The red terminal cover indicates positive polarity at that end. Care should be exercised when changing batteries because of the sharp edges on the battery holders.

2. Etched Board

The etched board and cover may be separated for troubleshooting. Proceed as follows:

- a. Remove the batteries to prevent electrical damage during disassembly.
- b. Remove the knob and mounting nut from the scale switch.
- c. Remove the two nuts from the meter studs.
- d. Separate the board and cover without putting undue stress on the wires.
- e. For troubleshooting, place jumpers from the meter studs to corresponding points on the board and replace the batteries.
- f. Reassemble in reverse order of disassembly.

B. PREVENTIVE MAINTENANCE

1. Keep the instrument clean and dry.
2. Replace the batteries when their check reading is below the acceptable level.
3. Remove the batteries if the instrument is to be inactive for six months or more.

C. CALIBRATION

For maximum accuracy, the instrument should be calibrated under the same conditions as it will be used. Refer to Section 1.B. for effects of gamma energy, battery voltage, and temperature. Proceed as follows:

1. Each range is individually calibrated by a calibration control ($\times 1$, $\times 1$, $\times 10$). Repeat the procedure below for each range.

- a. Position the instrument on a calibration range so the detector center is in a field corresponding to near three-quarter scale meter reading.

- b. Expose the gamma source and note the instrument reading. Adjust the calibration control for the range selected until the meter indication agrees with the field.

2. Calibrations in Counts per Minute

If counts per minute is to be read instead of mR/h, then calibration should be to true frequency. Capacitively couple a pulse generator into the probe connector using a capacitor with a 1 kV or higher voltage rating. The pulse generator must have a negative pulse approximately 350 mV amplitude and frequency covering the instrument range.

Adjust the pulse generator frequency to correspond with approximately three-quarter scale meter reading and adjust the calibration control for the range selected until the meter agrees with the frequency. Repeat for each range ($\times 1$, $\times 1$, $\times 10$).

D. TROUBLESHOOTING

Typical voltages and waveforms are given on the schematic (Figure 6-1), and component locations are shown in Figure 6-2.

Voltages are measured with a 20,000 Ω/V , or greater, voltmeter except the 900 V point. An electrostatic voltmeter or voltmeter with 1000 M Ω minimum input impedance should be used to check the 900 V; however, if one is not available a conventional meter may be used for an indication of the presence of high voltage.

SECTION V

PARTS LIST

The following table lists the electronic items incorporated in the Model E-120/E-120E and should contain any part necessary for normal electronic repair. Unless otherwise specified, callouts of manufacturers and manufacturers' part numbers are to be considered typical examples only. There are no restrictions against using equivalent parts with the same operating characteristics. When ordering parts from Eberline, specify model number, serial number, reference designation, value, Eberline part number, or a word description if the part has no reference designation. Eberline will automatically substitute equivalent parts when the one called out by the manufacturers' part number is not available.

REF DESIG	PART	DESCRIPTION	MANUFACTURER AND PART NUMBER	EBERLINE PART NUMBER
A1	Integrated Circuit	RTL Dual NOR Gate	Motorola MC810G, MC710G or MC910G	ICRTC0810G(2)
BT1, BT2	Battery	Alkaline "D" Cell	Eveready type E95 or equivalent	BTAK3(4)
	Battery Holder Kit			BTBH4(5)
C1, C9	Capacitor	330 μ F, 10%, 6 V	Sprague 150D or equivalent	CPTA331M15D(1)
C2	Capacitor	0.047 μ F, 10%, 100 V	Sprague 225P47391WD3	CPPF473P5P(2)
C3, C10	Capacitor	3.3 μ F, 10%, 15 V	CS13	CPTA335P3H(5)
C4	Capacitor	0.01 μ F, 1.6 kV, 20%	CRL DD16-103	CPCE103PXV(3)
C5	Capacitor	0.001 μ F, 3 kV, 10%	Centralab DD30-102	CPCE102P3Y(7)
C6	Capacitor	0.0068 μ F, 10%, 80 V	SPRAGUE 192P6629R8	CPPF682P3O(9)
C7	Capacitor	0.008 μ F, 10%, 200 V	SPRAGUE 192P68392	CPPF683P3R(4)
C8	Capacitor	0.68 μ F, 10%, 35 V	CS13	CPTA684F3L(0)
C11	Capacitor	33 μ F, 10%, 10 V	CS13	CPTA330M3F(1)
CR1, CR2	Diode	Zener, 3.9V	1N748	CRZR1N0748(3)
CR3	Diode		1N4148	CRS11N4148(7)
CR4	Diode	High Voltage	Electronic Devices, Inc. HX25PD	CRSIVA0025(3)
J1	Phone Jack	Male Panel Connector	Switchcraft No. 5501 MP	COAF12(9)
M1	Meter	0-50 μ A (E-120 Face Standard)	Jewell MM-2T	MTPA23(4)
	Meter face ONLY (for E-120E)			ZP10472127(3)
Q1	Transistor	PNP	2N404	TRQP2N404A(2)
Q2, Q3, Q5, Q6	Transistor	NPN	2N4124	TRSN2N4124(2)
Q4	Transistor	PNP	2N4126	TRSP2N4126(3)
R1, R3	Resistor	270, 5%, 1/4 W		RECC271B22(7)
R2	Resistor	62k, 5%, 1/4 W		RECC623B22(9)

