

**WIPP FULL SCALE HYDROSTATIC TESTING
OF**

55 Gallon Waste Disposal Drums

FINAL REPORT

SwRI Project 18.18197.03

Issue 1

Purchase Order 1493421

prepared by

Mark Orłowski

prepared for

Sandia National Laboratories

4100 National Parks Highway, Bldg. A

Carlsbad, NM 88220

April 23, 2015



Southwest Research Institute®

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San Antonio, Texas 78228-0510

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April 23, 2015

Authored By:

Approved By:

Approved By:



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Research Engineer,

Principal QA Technologist,

P.E., Manager,

Structural Dynamics &

Audits & Surveillance

Ocean Simulation Laboratory

Product Assurance

0 Release Control Record

Below is a table documenting the various changes recorded in this report. Each issuance of the report is clearly marked with the revision number and date of issue.

Table 1: Revision Table

Issue No.	REASON FOR CHANGE	Date Issued
1	Original Release	04/23/15



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1 Introduction

Southwest Research Institute (SwRI®) was contracted by Sandia National Laboratories to perform hyperbaric testing on six 55-gallon waste disposal drums planned to be buried at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. The hyperbaric tests were performed at the facilities of Southwest Research Institute (SwRI) from February 9-16, 2015. Testing was completed to a full scale hydrostatic test procedure provided by Sandia National Laboratories. The hyperbaric testing was performed in SwRI's 50-inch I.D., 6,000 psig test chamber. The tests consisted of subjecting each drum to a series of pressure unload/reload loops; the final confining pressure goal was 2,175 psi. Testing was completed under an NQA-1 compliant quality program.

2 Test Setup

An example of a test sample prior to testing is shown in Figure 1 in Appendix I. 3/8" Swagelok tubing was used for all plumbing connections. Haskell air-operated pumps were used to apply the confining pressure. The tests were conducted in fresh water, and ambient and chamber temperature were measured by thermocouples supplied by SwRI. A calibrated 3,000 psi pressure transducer and a spirometer LVDT were supplied by Sandia National Laboratories; the pressure transducer was setup to measure the hyperbaric pressure in the pressure vessel and the spirometer LVDT was connected to the sample vent to derive the change in volume of air inside the test sample as the hyperbaric pressure caused it to compress. Each test sample was mounted inside the pressure vessel by a test fixture. A photograph of a test sample inside the fixture is provided in Figure 2. A calibrated load cell supplied by SwRI was attached to the test fixture to measure the reduction of buoyancy as hyperbaric pressure increased. Instrumentation used to support the test program is listed in Table 2. The calibration sheets for the calibrated equipment are included in Appendix III. All test parameters were monitored, recorded, and electronically stored using a SwRI test computer logging software program written in LabVIEW. The LabVIEW program calculated the volume strain by dividing the change in volume by the initial volume. A camera located inside the hyperbaric chamber monitored and recorded each drum's physical condition during testing.

Table 2: Calibrated Equipment

Make/Model	Item Measured	Asset #	Calibration Due Date
Stellar Technology Model PNC710-500LBTN-159	Reduction in Buoyancy	020800	05/26/15
FLUKE Model 714	Thermocouple Calibration	016644	02/21/15
*Omega Engineering Model PX309-3KGV	Pressure	6662865	12/09/15
*MHR Model 1000	Change in Volume	-	05/08/15

Note: Equipment marked with a * symbol was provided and calibrated by Sandia National Laboratories



3 Test Results

Water was injected into the hyperbaric chamber to produce a volumetric strain rate of the test sample of approximately $1\text{E-}4 \text{ sec}^{-1}$. When a volume strain of approximately 50% was reached, hyperbaric pressure was increased at an approximate rate of 87 psi/min. Pressurization rate was monitored and approved by Sandia personnel. Pressure unload/reload loops were performed at the intervals listed in Table 3. Each loop consisted of a rapid release in hyperbaric pressure followed by rapid increase to restore hyperbaric pressure to the original value. When hyperbaric pressure dropped uncontrollably, testing was paused and the sample was inspected for puncture or leak.

