HNF-MR-0543
Revision 0

# Final Test Report — Demonstration Testing in Support of the Track 3 System Waste Dislodging, Retrieval and Conveyance Concepts

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Prepared by
Delphinus Engineering, Inc.

Prepared for
Lockheed Martin Hanford Corporation
Contract Number MSH-SLD-A31517
Project Number 9702

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Prepared for the U.S. Department of Energy
*Assistant Secretary for Environmental Management*

*Project Hanford Management Contractor for the*
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# RELEASE AUTHORIZATION

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| **Document Number:** | HNF-MR-0543, Rev. 0 |
| **Document Title:** | Final Test Report - Demonstration Testing in Support of the Track 3 System Waste Dislodging, Retrieval and Conveyance Concepts |

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**DELPHINUS ENGINEERING, INC**

650 Baldwin Tower, Eddystone, PA 19022

July 14, 1997

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Ranjit K. Das
President, Delphinus Engineering, Inc.

**DELPHINUS ENGINEERING, INC.**

# MEMORANDUM

To: Jim Yount

From: Mike Kobran

Date: 7/14/97

Subject: Dynamic Response Software

With regard to the dynamic response graphs in **Appendix A** of the Final Report. We are unfortunately unable to provide an electronic version of these plots due to the complexity of the software. If you wish to obtain additional copies of these plots, we will provide them.

cc:

LOCKHEEDMARTIN

# FINAL TEST REPORT

## Demonstration Testing in Support of the Track 3 System Waste Dislodging, Retrieval and Conveyance Concepts

**RETRIEVAL SYSTEM CONCEPTS**
**CONTRACT NUMBER MSH-SLD-A31517**
**PROJECT NUMBER 9702**

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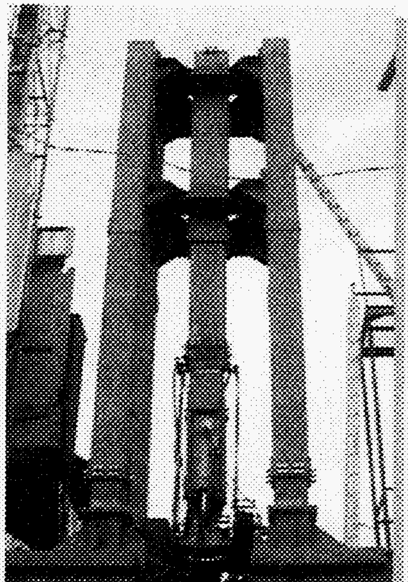
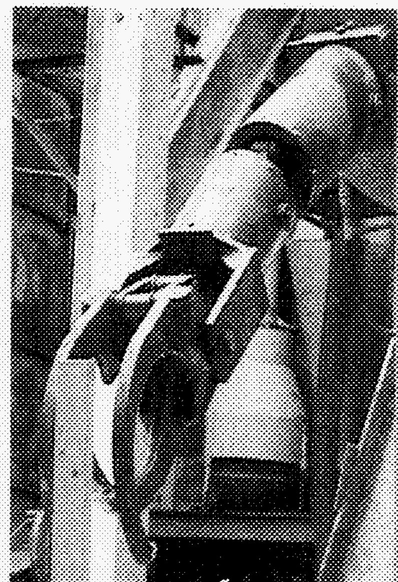
# EagleTech

# FINAL REPORT

## "Demonstration Testing in Support of the Track 3 System Waste Dislodging, Retrieval and Conveyance Concepts"





Lockheed Martin Hanford Co.
Retrieval System Concepts
Contract Number MSH-SLD-A31517
Project Number 9702

## ABSTRACT

This report contains the quantitative and qualitative data and information collected during performance of the Track 3 System testing protocol. Information contained herein focuses on the data collected during performance of the following Tests Procedures.

- •Test Procedure-1, Position Management
- •Test Procedure-2, Waste Dislodging, Retrieval, and Conveyance and Decontamination
- •Test Procedure-3, Dynamic Response
- •Test procedure-4, Safety Demonstration

The test procedures present test scenarios, which were developed to allow collection of data relative to supporting resolution of specific primary **issues**. Data collected as a result of test performance is presented in **Appendix A**. The primary **issues** were categorized and grouped in a matrix as presented in **Reference 1**. The compilation and interpretation of test data provides the basis upon which the key issues identified in **Reference 1** will be resolved and as such demonstrate the ability of the Track 3 System to meet the following objectives...

1. Perform operations deemed necessary to address technical issues and validate system design bases.
2. Allow for the extrapolation of technical data in support of the resolution of qualitative issues.
3. Validate Track 3 System operational characteristics.
4. Demonstrate the ability of the Track 3 System to remove simulated waste materials that have been characterized as those typically found in the single shell tanks at the Hanford site.

A synopsis of pertinent test results and recommendations founded upon the Track 3 System testing program are presented below.

The ability of the Track 3 System to navigate, maneuver and avoid obstacles is clearly proven and supported by the testing performed and the results obtained. These issues are especially important when one considers that in order to retrieve and convey waste from inside an underground storage tank the Track 3 system boom assemblies must navigate the maze of in-tank hardware such as risers, piping, and instrumentation tubes. This is no "small" feat considering the Track 3 System jib boom, which has been designed to extend 75 feet and support waste removal end-effectors is performing this task.

Key to in-tank waste removal operations is the Track 3 System "Command and Control software which is integral in performing "positional repeatability" tasks or repetitive operations. The Track 3 System proved conclusively that it can perform positional repeatability tasks without any discernable variation in path taken or ending point.

The WALDO (Waste and Liquid Dislodging Orbiter) end effector proved to be quite capable at dislodging, retrieving and conveying large volumes of waste simulant, ranging from 29 cubic feet for the peanut butter like consistency wet sludge, 38 cubic feet for a dried sludge comprised basically of hardened plaster of paris, to 24 cubic feet for the concrete like saltcake.

Overall the Track 3 system proved to be rugged, robust, and quite capable of responding to the challenge of providing the vehicle to address Hanford's underground storage tank concerns.

# TABLE OF CONTENTS

# 1. INTRODUCTION

Delphinus Engineering Inc. of Eddystone Pa. and EagleTech of Solon Ohio are the companies involved in performing the Track 3 System testing program. The testing took place in Wellington Ohio on the Nesbitt farm from July 7, 1997 to July 10, 1997. Vendors providing specialized equipment or services in support of specific tests are identified within the body of this report. The major limitation with respect to performance of the testing protocols is the inability of the jib boom to extend 75 feet. In this regard any test procedures previously identifying test protocol requirements at 75 feet have been amended in the field to reflect other parameters. Test modifications are identified in the following sections and in Appendix A of this report.

# 2. TESTS PERFORMED

## 2.1. Position Management

The purpose of the Position Management tests is to demonstrate the capability of the Track 3 System to operate safely within the confines of a tank which contains risers, cables, structural members and miscellaneous debris of various size. Data collected is presented in **Appendix A Section 1.** The Position Management testing program addresses the following key issues.

- Access
- Positional Repeatability
- Obstacles
- In-Tank Navigation
- Visibility
- Mapping
- Umbilical Management

### 2.1.1. Access Testing

#### 2.1.1.1. Description of Test

The capability of the Track 3 System to access a 36 inch diameter riser was tested. This test entailed visually observing and measuring tolerances, and documenting the Track 3 System boom sections, including end-effectors and knuckle joint assemblies capability to clear the test riser opening without any impingement upon the riser.

Materials utilized to perform access testing included a steel plate measuring 44 inches square by ¼ inch with a 36 inch diameter circular cut-out. A notch was cut in the steel plate allowing the plate the ability to wrap around the vertical mast assembly.

#### 2.1.1.2. Test Method and Test Equipment

Access testing was performed by placing a steel plate measuring 44 inches square by ¼ inch with a 36 inch diameter circular cut-out on the vertical boom assembly and lowering the plate over the knuckle joint in order to verify that the knuckle assembly "clears" a 36 inch diameter opening as shown in **Figure 2.1.1-1**. Measurements relative to this test were obtained using a standard rule and by visual observation. Data collected from the performance of testing is presented in **Appendix A Section 1**.

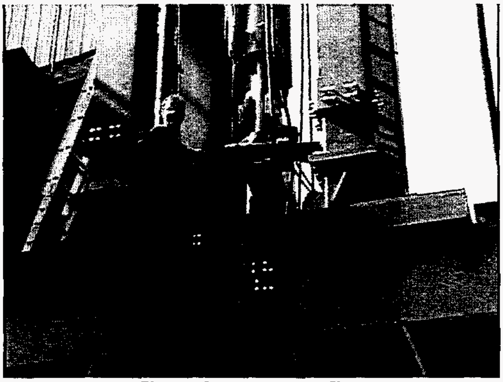


**Figure 2.1-1: Access Test**

**2.1.1.3.Test Results**

The purpose of the access test was to verify that the Track 3 System vertical and jib boom sections were designed and constructed to tolerances which would allow access through a 36 inch diameter opening. The 36 inch diameter opening is representative of a typical riser assembly opening which will be utilized for accessing tanks. Upon inspection of the Track 3 System it was quite evident that the knuckle assembly which connects the vertical boom to the jib boom maintained the limiting dimension for tank access. The results of the access test verified that the knuckle assembly could not clear the 36 inch diameter simulated tank access hole. Measurement were taken which indicate that relative to the present design the knuckle assembly would require at a minimum a 41 inch diameter opening in order to obtain tank access.

The prescribed mode of operation for obtaining access to a tank through a 36 inch diameter riser requires the Track 3 System mast assembly to be lifted using the hydraulic mast cylinders to an elevation which would allow the jib boom to be unfolded from its stowed position into a vertical position directly above the tank access. This method of access was to be demonstrated, however as a result of the mast assembly hydraulic cylinders being inoperative at the time of testing the method utilizing the metal template was employed. Irregardless of the method employed to demonstrate the ability of the Track 3 System to successfully clear a 36 inch diameter riser the results would have been identical. Data obtained as a result of performing access testing is presented in **Appendix A Section 1.**

**2.1.1.4.Issues Resolved**

The issue of tank access pertains to the ability of the Track 3 System to safely enter a tank through a 36 inch diameter riser and perform tank waste removal operations. The significance of this issue is straight forward in that in order to clean a tank, the Track 3 System must first be capable of accessing the tank. In order to achieve this goal all components of the Track 3 System which are required to enter a tank must be appropriately designed to accommodate the restrictions of a 36 inch diameter riser opening. This includes but is not limited to all end effectors, jib boom assembly knuckle joint vertical boom assembly umbilical hoses, wires, and all ancillary items such as cameras and other electronic or mechanical devices.

**2.1.1.5.Method of Resolution**

The method employed to resolve the issue of tank access was to directly measure the knuckle joint which is the most limiting feature of the Track 3 System that would be required to have tank access. For additional information on this subject refer to **Section 2.1.1.3.**

**2.1.1.6.Results**

The resulting resolution to access testing as described herein is that the Track 3 System is not capable of accessing a 36 inch diameter riser. In fact, given the present design configuration of the knuckle assembly the Track 3 System would require a riser opening in excess of 41 inches diameter. The applicability of these results to overall tank waste removal operations is that the Track 3

System is limited in its ability to access tanks and thusly in its present configuration can only be utilized in tanks which maintain provisions for access greater than 41 inches diameter.

Actions that will be taken due to the result of the access test is to re-design the knuckle joint in order to ensure that the Track 3 System can safely access a 36 inch diameter riser and thereby perform a complete gambit of tank waste removal operations.

#### 2.1.1.7.Disposition of Test Item

Access testing is complete. The materials used to perform tank access testing include the 44 inch square by ¼ metal template. This template will be recycled on the Nesbitt farm.

#### 2.1.1.8.References

Letter from Delphinus Engineering Inc to Lockheed Martin Hanford Co. dated December 27, 1997.

### 2.1.2. Positional Repeatability

#### 2.1.2.1.Description of Test

This demonstration test focused upon the issue of "Positional Repeatability". The issue of **"Mapping"** is indirectly addressed by virtue of the testing protocol. The capability of the Track 3 System to perform positional repeatability or perform iterative actions without a noticeable or measurable degradation in position, is founded upon the capabilities of the "Command and Control" software program being employed.

Materials utilized to perform positional repeatability testing included the following:

- Track 3 System with dual arm gripper attached
- One 5 foot tall standard.

- Command and Control software.

**Figure 2.1.2-1** depicts the field arrangement of the aforementioned materials.

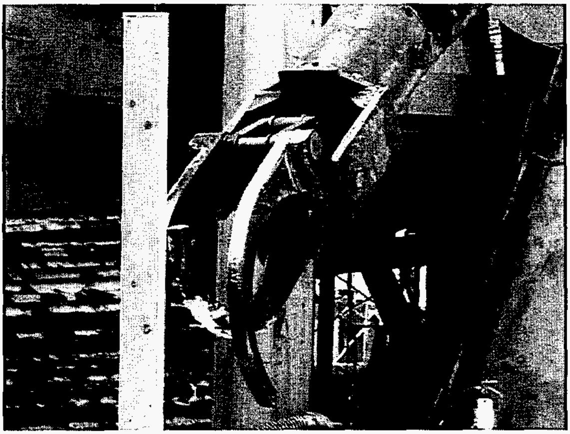


**Figure 2.1.2-1 Positional Repeatability**

The "Command and Control" software is actually a collection of programs. Created using a combination of commercial software, proprietary application programming interfaces and original code. Borland Pascal and assembly language were used in conjunction with object-oriented programming (OOP) technology to produce the programs. The software is designed to run on 386, 486 and Pentium-based personal computers with one megabyte of RAM, one floppy diskette drive, one serial communication port, a color monitor and joystick throttle control. The programs are designed to be run under DOS. Windows was not used because real-time control processes running under Windows can be subject to "interrupt jitter", which could be disruptive or even dangerous.

Program objects were created to handle specific tasks, functions and devices. These include objects to control hydraulic valves, to measure the motions of the "arm", to sense the throttle, and to learn, record and playback a series of movement commands. OOP technology produces program code that is reusable, saving time and increasing reliability. Some of the objects were used to build a program to calibrate and test the electrohydraulic valve controls.

Additional objects were combined to create the command and control software to run the "arm". This software is capable of managing up to twelve axes. It simultaneously controls the valves, gathers data from the motion sensors, monitors analog throttle input, watches for and responds to commands from the keyboard, sets and adjusts movement limits, checks for and reacts to emergency conditions, and displays and records telemetry.

A software simulator was devised to mimic the behavior and responses of the "arm". The simulator can be used to test new program features, investigate and solve operational problems, and train "arm" operators. It integrates seamlessly with both the calibration and command and control programs.

#### 2.1.2.2.Test Method and Test Equipment

The following describes how positional repeatability testing was performed and how measurements were taken.

Positional Repeatability testing was performed by placing the 5 foot standard at an arbitrary location in the field of motion of the Track 3 System. The Track 3 System operator utilizing the radio remote control system was tasked with plotting a course and touching the standard. From a neutral position in the test pit the operator executed the following commands.

- Jib boom up
- Extend jib boom.
- Touch standard.
- Withdraw vertical boom while maintaining contact with standard.

- Extend vertical boom while maintaining contact with standard.
- Retract jib boom.
- Lower jib boom into tank.
- Cease operations.

In parallel with the above the "Command and Control" software recorded the movements of the Track 3 System. The Track 3 System operator executed the appropriate commands for the "Command and Control" software to control the movements of the Track 3 System by repeating the aforementioned path. The Track 3 System repeated this path three times without any operator intervention, with no discernable or measurable deviation, essentially hands-free operation.

**2.1.2.3.Test Results-Positional Repeatability**

The results of the positional repeatability testing verified the ability of the "Command and Control" software to maintain safe paths of movement. There was no observable or measurable deviation in the path traveled. Data obtained as a result of performing positional repeatability testing is presented in **Appendix A Section 1.**

**2.1.2.4.Issues Resolved**

The purpose of the positional repeatability testing is to demonstrate the ability of the Track 3 System to negotiate a "safe" path through a tank, i.e. no *hits* upon in-tank hardware or components as a result of the application of the "Command and Control" software interface committing to memory successful (no hit) pathways. The applicability of the positional repeatability function of the "Command and Control" software to tank waste removal operations is significant. Consider that the "teach and learn" aspect of the "Command and Control" software will actually allow the Track 3 System operator the ability to manually establish a multitude of safe paths of movement inside a tank and record these paths using the software. This function of the software will allow enhanced operations of repetitive tasks. In essence the

"Command and Control" software in conjunction with the "teach and learn" function of the software will allow for the mapping of safe paths inside of waste tanks.

**2.1.2.5.Method of Resolution**

The testing employed to address the issue of positional repeatability is outlined in **Section 2.1.2.2.**

**2.1.2.6.Results**

The resulting resolution to the issue of positional repeatability is that the "Command and Control" software is capable of recording and duplicating "safe" path's traveled by the Track 3 System. The applicability of positional repeatability to in-tank waste retrieval, represents enhanced operations with respect to repetitive Track 3 System tasks such as safely travelling to a point in space and performing many identical iterations of a pre-determined action such as dislodging and retrieving waste. Positional repeatability enhances safety due to the fact that only proven "safe" paths are followed. Additionally positional repeatability enhances overall production by allowing Track 3 System operators the ability to select proven safe paths of operation, and thusly not have to tediously maneuver through the same field of in-tank hardware over numerous occasions.

The efficiency of the "Command and Control software has certain limitations. For instance, the instructions for the "Command and Control" software to manipulate the Track 3 System is a direct reflection of the Track 3 System operator's ability to maneuver within the confines of a tank. Also the visibility and camera angle available to an operator performing "teach and learn" maneuvers inside a tank may prove to be deleterious if an operator misjudges distance and impacts in-tank hardware with sufficient force. The application of a laser range finder, PC based system integral to the "teach and learn" function of the "Command and Control" software would prove advantageous in assuring that in-tank maneuvers could be sufficiently controlled such that hits upon in-tank hardware would be minimized. This type of system was proposed for the testing program however as a result of budget concerns was not implemented.

In an effort to assist operators with respect to enhancing the "teach and learn" function of the "Command and Control" software, Geodetic and Photogrammetric mapping programs are available as a remedy to this situation. The issue of mapping pertains to the ability to obtain a "picture" of in-tank hardware, obstacles and waste arrangements. This "picture" is utilized to ensure safe in-tank operations. Mapping techniques employ a methodology which basically models and identifies all in-tank hardware using an array of laser range finders. The Geodetic and Photogrammetric techniques are PC based and have the ability to interface with the "teach and learn" function of the "Command and Control" software. The aforementioned mapping systems were not demonstrated.

In addition to the above it is noted that the positional repeatability tests were performed with the jib boom extended approximately 40 feet. There was no observable jerking or swaying in the movement of the jib boom at this distance. These tests were originally planned to be executed with the boom sections fully extended. In this regard sufficient deflection and drift of the boom may not be as precisely controllable as demonstrated at 40 feet reach.

#### 2.1.2.7. Disposition of Test Item

Testing with respect to performance of positional repeatability is complete. The wooden standard utilized in the test program will be recycled on the Nesbitt farm..

### 2.1.3. In-Tank Navigation

#### 2.1.3.1. Description of Test

This demonstration test focused upon the issue of "In-Tank Navigation". The issues of **"Obstacle Avoidance"** and **"Visibility"** are indirectly addressed by virtue of the testing protocol. The system being tested is the Track 3 System control capabilities relative to operator actions.

The following provides information specific to the identification of materials, components or systems tested.

Materials utilized to perform "in-tank navigation" testing included the following.

- Track 3 System with Rotec and positional pointer attached
- Four 5 foot tall standards with orange targets located at various elevations.
- Two EXXIS EO6500 Closed Circuit cameras.
- One EXXIS EO2120 black and white observation system.

**2.1.3.2.Test Method and Test Equipment**

The following describes how "in-tank navigation" testing was performed.

In -tank navigation was performed by placing four standards in various locations within the navigation field or range of the Track 3 System. These standards each had an orange target spray painted on it at various locations. In addition an orange target was placed on the left hand wall (as you face the Track 3 system) of the test area. Each target was numbered 1 through 5. The Track 3 System operator was tasked with navigating to each target and gently tagging the target with the pointer attached to the Rotec assembly, which in turn was attached to the jib boom. See **Figure 2.1.3-1** for arrangement of standards.

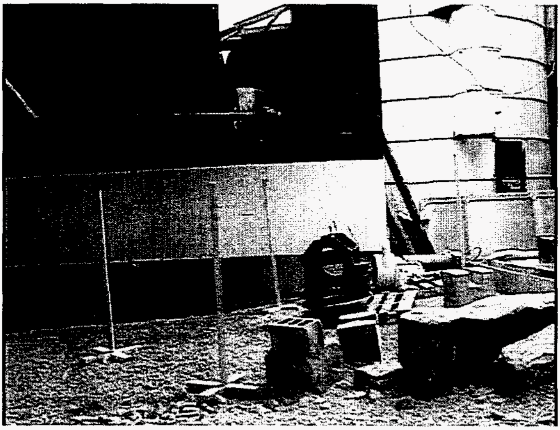


**Figure 2.1.3-1: Navigation Field**

Plan and elevation drawings depicting the naviagation course are presented in Appendix A, Section 1. Measurements relative to this test were obtained using a standard rule and by visual observation. Data collected from performance of testing is presented in **Appendix A, Section 1.**

### 2.1.3.3. Test Results

The results of the "in-tank navigation" testing verified the ability of the of the Track 3 System operator to use CCD cameras to navigate to pre-determined points located on the wooden standards. One in-tank navigation test was performed the results of which indicate 5 perfect target tags. For additional information pertaining to the similar issue topic of positional repeatability refer to **Section 2.1.2** of this report. Data obtained as a result of performing positional repeatability testing is presented in **Appendix A Section 1.**

**2.1.3.4.Issues Resolved**

The issue of **"in-tank navigation"** pertains to the ability of the Track 3 System to be maneuvered within a tank without impacting in-tank hardware. The significance of this issue relates to the ability of the Track 3 System to be controlled by an operator and perform intricate maneuvers in various planes and directions without impacting in-tank hardware and thusly achieving path goals. This test also demonstrates the ability of the Track3 System responsiveness to control software commands. The issue of **visibility** and **obstacle avoidance** are addressed in **Section 2.1.3.6**

**2.1.3.5.Method of Resolution**

The testing method employed to address the issue of "In-Tank Navigation" is outlined in **Section 2.3.2.**

**2.1.3.6.Results**

The resulting resolution to the issue of **In-Tank Navigation** is that the Track 3 System maintains the ability to navigate and maneuver through an intricate path without impacting in-tank hardware. This is achieved as a direct result of the responsiveness of the Track 3 System to control system commands. Applicability of In-Tank Navigation relates directly to initial waste removal operations and for exploring in-tank hardware and obstacles in an effort to establish safe paths which are integral to maintaining a positional repeatability data base of "safe" paths. In other words positional repeatability "safe" paths are contingent upon the responsiveness of the Track 3 System control software to operator commands and ultimately the responsiveness of the Track 3 System to the software commands. The in-tank navigation test results prove that operators can safely navigate and maneuver the Track 3 System to safe positions.

Limitations with respect to in-tank navigation relate to visibility in the tank. The issue of **visibility** pertains to the operators ability to see clearly any in-tank hardware or obstacle which could present a challenge to achieving a safe path. The issue of **obstacle avoidance** pertains to the ability of the Track 3 System to avoid collisions with in-tank hardware. The results of the Track 3 System testing protocol for in-tank navigation indirectly addressed the issues of visibility and obstacle avoidance. With respect to visibility the operator was able to see the target and standards on the closed circuit monitor well enough to allow for the navigation of the Track 3 System to the pre-determined target. Additionally while navigating to the target it was observed that the operator maintained a steady course with little deviation except to avoid obstacles in the test field. The in-tank navigation testing was performed in broad daylight, it is noted that the operator had a difficult time with depth perception. Although the operator completed the in-tank navigation testing flawlessly the use of color cameras and laser range finders could improve overall navigation of the Track 3 System. Refer to **Appendix A, Section 1** figures for the location of the CCD cameras on the jib boom and in the peripheral test field. Future testing of in-tank navigation, visibility and obstacle avoidance should include a more challenging array of targets and obstacles in addition to performance of testing in a dark tank using lighting fixtures attached to the Track 3 System.

#### 2.1.3.7.Disposition of Test Item

Testing with respect to performance of "in-tank navigation" is complete. The wooden standard utilized in the test program will be recycled on the Nesbitt farm..

### 2.1.4. Umbilical Management

#### 2.1.4.1.Description of Test

This section describes the umbilical management system. The umbilical management system is comprised of an array of retracting spools in addition to 6 roller assemblies strategically attached to the vertical and jib boom assemblies. See **Figure 2.1.4-1** for a view of the retracting spools. **Figure 2.1.4-2** depicts a view of the umbilicals as they run along the jib boom. The function of the umbilical management system is to ensure that umbilicals that provide services to the Track 3 System are easily maintainable, accessible, and serviceable. The umbilical management system also ensures that umbilical lines do not interfere with the operation of the Track 3 System i.e. umbilicals do not become entangled or severed and that minimum length umbilical is exposed to the in-tank environment. The types of umbilicals serviced by the umbilical management system include the following.

- 1-1 inch air line.
- 1-1 inch water line.
- 1-4 inch vacuum line.
- 8-1 inch hydraulic oil fluid lines which operate the boom cylinders end effector.
- Low voltage power lines which are used to operate the CCD cameras.

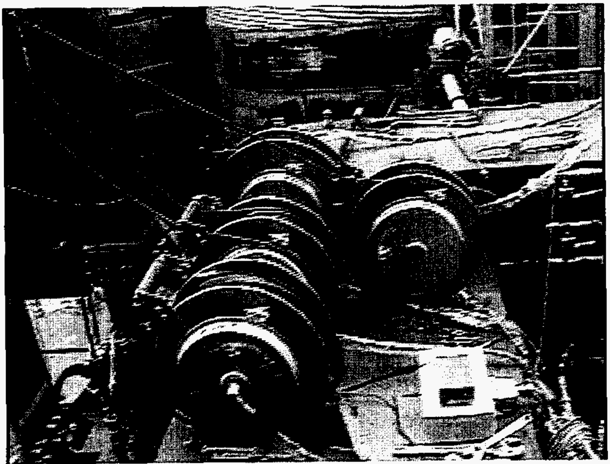


**Figure 2.1.4-1: Retracting Reels**

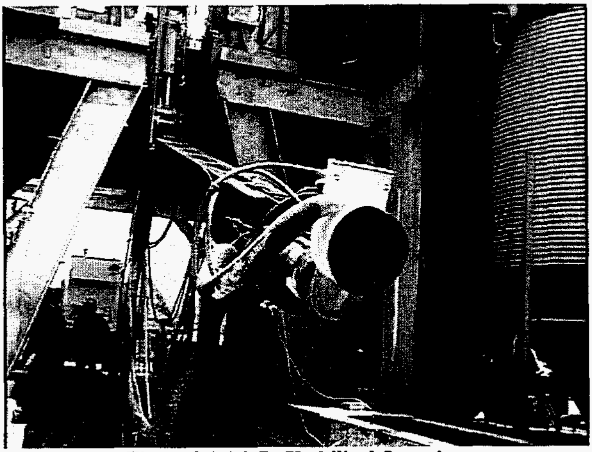


**Figure 2.1.4-2-7: Umbilical Overview**

**2.1.4.2.Test Method and Test Equipment**

Umbilical management testing was strictly an observational test. Test results are contingent upon the number of umbilical interference's observed which caused a delay or interruption in the testing program.

**2.1.4.3.Test Results**

The results of the umbilical management tests verify that an umbilical management concern exists. Track 3 System testing was interrupted more than 10 times as a result of umbilical interference's. Data collected from the performance of testing is presented in **Appendix A Section 1**

**2.1.4.4.Issues Resolved**

The issue of umbilical management pertains to the ability of the Track 3 system to control or effectively "manage" the position of hoses of various lengths and diameters in addition to any other support service such as low voltage wires required during any phase of operation the Track 3 System. The significance of this issue pertains directly to ensuring that umbilical's do not interfere with the safe operation of the Track 3 System. In other words umbilicals should be controlled to ensure the following...

- Entanglement with in-tank hardware is precluded.
- Severance of umbilical lines as a result of operations is precluded.
- Contamination of lines entering the tank and being retracted is minimized.
- Tripping and safety hazards minimized.
- Line segregation and identification is enhanced.

**2.1.4.5.Method of Resolution**

The method employed to address the issue of umbilical management was direct observation of the Track 3 System during operation. For additional information pertaining to this subject refer to **Section 2.1.4.2.**

**2.1.4.6.Results**

The results of the umbilical management test indicates that the Track 3 system in its current configuration does not effectively and safely manage umbilicals. In order to address this condition the following modifications are noted.

- Power operated spool reels are required with sufficient capacity to retract the umbilicals and yet allow for easy withdrawal in support of long reach in-tank operations.
- Umbilical routing should be through the boom sections.
- Umbilical management devices attached to the outside of the boom should not compromise tank access requirements.

**2.1.4.7.Disposition of Test Items**

Testing of the umbilical management system is complete. There are no items to be disposed of as a result of the performance of this test protocol.

## 2.2. Waste Dislodging, Retrieval and Conveyance, and Decontamination

The purpose of this test is to demonstrate the capability of the Track 3 system to deploy end-effectors into the tank and effectively dislodge various wastes with different compressive strengths. This test shall also evaluate the capability of the Track 3 system to retrieve and convey waste out of the tanks to a remote location for storage or processing. The capability of a proposed method of decontamination to effectively remove contaminants shall also be demonstrated. The Waste Dislodging, Retrieval and Conveyance portion of testing shall address the following key issues.

- Tank Shell Integrity
- Convey Simulants
- Retrieval Efficiency
- Actual vs. Simulated waste
- Scavenge Water
- Retrieval Rate
- Stand-Off Distance
- Decontamination

### 2.2.1. Waste Dislodging and Conveyance

#### 2.2.1.1.Description of Test

This following section provides information specific to the identification of materials, components or systems tested.

Three types of waste simulants were used for this test. These waste simulants are referred to as salt cake, wet sludge and dried sludge throughout this document. The recipe for the waste simulants are provided by the Department of Energy (DOE) and is presented in the Appendix C. The ingredients of salt cake, wet sludge and dried sludge corresponds to recipe number 4, 1 and 3 respectively. These simulants were prepared in accordance with the recipe and were stored in three cylindrical tanks with a diameter of 8 ft. The simulant filled tanks were kept in a pit 15 ft in depth (**Figure 2.2.1-**

1). This arrangement was made so as to mimic the actual tank cleanup operation.

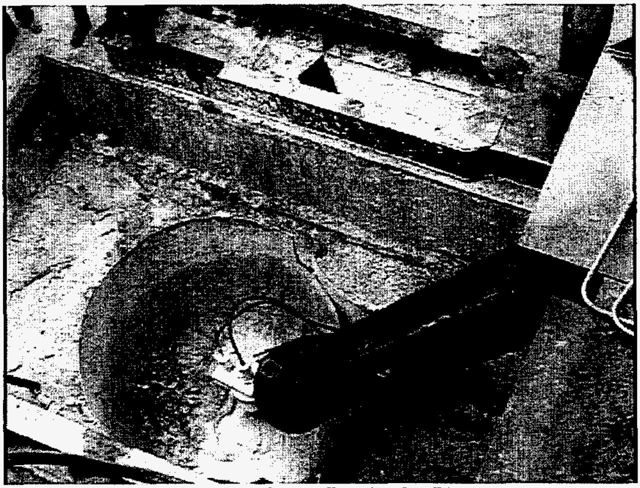


**Figure 2.2.1-1: Dry Sludge Pit**

Waste dislodging was performed by a scarifying device. In this document this device shall be referred to as WALDO or the Waste And Liquid Dislodging Orbitor. It consists of a spin jet nozzle mounted at the center of the shroud (See **Figure 2.2.1-2** and **2.2.1-3**). The nozzle is capable of providing a water jet at various pressures used for sluicing purpose. Liquid and the dislodged waste is removed by vacuum. The vacuum pipe (4 inches in diameter) is attached to the shroud wall of WALDO.

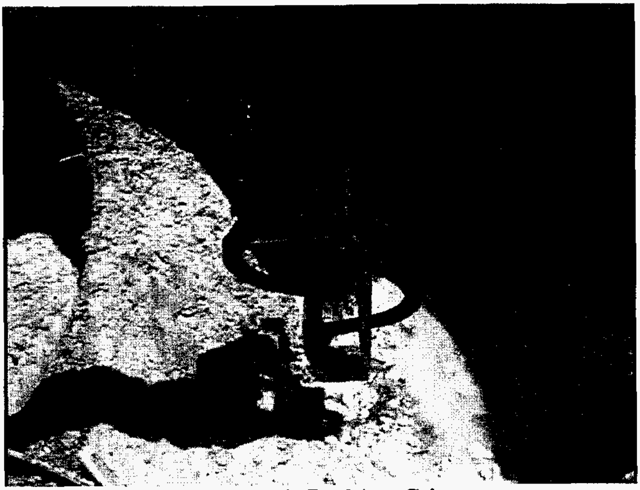


**Figure 2.2.1-4: Dual Arm Gripper**

Dislodged waste and the water used for the sluicing operation was retrieved using two separate systems. In one set of test, the waste was retrieved by vacuum and discharged into a vacuum truck using a twin lobe blower providing 27 inches of Hg vacuum (**Figure 2.2.1-6**). The vacuum truck is a MASTERVAC Model 3127DC. In the second set of retrieval tests, vacuum was used to transfer the waste from the tank to an intermediate holding tank called the CATS or Conditioning And Transfer System. CATS consists of a vertical cylindrical shell 20 inches in diameter and 15 ft in height. A pump placed at the bottom of the shell is capable of discharging the waste present in CATS (**Figure 2.2.1-7**). By opening and closing appropriate valves, more water can be added to the waste present inside CATS and the waste can be recirculated so as to produce an uniformly dispersed waste throughout the body of the liquid.