MODEL E-120/E-120E

REF DESIG	PART	DESCRIPTION	MANUFACTURER AND PART NUMBER	EBERLINE PART NUMBER
R4	Resistor	330, 5%, 1/4 W	CTS (Type X201R103B) #RR9167	RECC331B22(9)
R5	Resistor	22M, 5%, 1/2 W		RECC226B23(0)
R6	Resistor	1M, 5%, 1/4 W		RECC105B22(7)
R7	Resistor	4.7k, 5%, 1/4 W		RECC472B22(1)
R8	Resistor	24k, 5%, 1/4 W		RECC243B22(0)
R9	Resistor	27k, 5%, 1/4 W		RECC273B22(3)
R10	Resistor	2.2k, 5%, 1/4 W		RECC222B22(0)
R11	Resistor	2.7k, 5%, 1/4 W		RECC272B22(5)
R12, R13, R14	Potentiometer	10k		PTCC103B02(0)
R15	Resistor	220, 5%, 1/4 W		RECC221B22(2)
R16	Potentiometer	MIL-R-94B, RV6 Style, 10k, 20%, linear taper, 1/4-32 x 1/4 Long FMS Non-Lock Bushing, 1/8 x 1/2 Long FMS Flatted Shaft (for set screw)	CTS Series 3000 or equivalent CTS 42444	PTCC103B43(1)
R17	Resistor	10k, 5%, 1/4 W	Grayhill 30-1	RECC103B22(2)
R18	Resistor	1k, 5%, 1/4 W		RECC102B22(4)
S1	Switch, Rotary	Scale		SWRO27(9)
S2	Switch, NO	RESET	Microtran M7120	SWPB5(8)
T1	Transformer			TFHV2(0)
V1	Regulator Tube	900 V, 2%	Victoreen GV3B-900 or 5841	TUVR900(4)
J2	Connector, Probe		UG-1098/u	CXBN9(0)
	Probe Cable	BNC-BNC, 36" long		CA-1-36(3)
	Probe Cable	BNC-BNC, 60" long		(STANDARD) CA-1-60(3) (OPTIONAL)

Figure 6-1. General Schematic of E-120/E-120E (10434-C07.1)

CHANGE 10

C-30

ISU
USER MANUAL

ULTRASONIC
LEVEL MEASUREMENT
MOTION CONTROL AND
PROXIMITY SENSOR
PRODUCTS

CONTAQ TECHNOLOGIES CORPORATION

15 MAIN STREET

BRISTOL, VERMONT 05443

802/453-3332

FAX 802/453-4250

ISU
INTELLIGENT SENSOR UNIT
INSTALLATION AND OPERATING INSTRUCTIONS

1.0 DESCRIPTION:

The ISU generates measurement data based on the distance of objects located in front of the transducer. This measurement data is used internally to control HMI/OW limit relays. The measurement data is scaled as an analog output and transmitted in ASCII data format for units with these features. ISU operating parameters are set either at the factory; by the Sensor Programmer Unit (SPU); or under program control.

2.0 INSTALLATION:

2.1 Mount the ISU as is appropriate for your application. The ISU is designed with a standard 2" NPT thread for easy installation. The transducer (12 degree beamwidth) should be aimed as squarely as possible at the intended target.