Table 3: Pressure Loop Intervals

Loop #	Volumetric Strain ϵ_v	Hyperbaric Pressure (psi)
1	0.12	-
2	0.24	-
3	0.36	-
4	-	50
5	-	100
6	-	200
7	-	400
8	-	800
9	-	1500
10	-	2175

The first drum tested was labeled WC-HC-NDF-01, and it was an unjacketed test sample. Pressure loops 1 through 5 were successfully completed before testing was stopped due to a leak at the top of the drum. The collapsed drum is shown in Figure 3. Pressure versus volume strain and pressure versus load measurements for this test are shown in Figure 8 and Figure 9, respectively.

The second sample tested was a jacketed drum labeled WC-HC-NDF-05. Pressure loops 1 through 4 were successfully completed before testing was paused due to a leak at the bung location. The damage is shown in Figure 4. Pressure versus volume strain and pressure versus load measurements for this test are shown in Figure 10 and Figure 11, respectively.

Based upon the inspection of the failure of WC-HC-NDF-05, Sandia personnel induced minor buckling at strategic locations on the unjacketed sample labeled WC-HC-NDF-02 in an attempt to avoid pinching at the bung location. The induced buckling successfully influenced the buckling pattern to avoid this failure mechanism which would not be experienced in real-world applications. This buckling pattern is shown in Figure 5. Hyperbaric pressure was applied until a leak occurred at 268 psi. Sandia personnel induced minor buckling in the two remaining test samples to similarly influence the buckling pattern.

The fourth sample tested was a jacketed drum labeled WC-HC-NDF-06. Pressure loops 1 through 7 were successfully completed before testing was stopped due to a pin hole on the side wall of the drum preventing further pressurization. The collapsed drum is shown in Figure 6. Pressure versus volume strain and pressure versus load measurements for this test are shown in Figure 12 and Figure 13, respectively.



The fifth sample tested was a jacketed drum labeled WC-HC-NDF-07. Pressure loops 1 through 8 were successfully completed before testing was stopped due to a leak in the drum. The collapsed drum is shown in Figure 7. Pressure versus volume strain and pressure versus load measurements for this test are shown in Figure 14 and Figure 15, respectively.

None of the test samples sustained a confining pressure of 2,175 psi before leaking.