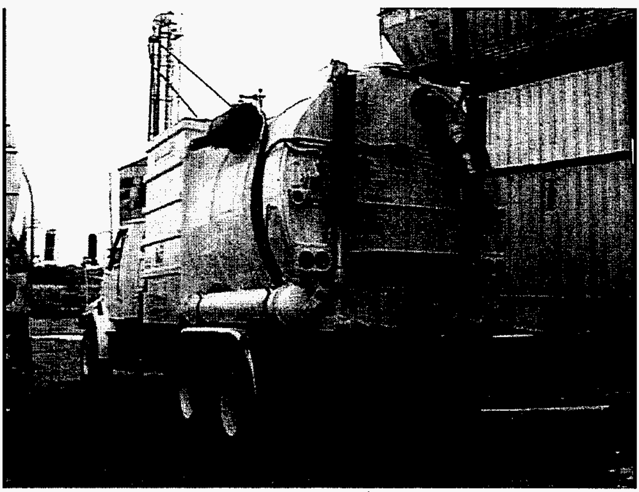


**Figure 2.2.1-8: VACTRUCK**

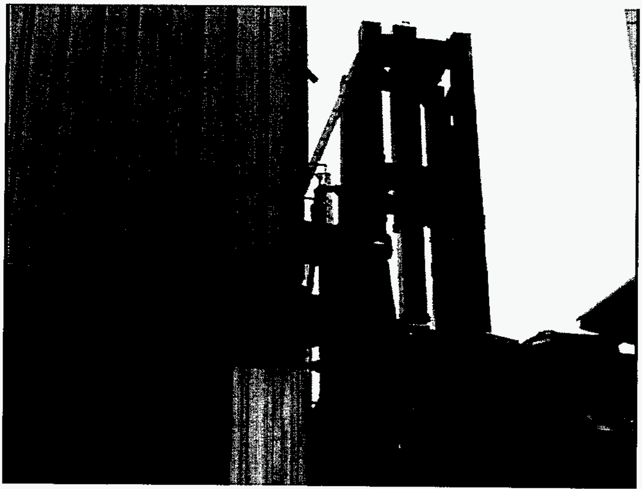


**Figure 2.2.1-9: CATS**

The high pressure water jet used for the sluicing operation was provided by National Liquid Blasting (NLB) corporation using Model No. 20253D High Pressure Liquid Jetting System (**Figure 2.2.1-10**).

**Figure 2.2.1-10: Hydrolaser Vehicle**

### 2.2.1.2.Test Method and Test Equipment

The following describes how the test was performed and how measurements were taken.

Track 3 System deployed WALDO in each of the simulant tanks for the purpose of dislodging and retrieving waste. WALDO utilized a high pressure water jet attached to a spin jet to dislodge waste. The waste was then retrieved using vacuum suction(**Figure 2.2.1-11**).

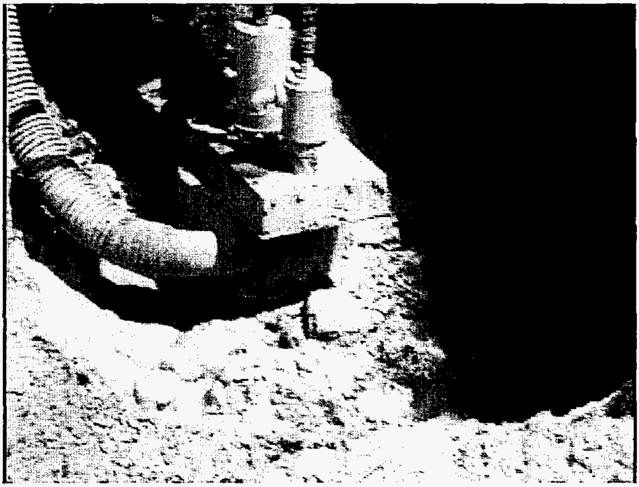


**Figure 2.2.1-11: Waste Dislodging**

As mentioned earlier two types of retrieval system were tested investigated. In the first set of tests CATS was used for waste retrieval. Wet sludge and dried sludge were sluiced with the water jet employing three separate pressures: 5000, 15000, and 20000. Salt cake having a high compressive strength (20, 700 kPa) could not be eroded significantly employing lower pressures. Consequently only 20,000 psi was used to dislodge saltcake. Waste present in the CATS was then discharged to a sampling station located 40 ft above grade. At the sampling station, samples were taken to determine percentage solids and CATS discharge rate was determined by filling a calibrated drum in a given period of time (**Figure 2.2.1-12**).

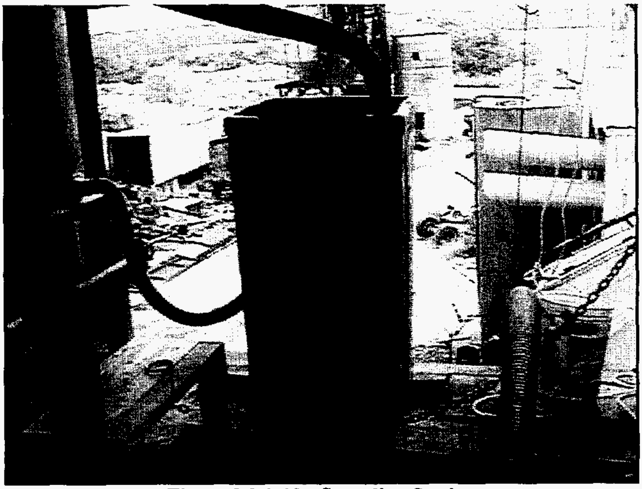


**Figure 2.2.1-12: Sampling Station**

In the second set of tests waste was discharged into the vacuum truck instead of CATS. In these set of tests only 20,000 psi was used as the sluicing pressure. Conveyance rate for each operation was determined by measuring the volume of waste in the vacuum truck and dividing it by the time period of operation. Conveyance rate indicates the rate of waste removal from the tank. This should not be confused with the discharge rate calculated for the CATS. In these set of tests only a limited number of samples were grabbed for percentage solids analysis.

Dislodging and retrieval operations involved blasting the simulant with high pressure water jets and the dislodged waste and the sluicing water was retrieved using vacuum. Although vacuum was deployed throughout the operation, water blasting was used intermittently so as to minimize the continuous use of water. Typically, blasting was deployed for 1 minute and turned off. The waste liquid created by the blasting operation was then suctioned off by lowering WALDO into the pool of liquid, displaying our ability to scavage water. The blasting operation was again deployed after the removal of the waste liquid. The mining operation continued until the bottom of the simulant tanks were exposed. The orientation of WALDO was adjusted with help of the ROTEC mounted on the jib boom, so as to deploy the water jet perpendicular to the tank wall. This feature of the Track 3 System was utilized to clean the tank wall. (**Figure 2.2.1-13**)

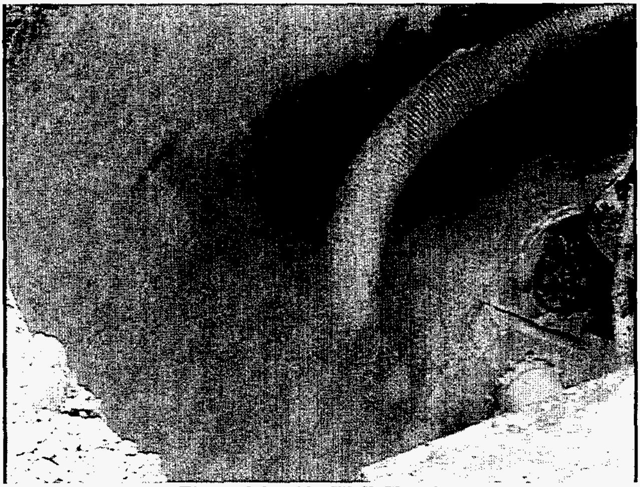


**Figure 2.2.1-13: Wall Cleaning**

In an effort to visualize the decontamination process we have added traces of Sodium-Fluorescene to the wet sludge simulant. After dislodging and retrieval of simulated wastes, traces of fluorescene should adhere to the end effector and should fluoresce under black light (wave length of 490 nm) examination. Small particles of simulant which are imperceptible to the human eye can be detected due to fluorescence.

Since all three simulants are inorganic compounds, water wash decontamination system was deemed most effective. For the purpose of decontamination, the end effector (WALDO) was rinsed with 5000 psi water jet for 2 minutes. The rinse water was collected. The end-effector was again rinsed with 5000 psi water jet for 2 minutes. The second rinse water was also collected. The level of fluorescence of the initial and final rinse water can determine the level of contamination present in the samples and thus indicating the effectiveness of the decontamination process. Visual examination of the decontaminated end-effector was performed under black light (wavelength 490 nm) (**Figure 2.2.1-14**).

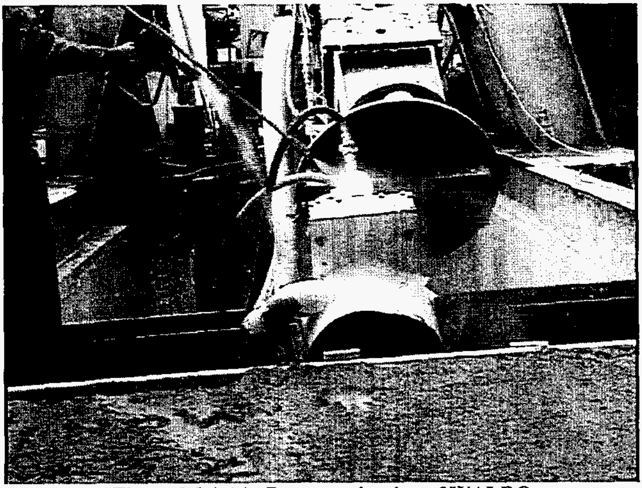


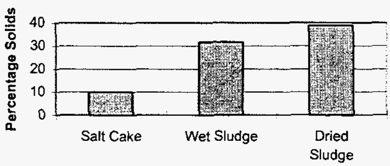
**Figure 2.2.1-14: Decontamination of WALDO**

### 2.2.1.3.Test Results

As mentioned earlier, three water jet pressures were employed for dislodging waste simulant: 5,000; 15,000 and 20,000. With wet sludge and dry sludge, it was evident that higher pressure produced deeper penetration. For salt cake, 5000 psi and 15000 psi did not produce any significant erosion of the waste. Consequently, for saltcake removal only 20,000 psi was used for all mining operations.

Hydrolasing of the wet sludge produced small clumps of the waste dispersed throughout the body of the liquid. The resulting liquid was fairly homogeneous. Allowing the liquid to stand would tend to allow small clumps to settle out. Dried sludge produced a thick viscous liquid, where the kaolin clay was completely dispersed and does not separate out with time. Both the liquid and solids can be sucked by the vacuum without any problem. Saltcake having a high compressive strength produced liquid waste containing almost 90% water with very fine grains of sand like salkcake dispersed in water. This observation is supported by the analysis of percentage solids found in waste sample obtained at 20,000 psi blasting pressure for various simulants (**Figure 2.2-11**).

**Figure 2.2-11. Effect of 20,000 psi Blasting Pressure on Simulated Wastes**




The **Figure 2.2-11** shows that percentage solid for salt cake is well below 30% and therefore does not pose a clogging problem. However, waste liquid from the wet sludge and dried sludge contains between 30% to 40% total solids and may require further dilution by addition of water. During the performance of tests no major clogging was observed except once: discharge of the CATS was clogged by dried sludge. The clog was easily removed by applying vacuum. This is expected since the above graph shows that dried sludge produced the maximum percentage solids. This problem can be dealt with by using back flush and/or dilution. Dilution can be achieved by adding water to the CATS.

Percentage solid is governed by the blasting pressure. The effect of blasting pressure on the percentage solids of wet sludge and dried sludge is shown in **Figures 2.2-12** and **2.2-13.**

**Figure 2.2-12. Effect of Blasting Pressure on Dried Sludge**

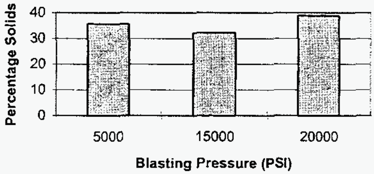
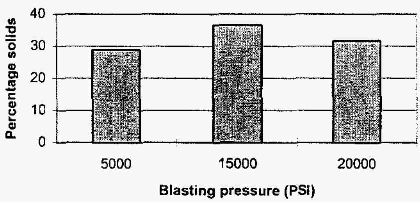



**Figure 2.2-13. Effect of blasting pressure on Wet Sludge**

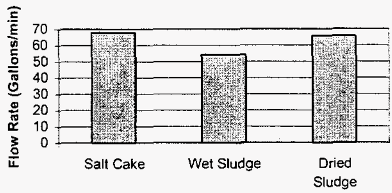



In both dried sludge and wet sludge, 20,000 psi produced higher percentage solids than 5,000 psi. This may be because increase in blasting pressure caused increased dislodging of the simulated waste. However, a different trend was noticed at 15,000 psi: for dried sludge, 15000 psi produced less percentage soilds whereas for wet sludge it produced higher percentage solid compared to 5,000 psi. This difference in trend may be due to the inherent property of wet and dried sludge.

As mentioned earlier, two types of retrieval systems were investigated: CATS and direct to the vacuum truck. When

CATS was used, the waste from the tank is temporarily stored in a holding tank and then the waste is eventually pumped out of CATS with or without conditioning of the waste. The graph below (**Figure 2.2-14**) shows the rate of discharge from the CATS for three waste simulants.

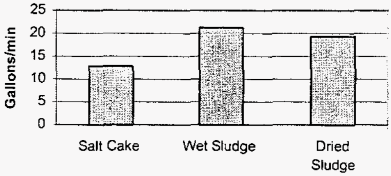
**Figure 2.2-14. Waste Discharge from the CATS**




The above graph shows that the rate of waste discharge is well above the required 30 GPM flow rate (**Figure 2.2-14**).

It must be noted that the flow shown above is the rate of discharge from CATS and is not indicative of rate of waste removal from the tank. The rate of waste conveyance from the tank was measured in the second set of tests. In these tests waste from the simulant tank was discharged into the vacuum truck. For each waste removal operation, the total volume of waste removed from the tank as well as the time period of operation was noted to calculate the conveyance rate from the tank:

**Figure 2.2-15. Conveyance Rate of WALDO**




The above graph (**Figure 2.2-15**) shows that retrieval rate from the tank was well below 30 GPM. The low retrieval rate is the result of the manner it was calculated. For example, flow rate was calculated as the volume retrieved over the time period of operation. However, WALDO was not engaged in retrieval operations throughout the entire period of operation: no significant amount of liquid was retrieved during the blasting operation and other maneuverings of WALDO. This has artificially lowered the retrieval rate values.

The waste dislodging operation was carried out with a high degree of accuracy without undergoing collision with the tank wall or other structures. The cavity in each of the simulant tanks was carved out by precisely guiding the arm in a given direction within the tank. The presence of the shroud in WALDO effectively eliminated any misting. Some misting was observed when the stand-off distances were large. Wet sludge and dried sludge operations were continued until the bottom of the tank was exposed. No damage of the tank bottom was observed. The Bottom of the tank containing saltcake was not exposed since mining operation was discontinued due to time constraint; 61 minutes was required to carve a cavity with dimensions 26"x28"x42" (**Figure 2.2.1-15, 2.2-16, 2.2-17**).

**Figure 2.2.1-15: Wet Sludge**

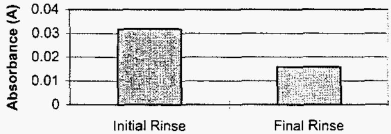
**Figure 2.2.1-16: Dried Sludge**


**Figure 2.2.1-17: Salt Cake**

The usual angle of attack was 90°. Changing the angle of attack did not produce any change in the dislodging capability. A limited number of operations was performed with a smaller size nozzle. Use of smaller nozzle resulted in the lowering of force delivered and thus lowered the depth of penetration. Also, the temperature of the water jet was elevated resulting in the generation of steam. This contributed to misting.

Visual examination of the end effector showed the presence of simulants adhering to its surface. However, the interior of the WALDO was free of any simulant particles. This may due the intense turbulence created during the blasting operation. Due to cost constraints, fluorimetric analysis could not be performed. Consequently, no quantitative data for the effectiveness of decontamination could be collected. However, the initial and final rinse sample were colorimetrically analyzed (Figure 2.2-19):

**Figure 2.2-19. Effectiveness of Decontamination**




The above graph (Figure 2.2-19) shows that there is almost 50% reduction in the absorbance reading. It is not clear if this is due to reduction in the Sodium-fluorescene level. Black light (wavelength of 490 nm) examination of the end-effector was performed. No flourescence was detected on the end-effoector. However, parts of the ROTEC where no decontamination was performed, fluorescence was observed under black light examination.

### 2.2.1.4.Issues Resolved-Tank Shell Integrity

#### 2.2.1.4.1.Description of the Issue Resolved

The issue of tank shell integrity pertains to the ability of the Track 3 System to enter the simulant tank safety and effectively dislodge the waste without compromising the structural integrity of the tank. Since high pressure jet was used for dislodging the waste, care must be taken to observe the effect of clean-up on the tank walls. This also includes the occurrence of events such as collision of the Track 3 System with the tank wall.

#### 2.2.1.4.2.Method of Resolution

The method employed to resolve this issue was to deploy the Track 3 System for the purpose of dislodging simulated waste. Efforts were made such that the operations exposed the bottom of the tanks. Also, water jet was applied perpendicular to the tank wall and visual observations were made.

#### 2.2.1.4.3.Results

The Track 3 System found to be capable of maneuvering inside the tank and effectively dislodge simulated waste without compromising the structural integrity of the tank. No physical collision of the Track 3 System with the tank wall was observed. No damage or leakage of the tank due to the sluicing operation was discernible. When 20,000 psi was applied perpendicular to the tank wall, it was able to remove paint. However, no structural damage was observed

**2.2.1.4.4.Disposition of Test Item**

All material used in this test shall be recycled or shall be disposed of in compliance with environmental laws

**2.2.1.5.Issues Resolved - Convey Simulants, Retrieval Rate**

**2.2.1.5.1.Description of Issues Resolved**

This pertains to the ability of the Track 3 System to convey various type of simulant out of the tank. Efforts shall be made to quantitatively determine the retrieval rate of simulants from the tank

**2.2.1.5.2.Method of Resolution**

The method employed to resolve this issue was to deploy the Track 3 System for the purpose of retrieving dislodged waste and sluicing water from the tank. Discharge rate from the CATS was measured. Rate of waste removal from the tank was also measured. Observations were made as to how easily various simulants were transferred out of the tank.

**2.2.1.5.3.Results**

The respective discharge rate for salt cake, wet sludge and dried sludge from CATS was found to be 68, 54.4 and 66 gallons/min. This flow rate is well above the required 30-60 gallons/min. However, this number does not represent the rate of waste removal from the tank. A superficial waste removal rate for saltcake, wet sludge and dried sludge was calculated to be 12.9, 21.3 and 19.4 gallons/min respectively. Reason for the apparent low value of the flow rate is explained in section 2.2.3. The waste liquid resulting from the salt cake is low in percentage solid and therefore does not pose clogging problems. However, wet sludge and dried sludge are higher in percentage solids (greater than 30% but less than 40%). In one occasion CATS discharge pipe was clogged by dried sludge. This can be remedied by diluting the liquid waste by adding water to the CATS. It must be noted that no clogging was observed when CATS was not employed, i.e. waste was directly discharged into the vacuum truck.

#### 2.2.1.5.4.Disposition of Test Item

All material used in this test shall be recycled or shall be disposed of in compliance with environmental laws

### 2.2.1.6.Issues Resolved - Retrieval Efficiency, Scavenge Water

#### 2.2.1.6.1.Description of the Issues Resolved

These issues pertain to the ability of the Track 3 System to efficiently retrieve waste. Sluicing of the waste with water can create large quantity of water inside the tank. In an effort to minimize that, Track 3 System should be capable of scavenging water generated during the sluicing operation.

#### 2.2.1.6.2.Method of Resolution

The method employed to resolve this issue was to deploy the Track 3 System for the purpose of dislodging and retrieving simulated waste from tanks. Time required to carve out a given volume of waste from the tank was noted. Also, visual observations were made as to the ability of the Track 3 System to scavenge water.

#### 2.2.1.6.3.Results

Wet sludge and dried sludge can be readily dislodged and retrieved. However, saltcake having a higher compressive strength requires longer sluicing time. For example, 61 minutes were required to curve out a rectangular cavity in salt cake measuring 26"x38"x42". Whereas creation of a rectangular cavity in dried sludge (28"x45"x52") took approximately 12.5 minutes. For wet sludge and dried sludge, the liquid waste generated due to the sluicing operation can be easily scavenged since WALDO can burrow its way through the softened dried sludge and wet sludge. Such a maneuver is not possible in the case of salt cake. Sluicing of the salt cake often produces cavities filled with water. Since the surface of the salt cake is hard, the vacuum nozzle of WALDO can not get close enough to scavenge water in large volumes. This can be remedied by making modification to WALDO.

#### 2.2.1.6.4.Disposition of Test Item

All material used in this test shall be recycled or shall be disposed of in compliance with environmental laws

### 2.2.1.7.Issue Resolved - Stand-Off Distance

#### 2.2.1.7.1.Description of the Issue Resolve

This issue pertains to the determination of **stand-off distance** of the high pressure water jet for effective waste dislodging. Stand-Off distance determines the force delivered to the impinging surface. Low stand-off distance may compromise the structural integrity of the tank wall. On the other hand, high stand-off distance may lower the ability of the system to dislodge waste.

#### 2.2.1.7.2.Method of Resolution

The method employed to resolve this issue was to deploy the Track 3 System for the purpose of retrieving dislodged waste from the tank. No quantitative data were taken to investigate the effect of stand-off distance. Rather, visual observations were made with regard to stand-off distance

#### 2.2.1.7.3.Results

The distance between the spin jet nozzle and the WALDO shroud was 3 inches. Therefore the minimum stand-off distance employed was 3 inches. Maximum penetration was achieved when the stand-off distance was minimum, i.e. 3 inches. A dramatic lowering of the sluicing effort was notices with large stand-off distances specially with saltcake dislodging. Also, large stand-off distance contributed to misting thus lowering visibility.

**2.2.1.7.4.Disposition of Test Items**

All material used in this test shall be recycled or shall be disposed of in compliance with environmental laws

**2.2.1.8.Issues resolved - Decontamination, Maintenance Decontamination**

**2.2.1.8.1.Description of the Issue Resolved**

The Track 3 System shall be deployed to clean up single shell tank (SST) in the Hanford Reservation. Since these tanks were used to store chemicals formed during the plutonium recovery process, they will contain high level of contamination. Therefore, the manipulator arm, end-effectors and other equipment that will be placed in the tank should be designed for ease of **decontamination**.

**2.2.1.8.2.Method of Resolution**

The method employed to resolve this issue was to deploy the Track 3 System for dislodging and retrieving wet sludge containing traces of Sodium-Fluorescene. Then the end-effector was rinsed twice with a 5000 psi water jet for 2 minutes. The rinse water resulting from the above process was collected and analyzed colorimetrically. Also, the decontaminated end-effector was examined under black light (wavelength of 490 nm).

**2.2.1.8.3.Results**

The simulated waste being inorganic compounds, water wash decontamination system was found to be effective in removing contamination. This was evidenced by the colorimetric analysis and black light examination (See section 2.2.3 for details).

**2.2.1.9.Issues Resolved - Actual Waste vs. Simulated Waste**

**2.2.1.9.1.Description of the Issue Resolved**

When the wastes from the reprocessing plant were discharged into the Hanford SST, it consisted of liquid and sludges. The liquid contained various compounds such as hydroxides, sulfates, and phosphates of iron, aluminum, and zirconium that did not dissolve. These formed a sludge layer in the tank bottom. In later years, in order to make room for more waste, more saltcakes were precipitated by adding different additives. The Track 3 System should be designed such that it is capable of dislodging and retrieving these wastes from the SST.

**2.2.1.9.2.Method of Resolution**

A kaolin clay simulant and a potassium magnesium sulfate have been developed by DOE as a limited representation of the of sludge and salt cake wastes. The three simulants present in the tank were prepared in accordance with a DOE recipe (Appendix C). Several samples of the simulated waste were sent to DOE laboratory for analysis of their compressive strength.

**2.2.1.9.3.Results**

Although there is no guarantee that simulated waste shall represent the actual waste, we are confident that if the Track 3 System is capable of handling the two extreme case such as the salt cake and sludges, it can be effectively deployed to clean-up actual tank. Also, a number of debris material are present in the actual tanks. We have tried to mimic this by introducing gravel and large stones. The Track 3 System had no problem in retrieving stone and gravel. We have also utilized a dual arm gripper to retrieve large objects from the tank.

## 2.3. Static and Dynamic Testing

The purpose of the Static and Dynamic Testing is to insure that forces and frequencies, vibration modes, dynamic response, resonant frequencies, and mode shapes do not pose a safety consideration in terms of the structural capability of the Track 3 System. Data collected is presented in **Appendix A, Section 3**. The Dynamic testing program addresses the following key issues.

- Forces and Frequencies
- Mode Shapes
- Vibration Modes
- Dynamic Response
- Resonance Frequencies
- Static Deflection

### 2.3.1. Dynamic Testing

#### 2.3.1.1. Description of Test

The response of the Track 3 System to dynamic stimulation is being tested. The components and testing equipment used to determine frequency response, vibration modes, and mode shapes of the Track 3 System are identified herein.

#### 2.3.1.2. Test Method and Test Equipment

Dynamic testing was performed by placing accelerometers on predetermined locations on the Track 3 System and then striking with a hammer to produce vibrations. The frequency response of the Track 3 System was detected by the accelerometers.

The test equipment utilized to perform the testing included the following items:

- 4-Integrated Circuit Piezoelectric (ICP) triaxial accelerometers
- 2-multi channel programmable ICP power supply 8 channel signal conditioners
- 12lb calibrated hammer
- 10lb steel sledge hammer
- Dell XPS P133c computer

- CIO-DAS1401/12 data acquisition board
- HP VEE Visual Programming Software

The accelerometers are the focal point of the testing program. They have a magnetic base for mounting the arm and emit a signal at 100mV per unit of gravity. The accelerometer contains three outputs (one for each axis of direction). **Figure 3.1.1-1** shows the accelerometer.

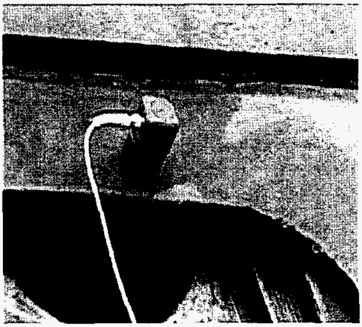


**Figure 3.1.1-1 Accelerometer**

The accelerometers are connected to an 8 channel signal conditioner which provides the power supply for its inputs as depicted in **Figure 3.1.1-2**. The signal conditioner is connected to the data acquisition board and emits analog signals which are converted to digital signals. The digital signals are used with the HP VEE program . The calibrated hammer resembles a sledgehammer and weighs 12lbs. This hammer is depicted in **Figure 3.1.1-3**. It has different textured tips for the head which provide different sensitivity.

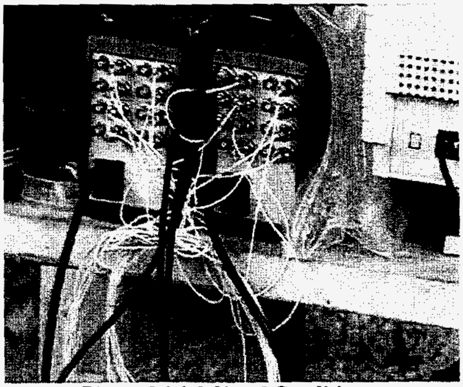


**Figure 3.1.1-2 Signal Conditioner**

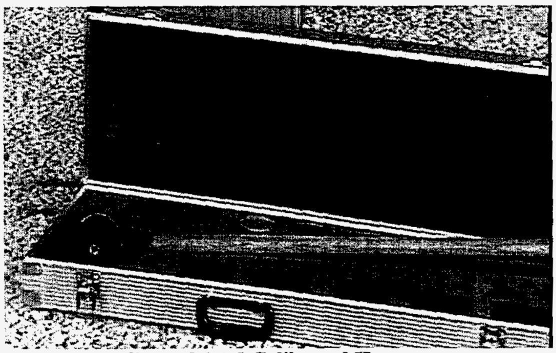


**Figure 3.1.1-3 Calibrated Hammer**

HP VEE(Hewlett Packard Visual Engineering Environment) software was used as part of the testing protocol. HP VEE is a powerful visual computer programming language. To develop programs, you connect graphical objects instead of writing lines of code. These programs resemble easy to understand block diagrams with lines. The methods of programming was used by using **References 3 and 4**. You can visualize the data on any type of graph in real time or its fourier transform. The program also stores your raw data into a file to be used for later use. For example, a data file that was performed in real time can be later converted into the frequency domain. **Figure 3.1.1-4** depicts the computer workstation.

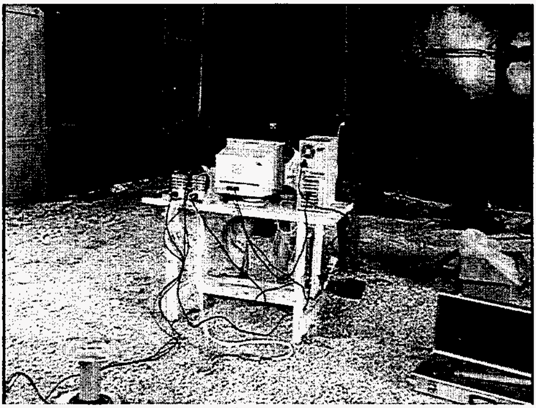


**Figure 3.1.1-4 Computer Workstation**

In order for HP VEE to recognize the accelerometer's signal, the computer must have a data acquisition board. The board used for this project is the CIO-DAS1401/12 which is manufactured by Computer Boards, Inc. Its primary function is to perform analog to digital conversions. The board can acquire data from 16 single ended channels at a time. Specifying the sampling rate and duration of the test is done in HP VEE. Board installation and setup was achieved by using **References 1 and 2**.

Originally, the dynamic testing program required an accelerometer to be placed at each telescoping boom segment. Due to a cable failure at the site, we were limited as to the number of sensors that could be used. Four accelerometers were placed on the jib boom and two accelerometers were placed on the mast assembly and the vertical boom.

Another modification to our original test procedure is the use of a standard 10lb steel sledgehammer. The use of this hammer allowed for increased vibration, hence better data to compare to the calibrated hammer.

As the arm is impacted by a hammer, the vibration sensed by the sensors is sampled by the HP VEE program. When the duration of the test is over, the program stops running and a real time graph for each individual accelerometer is displayed. The raw data is saved to a file which will be used in the future for observing its frequency characteristics.

**2.3.1.2.1.Jib Boom Testing**

Four accelerometers were placed on the jib boom The jib boom was at an angle of 30 degrees and experiencing an additional load of 1180 lbs as a result of the Rotec and WALDO assemblies. Each accelerometer was located as follows:

- Accelerometer One: Bottom tip of the boom
- Accelerometer Two: Top of outermost telescoping section
- Accelerometer Three: Stationary Boom
- Accelerometer Four: Knuckle Assembly

**Figure 3.1.1-5** depicts the placement of an accelerometer.

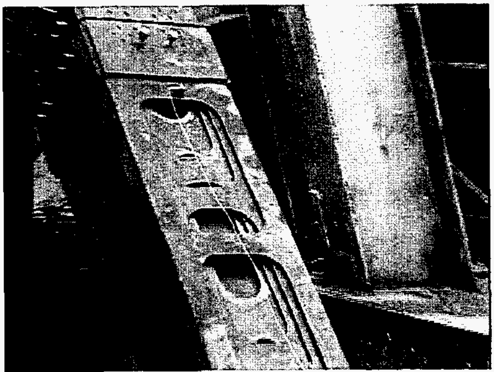


**Figure 3.1.1-5 Sensor placement on jib boom**

There were two types of tests. One striking the jib boom at the bottom tip of the boom with a non-calibrated steel sledgehammer, the other striking it with the calibrated hammer. There were three trials taken for each hammer in order to obtain data. The sampling rate was 60Hz and the duration of each test was 30 seconds. Striking the arm and the direction of axes is depicted in **Figure 3.1.1-6**.