2.2 Connect the power source using the color coded leads. RED for (+) and BLACK for (-). Be sure the polarity is not reversed or damage to the instrument may result.

2.3 The relay leads are normally open (BROWN), normally closed (GREEN), and common (WHITE). Connect them as required.

2.4 For the -I option 4/20ma output, connect the external voltage to the ORANGE lead (current sink) and the BLUE lead (return) to ground. For the -IS option (self excited) use TAN (4/20ma source) and Orange (return).

2.5 If you have an ISU with the RS422 serial communications protocol, connect the communication leads as follows:

TX+ (PURPLE) and TX- (YELLOW) are the signals transmitting data from the ISU and should be connected to the appropriate receiver.

RX+ (PINK) and RX- (GREY) are the signals receiving commands from the remote computer or terminal and should be connected to the appropriate transmitter.

2.6 If you have selected a version of ISU with the RS485 serial communications protocol, connect the PINK lead to RS485(+), the GREY communications lead to RS485(-).

3.0 POWER ON:

3.1 ISU begins operating and making measurements as soon as power is applied. This is indicated by an audible clacking from the sensor; from the state of its internal relays; and from its analog or serial outputs, if any.

4.0 OPERATING PARAMETERS:

4.1 H/L/O limits which control the condition of the internal relay(s) can be set at the factory, with the Sensor Programmer Unit (SPU) or under computer control (for units with serial communications protocols).

4.2 In single relay units, when a target is found inside the H/L/O range, the relay is actuated; otherwise, the relay remains in its normal condition.

4.3 In two relay units, one relay is actuated for targets found at or below the LOW limit; the other relay is actuated at or above the HIGH limit.

4.4 Relay "OFF DELAY" is from 0 to 5 seconds and can be set at the factory by the SPU or by a computer or controller via the communications protocol. Whenever "OFF DELAY" is set, it is applied to all relays.

4.5 Limit setting via the serial port is accomplished by using the commands and data format described in the Communications Protocol.

4.6 The limits can be changed as often as necessary but not greater than 10,000 times.

4.7 Analog signals represent the current measurements and are set to maximum at or above the "H/L/O" limit. They are set to minimum at or below the "LOW" limit and are scaled as 256 steps within the H/L/O range. The 4-20 ma output current sink requires an external voltage source.

5.0 TEMPERATURE COMPENSATION MODE:

The ISU incorporates a high accuracy Self Calibration Mode (CAL Mode). This mode requires an external reference target used by the ISU to make real-time measurement corrections for all environmental changes. This mode can be turned on and off by the SPU or from a controller or computer via the communications protocol. In this mode, measurement accuracies of less than $\pm 1\%$ can be obtained.

ISU S/89

PRODUCT SPECIFICATION

1. Description

The ISU Series is a remote intelligent echo type ultrasonic transducer which can be used alone or in "multi-drop" or "daisy-chain" type of multiple transducer installations. ISU uses ultrasonic technology to determine the distance to an object or surface. ISU can be used in discrete, continuous and digital level measurement and motion control applications requiring analog, relay and serial data. ISU is available in user selectable factory set ranges or with an ISU intelligent programmer (SPU). ISU is also supported by a separate display (SDU) and a console controller (CCU).

The intelligent transducer (ISU) measures tank solids or liquid levels and continuously transmits measurement data as a 4-20ma analog current source. The scaling of the analog output is based on the programmed limit settings. The condition of the external relays is determined by the output, the "on" delay and the non-recent measurement. ISU is programmed by the SPU and both are controlled by internal test memory programs. The ISU-1001 Series can be programmed by any terminal supporting the RS-232C interface and the ISU protocol. The ISU-801 Series can be programmed by any terminal supporting the RS-422 interface and the ISU protocol.

The SPU has the capacity to display the measurement and setpoint data, alter the setpoints, display relay status, alter relay delay and select the scaling and polarity. Scale polarity is determined by the relationship of the H/L/O setpoints to each other. Communications between the ISU-1001 and ISU-801 Series and their corresponding SPU are carried out over serial digital lines under the control of a common protocol formatted as ASCII data transmitted at 9600 baud.