Appendix I

Pictures and Pressure Graphs



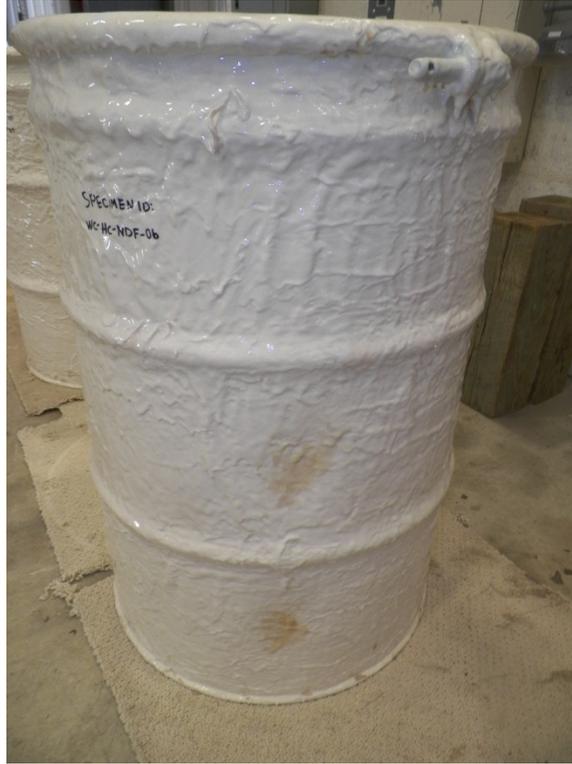


Figure 1: Jacketed Drum before Hyperbaric Testing



Figure 2: Sample Mounted Inside Test Fixture



Figure 3: Test Sample WC-HC-NDF-01 after Hyperbaric Testing



Figure 4: Failure at Bung Location for Test Sample WC-HC-NDF-05



Figure 5: Test Sample WC-HC-NDF-02 after Hyperbaric Testing