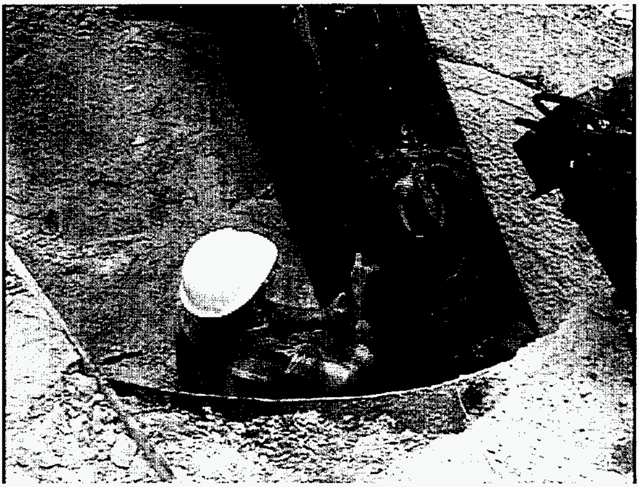


**Figure 3.1.1-6: Striking of the jib boom**

The direction of the accelerometer axes are as noted below:

X: Perpendicular to the jib boom to the left when facing the arm from the pole barn

Y: Towards the knuckle joint

Z: Towards the sky

### 2.3.1.2.2.Mast Assembly Testing

Two accelerometers were placed on the mast assembly. Accelerometer one was placed on top of the mast while accelerometer 2 was placed closer to the platform. Refer to **Figure 3.1.1-7** for placement of an accelerometer.

**Figure 3.1.1-7: Placement of sensor on mast assembly**

The jib boom was horizontal and did not have any load attached to it. Two types of tests were performed. One striking the mast with a non-calibrated steel sledgehammer, the other striking with the calibrated hammer. The sampling rate was 60Hz and the duration of test was 30 seconds. This test had two trials for each hammer. As a result of only having two accelerometers on the Mast Assembly, another test was performed with the accelerometers located in intermediate positions. This test correlates with trials 3 and 4. Accelerometer 2 was placed 8'6" above it's relative location in trials 1 and 2 in order to observe the frequency response at different location on the mast. This was performed for both hammers. Striking the arm and the direction of axes is depicted in **Figure 3.1.1-8**.

**Figure 3.1.1-8: Striking the mast assembly**

The direction of the accelerometer axes are as noted below:

- X: Towards the camera
- Y: Towards the sky
- Z: Towards the right when facing the arm from the pole barn

**2.3.1.2.3. Vertical Boom Testing**

Two accelerometers were placed on the vertical boom. Accelerometer one was placed at the top of the vertical mast while accelerometer two was placed on the knuckle. Refer to **Figure 3.1.1-9** for placement of the accelerometers.

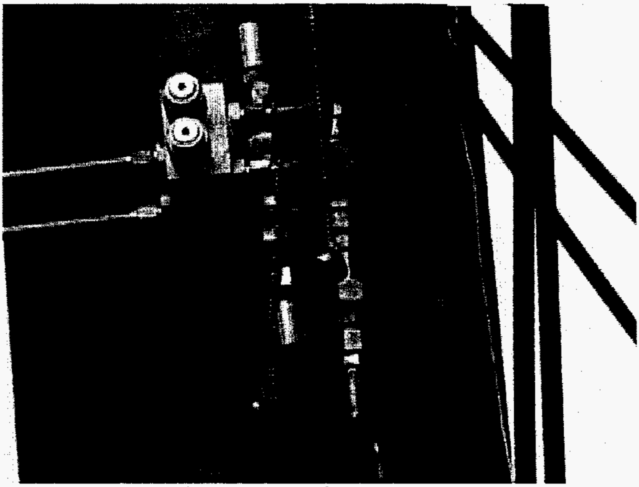


**Figure 3.1.1-9: Placement of a sensor on mast assembly**

The jib boom was horizontal and did not have any load attached to it. There were two types of tests performed. Striking the vertical boom with a non-calibrated steel sledgehammer, the other striking with the calibrated hammer. The sampling rate was set at 60Hz and the duration of each test was 30 seconds. Striking the arm and the direction of axes is depicted in **Figure 3.1.1-10**.

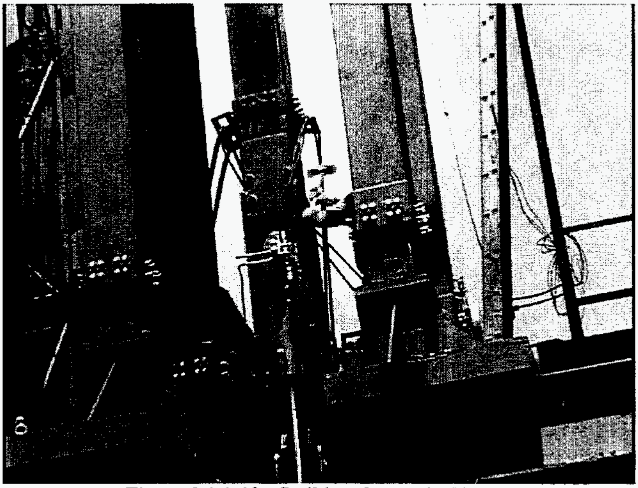


**Figure 3.1.1-10: Striking the vertical boom**

The direction of the accelerometer axes are as noted below:

- X: Towards the camera
- Y: Towards the sky
- Z: Towards the right when facing the arm from the pole barn

**2.3.1.3.Test Results**

Test results are discussed below and in **Appendix A , Section 3.**

There are two graphs on each page. The top graph is the fourier transform. The bottom graph is the magnitude vs. time. The magnitude is not a voltage value rather it is in counts. Therefore the conversion for voltage is:

(Magnitude/4095)*(10V /Gain)

The number 4095 corresponds to the maximum number of counts the board has and the gain corresponds to what was set on the signal conditioner. The value 10 is the voltage range of the board. The major divisions on the graph correspond to the number underneath the maximum of the range. For example, the first graph for Jib Boom Testing has a maximum of 1.4M. It has seven divisions each being 200k. Therefore 7*200k = 1.4M. The sampling rate of the system was at 60Hz. Each time a plot was performed at a range of 0 to 30 seconds. For the fourier transform, an interval that contained the most data was displayed. Each plot contains three curves which correspond to the three axis's of direction. Each are labeled accordingly. The accelerometer has a sensitivity reading of 100mV/g.

The calibrated hammer plot is performed in real time in a range of 0-30 seconds. Its plot is beside the fourier and time domain plots. The calibrated hammer has a sensitivity of 1.14mV/Ibf or .26mV/N.

#### 2.3.1.3.1.Jib Boom Test Results

Refer to **Appendix A, Section 3**, Jib Boom Data for all graphs.

Referring to the fourier transforms, it can be clearly observed that for accelerometer one, the metal hammer had higher magnitudes than the calibrated hammer. This is because the metal hammer produces higher vibration by striking steel on steel. The calibrated hammer is padded with a textured tip. Accelerometers 2, 3, and 4 had similar magnitudes for both hammers. It seems that there was an error to the reading of the calibrated hammer. Its waveform should have been a spike but instead it resembles a curve. Its gain was set to 10 for all of the trials.

It should be noted that the gains for the accelerometers 2, 3, and 4 were set fairly high because the system was not picking up the accelerometer's signal. Therefore clipping might have occurred for some of their plots graphs.

### 2.3.1.3.2.Mast Assembly Test Results

Refer to **Appendix A, Section 3**, Mast Assembly Data for these results.

The fourier transform plots show higher magnitude for accelerometer two since it was the closest to the hammer's impact. For the metal hammer, there is not a big difference between the magnitudes of both sensors as opposed to the calibrated hammer. Therefore the metal hammer produced significant vibration all along the whole mast assembly.

The hammer had a gain of 1 to 1 for all of the trials. In trial 2 for the calibrated hammer, the mast assembly was struck once and then the hammer was dropped on the floor. This results in two spikes for the hammer waveform vs. time graph.

It should be noted that the gain for accelerometer two was set fairly high because the system was not picking up the accelerometer's signal. Therefore clipping might have occurred for some of these graphs. Due to the nice breeze we had on this day, the sensors picked up the wind and the magnitudes are slightly higher.

Another important note is channel to channel skew. As can be seen from the calibrated hammer graphs for accelerometer one, the hammer's graph is identical to the waveform vs. time graph. This is because the accelerometer's X signal was so small that the specific channel on the data acquisition board picked up the hammer's signal. This is common with this model data acquisition board.

### 2.3.1.3.3.Vertical Boom Test Results

Refer to Appendix A, Section 3, Vertical Boom Data for all graphs.

From the metal hammer fourier transforms, it can be seen that accelerometer two had a considerably higher magnitude than accelerometer one. For the calibrated hammer both magnitudes were fairly close. Since the vertical boom was so dense, the gains for both sensor were set to 100. Due to the nice breeze and the high gain, the magnitudes are slightly higher. The hammer had a gain of 1 to 1 for all of the trials and it did not produce significant vibration to the vertical boom.

An important note is channel to channel skew. As can be seen from the calibrated hammer graphs for accelerometer one, the hammer's graph is identical to the waveform vs. time graph. This is because the accelerometer's X signal was so small that the specific channel on the data acquisition board picked up the hammer's signal. This is common with this model data acquisition board.

#### 2.3.1.4.Issues Resolved

The results of the dynamic testing program will be utilized to provide the foundation from which further dynamic analysis of the Track 3 System can proceed. In this regard, the final results relative to this topic will become available ten days following submittal of this document. The final analysis shall ensure that the issues of **forces and frequencies, vibration modes, dynamic response, resonant frequencies, and mode shapes** do not pose a safety consideration in terms of the structural capability of the Track 3 System. In addition, the dynamic analysis shall establish the location of accelerometers which will be utilized to sense potentially deleterious vibrations and thus automatically trip the Track 3 System.

#### 2.3.1.5.Method of Resolution

Fast fourier transfers of the captured data has been performed. These transfers define the system response spectra which will be used in the final dynamic analysis. See **Section 3.1.1.4**.

#### 2.3.1.6.Results

Results relative to the testing program are incomplete at this time. A final analysis of the Track 3 System including design recommendations will be available ten days after submittal of this document.

#### 2.3.1.7.Disposition of Test Item

The materials used to perform these tests include a steel sledgehammer, calibrated hammer, accelerometers, signal conditioners, computer, HP VEE software, and the data acquisition board. The accelerometers, signal conditioners, and the calibrated hammer have been returned to The Modal Shop. The computer, software, and the data acquisition board are the property of Delphinus Engineering and will be obtained for future use. The steel sledgehammer will remain on the Nesbett farm.

### 2.3.2. Static Deflection

#### 2.3.2.1.Description of Test

The following provides information specific to testing of the Track 3 System jib boom for static deflection.

Materials utilized to perform static deflection include a long piece of string, line level, and a 6 foot wooden post as depicted in **Figure 3.1.2-1**.

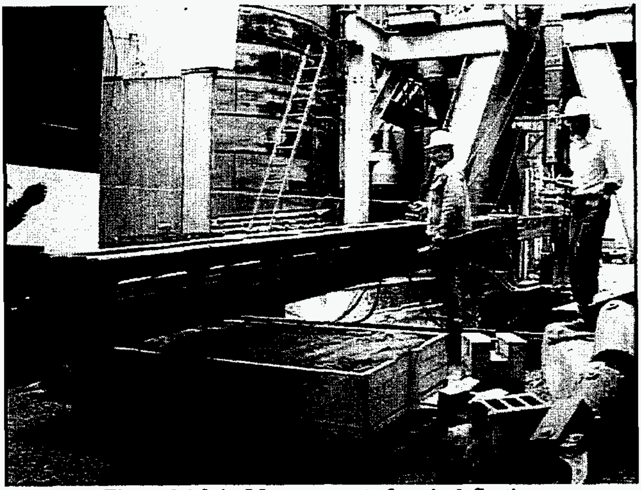


**Figure 3.1.2-1: Measurement of static deflection**

**2.3.2.2.Test Method and Test Equipment**

The following describes how static deflection was performed and how measurements were taken.

Static Deflection was performed by taking a piece of string with a line level attached, tying it to a wooden post and placing it parallel to the jib boom. This piece of string represented the true horizontal line. In order to measure deflection, a measurement would be taken from the jib boom to the string. The jib boom had the Rotec and WALDO attached, which resulted in a total additional load of 1180lbs. The jib boom was also perpendicular to the vertical boom. Data collected from the performance of testing is represented in **Appendix A Section 3.**

**2.3.2.3.Test Results**

The purpose of the static deflection test was to insure that the arm's deflection would not exceed +/- 4 inches during any mode of operation. Measurements using a standard rule and visual observation show that the total horizontal static deflection with 1180lb load is 11.5 inches. Therefore the Track 3 System exceeds the required range for static deflection.

**2.3.2.4.Issues Resolved**

The issue of static deflection pertains to the ability of the Track 3 System to safely navigate inside a tank with various end effectors attached with minimum deflection. This issue is important with respect to positional repeatability and navigation. The operator of the Track 3 System must be able to navigate the arm through the tank with unanticipated deflection in order to avoid collisions with in-tank hardware.

**2.3.2.5.Method of Resolution**

Calculations must be performed in support of physical deflection testing. The results of the calculations will basically be used to produce a graph of deflection vs. load vs. .jib boom extension which will be utilized during in-tank operations.

**2.3.2.6.Results**

The applicability of the resulting resolution will be used to enhance operations such as navigation and positional repeatability. It should be noted that all the jib boom wear plates were not fully torqued and as such contributed to the overall deflection of the jib boom.

**2.3.2.7.Disposition of Test Item**

The materials used to perform static deflection include string, line level, and a wooden post. These materials will be recycled on the Nesbett farm.

### 2.3.3. References

1. “CIO-DAS1400 User’s Manual”, Computer Boards Inc., Revision 3, June 1994.

2. "Universal Library Programmer's Manual", Computer Boards, Inc., Revision 3.3V, June 1996.

3. "HP VEE Reference Manual", Hewlett Packard Company, Edition 4, January 1995.

4. "HP VEE Advanced Programming", Hewlett Packard Company, Edition 2, June 1995.

## 2.4. System Safety Demonstration

The purpose of the Track 3 System Safety Demonstration Test is to demonstrate the inherent design capabilities of the Track 3 System to operate safely considering the effects of off-normal occurrences. Data collected is presented in **Appendix A, Section 4**. The System Safety Demonstration addresses the following two issues.

- Dynamic drift
- Failed Knuckle Cylinder

### 2.4.1. Dynamic Drift

#### 2.4.1.1. Description of Test

The inherent design features of the Track 3 System to resist drift is being tested.

Materials utilized to perform dynamic drift included a wooden board mounted on two six foot posts. The board had a standard scale drawn on it representing a ruler as depicted in **Figure 4.1.1-1**.

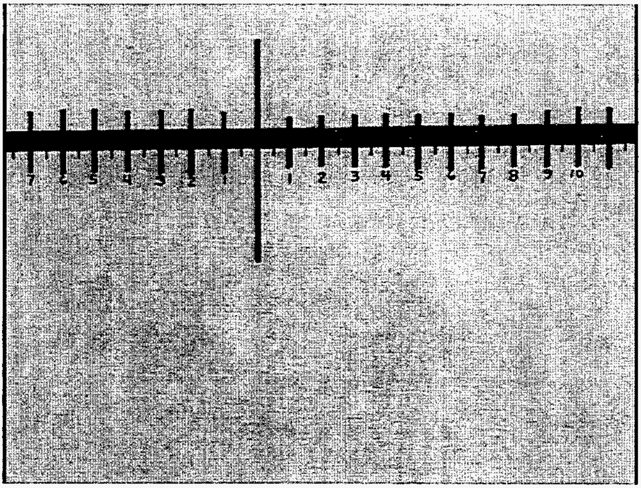



**Figure 4.1.1-1: Scale**

Attached to the Rotec is a pointer which assists in the measurement of drift . This is shown in **Figure 4.1.1-2**.

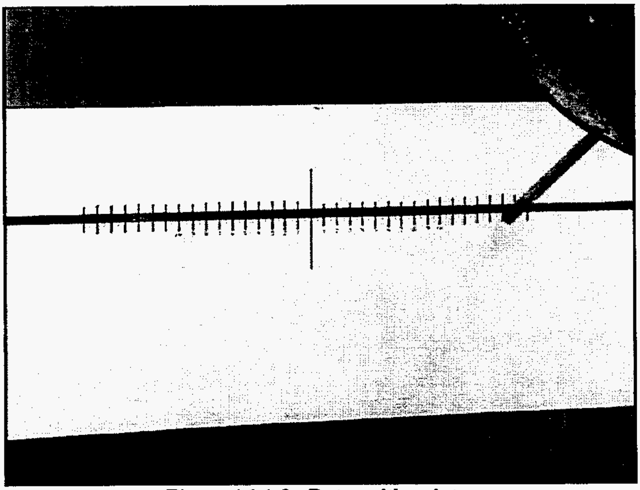


**Figure 4.1.1-2: Rotec with pointer**

### 2.4.1.2.Test Method and Test Equipment

The following describes how dynamic drift testing was performed and how measurements were taken.

There were two types of test performed for dynamic drift.

1. Uncontrolled motion - Moving the jib boom "fast" and then ceasing operation.

2. Controlled motion - Moving the jib boom with a "slow and steady" motion and then ceasing operation.

Direct measurement using the dynamic drift scale and visual observation were used to collect data in support of testing.

### 2.4.1.3.Test Results

The purpose of dynamic drift testing is to determine distance traversed by the Track 3 System from a referenced position as a result of inertia of motion after ceasing operation of the Track 3 System. Judging from the results, it is observed that for uncontrolled motion, there is a drift of approximately 10 inches and for controlled motion, there is a drift of approximately 1 inch. The acceptance criteria of dynamic drift is 2 inches.

#### 2.4.1.4.Issues Resolved

The issue of dynamic drift pertains to the ability of the Track 3 System to safely cease its motion while navigating the arm through a tank. The significance of the issue pertains to in tank operations in congested areas where clearance is less than 10 inches. This operational parameter can be used to gauge jib boom velocity while performing in tank operations.

#### 2.4.1.5.Method of Resolution

The issue of dynamic drift was addressed by directly testing the Track 3 System in the fashion outlined in **Section 4.1.1.2**.

#### 2.4.1.6.Results

The results of testing, pertaining to performance of the dynamic drift test indicate that in-tank safety and operations are greatly enhanced while operating at slow speeds. The applicability of these results can be directly applied to ensuring safe in-tank operations.

#### 2.4.1.7.Disposition of Test Item

The materials used to perform the dynamic drift testing include the scaled wooden board and two wooden posts. Each of these items will be recycled on the Nesbett farm.

### 2.4.2. Failed Knuckle Cylinder

#### 2.4.2.1.Description of Test

The purpose of this test is to set forth the actions that would have to be performed in the event the knuckle cylinder failed during waste removal operations.

### 2.4.2.2.Test Method and Test Equipment

In order to perform this test, the mast assembly would be required to be functional, which was not the case at the time of demonstration testing. As such an explanation of the steps necessary to recover from a failed cylinder was provided by the operator.

### 2.4.2.3.Test Results

In the event that a the knuckle cylinder failed during waste removal operations, the jib boom could not be operated safely. As a result, the jib boom must be removed in a safe and efficient manner. The jib boom is connected to the knuckle joint as depicted in **Figure 4.1.2-1**.

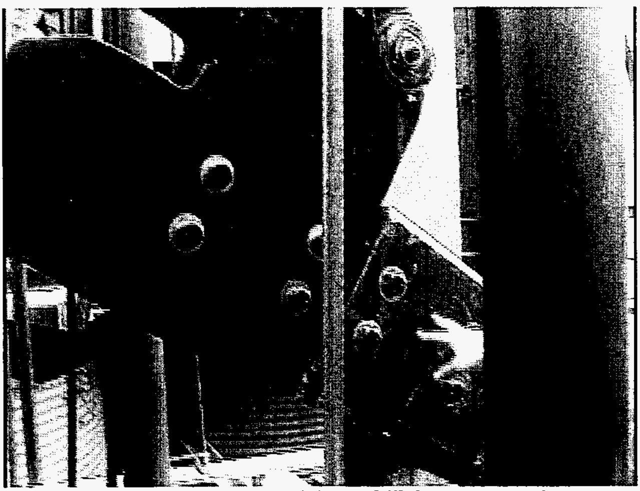


**Figure 4.1.2-1: Knuckle joint and jib boom connection**

There are three hydraulic pins that connect the jib boom to the knuckle that can be released. This action allows the jib boom to rotate around the pinned connection at the knuckle. The mast assembly and vertical boom are utilized to draw the jib boom out of the tank.

#### 2.4.2.4.Issues Resolved

The issue of a failed knuckle cylinder pertains to the ability of the Track 3 System to recover from an abnormal operating occurrence.

#### 2.4.2.5.Method of Resolution

The method of resolution pertaining to this issue was via dialog with Mr. Michael Johns of EagleTech, the Track 3 Systems chief operator.

#### 2.4.2.6.Results

The resulting resolution associated with a failed knuckle cylinder is to ensure that engineered mechanisms and operational methods exist which address abnormal operating occurrences. As in the case of the failed knuckle cylinder, 3 removable pins measuring 1.5 ft and 2.5 inches in diameter have been included in the design of the Track 3 System. The pins when removed allow the vertical boom and mast assembly the ability to easily withdraw the jib boom from inside the tank.

#### 2.4.2.7.Disposition of Test Item

There were no materials used.

## 2.5. Other Issues

This section of the Final report address the resolution of issues which were not "demonstration tested".

### 2.5.1. Issue Resolved-Safety

#### 2.5.1.1.Description of Issue

The issue of safety pertains to ensuring the health and welfare of personnel who are directly and indirectly (general public) involved in the design, engineering, construction, and operation of the Track 3 System.

#### 2.5.1.2.Method of Resolution and Results

The issue of safety as it relates to the design, engineering, construction, and operation of the Track 3 System is of paramount importance. Resolution of this issue is founded upon industry past experiences relating to safety issues which have been promulgated into rules and regulations. Additionally Delphinus and EagleTech "lessons learned" shall be included in maintaining safety throughout the life of the Track 3 System. It is the goal of the Track 3 System team to ensure that the Track 3 System is designed to ensure that the health and safety of the public is not compromised. Appropriate design codes such as the American Institute of Steel Constructors (AISC), American Society of Mechanical Engineers (ASME) and the Institute of Electronic and Electrical Engineers (IEEE) will be utilized. Overall quality assurance of the Track 3 System will be ensured by implementing the Delphinus NQA-1 program in addition to applicable portions of 10CFR50 Appendix B The Delphinus Engineering team is comprised of professionals with considerable experience performing safety analysis of commercial nuclear facilities as well as Department of Energy facilities. A safety analysis report will be prepared which describes the "authorization basis" or functional operating characteristics of the Track 3 System, equipment and components during normal and off-normal operating conditions.

In addition to the above and of significant importance to the overall success of the project it is recognized that an open dialogue with the DOE shall be a benefit to all parties. These "open lines" of communication ensure that applicable safety requirements which have been promulgated on other DOE projects are employed as part of the Track 3 System design process.

### 2.5.2. Issue Resolved -Regulatory

#### 2.5.2.1.Description of Issue

This issue pertains to the implementation of regulatory requirements and regulatory oversight they relate to the design, engineering, construction, and operation of the Track 3 System.

#### 2.5.2.2. Resolution and Results

Resolution of this issue relates to understanding the applicable rule or regulation and translating the regulation into design and engineering parameters which are incorporated into the Track 3 System. Delphinus Engineering is quite experienced in working in a regulated environment. Delphinus has successfully performed work at Hanford in a DOE regulated environment on Reactor 105-C and REDOX. Additionally the Delphinus staff has extensive experience working in the nuclear utility industry under the regulatory requirements of the NRC. The design of the Track 3 System is founded upon compliance with applicable regulatory requirements which prescribe bounding design criteria as promulgated in DOE, EPA, and NRC guidelines in addition to WAC and Tri-Party rules. The analysis of regulatory requirements will be performed in a manner which rates safety as a top priority yet weighs the cost/benefit against the level of improved or enhanced safety. In addition to the above the requirements of DOE 5480.21Unreviewed Safety Questions" will be employed to lend support to the analysis of modification or changes to an already approved design or procedure.

### 2.5.3. Issue Resolved-Institutional

#### 2.5.3.1. Description of Issue

This issue pertains to the methods that Delphinus will utilize to conduct "business" at the Hanford reservation. This issue entails safety, regulatory, and labor aspects relative to the Track 3 System.

#### 2.5.3.2. Method of Resolution and Results

The Delphinus/EagleTech team experience with respect to working with unions will prove invaluable in the resolution of this issue. Delphinus maintains experience in performing work at Hanford on projects such as the

"Interim Safe Storage' facility and at REDOX and at Savannah river on projects such as the Heavy Water Component Test Reactor or HWCTR. EagleTech also is knowledgeable with respect to conducting business at Hanford, and has for many year of experience working with local with local labor unions in the greater Cleveland area. Regulatory and safety issues which relate to the general public including tribal interfaces will be resolved to the satisfaction of all concerned parties.

### 2.5.4. Issue Resolved-Dome Loading

#### 2.5.4.1.Description of Issue

The issue of dome loading pertains to the ground forces transmitted to the underground storage tank as a result of placing the Track 3 System in position to perform waste removal operations and the ability of the underground storage tank to maintain its integrity under loading conditions.

#### 2.5.4.2.Resolution and Results

The resolution of this issue is contingent upon performance of an engineering analysis to establish the overall weight of the Track 3 System. Weight distribution and loading of the tank in various modes of operation will be analyzed. It is noted that the Track 3 System will be supported upon a bridge. The bridge may be of a configuration which may or may not straddle the tank. Irregardless, the bridge and Track 3 System will only transmit vertical loads. These loads will be sufficiently distributed using distribution pads such that dome loading will not be a concern.

### 2.5.5. Issue Resolved - Reliability

#### 2.5.5.1.Description of the Issue

Track 3 system shall be deployed to clean-up high level radioactive waste stored in Hanford SSTs. In addition to the radioactive component of the waste, some of the chemicals present in the waste, under adverse condition, may lead to explosion. This necessitates the Track 3 System to be highly reliable and robust.

#### 2.5.5.2.Method of Resolution and Results

The high degree of reliability of the Track 3 System is based on the inherent design consideration employed in the system design and engineering. The Track 3 System is designed with redundant components such that in the event of certain failures the back-up system shall prevail. For example, the manipulator arm is remotely operated by both radio-control and fiber optic cable. Also, most of the gear system present in the Track 3 System are operated by two motors rather than one. Procedures shall be developed to ensure that components meet or exceed the design requirements so as to preserve or enhance system reliability.

It must noted in this context that EagleTech, has designed and constructed scores of machine with physical characteristics similar to the Track 3 System. These machines have operated in hazardous and extreme environments without any substantial loss of operating time resulting from system failure or design flaw. Overall, Track 3 System reliance issues are demonstrated based upon safe operation documented on site and past performance.

### 2.5.6. Issues Resolved - Maintainability and Availability

#### 2.5.6.1.Description of Issues

As mentioned in Section 2.5.5, the Track 3 System shall be deployed in a highly radioactive and chemically harsh environment. In an effort to limit workers' exposure to radiation and other chemicals, the Track 3 System is designed to require a minimum of maintenance.

#### 2.5.6.2.Method of Resolution and Results

The design of the Track 3 System is based on the principles which promote continuous operation for up to 6 months in a radioactive and chemically harsh environment with only a minimum amount of maintenance. For example, the design of the Track 3 System allows for the vertical and jib boom segments including the manipulator arm to be withdrawn from the tank, decontaminated and extended onto the deck of the mobile bridge in order to perform any interim "hand on" maintenance or schedule periodic inspection in accordance with established programs. The high degree of maintainability is also due to the fact that the Track 3 System employs commercially available components. In this regard, spare boom sections, end effectors, pumps, diesel generators and other critical components can be stocked.

### 2.5.7. Issue Resolved-Interface Contractual

#### 2.5.7.1.Description of Issue

This issue pertains to the method that the Track 3 System team interacts with contractual requirements.

#### 2.5.7.2.Resolution and Results

Resolution of this issue focuses upon Delphinus and EagleTech experience with respect to working within the bounds of DOE contracts. In addition Delphinus is familiar with the terms and conditions of the Tri-Party agreement. This experience paired with the teams working knowledge of how to conduct business at the Hanford reservation is an asset with respect to resolution of this issue.

### 2.5.8. Issue Resolved-Interface Physical

#### 2.5.8.1.Description of Issue

This issue pertains to the identification of infrastructure necessary to mobilize and support the Track 3 System at the Hanford reservation.

#### 2.5.8.2.Resolution and Results

Resolution of this issue is directly tied to "lessons learned" during the demonstration testing program. For instance protocols for site layouts, utility requirements, and connections are all noted and documented in the Final Report video. Additionally general arrangement drawing, one line electrical drawings and system interface and connection drawings will be generated in support of Track 3 System operations at the Hanford facility.

### 2.5.9. Issue Resolved-Availability

#### 2.5.9.1.Description of Issue

This issue pertains to the amount of "down time" experienced by the Track 3 System as a result of operational or mechanical perturbations.

#### 2.5.9.2.Resolution of Issue

This issue will be addressed via implementation of a preventative maintenance program for the Track 3 System. In addition the concept of daily work plans will be instituted in order to access operational requirements such as manpower and operational supplies.

# FINAL REPORT

# APPENDIX A

# DATA

## TABLE OF CONTENTS

## A. TEST OBJECTIVE

The objective of the Track 3 System testing is to gather, evaluate, and quantify data pertaining to tank waste retrieval solutions as demonstrated on simulated waste materials that have been characterized as those typically found in the single shell tanks at the Hanford site. Each test is individually summarized on separate **"Data Reporting Sheets"**. Each of these sheets contain three sections:

**Purpose:** This section defines the aim and direction of testing. It provides a summary of the issues addressed.

**Acceptance Criteria:** This section defines the bounding parameters for test success.

**Test Results:** This section provides all data results for each specific test. It contains all graphs generated and all measurements taken. This section is referred to in the main body of the final report.

## B. DEFINITIONS

1. *Reference Position*-A location with known coordinates.
2. *Hits*- Non-damaging collisions, impacts, or impingement upon In-Tank Hardware (ITH) or tank wall.
3. *Interruptions*-Temporary cessation of operations.
4. *Category Group I*-Issues related to positioning the end effector ,manipulator and arm.
5. *Category Group II*-Issues related to dislodging waste
6. *Category Group III*-Issues related to retrieving waste
7. *Category Group IV*-Decontamination Issues
8. *Category Group. V*-Dynamic Issues
9. *Established Trip*-A path with known origin and termination coordinates.
10. *Reference START*-The origin coordinates of an established trip.
11. *Reference END*-The termination coordinates of an established trip.
12. *Actual reference*-Coordinate determination by actual physical measurement.
13. *Position management*-The ability to control location of the end effector, manipulator and arm during tank retrieval operations.
14. *Path success*-The ability to complete an established trip without any detrimental "hits" or collision with ITH.
15. *Hold Point*-A planned interruption of system operations allowing verification tasks, or parallel activities to ensue.
16. *Dynamic drift*-The distance traversed by the Track 3 System from a referenced position due to inertia of motion.
17. *Parallel testing*- The ability to test or collect data from a system or component which is not the primary test demonstration system or component.
18. *Hz*- Hertz or cycles per second
19. *V* - Volts
20. *M* - Mega
21. *k* - kilo
22. *mV/g*- millivolts per gravitational constant
23. *MV/lbf*- millivolts per pound force
24. *mV/N*- millivolts per Newton

## Data Reporting Sheet

# 1. TEST PROCEDURE 1 - POSITION MANAGEMENT

## 1.1. Purpose

The purpose of this Test Procedure is to demonstrate the capabilities of the Track 3 System to operate safely within the confines of a tank which contains risers, cables, structural members and miscellaneous debris of various size. This test will demonstrate the Track 3 System capabilities to perform the following "Category Group-I" issues:

1. Positional Repeatability
2. Obstacles
3. Umbilical Management
4. Navigation in Tank
5. Visibility
6. Mapping

## 1.2. Acceptance Criteria

### 1.2.1. Riser Access

The Dual Arm Gripper attached to the manipulator arm and boom assembly shall maneuver through a 36 inch diameter demonstration riser. Acceptance criteria for this test is 0 *hits* of the Dual Arm Gripper impinging upon the interior riser walls during this demonstration.

### 1.2.2. Positional Repeatability

Positional repeatability is based upon the ability of the manipulator arm with end effector to achieve the same in tank position. Acceptance is +/- 4 inches of *reference position*.

### 1.2.3. Obstacle Avoidance

Obstacle avoidance is based upon the ability of the manipulator arm with end effector to avoid collision with in-tank structures. Acceptance criteria for this test is 0 *hits* of the Dual Arm Gripper impinging upon any ITH during an *established trip*.

### 1.2.4. Umbilical Management

Umbilical management is based upon the ability of the manipulator arm with end effector to perform all aspects of integrated testing without interference from umbilical connections. Acceptance is contingent upon the number of times testing is *interrupted* as a direct result of umbilical interference and shall be less than 5 *interruptions* for the entire *position management* test.

### 1.2.5. Navigation

In-tank navigation is based upon the ability of the manipulator arm with end effector to maneuver inside the tank to operator selected locations without impacting, impinging or *hitting* in-tank hardware. Acceptance criteria is contingent upon total number of in-tank collisions being 0 *hits*.