2. Performance

2.1 Range:	5 to 60 feet (1.5 to 18.3 m)
2.2 Resolution:	0.077 ft (0.024 m)
2.3 Accuracy:	±1% (±1% with self target)
2.4 Sample Rate:	12 measurements per second

3. Physical

3.1 Weight:	2 lbs (0.9 kg)
3.2 Dimensions:	6" (152mm) x 2" (51mm) Dia., Nominal
3.3 Enclosure:	2" NPT Mounting

4. Outputs:

4.1 Relay: 5.0 amp, SPDT.

4.2 Current: 4 - 20 ma, 256 steps within setpoints.

5. Communication:

5.1 Electrical:

9600 baud, 8 bit data, no parity, 2 stop bits. RCVR/XMITT Run time 3ms min.

The ISU must be addressed with the proper code in order to respond to commands.

Data is transmitted by the ISU on command.

All commands are initiated by the SPU.

Commands are sent to and interpreted by ISU and data is stored and/or returned.

5.3 Commands:

SPU commands are derived from the status of as front panel switches and are coded as ASCII characters.

ISU measurement data is displayed continuously.

1. momentary actuation of the Low Limit switch displays the current LOW setpoint.

2. sustained actuation of the Low Limit switch sets the LOW setpoint to the current measurement.

3. momentary actuation of the High Limit switch displays the current HIGH setpoint.

4. sustained actuation of the High Limit switch sets the HIGH setpoint to the current measurement.

5. momentary actuation of the Delay switch displays the current relay "Off" delay.

6. sustained actuation of the Delay switch sets the "Off" delay by 1-second, from 0 to 5 secs.

7. momentary actuation of both Low and High Limit switches displays the current CAL ALCODE status.

8. sustained actuation of both Low and High Limit switches toggles the CAL ALCODE between ON and OFF.

6. Power:

6.1 Standard: All ISU Series require: 17 VDC @ 360 ma.

All SPU Series require: 12 VDC @ 460 ma.

6.2 AC Option: All ISU -AC require: 120 VAC, 0.7 Hz @ 100 ma.

7. Installation:

The ISU enclosure is provided with a 2" NPT thread for easy installation and is supplied with a 3 ft long cable pigtail for electrical interconnect.

The SPU is provided in a NEMA 4 enclosure with a 3 ft long cable pigtail for easy connection at a junction box.

The SPU is provided in a NEMA 4 enclosure with a 3 ft long cable terminated with alligator clips for easy temporary connection at a junction box.

8. Documentation:

Installation and operating instructions are supplied with each unit.

9. Service:

A one year warranty applies to properly installed and operated units. Warranty claims will be handled on a repair or replacement basis at the discretion of Contact Technologies Corporation. Custom configurations are available on request. Consult the factory for information and pricing.

ISUSP 1770

ISU-101 TO SPU-44

WIRING DIAGRAM

WIRING DIAGRAM

12VDC/AC	ALB	DC POWER IN / AC IN
DC GND/AC	BLACK	DC POWER / AC NEUTRAL
RLYNO #1	BROWN	N.O. RELAY #1
RLYNC #1	GREEN	N.C. RELAY #1
ALYCOM #1	WHITE	COMMON RELAY #1
PM -	ORANGE	ANALOG OUT (4-20 / VDC)
RM -	BLUE	ANALOG RETURN
RS485+ / RX -	PINK WHITE / RED	RS485+ / RS422 RECV +
RS485- / RX -	GRAY	RS485- / RS422 RECV -
IS	TAN WHITE / BLACK	CURRENT SOURCE
TX -	YELLOW	RS422 XMIT -
TX + / 101 COM PURPLE		RS422 XMIT + / 101/2 COM GND
RLYNO #2	WHITE / BROWN	N.O. RELAY #2
RLYNC #2	WHITE / YELLOW	N.C. RELAY #2
ALYCOM #2	WHITE / ORANGE	COMMON RELAY #2

NOTE: 13 CONDUCTOR CABLE ONLY

(\JHM\ISUM195.DRT)

ISU-EN2 OPTION OPERATING INSTRUCTIONS

1. Description

1.1 The ISU-EN2 option allows two or more ISU's to operate in a synchronized, non-interfering mode, located within one inch of each other. The ISU-EN2 will also operate as a standard ISU when not interconnected as described in paragraphs 2.1, 2.2 and 2.3.

NOTE: When an SPU is connected to any ISU in the LOOP to set the HIGH / LOW limits, DISCONNECT all WHITE-BROWN to WHITE-ORANGE WIRES to increase the speed of communications. Failure to do this will result in slower SPU data acquisition and display.

2. Operating Instructions

2.1 Connect the WHITE-BROWN WIRE of ISU #1 to the WHITE-ORANGE WIRE of ISU #2.

2.2 Connect the WHITE-BROWN WIRE of ISU #2 to the WHITE-ORANGE WIRE of ISU #3 etc.

2.3 Connect the WHITE-ORANGE WIRE of ISU #1 to the WHITE-BROWN WIRE of the LAST ISU in the loop.

2.4 Apply power to the ISU's.

2.5 All other instructions / specifications are standard ISU.

8/16/93

1. Description

An SPU Series programmer can be used with an individual ISU to display and control its operating parameters.

Communications between the ISU-1001 and ISU-801 Series are carried out over serial digital lines under the control of a common protocol formatted as ASCII data transmitted at 9600 baud. The ISU will be identified by one or the other of two addresses. One address will be serialized and unique to the particular ISU and the other address will be a wildcard for use by the SPTJ.

2. Communication

- 2.1 Electrical: 9600 baud, 8 bit data, no parity, 2 stop bits. RCVR/XMITR Turn Time: .3ms min.
- 2.2 Protocol: The ISU must be addressed with the proper code in order to respond to commands. This code is the ASCII character "Z" followed by the serial number of the selected ISU.
- Data Is transmitted by the ISU on command.
- All commands are initiated by the external device or driver.
- Commands are sent to and interpreted by ISU and data is stored and/or returned.

2.3 Commands:

Commands are coded as ASCII characters:

"Z"	Preface to node address.
"U"	ISU measurement data is returned on command.
"C"	returns the current LOW setpoint.
"L"	sets the LOW setpoint to the current measurement.
"B"	returns the current HIGH setpoint.
"R"	sets the HIGH setpoint to the current measurement.
"D"	returns the current relay "OFF" delay.
"I"	increments the "OFF" delay by 1 sec, from 0 to 5s.
"S"	returns the current CAL MODE status.
"T"	sets the CAL MODE to ON.
"V"	sets the CAL MODE to OFF.
"J"	returns RELAY 1 control status.
"E"	ISU RELAY 1 control enable.
"F"	ISU RELAY 1 control disable.
"A"	returns RELAY 1 status.
"G"	RELAY 1 activate.
"H"	RELAY 1 deactivate.
"N"	returns RELAY 2 control status.
"P"	ISU RELAY 2 control enable.
"M"	ISU RELAY 2 control disable.
"K"	returns RELAY 2 status.
"Q"	RELAY 2 activate.
"O"	RELAY 2 deactivate.

3. Programming Examples:

3.1 Read Data: ISU Serial Number 3456

Controller Sends: Z3456:U(CR)

ISU Returns: 12345(CR)

3.2 Check Relay I Control Status, Disable ISU Control and Activate Relay I from Controller.

Controller Sends: Z3456:(CR)

ISU Returns: ON(CR)

Controller Sends: Z3456:F(CR)

ISU Returns: OFF(CR)

Controller Sends: Z3456:G(CR)

ISU Returns: ON(CR)

3.3 Scaling: Inches = (Raw Count) X .007324218

4. Consult the factory for further information and pricing on currently available support software.

ISUCOM 6/89

TGS 822 - for the detection of Organic Solvent Vapors

Features:

- * High sensitivity to organic solvent vapors such as ethanol
- * High stability and reliability over a long period
- * Long life and low cost
- * Uses simple electrical circuit

Applications:

- * Breath alcohol detectors
- * Gas leak detectors/alarms
- * Solvent detectors for factories, dry cleaners, and semiconductor industries

The sensing element of Figaro gas sensors is a tin dioxide (SnO_2) semiconductor which has low conductivity in clean air. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration in the air. A simple electrical circuit can convert the change in conductivity to an output signal which corresponds to the gas concentration.

The TGS 822 has high sensitivity to the vapors of organic solvents as well as other volatile vapors. It also has sensitivity to a variety of combustible gases such as carbon monoxide, making it a good general purpose sensor. Also available with a ceramic base which is highly resistant to severe environments as high as 200°C (model# TGS 823).