### 1.2.6. Visibility

Visibility in the tank is based upon operator's ability to utilize a closed circuit camera system to view in-tank hardware and maneuver the manipulator arm with end effector without impacting or *hitting* in-tank hardware. Acceptance is contingent upon total number of in-tank hardware collisions using closed circuit cameras to maneuver and navigate being less than 0 hits.

### 1.2.7. Mapping

Mapping of the tank provides the Track 3 System operator with a visual image of the tank interior. This technique supports navigation and obstacle avoidance while maneuvering the end effector and boom assembly. Acceptance is based upon the ability of the anti-collision system to confirm the positional location of in-tank hardware to within +/- ¼ inch of the *actual reference* position of the mapped coordinates of the demonstration testing obstacles.

## 1.3. Position management tests

### 1.3.1. Tank access

**Test Number:** __1__

**Data collected:**

Time required to perform the operation: ______N/A___(minutes)

Number of hits: ____See Note 1______

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Riser access | 0 hits | Fail |

**Note 1** - The knuckle joint assembly measured 41 inches in width. Riser access was predicated upon cleaning a 36 inch diameter riser.

### 1.3.2. Positional Repeatability

**Test Number:** 1-3

**Data collected:**

Number of hits:____0____

Distance between the actual location and the reference point:____0____(inches)

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Positional Repeatability (Path 1) | +/- 4 inches of reference position | Pass |

### 1.3.3. Visibility, Obstacle Avoidance and In-tank Naviagation

**Test Number:**_____1____

**Data collected:**

Number of hits:_______0_______

Distance traversed:______38'-4"______

Time required to traverse path:______30_____(min)

| **Issue** | **Acceptance Criteria** | **Pass/Fail** |
|---|---|---|
| Obstacle Avoidance | 0 hits per established trip | Pass |
| In-tank navigation | 0 hits per established trip | Pass |
| Visibility | 0 hits using closed circuit camera | Pass |

### 1.3.4. Umbilical Management

**Test Number:**____1-5_____

**Data collected:**

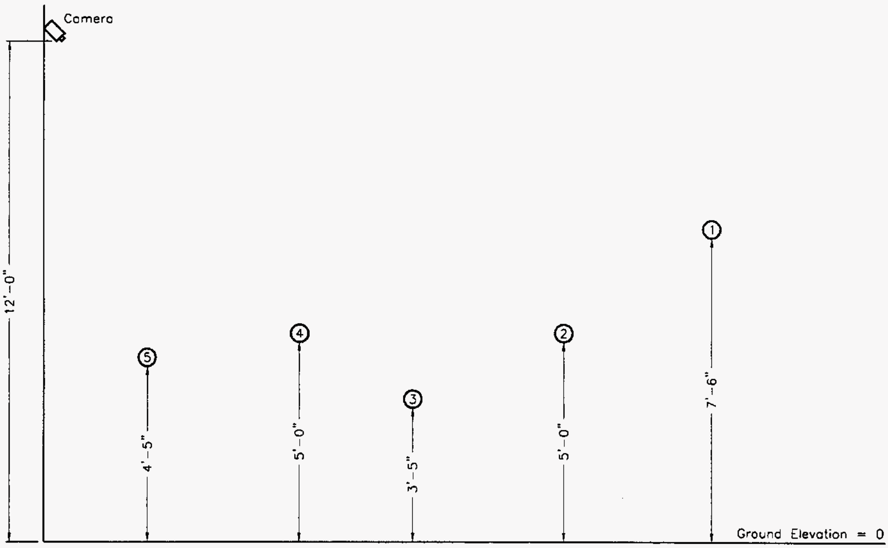
Number of interruptions: _more than 10

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Umbilical Management | Test interference from umbilical connections less than 5 interruptions. | Fail |

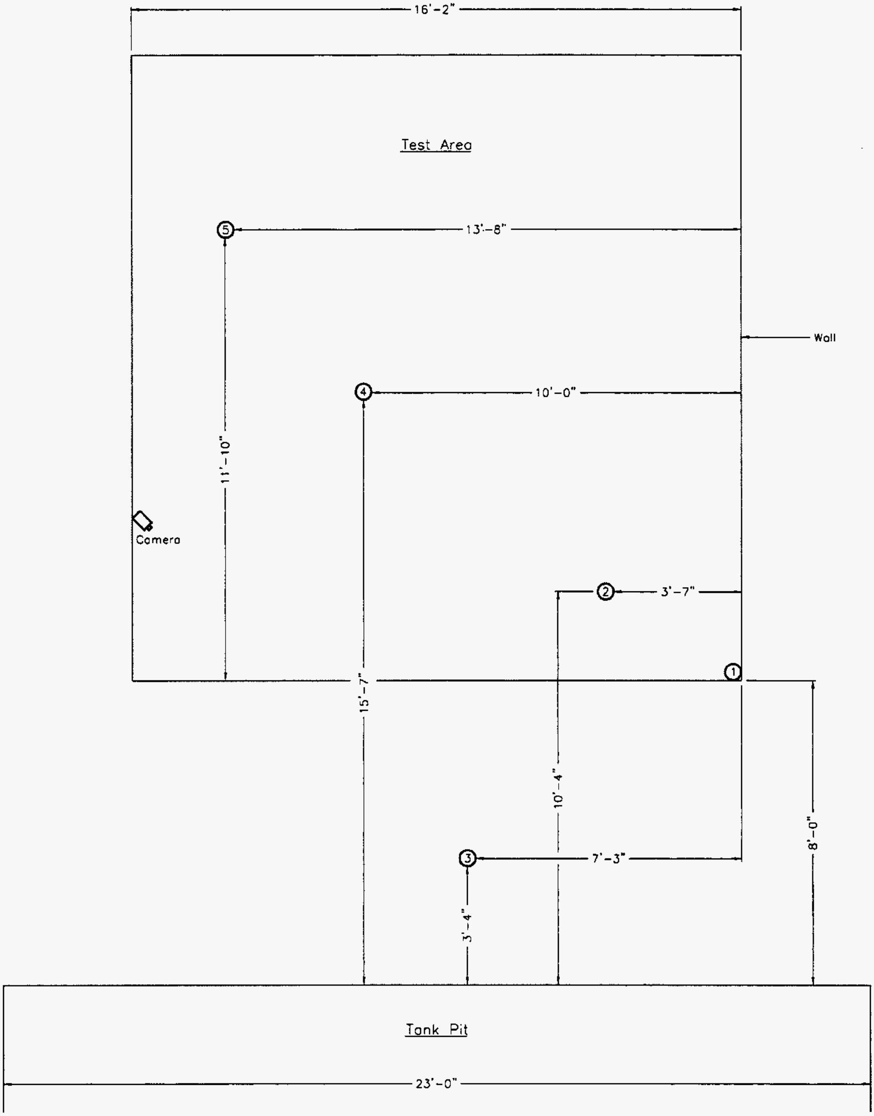
### 1.3.5. Mapping

**Test Number:____1____**

| **Issue** | **Acceptance Criteria** | **Pass/Fail** |
|---|---|---|
| Mapping | Path success based upon use of computer assisted "teach and learn" mapping technology | Pass |




ELEVATION
NAVIGATION TEST




PLAN
NAVIGATION TEST

## Data Reporting Sheet

## 2. TEST PROCEDURE 2 - WASTE DISLODGING, RETRIEVAL AND CONVEYANCE, AND DECONTAMINATION

### 2.1. Purpose

The purpose of this test procedure is to evaluate the capability of the Track 3 System to deploy various end-effectors for dislodging simulated waste in a tank "mock-up". Capability of various waste retrieval system will also be evaluated with regard to waste retrieval and waste conveyance of three types of simulated wastes. At the end of each operation, the end effectors will be cleaned using the Wash Water Decontamination system. Test procedures have been developed to assess the effectiveness of decontamination. In an effort to evaluate the performance of waste dislodging, waste retrieval and conveyance in no uncertain terms, acceptance criteria have been established. These acceptance criteria are defined below

### 2.2. Acceptance Criteria

#### 2.2.1. Tank Shell Integrity

Acceptance of each test carried out in this test procedure is contingent upon ensuring that end effector impingement upon the tank wall or simulated riser does not damage the equipment or the tank. Tank shell integrity shall be verified using visual examination for cracks and leaks.

#### 2.2.2. Stand-Off Distance

The acceptance criteria for stand-off distance is contingent upon the waste form being dislodged and the type of end effector being utilized.

#### 2.2.3. Dual Arm Gripper

The acceptance criteria for the Dual Arm Gripper is to demonstrate the ability of the gripper assembly to rotate left/right-right/left 360 degrees, and move in x, y, z cordinate planes. The Dual Arm Gripper and Jib Boom assembly shall be demonstrated capable of lifting a 200 pound load with the Jib Boom extended 75 ft. and configured at 90 degrees to the vertical boom.

#### 2.2.4. Water Jet End Effector

The acceptance criteria for the Water Jet end effector is to demonstrate the capability of the Water Jet to dislodge hard saltcakes, sludge and other waste forms with a retrieval rate of 30 to 60 gpm.

### 2.2.5. Waste Extraction System

The acceptance criteria for the Waste Extraction System is dependent upon the systems ability to remove liquid or dislodged waste at the rate of 30 to 60 gpm.

### 2.2.6. Retrieval Efficiency

The acceptance criteria associated with the ability of the Track 3 System to convey liquid or dislodged waste forms shall be demonstrated to achieve a 95% retrieval efficiency at flow rates between 30 to 60 gpm for the Waste Extraction System. Flow rate shall be verified per procedure 6.6 of reference 9702A021, Rev. A.

### 2.2.7. Actual Waste Forms vs. Simulated Waste Forms

The material properties of the simulated waste forms shall be determined via laboratory analysis in accordance with Department of Energy requirements (DOE). The (DOE) shall review the results of laboratory analysis of the simulated waste forms in order to verify that they maintain material properties and characteristics similar to DOE prepared baseline samples.

### 2.2.8. Scavenge Water

The acceptance criteria associated with the ability of the Track 3 System to scavenge water from the test tank is contingent upon the functional capabilities of the Waste Extraction System perform at flow rates of between 30 to 60 gpm. Flow rate shall be determined per procedure 6.6 of reference 9702A021, Rev. A.

### 2.2.9. Decontamination

The acceptance criteria associated with the application of the Water Wash decontamination system is that the system shall remove 95% to 99% of the simulated waste. The simulated waste being labelled with fluorescent tracer, examination of the end effector under black light will reveal the presence of simulated waste due to the fluorescence of the tracer.

## 2.3. Types of Test Procedures

These test procedures evaluate the performance of the Track 3 System on a wide range of issues. To aid in the interpretation of the test result, test procedures conducted here are divided into three types of operation: Waste Dislodging and Retrieval Operations, Decontamination Operations, and the Lifting Demonstration.

### 2.3.1. Waste Dislodging and Waste Retrieval and Conveyance Operations

Waste dislodging and waste retrieval operations of the Track 3 System was performed on three types of simulated wastes, namely, saltcake (recipe 5), dried sludge (recipe 3) and wet sludge (recipe 1). For each waste simulant three types of waste extraction systems were used. The observations and the data obtained from these test are outlined below:

### 2.3.2. Water Jet and Parallel Vacuum Retrieval/Conveyance

**Waste Simulant:** Saltcake (Recipe 4)

**Data Collected:** Total conveyance rate during this operation was calculated as total volume retrieved from the simulant tank over time period of operation

Total Volume Retrieved = 788 gallons

Time period of operation = 4 minutes

Rate of conveyance = 12.9 gallons/min

**Summary Sheet for Water Jet and parallel Vacuum**

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Tank Shell Integrity | Visual Examination for cracks and leaks | Pass |
| Stand-Off Distance | Capability of the end-effector at 4, 3, 2, and 1 inches from the simulant | Effect of various stand-Off distance was not evaluated. However, dramatic lowering of dislodging power was noticed with increase in stand-off distance |
| Actual vs. Simulated waste | Simulated waste sample reviewed by DOE | Not Available |
| Conveyance Rate | 30-60 GPM | 12.9 GPM (This value represents the total amount of waste and water removed from the tank per unit time averaged over the entire operation) |

### 2.3.3. Water Jet and CAT System Retrieval and Conveyance

**Waste Simulant:** Salt Cake (Recipe 4)

**Data Collected:** Three samples of waste discharge from the CATS were collected for a blasting pressure of 20,000 psi. These samples are analyzed for percentage solids (shown below). Flow rate of the discharge was measured by filling a calibrated drum in a known period of time.

**Percent Solids**

| Sample No | Flow | Percent Solids |
|---|---|---|
| SC-20-CAT-1 | 68 GPM | 10.0 |
| SC-20-CAT-2 | 68 GPM | 10.2 |
| SC-20-CAT-3 | 68 GPM | 10.5 |

**Summary Sheet for Water Jet and CATS**

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Tank Shell Integrity | Visual Examination for cracks and leaks | Pass |
| Stand-Off Distance | Capability of the end-effector at 4, 3, 2, and 1 inches from the simulant | Effect of various stand-Off distance was not evaluated. However, dramatic lowering of dislodging power was noticed with increase in stand-off distance |
| Actual vs. Simulated waste | Simulated waste sample reviewed by DOE | Not Available |
| Conveyance Rate | 30-60 GPM | 68 GPM (This value represents the total amount of waste and water removed from the tank per unit time averaged over the entire operation) |

### 2.3.4. Water Jet and Parallel Vacuum Retrieval/Conveyance

**Waste Simulant:** Dried Sludge (Recipe 3)

**Data Collected:** Total conveyance rate during this operation was calculated as total volume retrieved from the simulant tank over time period of operation

Total Volume Retrieved= 242 gallons

Time period of operation= 12.5 minutes

Rate of conveyance= 19.4 gallons/min

**Summary Sheet for Water Jet and parallel Vacuum**

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Tank Shell Integrity | Visual Examination for cracks and leaks | Pass |
| Stand-Off Distance | Capability of the end-effector at 4, 3, 2, and 1 inches from the simulant | Effect of various stand-Off distance was not evaluated. However, dramatic lowering of dislodging power was noticed with increase in stand-off distance |
| Actual vs. Simulated waste | Simulated waste sample reviewed by DOE | Not Available |
| Convey Simulants | 30-60 GPM | 19.4 GPM (This value represents the total amount of waste and water removed from the tank per unit time averaged over the entire operation) |

### 2.3.5. Water Jet and CAT System Retrieval and Conveyance

**Waste Simulant:** Dried Sludge (Recipe 3)

**Data Collected:** Three samples of waste discharge from the CATS were collected for each of the following blasting pressures: 5,000; 15000 and 20,000 psi. These samples are analyzed for percentage solids (shown below). Flow rate of the discharge was measured by filling a calibrated drum in a known period of time.

**Percent Solids**

| Sample No | Flow Rate (GPM) | Percent Solids |
|---|---|---|
| DS-5-CAT-1 | 60 | 35.9 |
| DS-5-CAT-2 | 60 | 35.8 |
| DS-5-CAT-3 | 60 | 35.7 |
| DS-15-CAT-1 | Not measured | 32.2 |
| DS-15-CAT-2 | Not measured | 32.8 |
| DS-15-CAT-3 | Not measured | 32.2 |
| DS-20-CAT-1 | 72 | 38.7 |
| DS-20-CAT-2 | 72 | 39.0 |
| DS-20-CAT-3 | 72 | 39.0 |

**Summary Sheet for Water Jet and CATS**

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Tank Shell Integrity | Visual Examination for cracks and leaks | Pass |
| Stand-Off Distance | Capability of the end-effector at 4, 3, 2, and 1 inches from the simulant | Effect of various stand-Off distance was not evaluated. However, dramatic lowering of dislodging power was noticed with increase in stand-off distance |
| Actual vs. Simulated waste | Simulated waste sample reviewed by DOE | Not Available |
| Convey Simulants | 30-60 GPM | 66 GPM (This value represents the total amount of waste and water removed from the tank per unit time averaged over the entire operation) |

### 2.3.6. Water Jet and Parallel Vacuum Retrieval/Conveyance

**Waste Simulant:** Wet Sludge (Simulant Recipe 1)

**Data Collected:** Total conveyance rate during this operation was calculated as total volume retrieved from the simulant tank over time period of operation

Total Volume Retrieved= 85 gallons

Time period of operation= 4 minutes

Rate of conveyance= 21.3 gallons/min

**Summary Sheet for Water Jet and parallel Vacuum**

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Tank Shell Integrity | Visual Examination for cracks and leaks | Pass |
| Stand-Off Distance | Capability of the end-effector at 4, 3, 2, and 1 inches from the simulant | Effect of various stand-Off distance was not evaluated. However, dramatic lowering of dislodging power was noticed with increase in stand-off distance |
| Actual vs. Simulated waste | Simulated waste sample reviewed by DOE | Not Available |
| Convey Simulants | 30-60 GPM | 21.3 GPM (This value represents the total amount of waste and water removed from the tank per unit time averaged over the entire operation) |

### 2.3.7. Water Jet and CAT System Retrieval and Conveyance

**Waste Simulant:** Wet Sludge (Recipe 1)

**Data Collected:** Three samples of waste discharge from the CATS were collected for each of the following blasting pressures: 5,000; 15000 and 20,000 psi. These samples are analyzed for percentage solids (shown below). Flow rate of the discharge was measured by filling a calibrated drum in a known period of time.

**Percent Solids**

| Sample No | Flow (GPM) | Percent Solids |
|---|---|---|
| WS-5-CAT-1 | 52 | 29 |
| WS-5-CAT-2 | 52 | 29 |
| WS-5-CAT-3 | 52 | 29 |
| WS-15-CAT-1 | 52 | 36.7 |
| WS-15-CAT-2 | 52 | 36.7 |
| WS-15-CAT-3 | 52 | 36.8 |
| WS-20-CAT-1 | 54.4 | 31.8 |
| WS-20-CAT-2 | 54.4 | 31.9 |
| WS-20-CAT-3 | 54.4 | 31.8 |

**Summary Sheet for Water Jet and CATS**

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Tank Shell Integrity | Visual Examination for cracks and leaks | Pass |
| Stand-Off Distance | Capability of the end-effector at 4, 3, 2, and 1 inches from the simulant | Effect of various stand-Off distance was not evaluated. However, dramatic lowering of dislodging power was noticed with increase in stand-off distance |
| Actual vs. Simulated waste | Simulated waste sample reviewed by DOE | Not Available |
| Convey Simulants | 30-60 GPM | 52.8 GPM (This value represents the total amount of waste and water removed from the tank per unit time averaged over the entire operation) |

## 2.4. Decontamination Operations

The wet sludge simulant was mixed with trace of Sodium-Fluorescene. Since Sodium-Fluorescene fluoresces under black light (wavelength of 490 nm), the presence of fluoresence shall indicate the presence of simulated waste. The decontamination process consisted of rinsing the end-effector with a 5000 psi water jet for 2 minutes. The rinse water resulting from this clean up was collected. After the initial decontamination, the end-effector was again rinsed with 5000 psi water jet for 2 minutes. The rinse water from this operation was also collected. The initial and final rinse water were colorimetrically analysed. The end effector did not reveal any fluorescence under black light examination.

| Sample No | Absorbance units |
|---|---|
| Initial Rinse -1 | 0.027 |
| Initial Rinse -1 | 0.021 |
| Initial Rinse -1 | 0.049 |
| Final Rinse -2 | 0.016 |
| Final Rinse -2 | 0.015 |
| Final Rinse -2 | 0.017 |

**Summary Sheet for Decontamination of Wet Sludge**

| Issue | Acceptance Criteria | Pass/fail |
|---|---|---|
| Decontamination | Visual examination for fluorescent label | Pass |

## 2.5. Lifting test demonstration

**Test Number:_____1____**

**Data collected:**

Time required to complete the test: one minute

The jib boom safely lifted 1000 pounds while it was extended in its most challenging position of 45 feet. The jib boom did not have the rotec or any end effector attached to it. The operator had complete control of the arm and was able to operate the machine without any problems.

| Issue | Acceptance Criteria | Pass/fail |
|---|---|---|
| Lifting Demonstration | Capability to lift 200 lb. at 75ft extension in most challenging moment loading configuration. | Fail |

## Data Reporting Sheet

# 3. TEST PROCEDURE 3 - DYNAMIC RESPONSE

## 3.1. Purpose

The purpose of this test procedure is to demonstrate the capability of the Track 3 System to dislodge, retrieve and convey waste simulant safely while being subjected to the dynamic operating forces of the various end effectors. This test procedure is designed to capture data via application of instrument monitoring devices. The data shall be analyzed following completion of the test program in order to demonstrate that the Track 3 System is designed, engineered and constructed in such a rugged and robust manner that the effects of dynamic forces are of no consequence to system operation and safety. The Track 3 system shall be analyzed for the following Category Group V issues.

1. Forces and Frequencies
2. Resonance Frequencies
3. Vibration Modes
4. Static Deflection
5. Mode Shapes
6. Dynamic Response

## 3.2. Acceptance Criteria

### 3.2.1. Dynamic forces:

Result from the operation of either dislodging or conveying end effectors working independently or together in any combination. Dynamic forces shall not induce resonant frequencies, excessive vibration or a dynamic response that could be detrimental to the safe operation of the Track 3 System.

### 3.2.2. Mode shapes:

Shall be established for the Track 3 System in order to ensure that natural frequencies for the manipulator system are sufficiently separated from the frequencies produced by the waste dislodging and conveyance systems end effectors. In other words the operating frequencies of the waste dislodging and conveyance systems shall not induce frequencies which could be detrimental to the operation of the Track 3 System.

**3.2.3. Static deflection:**

For the Track 3 System shall not exceed +/- 4 inches during any mode of operation.

### 3.3. Dynamic Response Tests-Jib Boom

**Test Number:** 1-6

**Data Collected:** All data is represented by the graphs.

| Issue | Acceptance Criteria | Test Results | Engineered Results |
|---|---|---|---|
| Forces and Frequencies | No destructive forces or frequencies | Refer to graphs | Will be provided at a later time |
| Dynamic Forces<br>Resonance frequencies<br>Vibration mode<br>Dynamic response | No destructive resonance frequencies<br>No destructive vibration modes<br>No dynamic instabilities | Refer to graphs | Will be provided at a later time |
| Mode shapes | Modal separation | Refer to graphs | Will be provided at a later time |

### 3.4. Dynamic Response Tests-Mast Assembly

**Test Number:** 1-8

**Data Collected:** All data is represented by the graphs.

| Issue | Acceptance Criteria | Test Results | Engineered Results |
|---|---|---|---|
| Forces and Frequencies | No destructive forces or frequencies | Refer to graphs | Will be provided at a later time |
| Dynamic Forces<br>Resonance frequencies<br>Vibration mode<br>Dynamic response | No destructive resonance frequencies<br>No destructive vibration modes<br>No dynamic instabilities | Refer to graphs | Will be provided at a later time |
| Mode shapes | Modal separation | Refer to graphs | Will be provided at a later time |

### 3.5. Dynamic Response Tests-Vertical Boom

**Test Number:** ____1-4____

**Data Collected:** All data is represented by the graphs.

| Issue | Acceptance Criteria | Test Results | Engineered Results |
|---|---|---|---|
| Forces and Frequencies | No destructive forces or frequencies | Refer to graphs | Will be provided at a later time |
| Dynamic Forces<br>Resonance frequencies<br>Vibration mode<br>Dynamic response | No destructive resonance frequencies<br>No destructive vibration modes<br>No dynamic instabilities | Refer to graphs | Will be provided at a later time |
| Mode shapes | Modal separation | Refer to graphs | Will be provided at a later time |

### 3.6. Static Deflection

**Test Number:** ____1____

**Data Collected:**

Total Measured Static Deflection: _11.5___ (inches)

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Static Deflection | Not to exceed +/- 4 inches | Fail |

## Data Reporting Sheet

# 4. TEST PROCEDURE 4 - SYSTEM SAFETY DEMONSTRATION

## 4.1. Purpose

The purpose of this test procedure is to demonstrate the inherent design capabilities of the Track 3 System to operate safely in the event of various off-normal occurrences. Operational safety of the arm with the end effectors shall be evaluated with regard to:

- Dynamic Drift
- Failed knuckle assembly hydraulic cylinder

The following acceptance criteria have been established for these tests:

## 4.2. Acceptance Criteria

### 4.2.1. Dynamic Drift

The dynamic drift of the Track 3 System boom assembly with any operating end effector combination shall not exceed +/- 2 inches. Dynamic drift is defined as the distance traversed by the Track 3 System from a referenced position due to inertia of motion.

### 4.2.2. Failed Knuckle Assembly Hydraulic Cylinder

Upon loss or failure of the Knuckle Assembly Hydraulic Cylinder, the mast cylinder shall have sufficient capacity to retrieve the boom assembly into the mast.

### 4.3. Dynamic Drift Test

**Test Number:** 1-2

**Data collected:**

Dynamic drift controlled motion: 1 (inches)

Dynamic drift uncontrolled motion: 10 (inches)

Refer to the scales to visualize the drift pattern of the jib boom.

| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Dynamic Drift (controlled motion) | +/- 2 inches dynamic drift | Pass |
| Dynamic Drift (uncontrolled motion) | +/- 2 inches dynamic drift | Fail |

### 4.4. Failed knuckle assembly hydraulic cylinder

**Test Number:** 1

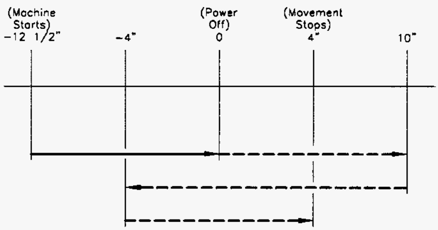
**Data collected:**

Time required to complete the test: See Note 2 (minutes)

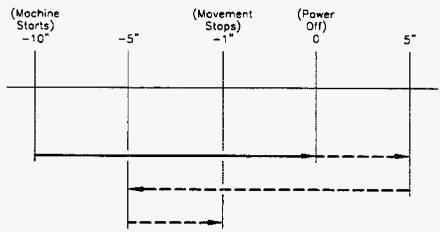
| Issue | Acceptance Criteria | Pass/Fail |
|---|---|---|
| Failed Boom Cylinder | Fail in a safe position maintained by hydraulic cylinder, retrievable via Mast hydraulic assemblies | N/A |

**Note 2** - This test was not performed due to the fact that the mast cylinders were not operating. Data presented herein is as a result of a dissertation by the Track 3 System Chief Operator.

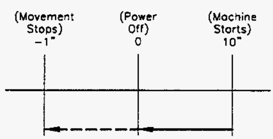
# Dynamic Drift Data



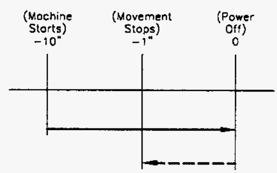

Test 1: Uncontrolled Motion




Test 3: Uncontrolled Motion




Test 2: Controlled Motion




Test 4: Controlled Motion

Legend:

Machine Operating Under Power

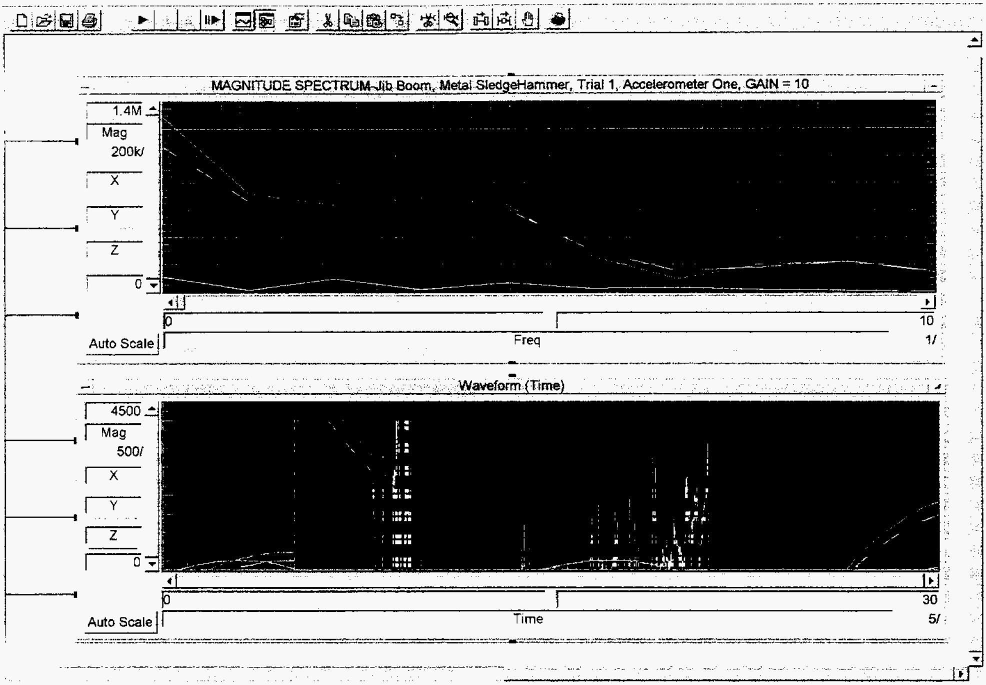
Machine Drifting (Power Off)

# FINAL REPORT

# APPENDIX B

# GRAPHS

# JIB BOOM DATA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200k/
X
Y
Z
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0
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Waveform (Time)
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Time
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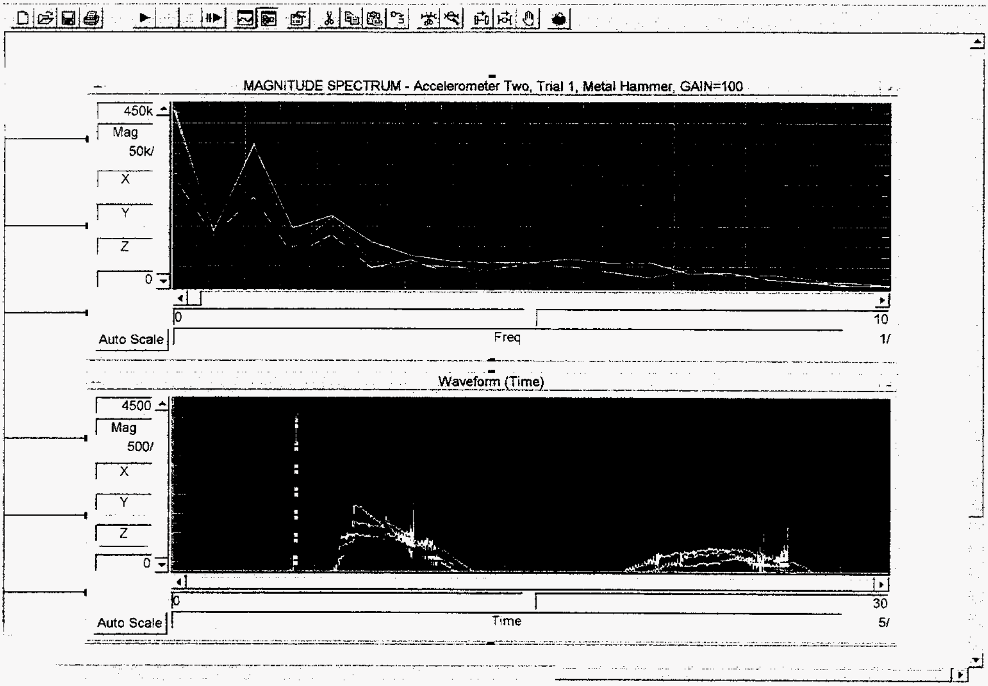
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Time
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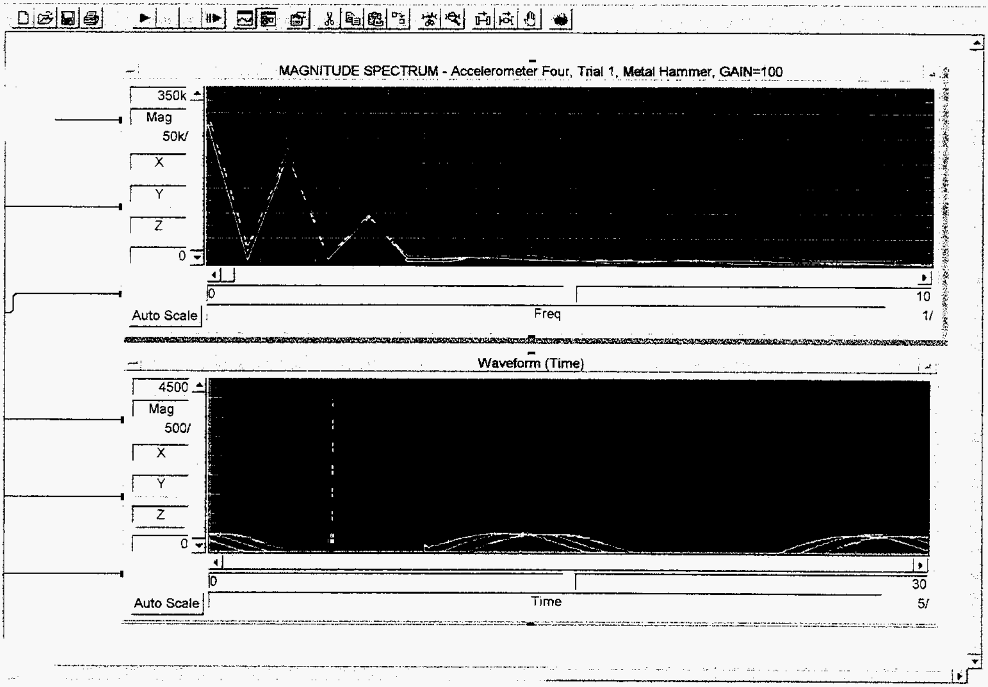
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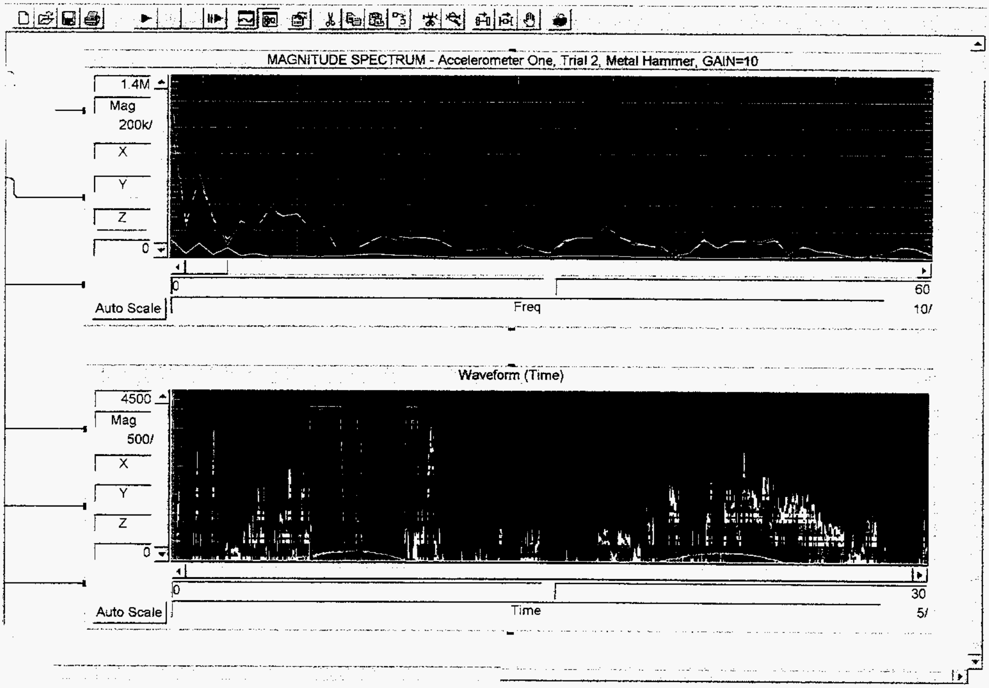
30
Time
5/
Auto Scale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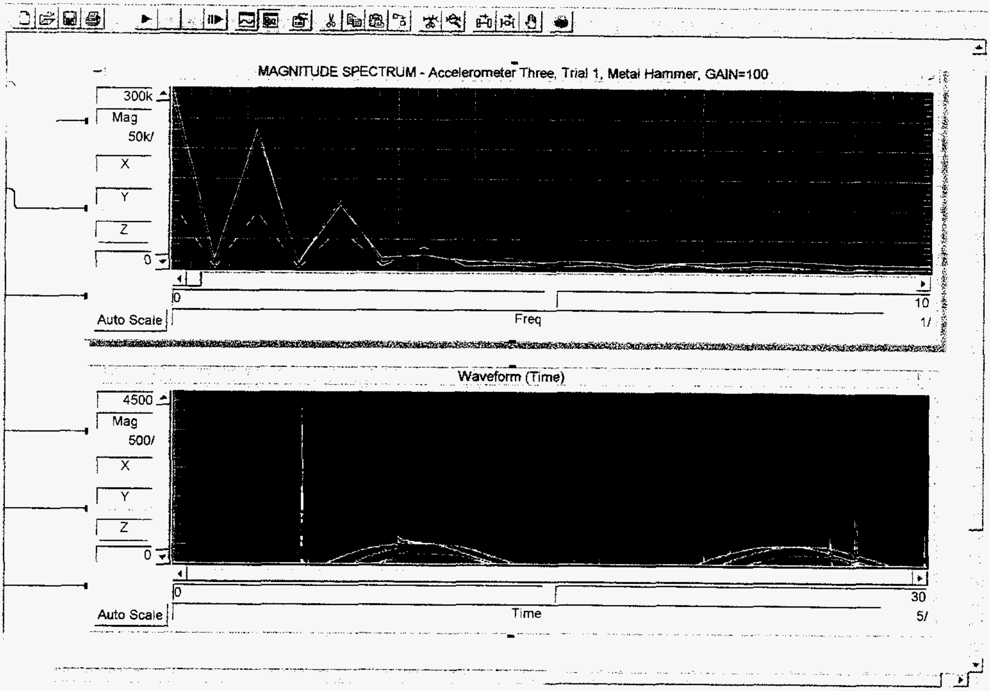
Time
5/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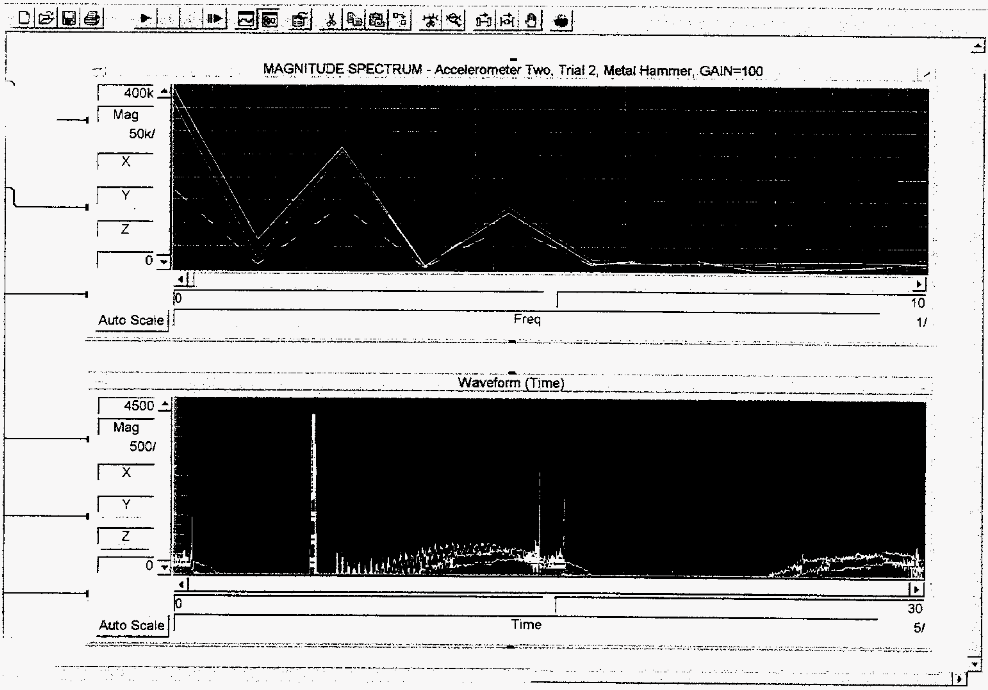

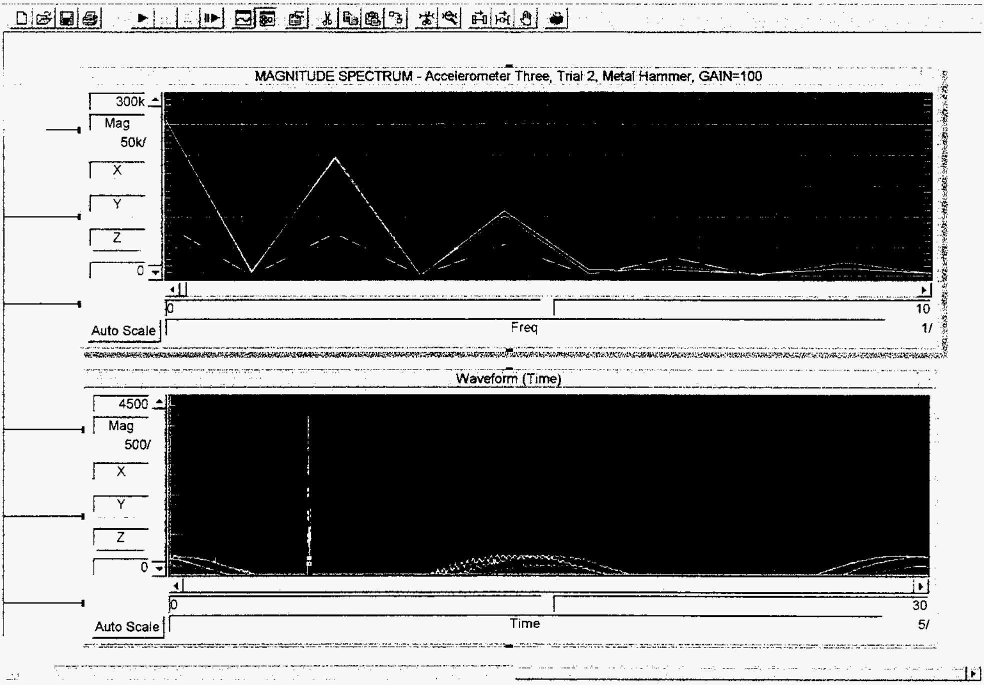
MAGNITUDE SPECTRUM - Accelerometer Three, Trial 2, Metal Hammer, GAIN=100
300k
Mag
50k/
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Y
Z
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10
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1/
Waveform (Time)
4500
Mag
500/
X
Y
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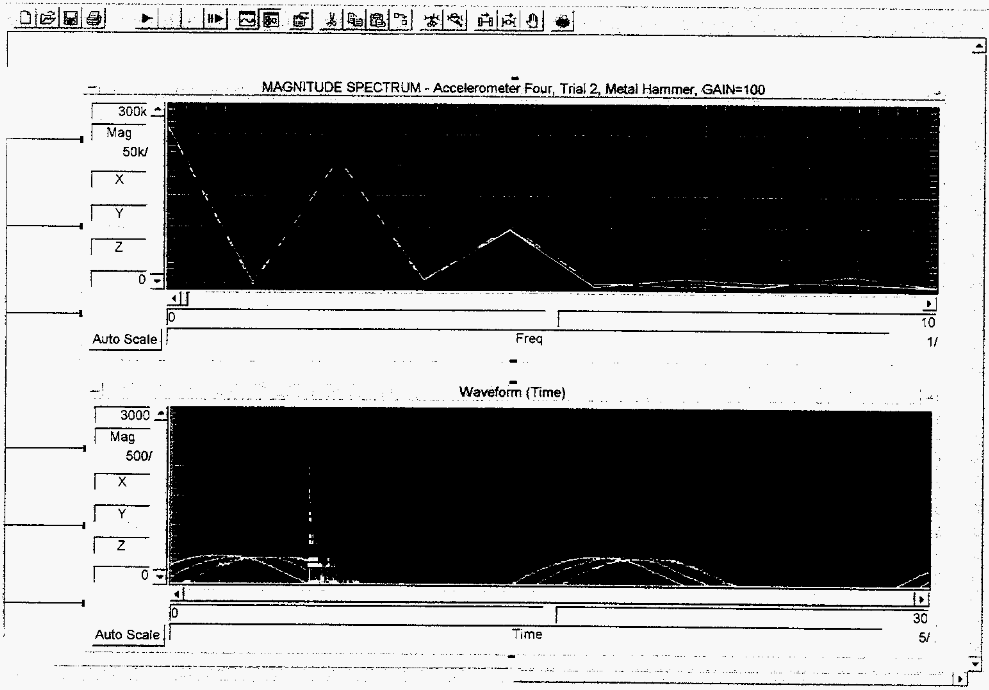
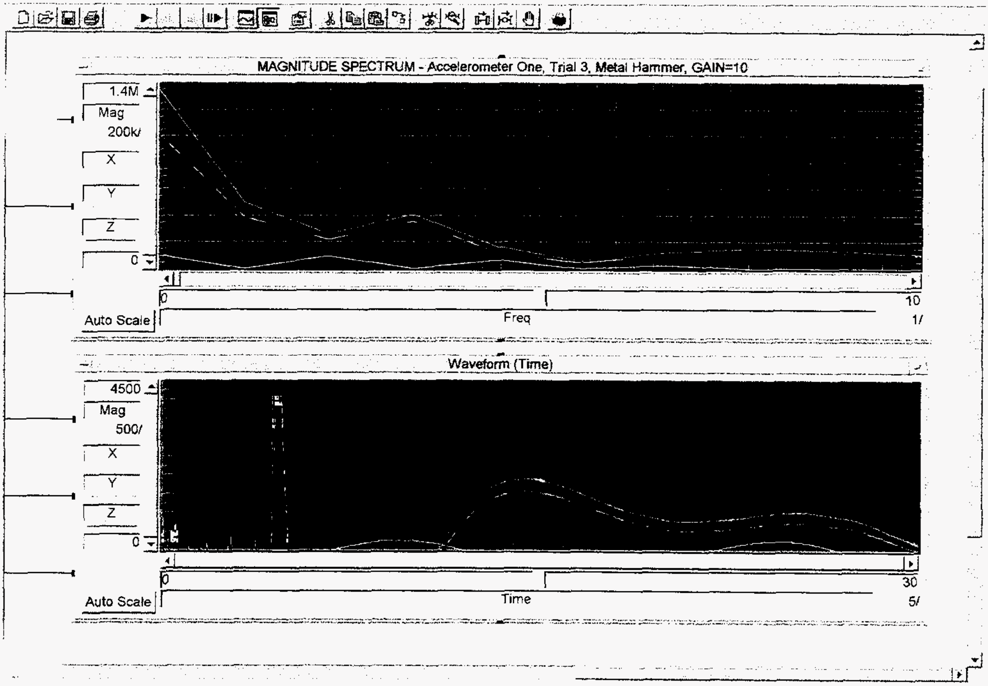
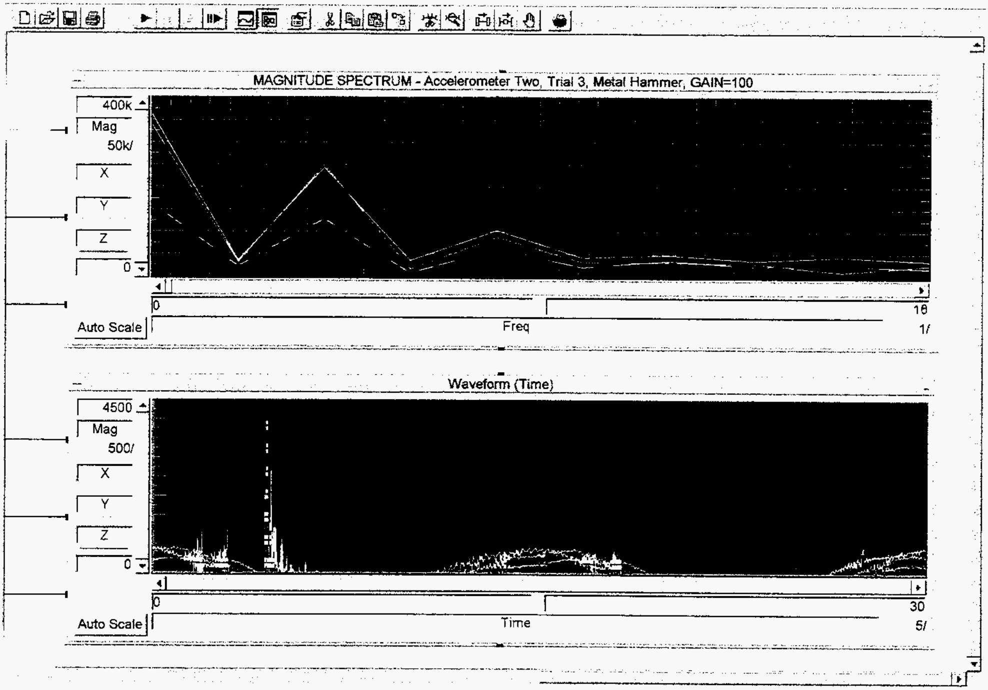
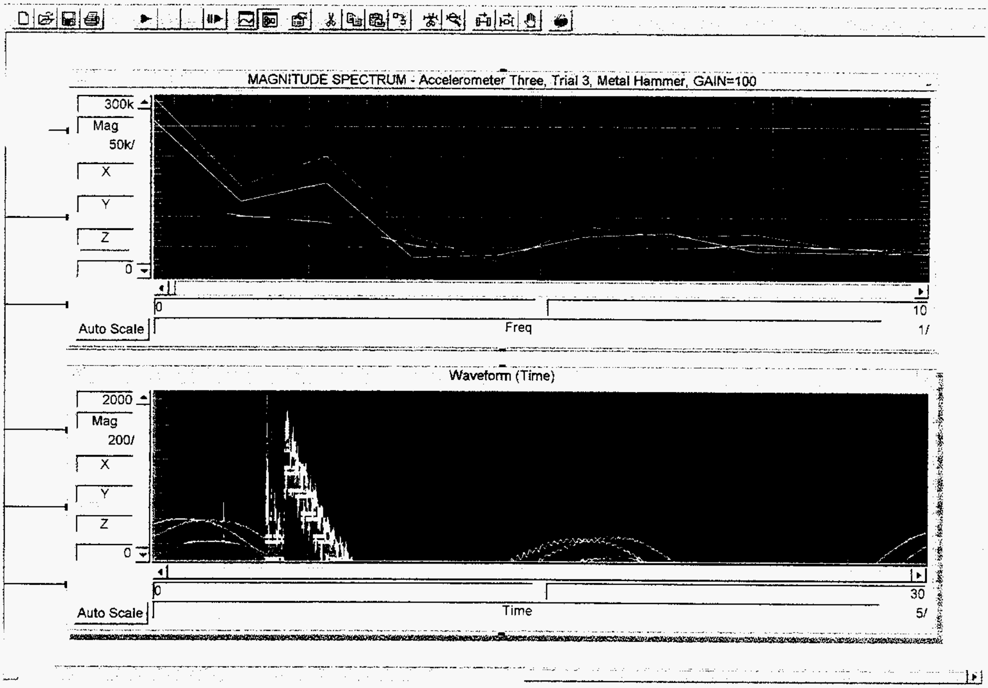
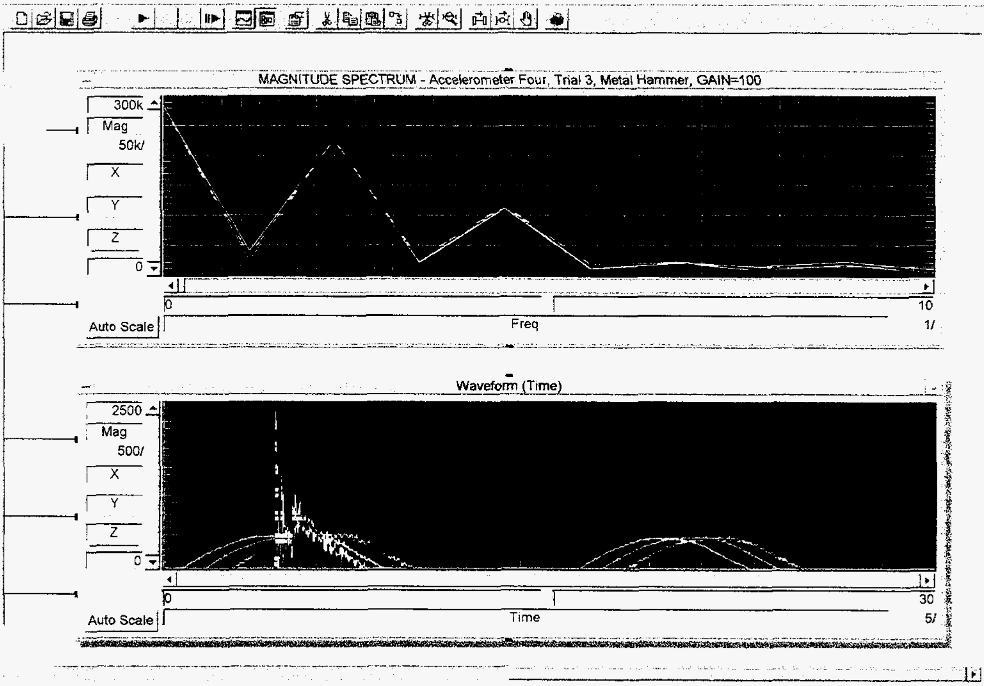
0
30
Auto Scale
Time
5/

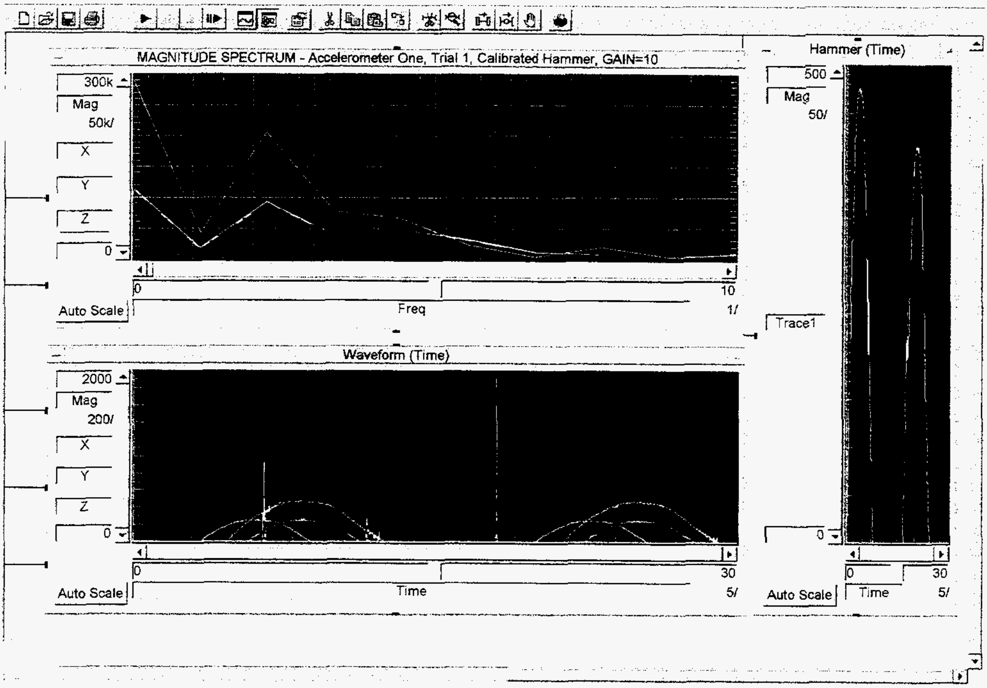

MAGNITUDE SPECTRUM - Accelerometer Four, Trial 2, Metal Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
3000
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

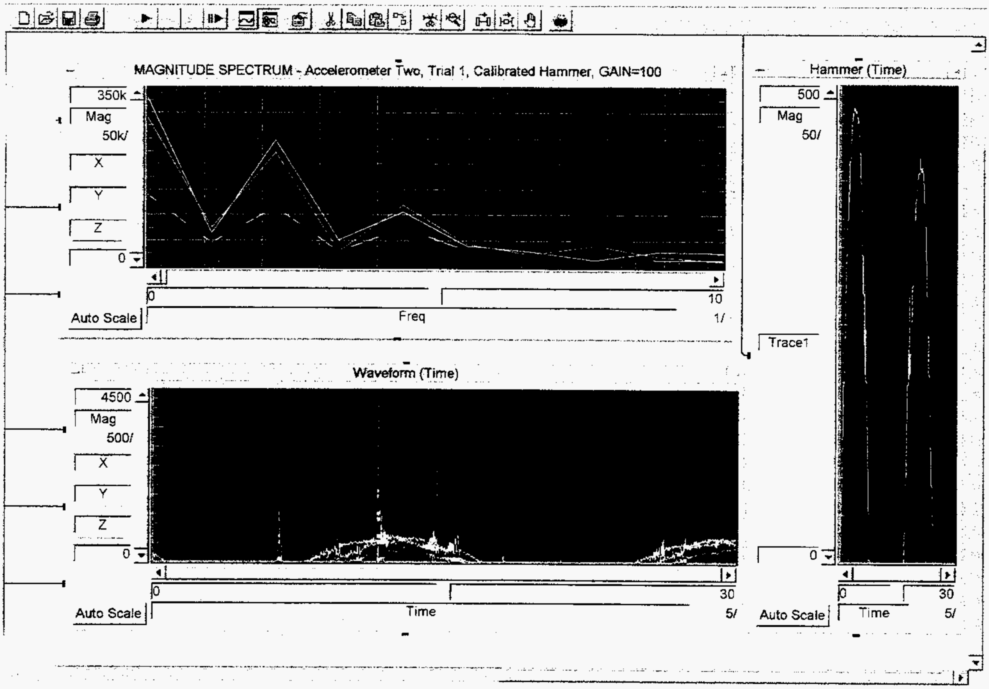

MAGNITUDE SPECTRUM - Accelerometer One, Trial 3, Metal Hammer, GAIN=10
1.4M
Mag
200k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

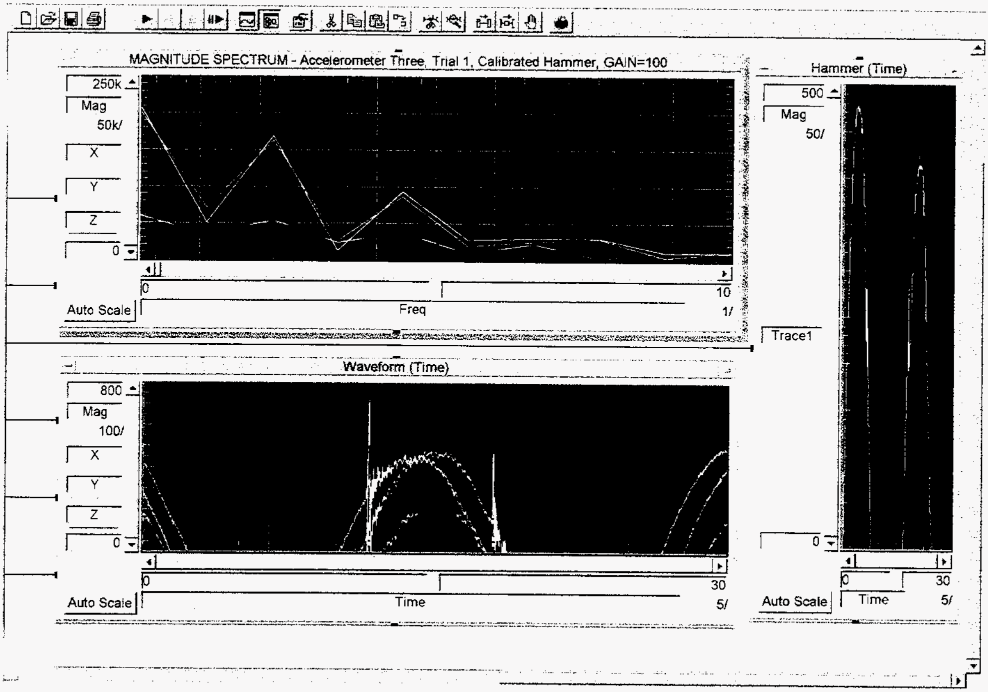

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 3, Metal Hammer, GAIN=100
400k
Mag
50k/
X
Y
Z
0
0
16
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

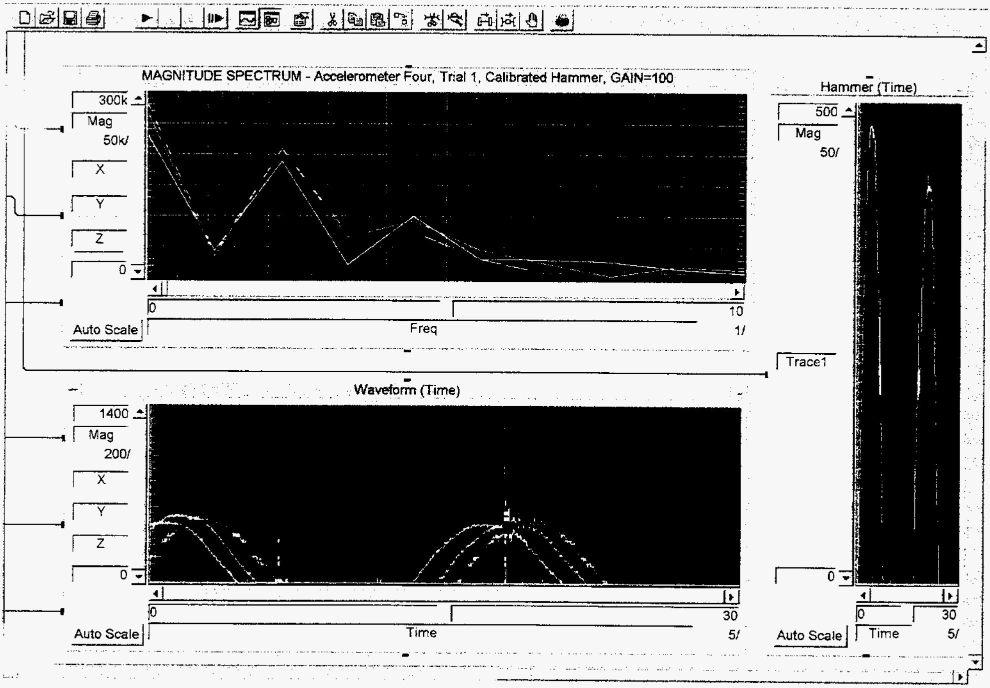

MAGNITUDE SPECTRUM - Accelerometer Three, Trial 3, Metal Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
2000
Mag
200/
X
Y
Z
0
0
30
Auto Scale
Time
5/

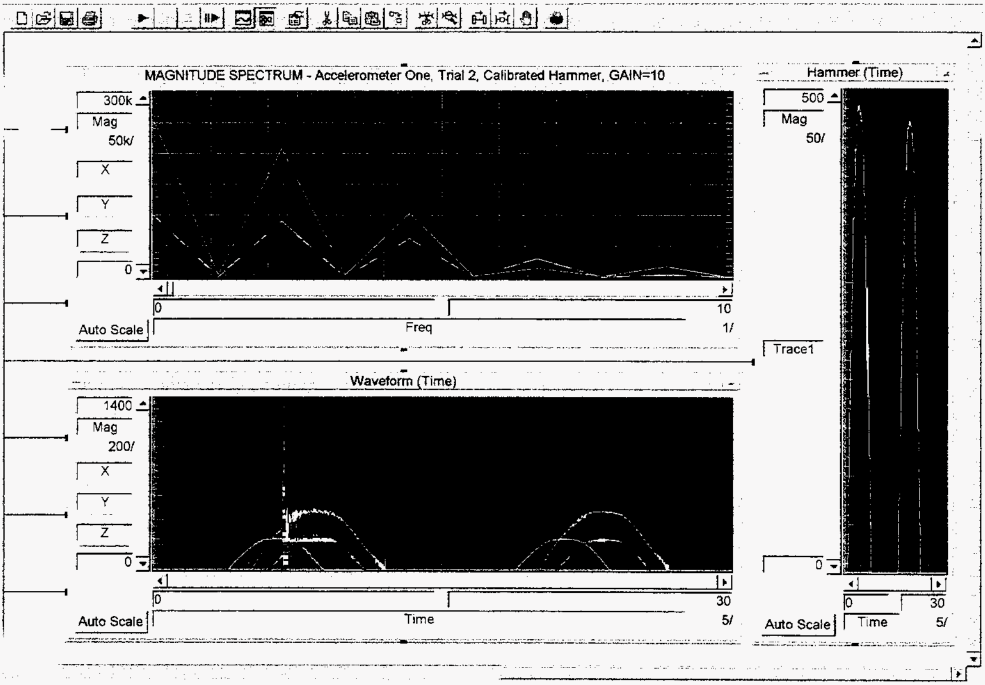

MAGNITUDE SPECTRUM - Accelerometer Four, Trial 3, Metal Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
2500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

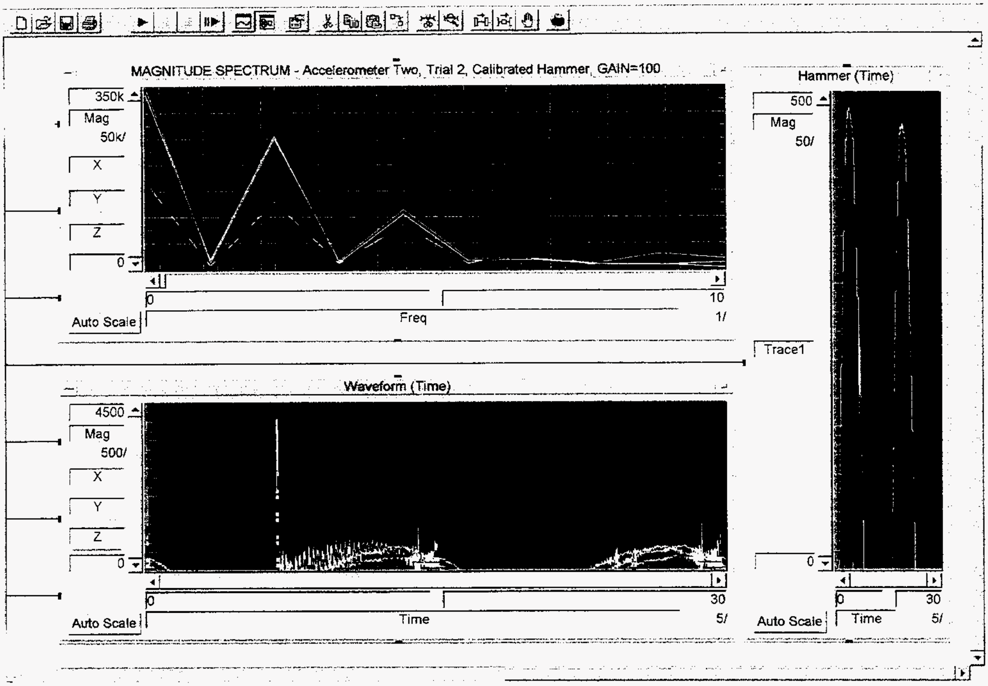

MAGNITUDE SPECTRUM - Accelerometer One, Trial 1, Calibrated Hammer, GAIN=10
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
2000
Mag
200/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/