The figure below represents typical sensitivity characteristics, all data having been gathered at standard test conditions (see reverse side of this sheet). The Y-axis is indicated as *sensor resistance ratio* (R_s/R_o) which is defined as follows:

R_s = Sensor resistance of displayed gases at various concentrations

R_o = Sensor resistance in 300ppm ethanol

Sensitivity Characteristics:

The figure below represents typical temperature and humidity dependency characteristics. Again, the Y-axis is indicated as *sensor resistance ratio* (R_s/R_o), defined as follows:

R_s = Sensor resistance at 300ppm of ethanol at various temperatures/humidities

R_o = Sensor resistance at 300ppm of ethanol at 20°C and 65% R.H.

Temperature/Humidity Dependency:

Structure and Dimensions:

- ① Sensing Element:
SnO₂ is sintered to form a thick film on the surface of an alumina ceramic tube which contains an internal heater.
- ② Cap:
Nylon 66
- ③ Sensor Base:
Nylon 66
- ④ Flame Arrestor:
100 mesh SUS 316 double gauze

Pin Connection and Basic Measuring Circuit:

The numbers shown around the sensor symbol in the circuit diagram at the right correspond with the pin numbers shown in the sensor's structure drawing (above). When the sensor is connected as shown in the basic circuit, output across the Load Resistor (V_L) increases as the sensor's resistance (R_s) decreases, depending on gas concentration.

Basic Measuring Circuit:

Standard Circuit Conditions:

Item	Symbol	Rated Values	Remarks
Heater Voltage	V_H	$5.0 \pm 0.2V$	AC or DC
Circuit Voltage	V_C	Max. 24V	AC or DC *PS $\leq 15mW$
Load Resistance	R_L	Variable	*PS $\leq 15mW$

Electrical Characteristics:

Item	Symbol	Condition	Specification
Sensor Resistance	R_s	Ethanol at 300ppm/Air	$1k\Omega - 10k\Omega$
Change Ratio of Sensor Resistance	R_s/R_0	$\frac{R_s \text{ (Ethanol at 300ppm/Air)}}{R_s \text{ (Ethanol at 50ppm/Air)}}$	0.40 ± 0.1
Heater Resistance	R_H	Room temperature	$38.0 \pm 3.0\Omega$
Heater Power Consumption	P_H	$V_H = 5.0V$	$660mW \pm 55mW$

Standard Test Conditions:

TGS 822 complies with the above electrical characteristics when the sensor is tested in standard conditions as specified below:

Test Gas Conditions: $20 \pm 2^\circ C$, $65 \pm 5\% R.H.$

Circuit Conditions: $V_C = 10.0 \pm 0.1V$ (AC or DC),

$V_H = 5.0 \pm 0.05V$ (AC or DC),

$R_L = 10.0k\Omega \pm 1\%$

Preheating period before testing: More than 7 days

Sensor Resistance (R_s) is calculated by the following formula:

$$R_s = \left(\frac{V_C}{V_L} - 1 \right) \times R_L$$

Power dissipation across sensor electrodes (P_s) is calculated by the following formula:

$$P_s = \frac{V_C \times R_s}{(R_s + R_L)}$$

FIGARO USA, INC.
1000 Skokie Blvd. Suite 575
Wilmette, Illinois 60091
Phone: (708)-256-3546
Fax: (708)-256-3884

IR t/cTM.2 Specifications

Addendum to IR t/c brochure. Please refer to standard IR t/c specifications in the brochure or manual with the following exceptions:

Signal Output: Thermocouple type J and K (type T and E available by special order).

Output Impedance: 4 K Ω - 10 K Ω nominal (depending on model)

Repeatability: $\pm 1\%$ over sensing range

Sensing Temperature Range: Blackbody (emissivity= 1) target temperature range of 0° to 2000°F (-18° to 1100°C) for all models

Case Operating Temperature: 0° to 212°F (-18° to 100°C)
(Sensor may be operated in ambient of 250°F (121°C) if air purge system used, higher ambients require air or water cooling of sensor)

Field of View: Nominal 2:1 (at distance X, spot size diameter is 1/2 X)

Minimum Spot Size: 0.16 inch (4 mm)

Dimensions: 2.45" length x 0.5" diameter (6.2 cm x 1.3 cm)