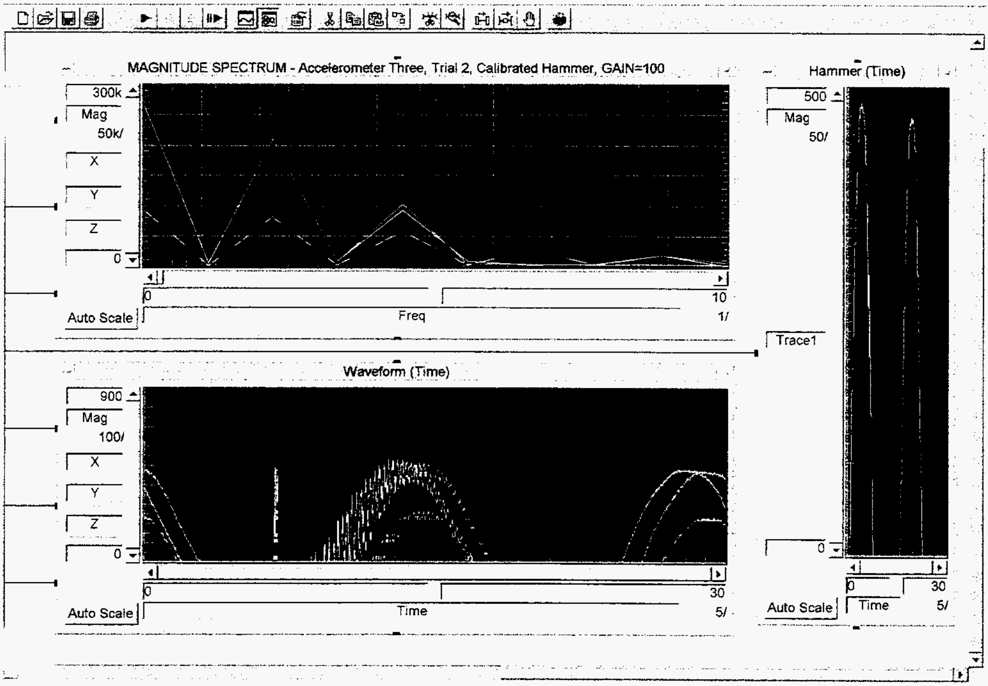

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 1, Calibrated Hammer, GAIN=100
350k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

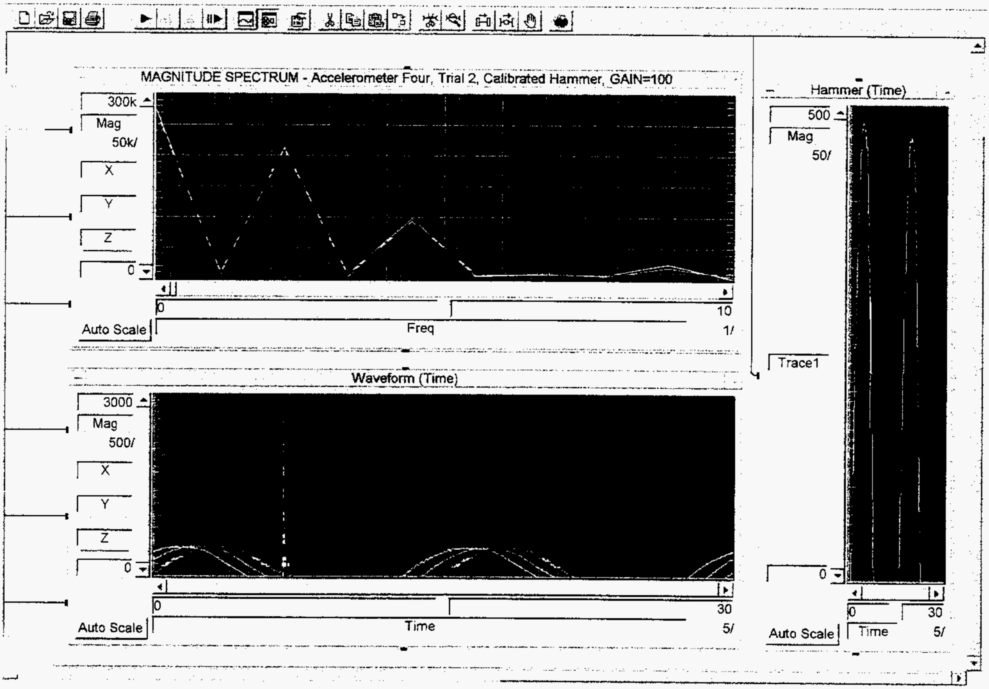

MAGNITUDE SPECTRUM - Accelerometer Three, Trial 1, Calibrated Hammer, GAIN=100
250k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/
Waveform (Time)
800
Mag
100/
X
Y
Z
0
0
30
Auto Scale
Time
5/

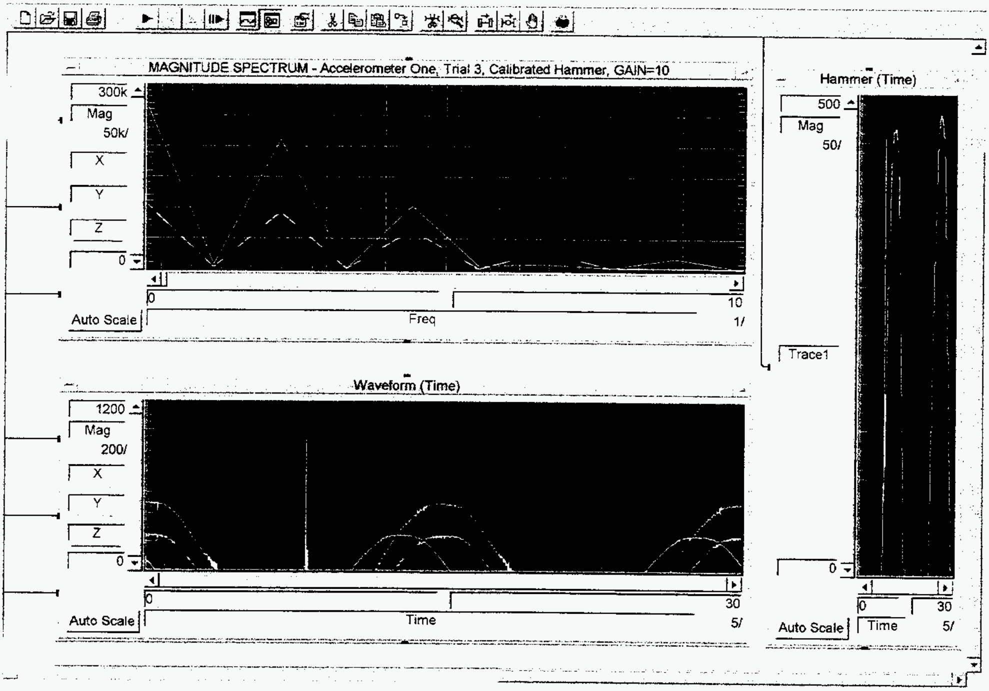

MAGNITUDE SPECTRUM - Accelerometer Four, Trial 1, Calibrated Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer (Time)
500
Mag
50/
Trace1
Waveform (Time)
1400
Mag
200/
X
Y
Z
0
0
30
Auto Scale
Time
5/
0
0
30
Auto Scale
Time
5/

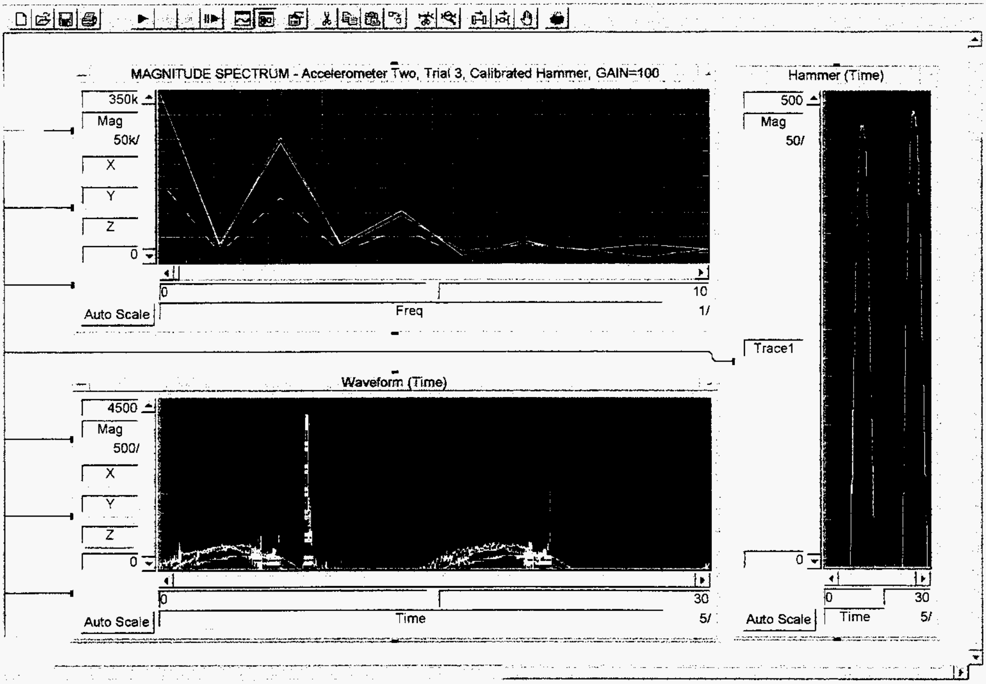

MAGNITUDE SPECTRUM - Accelerometer One, Trial 2, Calibrated Hammer, GAIN=10
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer (Time)
500
Mag
50/
Trace1
Waveform (Time)
1400
Mag
200/
X
Y
Z
0
0
30
Auto Scale
Time
5/
0
0
30
Auto Scale
Time
5/

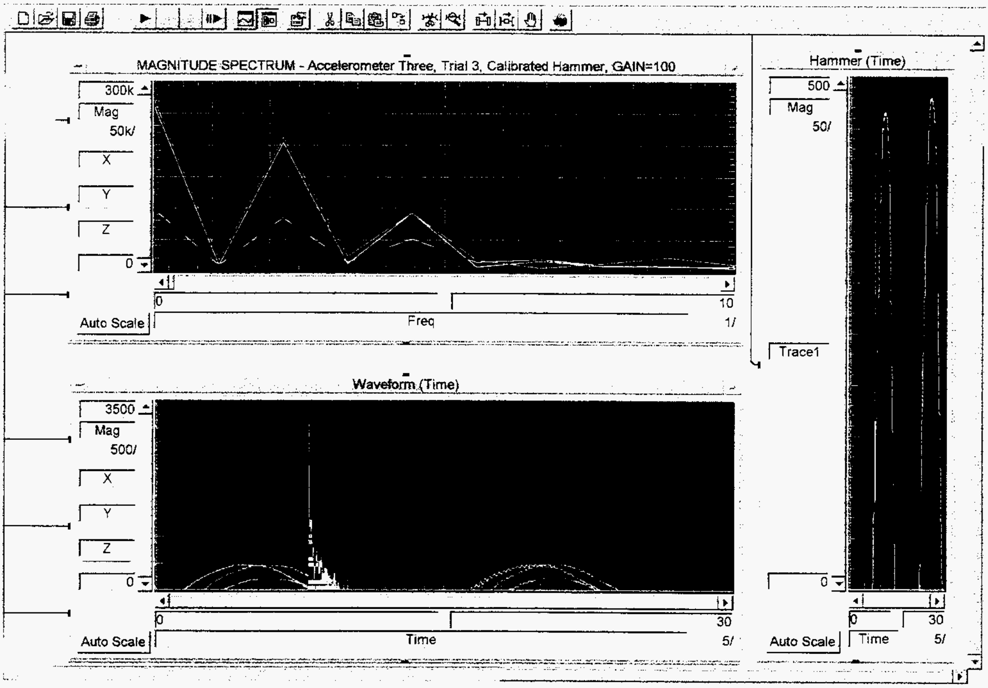

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 2, Calibrated Hammer, GAIN=100
350k
Mag
50k/
X
Y
Z
0
0
10
Freq
1/
Auto Scale
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Time
5/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale

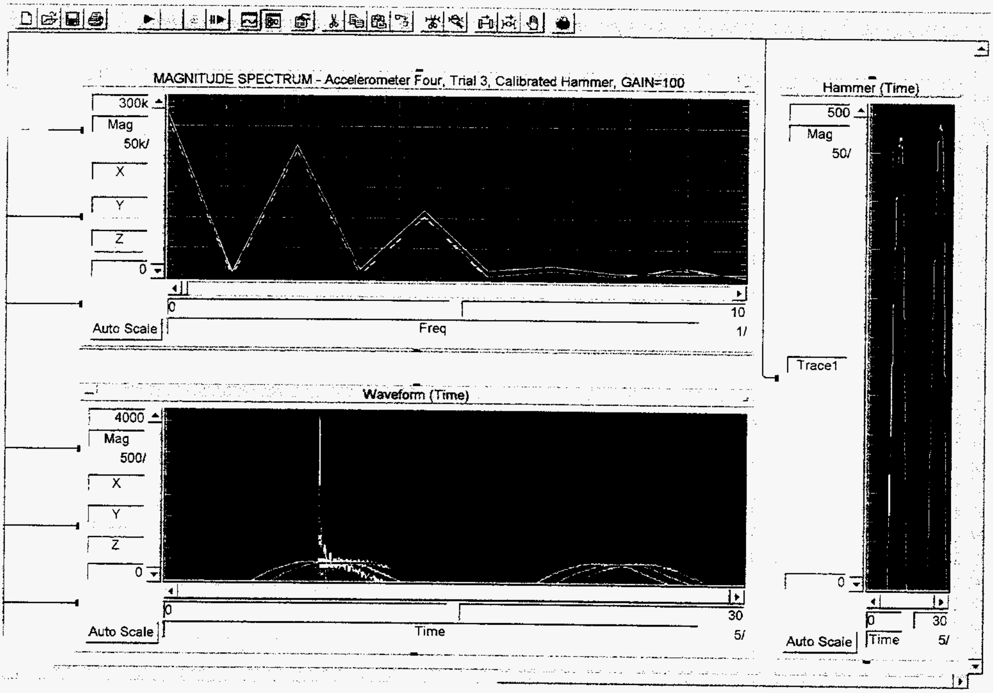

MAGNITUDE SPECTRUM - Accelerometer Three, Trial 2, Calibrated Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/
Waveform (Time)
900
Mag
100/
X
Y
Z
0
0
30
Auto Scale
Time
5/


MAGNITUDE SPECTRUM - Accelerometer Four, Trial 2, Calibrated Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
3000
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/

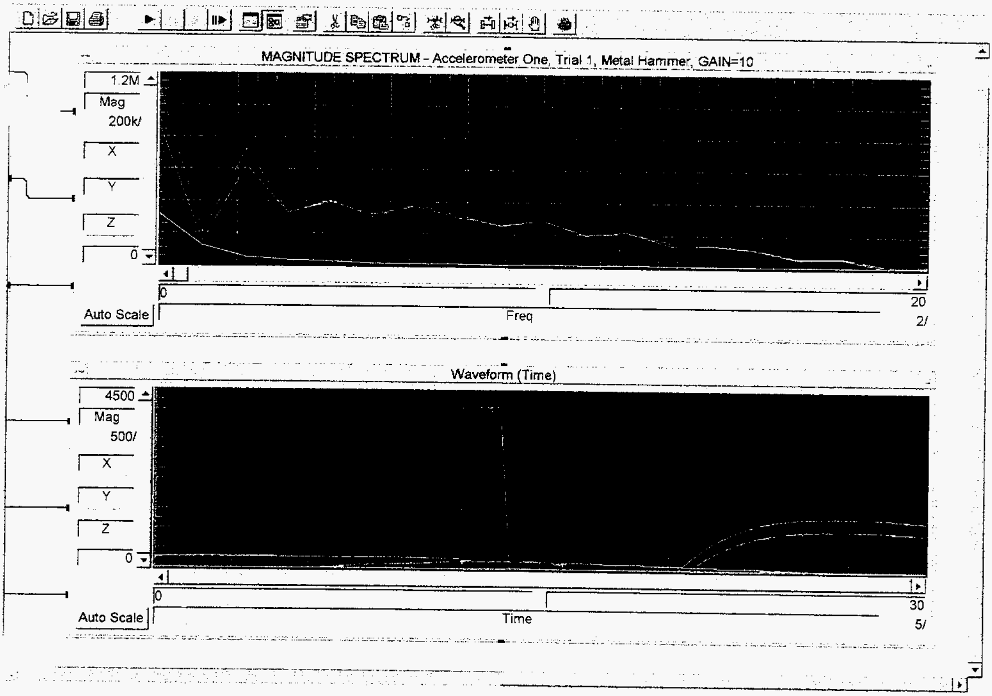

MAGNITUDE SPECTRUM - Accelerometer One, Trial 3, Calibrated Hammer, GAIN=10
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
1200
Mag
200/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/

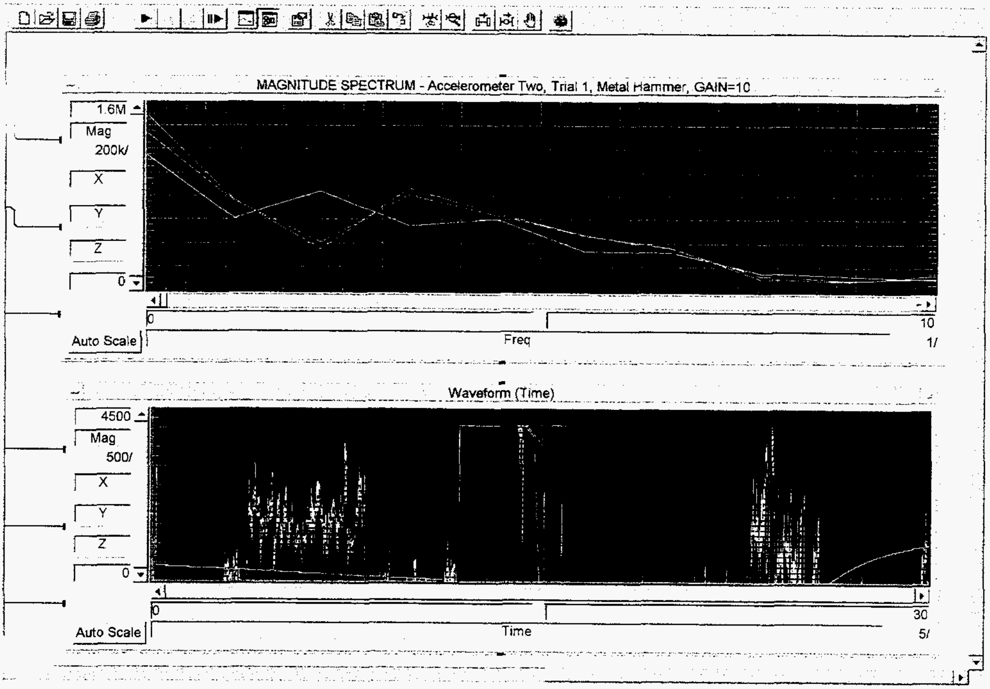

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 3, Calibrated Hammer, GAIN=100
350k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/

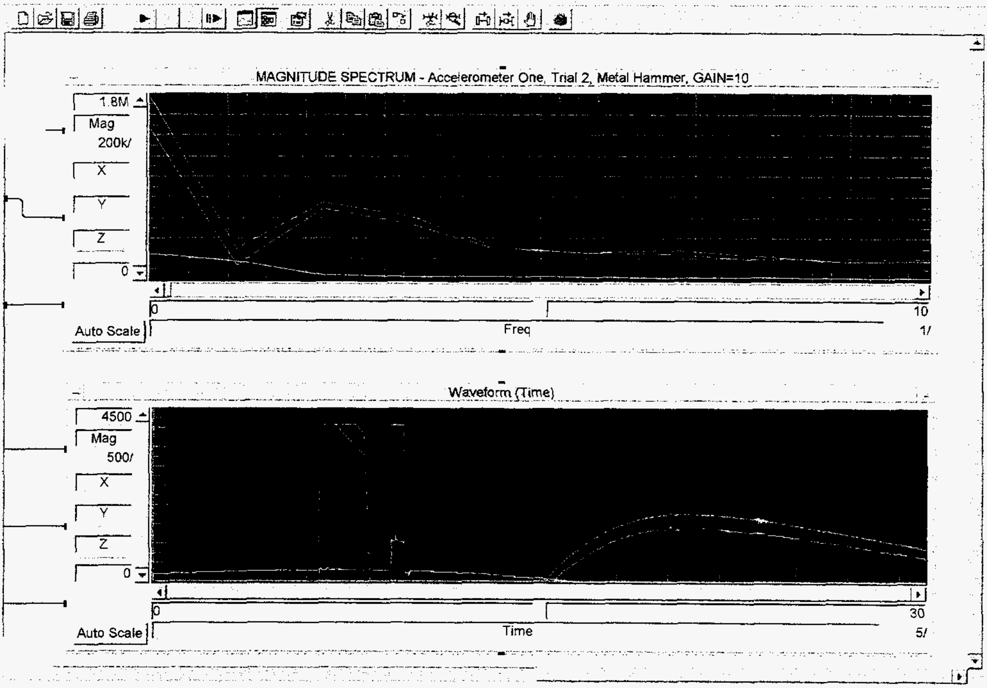

MAGNITUDE SPECTRUM - Accelerometer Three, Trial 3, Calibrated Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
3500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/

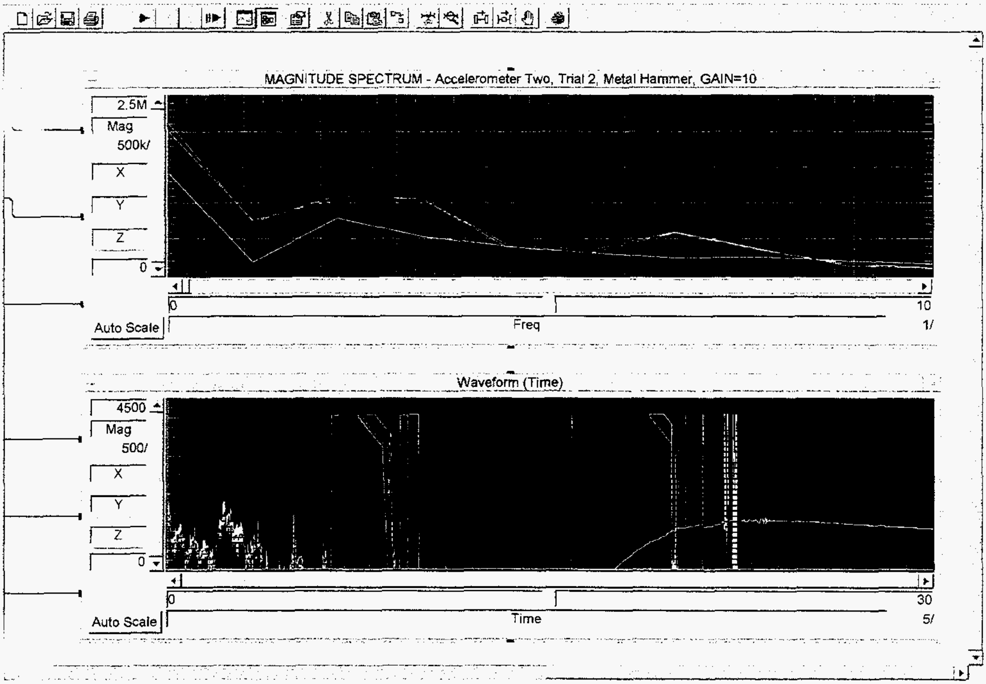

MAGNITUDE SPECTRUM - Accelerometer Four, Trial 3, Calibrated Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
4000
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer (Time)
500
Mag
50/
Trace1
0
0
30
Auto Scale
Time
5/

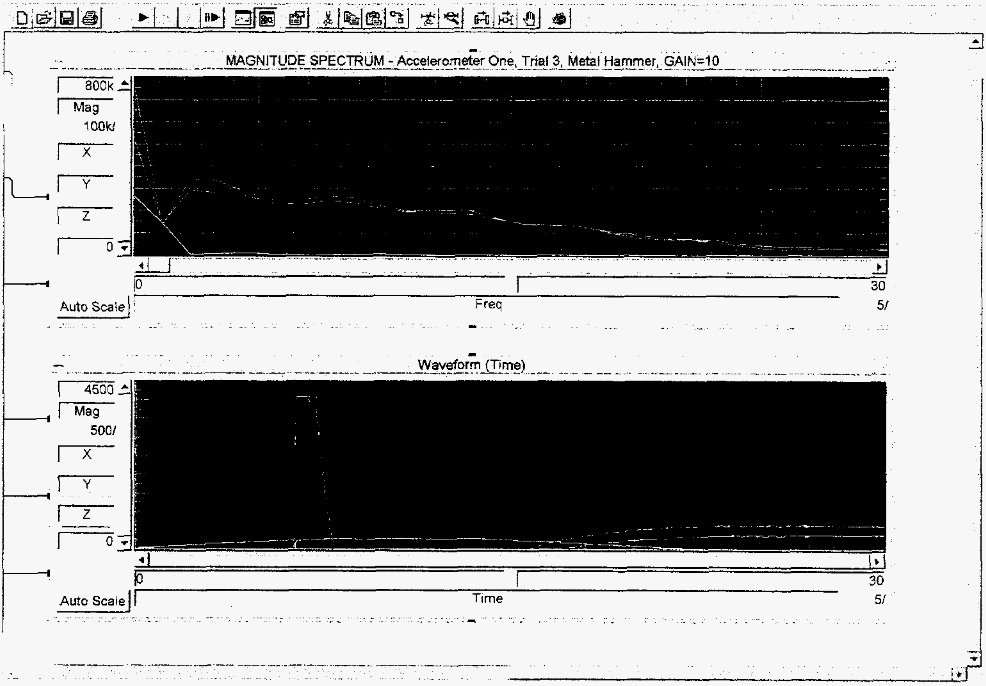
# MAST ASSEMBLY DATA

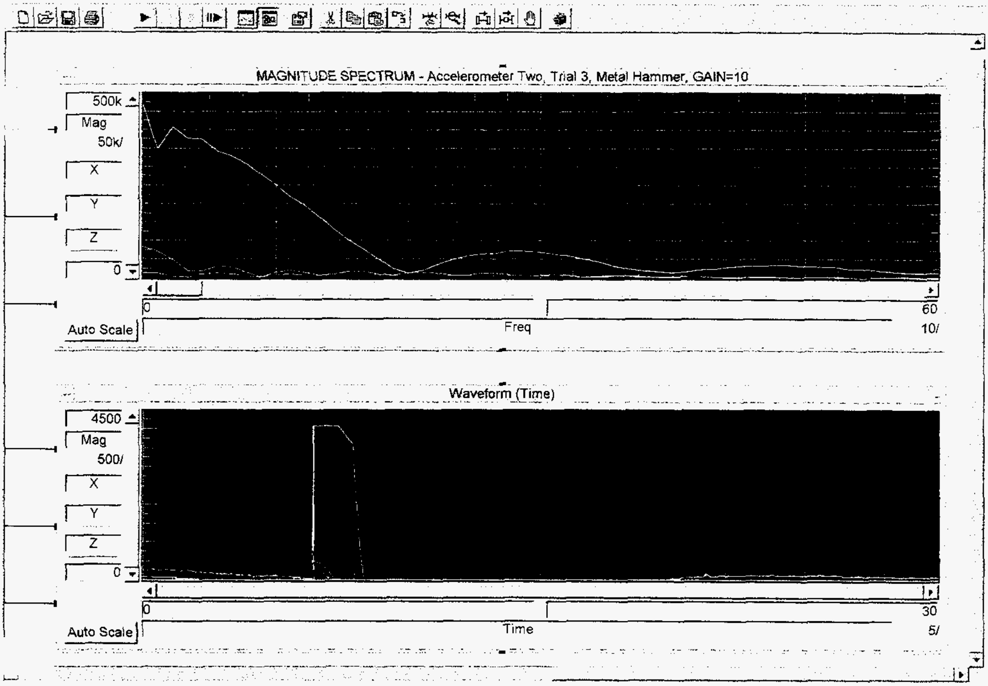

MAGNITUDE SPECTRUM - Accelerometer One, Trial 1, Metal Hammer, GAIN=10
1.2M
Mag
200k/
X
Y
Z
0
0
20
Freq
2/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale

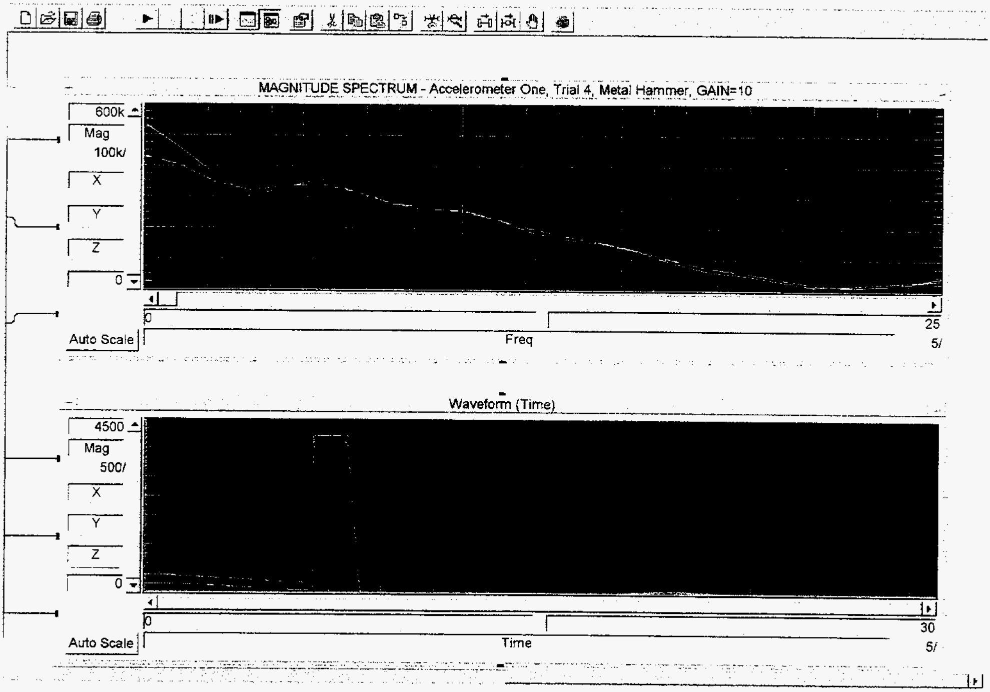

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 1, Metal Hammer, GAIN=10
1.6M
Mag
200k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

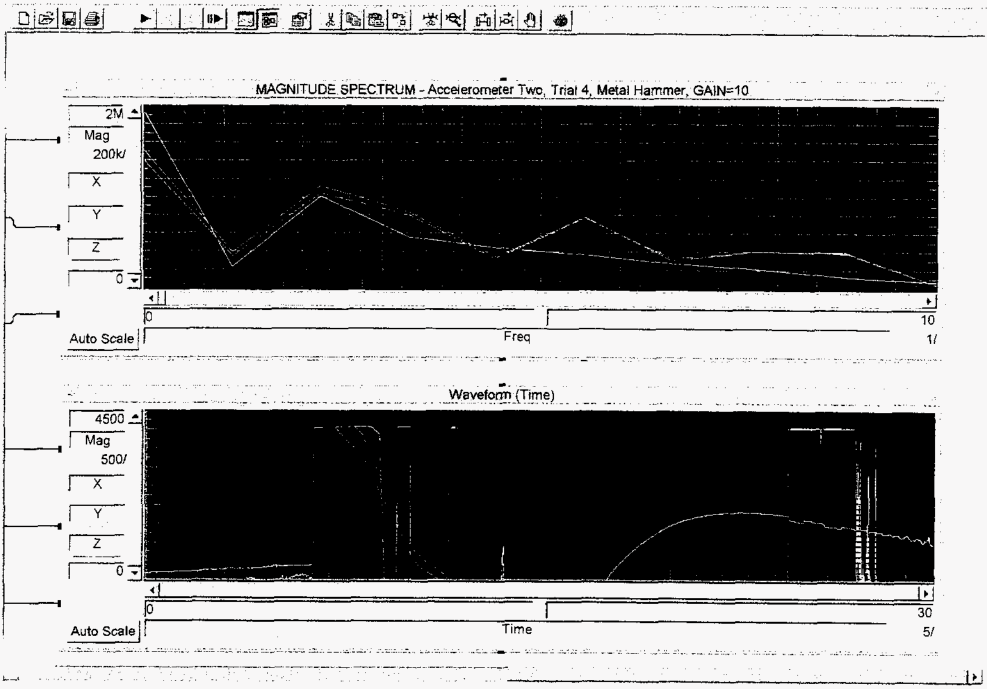

MAGNITUDE SPECTRUM - Accelerometer One, Trial 2, Metal Hammer, GAIN=10
1.8M
Mag
200k/
X
Y
Z
0
10
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
30
Auto Scale
Time
5/

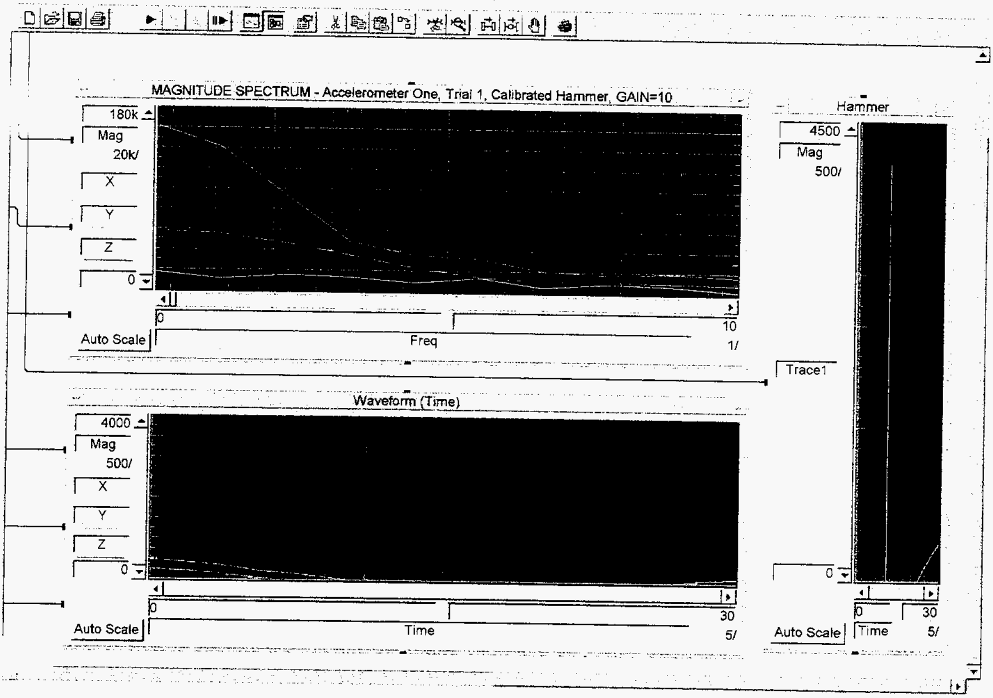

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 2, Metal Hammer, GAIN=10
2.5M
Mag
500k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

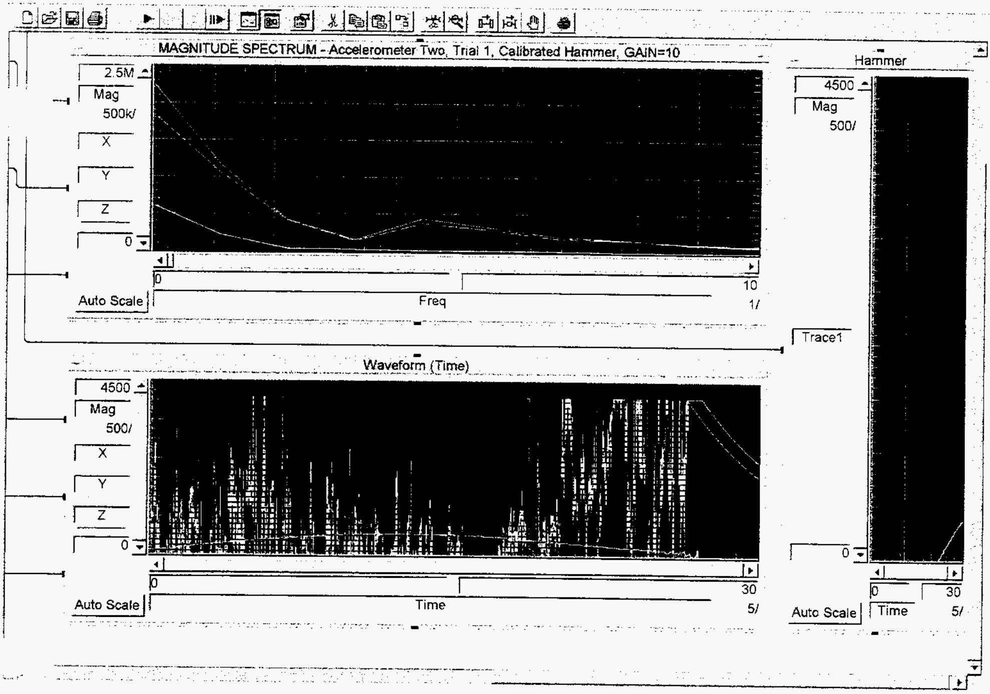

MAGNITUDE SPECTRUM - Accelerometer One, Trial 3, Metal Hammer, GAIN=10
800k
Mag
100k/
X
Y
Z
0
0
30
Auto Scale
Freq
5/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

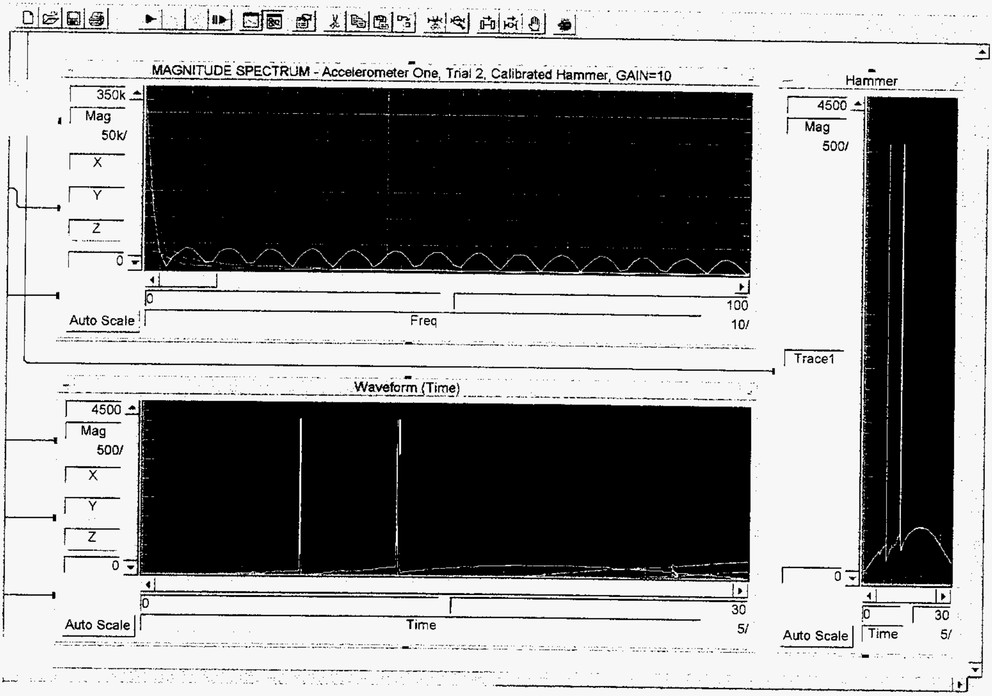

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 3, Metal Hammer, GAIN=10
500k
Mag
50k/
X
Y
Z
0
0
60
Auto Scale
Freq
10/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

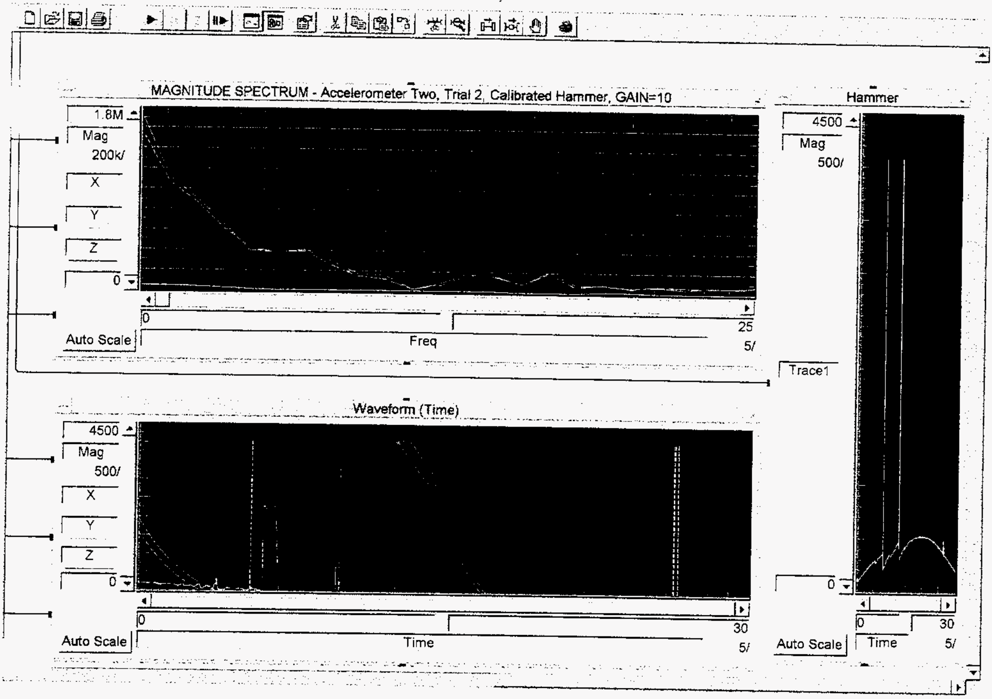

MAGNITUDE SPECTRUM - Accelerometer One, Trial 4, Metal Hammer, GAIN=10
600k
Mag
100k/
X
Y
Z
0
0
25
Auto Scale
Freq
5/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/

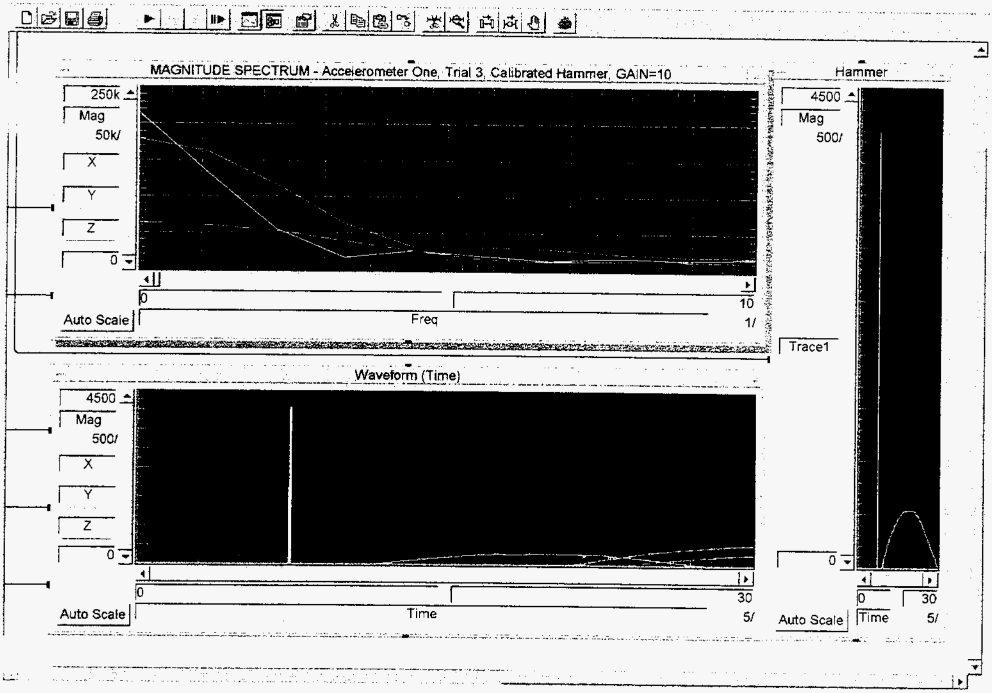

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 4, Metal Hammer, GAIN=10
2M
Mag
200k/
X
Y
Z
0
0
10
Freq
1/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale

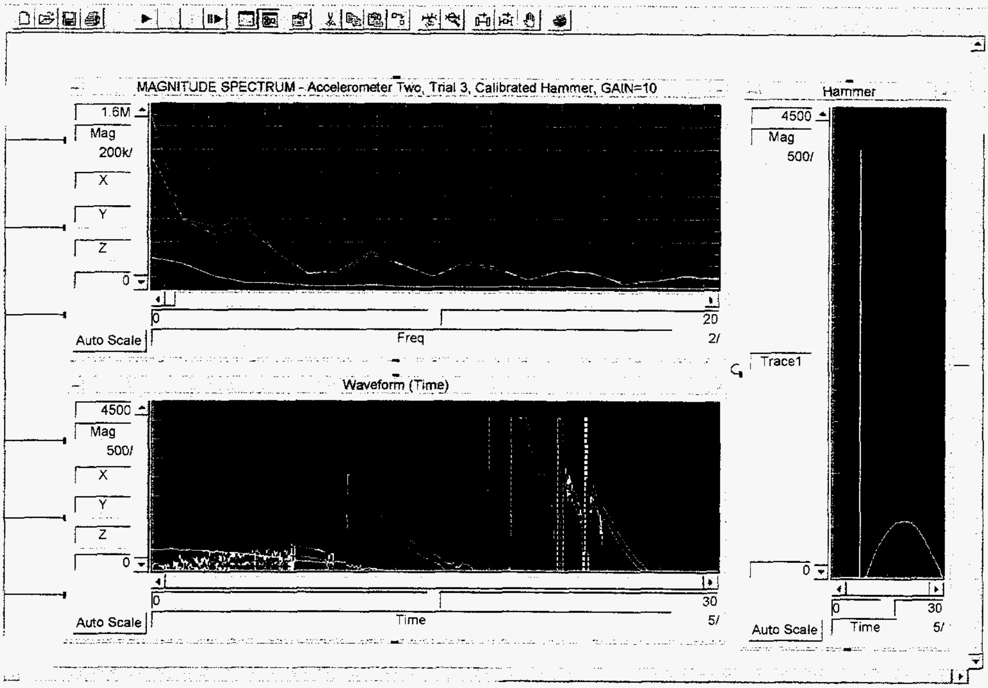

MAGNITUDE SPECTRUM - Accelerometer One, Trial 1, Calibrated Hammer, GAIN=10
180k
Mag
20k/
X
Y
Z
0
Auto Scale
0
10
Freq
1/
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4000
Mag
500/
X
Y
Z
0
Auto Scale
0
30
Time
5/
0
Auto Scale
0
30
Time
5/

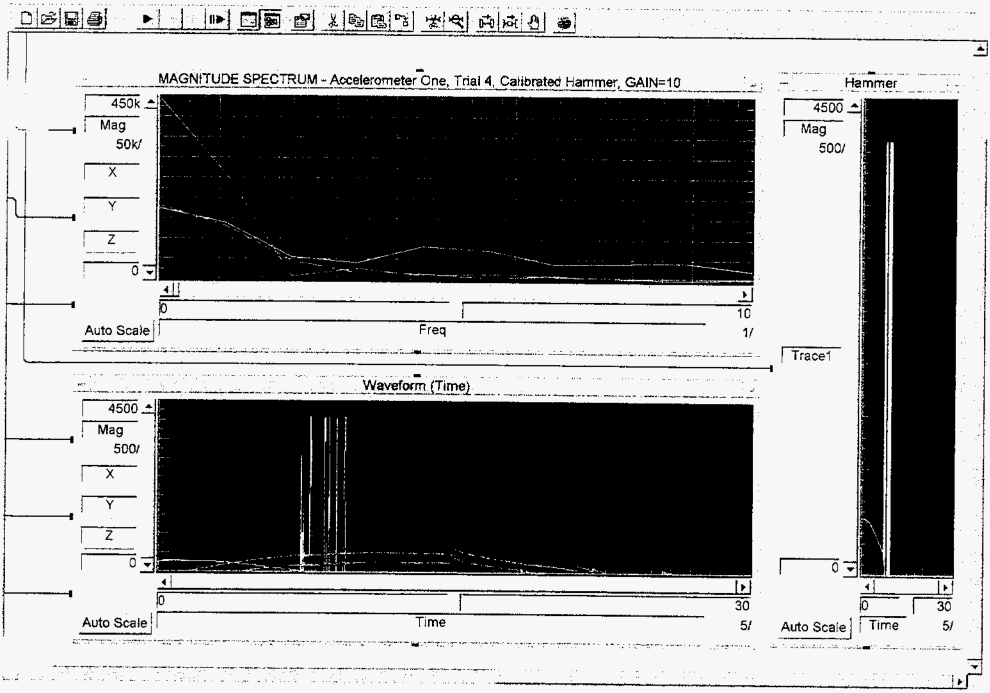

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 1, Calibrated Hammer, GAIN=10
2.5M
Mag
500k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
0
Auto Scale
0
30
Time
5/

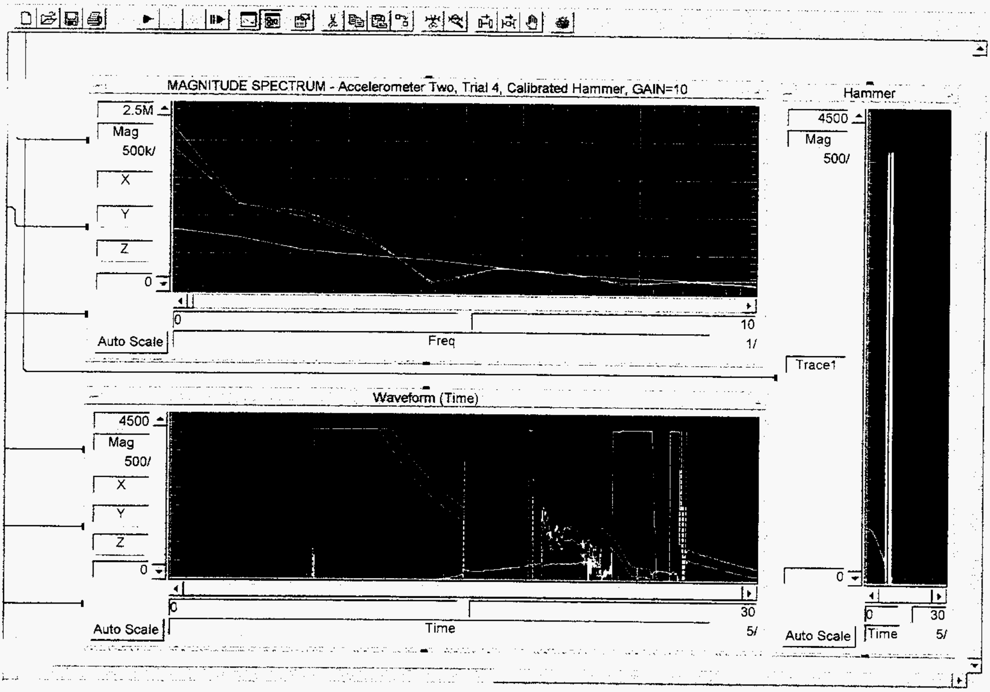

MAGNITUDE SPECTRUM - Accelerometer One, Trial 2, Calibrated Hammer, GAIN=10
350k
Mag
50k/
X
Y
Z
0
100
Auto Scale
Freq
10/
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
30
Auto Scale
Time
5/
0
30
Auto Scale
Time
5/


MAGNITUDE SPECTRUM - Accelerometer Two, Trial 2, Calibrated Hammer, GAIN=10
1.8M
Mag
200k/
X
Y
Z
0
Auto Scale
Freq
25
5/
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
Auto Scale
Time
30
5/
0
30
Auto Scale
Time
5/

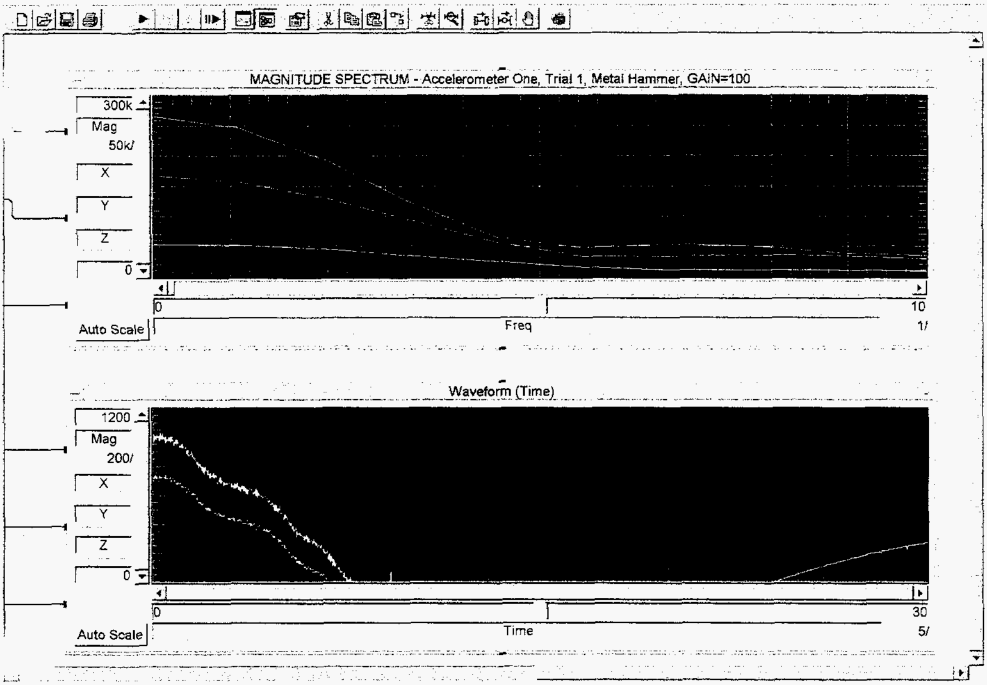

MAGNITUDE SPECTRUM - Accelerometer One, Trial 3, Calibrated Hammer, GAIN=10
250k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
0
0
30
Auto Scale
Time
5/

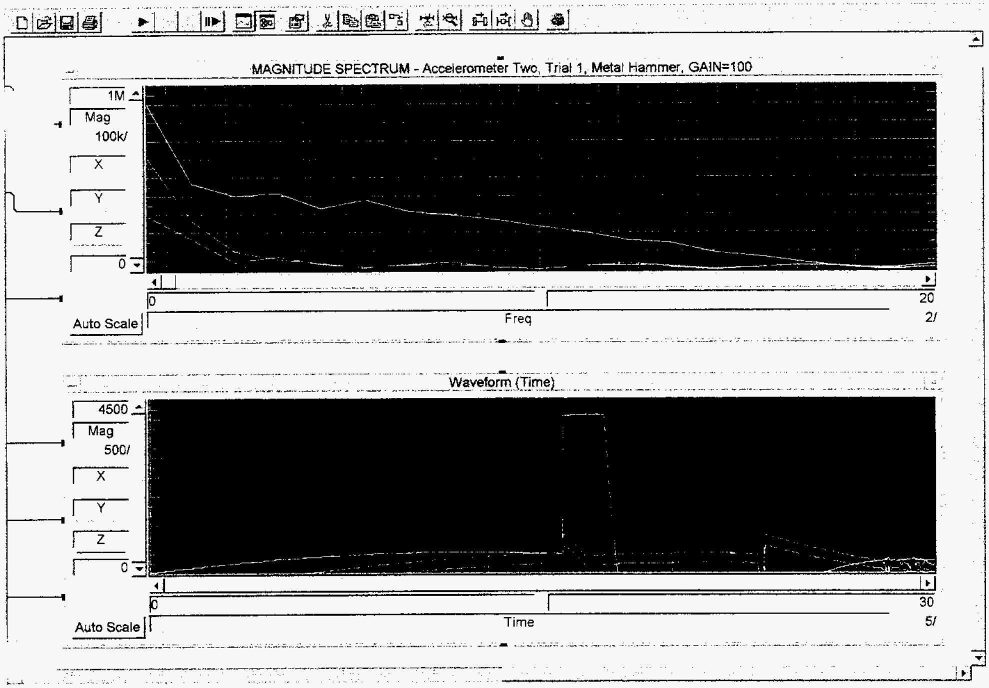

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 3, Calibrated Hammer, GAIN=10
1.6M
Mag
200k/
X
Y
Z
0
0
20
Freq
2/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale
Hammer
4500
Mag
500/
Trace1
0
0
30
Time
5/
Auto Scale

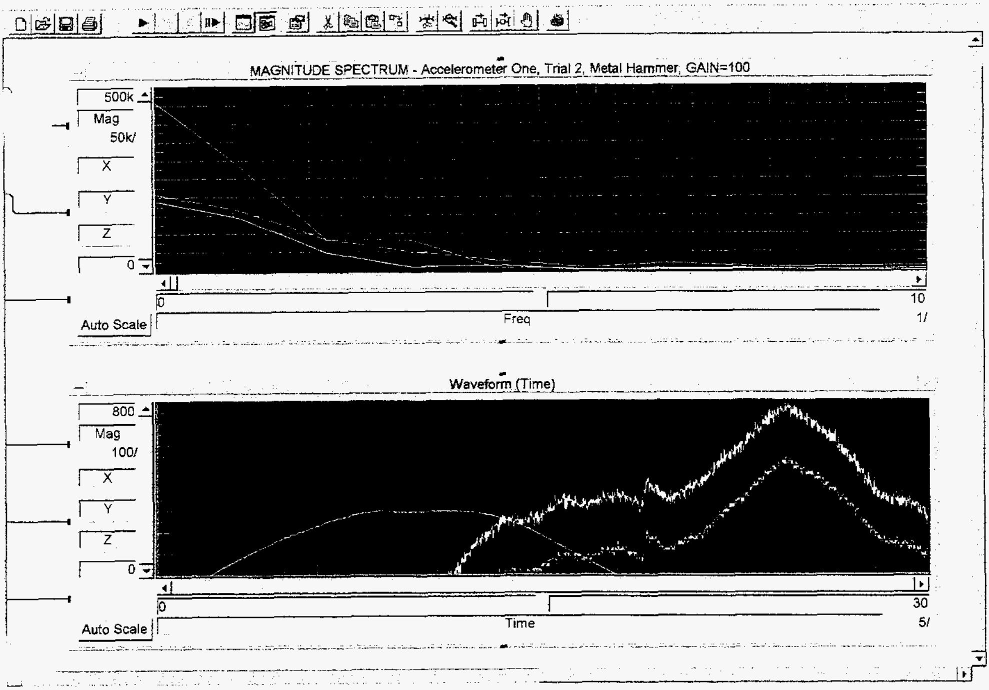

MAGNITUDE SPECTRUM - Accelerometer One, Trial 4, Calibrated Hammer, GAIN=10
450k
Mag
50k/
X
Y
Z
0
10
Freq
1/
Auto Scale
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
30
Time
5/
Auto Scale
0
30
Time
5/
Auto Scale

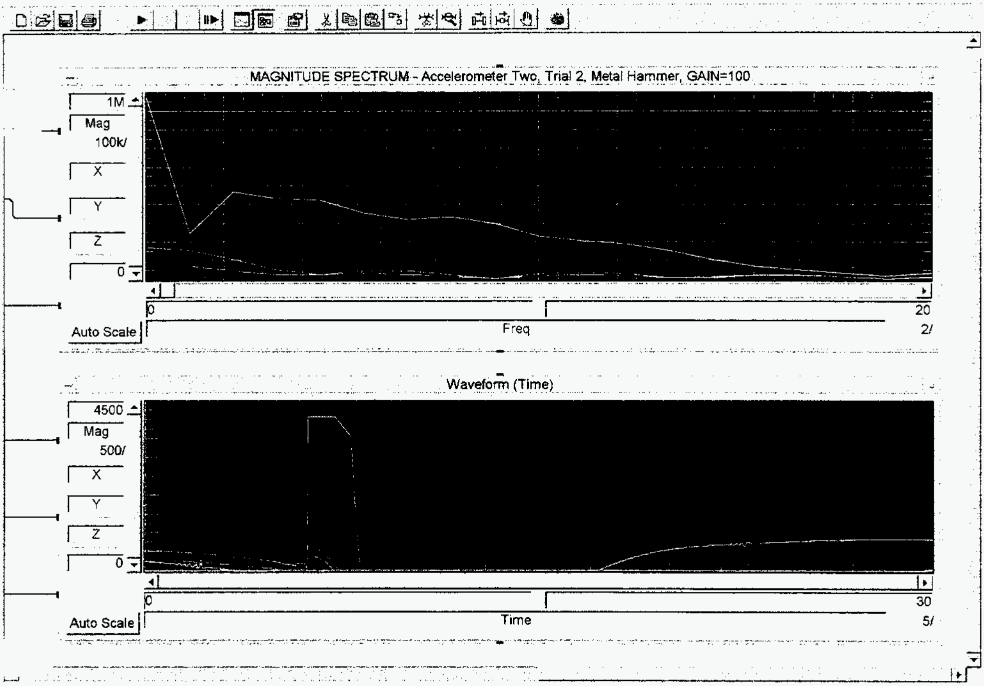

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 4, Calibrated Hammer, GAIN=10
2.5M
Mag
500k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
0
0
30
Auto Scale
Time
5/

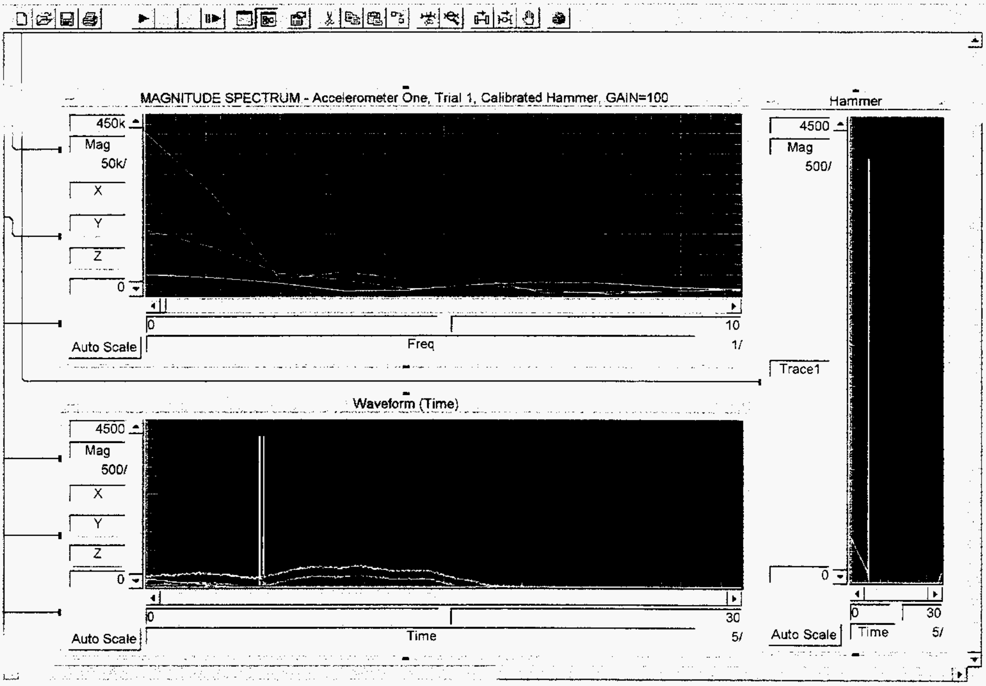
# VERTICAL BOOM DATA

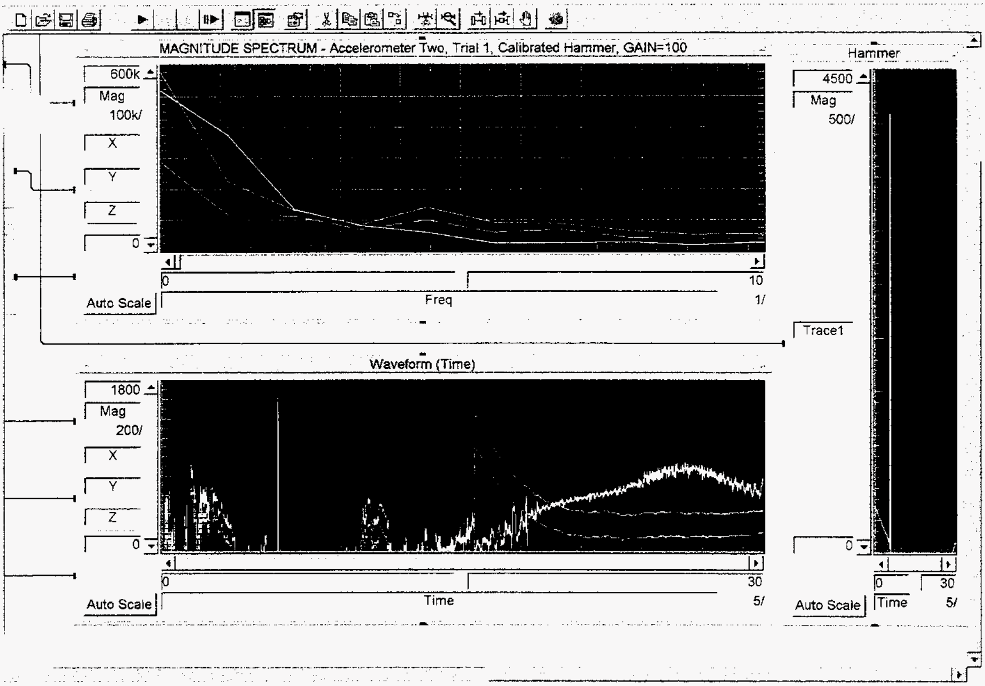

MAGNITUDE SPECTRUM - Accelerometer One, Trial 1, Metal Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Freq
1/
Auto Scale
Waveform (Time)
1200
Mag
200/
X
Y
Z
0
0
30
Time
5/
Auto Scale