Air-Purge Adaptor: Brass hexnut .75" span x .312" thick (19mm X 8mm) included

To Order: IR t/c.2-**-*** (example: IR t/c.2-K-140F-3)

*J,K,T,E

**98.6F/37C, 140F/60C, 180F/90C, 240F/120C, 280F/140C, 340F/170C, 440F/220C

***cable length 3 ft (.9 m) standard; additional lengths optional

ITEM	DESCRIPTION
1	N/A
2	N/A
3	C-41

DR	DATE
DRK	
APPD	
APPD	

EXERGEN
TITLE
OUTLINE; IR t/c.2
NFOV W/AIR PURGE
FILE DRAWING NO
B
SCALE 1X1
SHEET 1 OF 1

OMEGA
ENGINEERING, INC.
an OMEGA Technologies Company

OMEGA-CJ
Thermocouple
Cold-Junction
Compensator
Operator's Manual

SECTION	PAGE
SECTION 1 INTRODUCTION	1
1.1 General Description	1
1.2 Features	1
SECTION 2 UNPACKING	2
SECTION 3 OPERATION	2
3.1 Operating Procedure	2
3.2 Battery Replacement	4
3.2.1 Battery Life	4
3.2.2 Replacing the Battery	4
SECTION 4 THEORY OF OPERATION	5
SECTION 5 CALIBRATION	7
SECTION 6 SPECIFICATIONS	8

Sales: 1-800-265-4291 • JCB-FC CMEGA

Call 1-800-833-2211 for more information.

Engineering Association 1-800-872-9436 / 1-800-872-9436

International Ltd. VEH620

CABLE CINECA

TEL: 993401

EASTMAN KODAK

FAX 1211.15

Refuse fleque styling

Direct all warranty and repair requests inquiries to OMEGA Customer Service Department, telephone number 1-800-672-2178, International (303) 358-6550. BEFORE RETURNING ANY INSTRUMENT, PLEASE CONTACT THE OMEGA CUSTOMER SERVICE DEPARTMENT TO OBTAIN AN AUTHORIZED RETURN (AR) NUMBER. The designated AR number should then be marked on the outside of the return package.

To avoid excessive data, also please be sure to include:

1. Returnee's name, address, and phone number.
2. Model and Serial numbers.
3. Remarks/Instructions.

CBEGL's policy is to make running changes, not model changes, whenever an improvement is possible. That is, we change the way we do things, not the way we think about things.

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SECTION 1 INTRODUCTION

1.1 GENERAL DESCRIPTION

The OMEGA® CJ is a portable battery-powered automatic cold junction compensator for use in thermocouple circuits. It provides the physical and electrical equivalents of an ice bath reference thermocouple at 0°C or 32°F.

Thermocouples can be plugged directly into the OMEGA-CJ. A quick disconnect male plug and output jack with banana plugs are provided for connecting the CJ to potentiometers as well as to meters and recorders of high input impedance.

1.2 FEATURES

- High reliability — solid state circuitry with self contained battery
- Rugged construction
- Color coded thermocouple calibration
- Instantaneous warm-up
- High Stability — better than $\pm 0.2^\circ\text{C}$ at any stabilized temperature over its full $+10^\circ$ to 50°C range
- Extreme versatility — unit can be plugged directly into a thermocouple or into a jack panel
- Long battery life — 1500 hours or longer depending on calibration

SECTION 2 UNPACKING

Remove the Packing List and verify that all equipment has been received. If there are any questions about the shipment, please call OMEGA Customer Service Department at (203) 359-1660.

Upon receipt of shipment, inspect the container and equipment for any signs of damage. Take particular note of any evidence of rough handling in transit. Immediately report any damage to the shipping agent.

NOTE

The carrier will not honor any claims unless all shipping material is saved for their examination. After examining and removing contents, save packing material and carton in the event reshipment is necessary.

SECTION 3 OPERATION

3.1 OPERATING PROCEDURE

The OMEGA-CJ comes complete with quick disconnect male plug and output jack with banana plugs for connecting to potentiometers, meters and recorders of high impedance. Thermocouples can be plugged directly into the OMEGA CJ.

Operation is instant; the OMEGA-CJ's solid state design requires no warm-up.

1. Connect output to OMEGA-CJ (TO INSTRUMENT) to readout instrument. Copper wire extension leads must be used.
2. Connect thermocouple to other end of OMEGA-CJ (TO THERMOCOUPLE). If thermocouple probe is not directly coupled to OMEGA-CJ, it is necessary to use thermocouple extension wires from the thermocouple to the OMEGA-CJ.
3. Move ON-OFF slide switch to ON to energize unit.
4. The readout instrument will now indicate the actual temperature, unaffected by ambient temperature changes.

NOTES

OMEGA-CJ has an internal resistance of up to 250 ohms, depending on calibration; therefore, readout instruments of high input resistance (impedance) must be used to minimize errors.

Following use, always move ON OFF slide switch to OFF to conserve the battery.

3.2 BATTERY REPLACEMENT

3.2.1 Battery Life

The self-contained battery is a mercury cell—1.35 V Mallory RM401R, or equivalent. Design life in continuous operation is as follows:

Calibration	Approximate Life (hours)
Chromel-Alumel	3000
Iron-Constantan	1500
Copper-Constantan	3800
Chromel Constantan	1800
Pt/10% Rh-Pt	7800
Pt/13% Rh-Pt	7800
W-W/26% Re	5000
W/5% Re-W/26% Re	5000
W/3% Re-W/25% Re	5000

3.2.2 Replacing the Battery

The indicator on the face of the OMEGA-CJ, energized by depressing the BAT TEST push button, indicates when battery replacement is necessary. The battery should be replaced when the indicator becomes dim.

To replace the battery, remove the cover plate by unscrewing the single flathead screw and snap out the battery. Follow correct polarity when installing the replacement battery.

NOTE

For extended shelf-life of the mercury battery, avoid storage at high temperatures.

SECTION 4 THEORY OF OPERATION

The OMEGA-CJ introduces an emf into the circuit which is equivalent to an ice bath. This emf is regulated by a temperature sensitive resistor (R_T) in an electrical bridge network (see Figure 4-1) which compensates for ambient temperature changes, always maintaining a 0°C or 32°F reference equivalent.

The temperature sensitive resistor (R_T) is thermally integrated with the cold junction (T_2), with the bridge being energized by a 1.35 V mercury battery.

Figure 4-1. Wiring Diagram

As the ambient temperature surrounding the cold junction varies, a thermally generated voltage appears and produces an "error". However, an equal and opposite voltage produced by the bridge is automatically introduced in series with the "error" voltage, canceling the "error". This maintains the reference temperature over a wide ambient temperature range with a high degree of accuracy.

By integrating copper leads with the cold junction, the thermocouple material itself is not connected to the input terminals of the measurement instrument, thereby eliminating secondary errors.

SECTION 5 CALIBRATION

1. Remove the cover plate by unscrewing the single flathead screw located on the back of the unit (see Figure 5-1).

Figure 5-1. OMEGA-CJ

2. Connect CJ to the thermocouple probe and readout instrument.
3. Place the thermocouple probe into an icebath and wait about 10 minutes for system to stabilize.
4. Adjust the ZERO POTENTIOMETER (located on the printed circuit board inside the CJ) until the readout instrument shows "0" (zero).
5. Replace cover plate and secure with screw.

SECTION 6 SPECIFICATIONS

REFERENCE TEMPERATURE SETTING: 0°C or 32°F

COMPENSATION ACCURACY: ± 1/2 °C at 25°C ambient setting
± 1/2 °C from 15° to 35°C ambient
± 1/2 °C from 10° to 50°C ambient

STORAGE TEMPERATURE: -25° to +75°C (without battery)

INTERNAL RESISTANCE (IMPEDANCE): Less than 250 ohms

CALIBRATIONS AVAILABLE:
Chromel-Alumel
Iron-Constantan
Copper-Constantan
Chromel-Constantan
Pt/10% Rh-Pt
Pt/10% Rh-Pt
W/5% Re-W/26% Re
W/5% Re-W/26% Re
W/3% Re-W/25% Re

BATTERY: 1.35 V Mallory mercury cell
(RM-401R)

DIMENSIONS: H: 1 1/2" (44.45 mm) x L: 4 1/4" (106.36 mm) x W: 3/4" (19.05 mm)

WEIGHT: 12 oz. (342.0 g)

DATE

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END