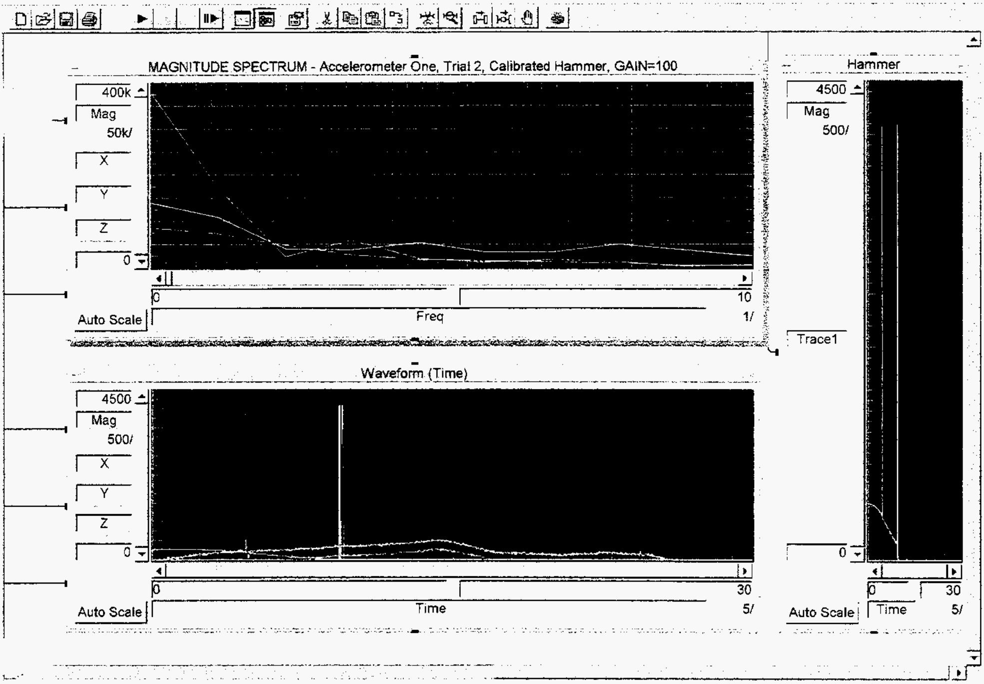

MAGNITUDE SPECTRUM - Accelerometer Two, Trial 1, Metal Hammer, GAIN=100
1M
Mag
100k/
X
Y
Z
0
0
20
Freq
2/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale

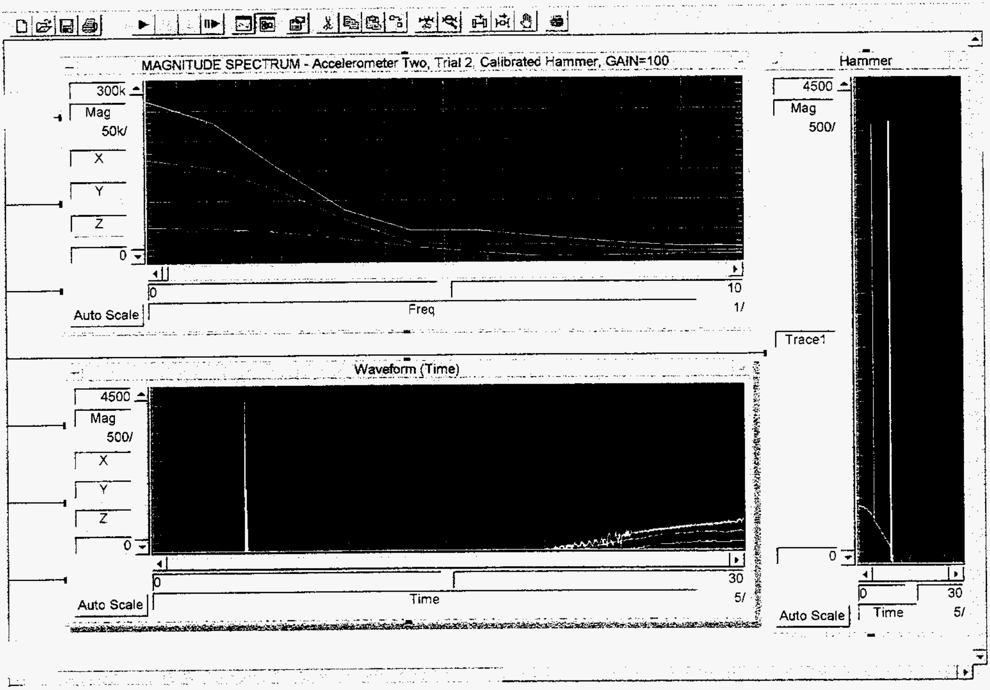

MAGNITUDE SPECTRUM - Accelerometer One, Trial 2, Metal Hammer, GAIN=100
500k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
800
Mag
100/
X
Y
Z
0
0
30
Auto Scale
Time
5/


MAGNITUDE SPECTRUM - Accelerometer Two, Trial 2, Metal Hammer, GAIN=100
1M
Mag
100k/
X
Y
Z
0
0
20
Auto Scale
Freq
2/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/


MAGNITUDE SPECTRUM - Accelerometer One, Trial 1, Calibrated Hammer, GAIN=100
450k
Mag
50k/
X
Y
Z
0
0
10
Freq
1/
Auto Scale
Hammer
4500
Mag
500/
Trace1
0
0
30
Time
5/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale


MAGNITUDE SPECTRUM - Accelerometer Two, Trial 1, Calibrated Hammer, GAIN=100
600k
Mag
100k/
X
Y
Z
0
0
10
Freq
1/
Auto Scale
Hammer
4500
Mag
500/
Trace1
Waveform (Time)
1800
Mag
200/
X
Y
Z
0
0
30
Time
5/
Auto Scale
0
0
30
Time
5/
Auto Scale


MAGNITUDE SPECTRUM - Accelerometer One, Trial 2, Calibrated Hammer, GAIN=100
400k
Mag
50k/
X
Y
Z
0
0
10
Auto Scale
Freq
1/
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Auto Scale
Time
5/
Hammer
4500
Mag
500/
Trace1
0
0
30
Auto Scale
Time
5/


MAGNITUDE SPECTRUM - Accelerometer Two, Trial 2, Calibrated Hammer, GAIN=100
300k
Mag
50k/
X
Y
Z
0
0
10
Freq
1/
Auto Scale
Waveform (Time)
4500
Mag
500/
X
Y
Z
0
0
30
Time
5/
Auto Scale
Hammer
4500
Mag
500/
Trace1
0
0
30
Time
5/
Auto Scale

# FINAL REPORT

# APPENDIX C

# SIMULANT REPORT

May 13, 1997

DRAFT

MEMORANDUM

To: Irv Mermelstein
From: Pete Pedersen
Subject: Hanford Demonstration - Documentation of Preparation of Waste Simulant #2: Salt Cake

The demonstration-sized batch of Salt Cake #1 waste simulant (84% Dynamate, 16% water) was prepared yesterday at the test site. The entire mixing process was documented and photographed. Test specimens were taken. The mix tank was covered at the conclusion of the batch preparation.

Site Location: The Demonstration, scheduled for the end of May, is to be held at the Nesbett & Sons shop/farm facility located adjacent to State Route 58 north of Huntington, Ohio. This facility has been utilized for a variety of businesses including feed and grain storage and processing, trucking depot, farming, and truck repair. A pit has been excavated within an old truck scale area. This pit is about 14 feet deep, measured from the area's concrete floor elevation. The Salt Cake #1 batch was mixed and placed into a steel tank in the pit's bottom.

Site Conditions: The pit area was slightly damp, and muddy at the southern end. No ground water seepage was evident. The pit walls below floor level are non-reinforced earth. Minor sloughing was evident. The pit is beneath a steel superstructure used to hold grain bins. Bins will be removed and the superstructure will be modified to hold the manipulator mast. This modification will leave the pit uncovered.

At the time of mixing, the weather was variable, with sun followed by clouds and occasional rain. No significant precipitation occurred during the mixing or placement of the Salt Cake. The temperature ranged from mid 50's to mid 60's °F.

The waste simulant holding tank is approximately 8 feet in diameter with side walls varying from 5.5 to 14.0 feet in height. A longer side wall was constructed on the north side of the pit to protect the batch and to retain the pit wall. The batch tank has been fabricated from a used fuel tank, which was sandblasted and painted before installation into the pit. Apertures below the waste line were plugged.

Mixing was done over the tank by straddling the pit with planks and plywood.

Salt Cake # 1 Mixing: Dynamate fertilizer was mixed with water in a gasoline-powered mortar mixer rented for the day. Three 50-lb. bags of Dynamate were mixed with 3.42 gallons of water. Water supply is municipal. A plastic bucket was calibrated for a three-bag mix, and was refilled by a hose run to the test area.

DRAFT

May 13, 1997 Memorandum
page 2

Water was added to the mixer, then each bag of Dynamate was broken over the mixer screen and dumped. After all three bags were dumped into the mixer, agitation proceeded for about 1 minute before the mixer was tipped. The waste simulant was then allowed to fall into the tank.

Mixing was continuous, beginning at 12:30 p.m. and terminating at 2:45 p.m.

Care was taken to avoid the addition of extra water by spillage or splashing.

The mixer was partially supported by the extended tank walls. Normal operation imparted some vibration to the simulant, evidenced by the "leveling" of the simulant's surface as operations proceeded.

Miscellaneous materials were randomly added to the simulant in the tank. These materials included dirt, rock (1 to 4 inches in size), steel wire, and old truck trim. As mixing and dumping proceeded it was noted that the wire and truck trim had a tendency to rise towards the simulant surface.

Seventy-eight mixer loads (234 bags) were logged. The tank was filled to over two feet.

Sampling: Five random samples were taken and placed into 6" diameter, 12" deep plastic cylinders. Samples were capped, labeled, and placed alongside the pit to cure. Sample designation and origin are as follows.

| | |
|---|---|
| Sample 1 | Mixer batch 9 |
| Sample 2 | Mixer batch 39 |
| Delphinus Control | Mixer batch 56 |
| Sample 3 | Mixer batch 64 |
| Sample 4 | Mixer batch 73 |

The sampling method consisted of placing a shovel under the mixer as it was tipped, then shoveling simulant quickly into a plastic wheel barrow. About three shovel loads were taken. These were then mixed in the wheel barrow to form a composite. The composite was placed into the cylinders in three equal layers. Each layer was compacted using a 1" diameter steel rod. Compaction was done until moisture was visible at the layer interface.

Tank Covering: The tank was covered with plastic at the conclusion of the mixing operation.

Distribution: Tom Nesbett, EagleTech, Delphinus, file

DELPHINUS ENGINEERING, INC.

## MEMORANDUM

To: David Shaffer

From: Irv Mermelstein, Mike Kobran, Anindya Dasgupta

Date: 6/9/97

Subject: HTI demonstration - Mixing of Wet Sludge and Dried Sludge Simulants

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The purpose of this memorandum is to document the effort undertaken to prepare wet sludge and dried sludge simulants. These simulants were prepared in accordance with the recipes provided by DOE. Wet sludge corresponds to recipe #1 and dried sludge corresponds to recipe #3. The entire mixing process has been documented by video tape. The tanks containing the simulants were covered at the conclusion of the opertion.

Site Location: The demonstration is scheduled to be held at Nesbitt & Sons shop/farm facility located at the intersection of Bursley Road and State Route 58, north of Huntington, Ohio. A 15 ft pit has been excavated and three cylindrical tanks 8 ft in diameter have been placed. The first tank is already filled with salt cake simulant. Wet sludge and dried sludge shall be placed in the next two tanks.

Site condition: For the purpose of mixing simulants, the Delphinus team arrived at the test site on 6/7/97 (Saturday), around 8:00 am. The area near the simulant tanks were prepared to facilitate the mixing process: Bags containing kaolin clay and plaster of Paris were kept near the tanks; arrangements were made for water supply; buckets were calibrated for adding water. Mixing was done over the tank by straddling the pit with planks and plywood. Mixing was performed for straight 10 hours. The temperature varied from 75°F in the morning to about 90°F in the afternoon.

Dried Sludge Mixing: Dried sludge is obtained by mixing 40% Plaster of Paris, 22.5% Kaolin Clay and 37.5% water. Mixing was performed in batches and subsequently, dropped into the tank. Each batch consists of 100 lbs of plaster, 56.25 lbs of clay and 11.25 gallons of water. This turned out to be 4 bags of plaster, 1 bag of clay plus 6.25 lbs. Calibrated buckets were used to add water.

Water was added to the mixer. Then each bag was broken over the screen and dropped into the tank. Initially, the mixer was agitated for 1 minute. However, as the ambient temperature rose, the mixture congealed inside the mixer and had to be chipped out. In effort to prevent this, the mixing time was reduced to 30 seconds. A total of 42 batches were mixed. During the mixing process, miscellaneous materials were randomly added to the tank. These materials include rocks and gravel.

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**Memorandum**
(Continued)
Page 2 of 2

Five random samples were taken and placed into a 6" diameter, 12" deep plastic cylinders. Samples were capped, labeled and placed alongside the pit to cure. Following batches were collected for samples: 10, 11, 26, 37 and 42.

Wet Sludge Mixing: Wet Sludge is obtained by mixing 66% Kaolin Clay and 34% water. As mentioned earlier, mixing was done in batches and dropped into the tank. Initially, 3 bags of Kaolin Clay weighing 150 lb and 9.3 gallons of water was used. However, it was difficult to maneuver this load and, therefore, for the next subsequent batches 100 lb of clay and 6.2 gallons of water was used. The mixture was agitated for 30 second before dropping it into the tank. A total of 38 samples were mixed. Four random sample were collected: Batch 9, 18, 22, and 36.

cc:

Table A - Sampling Information

| Recipe # | Description (Composition #) | Minimum Samples | Sampling Procedure | Minimum Cure Time before Shipment | Composition | Strength kPa (lbf/in²) | Density g/cm³ (lb/ft³) |
|---|---|---|---|---|---|---|---|
| 1 | Wet sludge (NA) | 3 | Pour into the sample container (as the initial consistency is similar to a milkshake). Once the container is mostly filled, tap the container against a hard surface to encourage the release of any large entrained air bubbles.<br><br>Note: Vigorous tapping may be required to remove air from the wet sludge and it may be best to fill the sample container a couple inches at a time and tap to remove air between each. | None | 66 wt% clay, 34 wt%water | 3.5 (0.51) | 1.65 (103) |
| 2 | Hardpan/dried sludge (Composition #1) | 3 | Pour into the sample container (as the initial consistency is similar to a milkshake). Once the container is mostly filled, tap the container against a hard surface to encourage the release of any large entrained air bubbles. | 24 hours | 30 wt% plaster, 27.5 wt% clay, 42.5 wt% water | 32 (4.6) | 1.48 (92.4) |
| 3 | Hardpan/dried sludge (Composition #2) | 3 | | 24 hours | 40 wt% plaster, 22.5 wt% clay, 37.5 wt% water | 150 (21.8) | 1.65 (103) |
| 4 | Hard salt cake (Composition #1) | 4 | Pour in 2 inch lifts and then tamp to remove air. Repeat until sample container is full. | 10 days | 84 wt% K-Mag, 16 wt% water | 20,700 (3,000) | 2.25 (140) |
| 5 | Hard salt cake (Composition #2) | 4 | | 10 days | 88 wt% K-Mag, 12 wt% water | 10,300 (1,500) | 1.94 (121) |
| 6 | Hard salt cake (Composition #3) | 4 | | 10 days | 75 wt% K-Mag, 25 wt% water | 10,300 (1,500) | 2.27 (142) |
| 7 | Soft salt cake (Composition #4) | 4 | Pour 2 inch lifts and then GENTLY tamp (enough to ensure that there aren't any "large" gaps between the salt chunks). Repeat until sample container is full.<br>Note: There may be air voids in the soft saltcake simulants just because there isn't enough liquid to fill the spaces between the chunks of salt. | 24 hours | 86 wt% salt, 9.33 wt% plaster, 4.67 wt% water | 55 (8.0) | 1.20 (74.9) |
| 8 | Soft salt cake (Composition #5) | 4 | | 24 hours | 95 wt% salt, 3.33 wt% plaster, 1.67 wt% water | 10 (1.5) | 1.20 (74.9) |

clay = kaolin clay
K-Mag = potassium magnesium sulfate
plaster = plaster of Paris
salt = sodium chloride rock salt

# FINAL REPORT

# APPENDIX D

# VIDEO DATABASE

## 1. INSTRUCTIONS FOR USE

The first field is the number of the Sony Digital tape used for recording. Each tape is marked only on the outside, so be careful to return the tape to its proper case. The second field is the file name. Please notice that files carry over to other tapes. The third field is the segment. A segment of tape is defined as a portion that resets to 0:00 on the time counter. The last field is the time counter off of the camera.

| Digital Tape # | File Name | Segment | Frames |
|---|---|---|---|
| HTI - 1 | Retrieve/Convey - 2 | 5 | 0:00 - 24:01 |
| HTI - 1 | Dynamic - 1 | 1 | 0:00 - 5:43 |
| HTI - 1 | Dynamic - 2 | 2 | 0:00 - 5:43 |
| HTI - 1 | Retrieve/Convey - 1 | 3 | 0:00 - 20:09 |
| HTI - 1 | CATS Adjust | 4 | 0:00 - 1:55 |
| HTI - 2 | Retrieve/Convey - 3 | 1 | 0:00 - 29:25 |
| HTI - 2 | Decon | 1 | 29:26 - 32:33 |
| HTI - 2 | Decon - Night | 2 | 0:00 - 3:01 |
| HTI - 2 | Decon - Notes | 3 | 0:00 - 1:09 |
| HTI - 2 | WALDO - Prop. | 3 | 1:09 - 1:44 |
| HTI - 2 | Frogs | 3 | 1:45 - 1:57 |
| HTI - 2 | Retrieve/Convey - 4 | 3 | 1:58 - 3:14 |
| HTI - 2 | Grout | 3 | 3:15 - 6:21 |
| HTI - 2 | Static def. | 3 | 7:06 - 8:25 |
| HTI - 2 | Dyn. Drift | 3 | 8:25 - 21:06 |
| HTI - 3 | Site Doc | 1 | 5:37 - 25:43 |
| HTI - 3 | Safety | 2 | 0:24 - 2:01 |
| HTI - 3 | Lift | 3 | 2:02 - 8:32 |
| HTI - 3 | Nav - 1 | 3 | 8:33 - 9:34 |
| HTI - 3 | Nav - 2 | 4 | 0:00 - 8:13 |
| HTI - 3 | Pos. Rep. - 1 | 4 | 8:14 - 10:01 |
| HTI - 3 | Dexterity | 4 | 10:02 - 19:25 |
| HTI - 3 | Pos. Rep. - 2 | 4 | 19:26 - 21:47 |
| HTI - 4 | Pos. Rep. - 3 | 4 | 0:00 - 20:30 |
| HTI - 4 | Access | 4 | 20:31 - 21:10 |

| Proprietary Film Clip List | |
|---|---|
| | |
| **File Name** | **Proprietary Clip** |
| Retrieve/Convey - 1 **Audio Only** | 8:05 - 9:08 |
| Retrieve/Convey - 1 **Audio Only** | 19:01 - 19:40 |
| Retrieve/Convey - 2 **Audio Only** | 19:21 - 19:33 |
| Retrieve/Convey - 2 **Video & Audio** | 1:35 - 2:20 |
| Retrieve/Convey -2 **Audio Only** | 14:05 - 14:20 |
| CATS Adjust **Video & Audio** | 0:00 - 1:55 |
| WALDO - Prop. **Video & Audio** | 1:09 - 1:44 |
| Retrieve/Convey - 3 **Audio Only** | 22:08 - 22:26 |
| Retrieve/Convey - 3 **Audio Only** | 28:25 - 28:44 |
| Grout **Video & Audio** | 4:05 - 4:19 |
| Retrieve/Convey - 4 **Audio Only** | 2:30 - 2:45 |

The above frames have been removed from the Proprietary VCR tapes in order to create the Non-Proprietary for public distribution.

## 2. HTI Demonstration VCR File Database

These files are in order of recording from the field digital tapes. For Non-Proprietary tapes please see the Proprietary film clip list.

| Tape # | File Name | Digital Frames | Proprietary VCR Frames |
|---|---|---|---|
| | | | |
| 1 | Site Doc | 5:37 - 25:43 | 0:00 - 20:23 |
| 1 | Dyn. Drift | 8:25 - 21:06 | 20:24 - 33:12 |
| 1 | Safety | 0:24 - 2:01 | 33:13 - 34:59 |
| 1 | Lift | 2:02 - 8:32 | 35:00 - 41:37 |
| 1 | Nav - 1 | 8:33 - 9:34 | 41:38 - 42:38 |
| 1 | Nav - 2 | 0:00 - 8:13 | 42:39 - 50:57 |
| 1 | Dexterity | 10:02 - 19:25 | 50:58 - 1:00:26 |
| 1 | Pos. Rep. - 1 | 8:14 - 10:01 | 1:00:27 - 1:02:20 |
| 1 | Pos. Rep. - 2 | 19:26 - 21:47 | 1:02:21 - 1:04:51 |
| 1 | Pos. Rep. - 3 | 0:00 - 20:30 | 1:04:52 - 1:25:26 |
| 1 | Access | 20:31 - 21:10 | 1:25:27 - 1:26:06 |
| 1 | Dynamic - 1 | 0:00 - 5:43 | 1:26:07 - 1:32:11 |
| 1 | Dynamic - 2 | 0:00 - 5:43 | 1:32:12 - 1:37:59 |
| 1 | Static Def | 7:06 - 8:25 | 1:38:00 - 1:39:27 |
| 2 | Retrieve/Convey - 1* | 0:01 - 20:09 | 0:00 - 20:14 |
| 2 | CATS Adjust* | 0:00 - 1:55 | 20:15 - 22:20 |
| 2 | Retrieve/Convey - 2* | 0:00 - 24:01 | 22:21 - 46:28 |
| 2 | Retrieve/Convey - 3* | 0:00 - 29:25 | 46:29 - 1:16:02 |
| 2 | WALDO Prop.* | 1:09 - 1:44 | 1:16:03 - 1:16:44 |
| 2 | Frogs | 1:45 - 1:57 | 1:16:45 - 1:16:58 |
| 2 | Retreive/Convey - 4* | 1:58 - 3:14 | 1:16:59 - 1:18:20 |
| 2 | Grout * | 3:15 - 6:21 | 1:18:21 - 1:21:28 |
| 2 | Decon | 29:26 - 32:33 | 1:21:29 - 1:24:43 |
| 2 | Decon - Night | 0:00 - 3:01 | 1:24:44 - 1:27:54 |
| 2 | Decon - Notes | 0:00 - 1:09 | 1:27:55 - 1:29:08 |

An asterisk (*) by the file name indicates that either a portion of this file is proprietary and has been omitted entirely or a section of the film will not have audio. This applies to the non-proprietary tapes.

# FINAL REPORT

# APPENDIX E

# VIDEO SCRIPTS

# POSITION MANAGEMENT

## Test Procedure 1, Position Management

**1. TEST OBJECTIVE**

Demonstrate the arm assembly:

•Positional Repeatability

•Obstacles

•Umbilical Management

•Navigation in Tank

•Visibility

•Mapping

**2. REQUIRED MATERIALS**

**End Effectors**
•Dual Arm Gripper
**Monitoring Equipment**
•Video Cameras
•Teach & Learn Software
**Simulated Test Fixture**
•Start and End Reference Points

**3. PROCEDURE**

•Attach dual arm gripper to manipulator arm assembly.

•Maneuver the arm assembly to the **reference START** point.

•Confirm position using the encoder function of the anti-collision system . **NOTE:** This activity represents a parallel testing activity as part of the mapping demonstration.

•Maneuver the arm assembly from **reference START** to **reference END** position along path 1. Maneuver using camera system and the anti-collision system.

•Confirm **reference END** position using the laser range function of the anti-collision system. **NOTE:** This activity represents a parallel testing activity as part of the mapping demonstration. Independently verify the **reference END** position using a tape measure

•Withdraw arm assembly through the tank from **reference END** to **reference START** position reverse along PATH 1. Maneuver using the "TEACH AND LEARN" system which captured the path on its forward pass.

•Repeat previous steps for PATH 2.

**4. TEST**
•Tank Access
•Positional Repeatability (Path 1)
•Positional Repeatability (Path 2)
•Obstacle Avoidance - Camera System (Path 1)
•In-tank navigation - Teach & Learn (Path 1)
•Obstacle Avoidance - Camera System (Path 2)
•In-tank Navigation - Teach & Learn (Path 2)
•Umbilical Management
•Navigation
•Visibility
•Mapping

# STATIC AND DYNAMIC ANALYSIS

## Test Procedure 1, Static and Dynamic Response

### 1. TEST OBJECTIVE

a) Collect Track 3 System static and dynamic response to measured excitations.

### 2. REQUIRED MATERIALS

a) Integrated Circuit Piezoelectronic (ICP) Triaxial accelerometers.

b) Channel signal conditioner.

c) PC-based data acquisition system.

d) 12-pound instrumented hammer.

e) 10-pound sledge hammer

### 3. PROCEDURE

a) Extend Jib-Boom.

b) Attach ICP accelerometer to the center of each of the Jib-Boom segments.

c) Ensure all associated recording instrumentation is properly calibrated, and connected.

d) Impact the Jib-boom with the instrumented hammer and the 10-pound sledge.

e) Record the Jib-Boom response.

f) Ensure all associated recording instrumentation is properly calibrated and connected.

g) Impact the Vertical-Boom with the instrumented hammer at the closest point above the knuckle joint.

h) Record the response.

### 4. TEST

a) Forces and Frequencies

b) Static deflection

c) Vibration Modes

d) Resonance Frequencies

e) Mode Shapes

# LIFTING TEST

**Static Deflection Test (carried out as a parallel testing effort)**

## Test Procedure 2

**1. TEST OBJECTIVE**

Demonstrate the capability of the arm and the dual arm gripper to:

- Lift a 200-lb object while extended 18 feet.
- Track 3 System maneuverability while loaded.
- Measure manipulator arm deflection under static loading (this test is to be conducted parallel to the lifting test)

**2. REQUIRED MATERIALS**

**End Effectors**

- Dual Arm Gripper

**Miscellaneous**

- 1000-lb Rated Cable
- 200-lb Weight

**3. PROCEDURE**

a) Attach the dual arm gripper to the manipulator arm.

b) Attach 1000-lb rated cable and secure to a 200-lb weight.

c) Maneuver dual-arm gripper arm assembly with weight.

d) Lower the weight to a location outside of the test pit.

e) Return the dual arm gripper to the stowed position.

**4. PARALLEL TEST PROCEDURE FOR STATIC DEFLECTION**

a) Attach a line to the knuckle assembly of the manipulator arm

b) Stretch the line horizontally and the tie the other end to a rigid post

c) Use a level indicator to maintain the line horizontal

d) Measure the deflection of the tip of the arm from the horizontal line

**5. TEST**

- Lifting Demonstration
- Static Deflection

# WASTE DISLODGING, RETRIEVAL AND CONVEYANCE

## Test Procedure 2

### 1. TEST OBJECTIVE

Demonstrate the capability of the arm and its end effectors to:

- Efficiently dislodge waste without compositing tank shell integrity
- Maneuver through entry access risers and throughout tank
- Remove waste from tanks
- Convey waste forms for remote processing
- Effectively extract simulated waste forms.

### 2. REQUIRED MATERIALS

**End Effectors**

•Dual Arm Gripper

•Water Jet End Effector

•Waste Extractor

**Waste Conveying Equipment**

•a) Parallel shrouded water jet and waste extractor

•b)CATS

**Monitoring Equipment**

•Flow monitoring

•Grab sample set-up

•Video recording.

•Flourescene decontamination set-up

**Simulated Test Fixture**

•Simulated Waste

### 3. PROCEDURE

•Perform baseline contamination examination of the water jet.

•Maneuver arm into tank.

•a)Activate water jet and begin dislodging waste. Explore removal efficiency by moving water jet nearer and farther from waste. Record optimum stand-off distance.

•b)Activate waste retrieval and conveyance using shrouded extractor and hydrolaser assembly.

•c)Record conveyance flows.

•d)Take percent solids samples

•e)Terminate water jet.

•f)Pre-Op CAT system for waste retrieval and conveyance.

•g)Repeat steps a, b (Using CAT system and Vacuum Truck).

•h)Repeat steps a, b (Using waste extraction system and using the arm gripper, direct waste into the waste extraction pump) c, d, and e.

•Maneuver manipulator arm to outside the tank.

### 4. TESTS

**Waste Dislodging**
Stand-off distance (S,D,W)
Tank Shell Integrity (S,D,W)

**Lifting Demonstration**
S = Saltcake
D = Dried Sludge
W = Wet Sludge

**Retrieval/Conveyance**

| Water Jet & Vacuum(S,D,W) | Cat(S,D,W) |
|---|---|
| Conveyance Flows | Conveyance Flows |
| Percent Solids | Percent Solids |
| Retrieval Rate | Retrieval Rate |
| Decontamination | Decontamination |

# LOSS OF POWER AND DYNAMIC DRIFT

## Test Procedure 4, Safety Demonstration

**1. TEST OBJECTIVE**

Demonstrate the capability of the Track 3 System upon loss of power to:

•Maintain dynamic drift within acceptable levels.

•Fail in a safe position

**2. REQUIRED MATERIALS**

**End Effectors**

•Dual Arm Gripper

**Monitoring Equipment**

•Marked Target

**Simulated Test Fixture**

•Start and End Reference Points

**3. PROCEDURE**

•Attach the Dual Arm Gripper to the manipulator arm assembly.

•Establish the **reference START** and **reference END** position. Independently verify the **reference Start** and **reference end positions** using a tape measure.

•At a point in travel, interrupt power to the arm by opening the main disconnect breaker.

•These measurements shall be taken in order to determine the **dynamic drift** of the Dual Arm Gripper and manipulator arm assembly.

•Visual examination of the Track 3 System shall verify its fail safe position in space.

**4. TEST**

•Loss of Power Test

•Dynamic Drift Test

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# FAILED KNUCKLE ASSEMBLY HYDRAULIC CYLINDER

## Test Procedure 4, Safety Demonstration

**1. TEST OBJECTIVE**

Demonstrate the capability of the Track 3 System upon loss of hydraulic boom cylinder to:

•Retrieve the manipulator arm and boom assembly safely from inside a tank.

•Maneuver arm assembly through tank entry riser.

**2. REQUIRED MATERIALS**

**End Effectors**

•Dual Arm Gripper

**3. PROCEDURE**

•Attach the dual arm gripper to the manipulator arm.

•Lower arm assembly through the demonstration riser.

•Maneuver the arm assembly such that the jib boom is at a right angle to the vertical boom.

•Lower the manipulator arm assembly until the jib boom lies horizontally on the test pit floor.

•Disengage spring loaded release device allowing the jib boom assembly to hang freely.

•Maneuver and withdraw the arm assembly through the entry riser and upward through the mast assembly.

•Stow arm in mast assembly

**4. TEST**

•Failed Mast Assembly

•Failed Knuckle

# FAILED MAST CYLINDER

## Test Procedure 4, Safety Demonstration

**1. TEST OBJECTIVE**

Demonstrate the capability of the arm and its end effectors to be withdrawn upon failure of the primary mast cylinder.

**2. REQUIRED MATERIALS**

**End Effectors**

•Dual Arm Gripper

**3. PROCEDURE**

•Attach dual arm gripper to the manipulator arm.

•Lower the arm assembly through the entry riser.

•Maneuver the arm assembly such that the horizontal boom is at a right angle to the vertical boom

•Lower the manipulator arm assembly until the jib boom lies horizontally on the test pit floor.

•Disable the primary hydraulic cylinder.

•Maneuver and withdraw the arm assembly through the entry riser and upward through the mast assembly.

•Stow arm in the mast assembly.

•Restore the system by lowering the arm assembly and enabling the primary hydraulic cylinder.

**4. TEST**

•Failed Mast

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