Figure 6: Test Sample WC-HC-NDF-06 after Hyperbaric Testing



Figure 7: Test Sample WC-HC-NDF-07 after Hyperbaric Testing

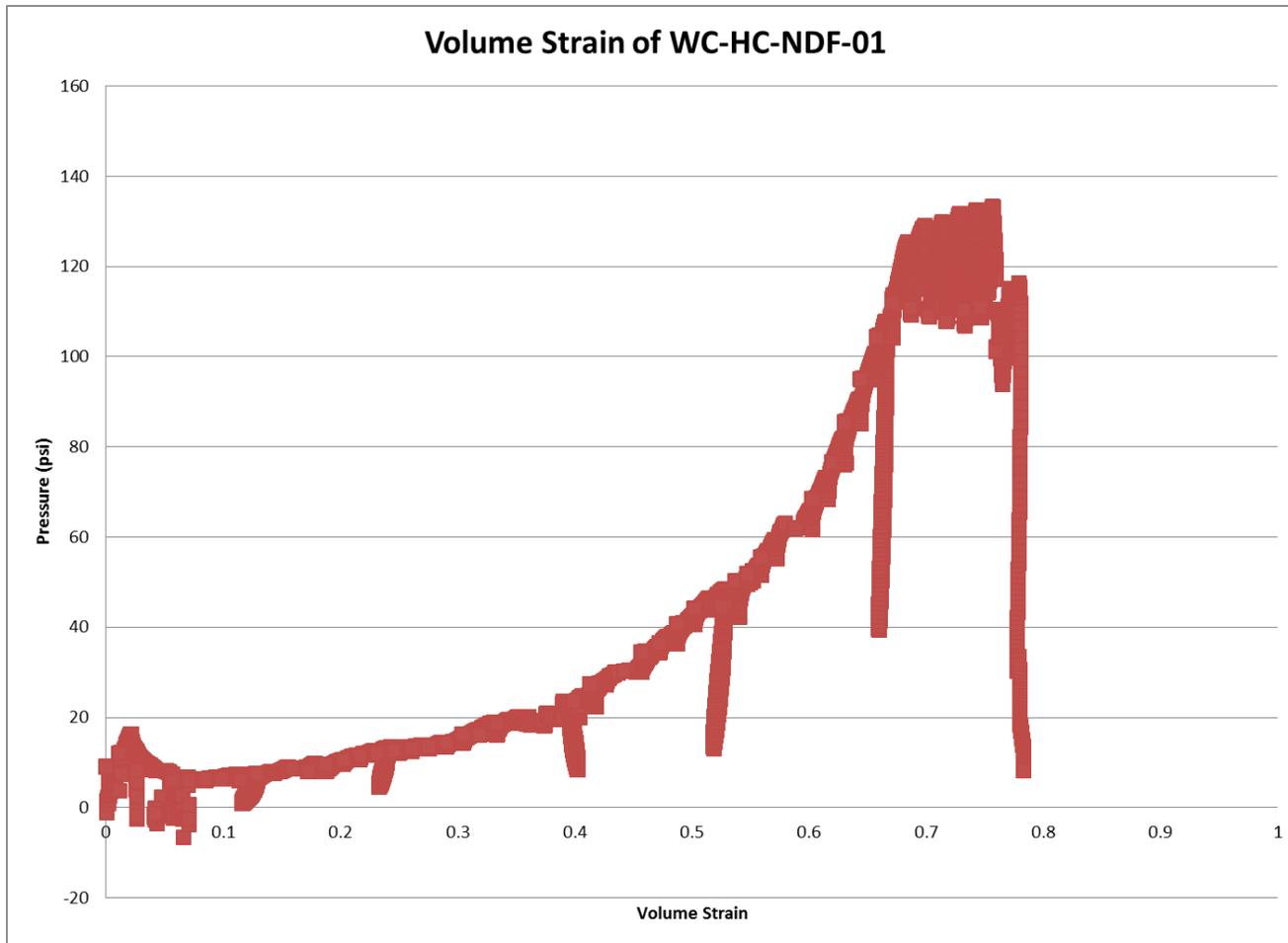


Figure 8: Volume Strain Calculated during Hydrostatic Testing of WC-HC-NDF-01



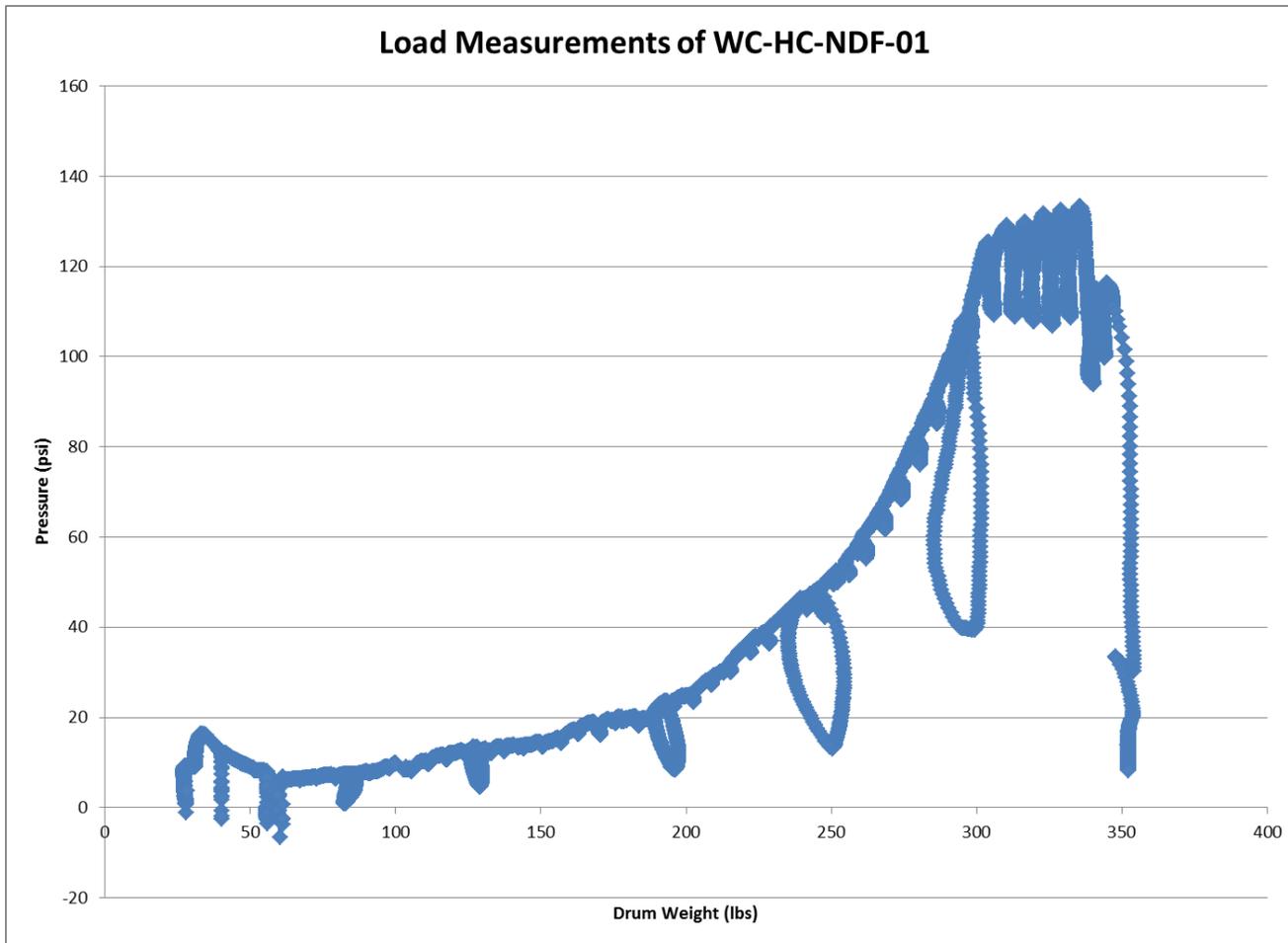


Figure 9: Buoyancy Reduction during Hydrostatic Testing of WC-HC-NDF-01



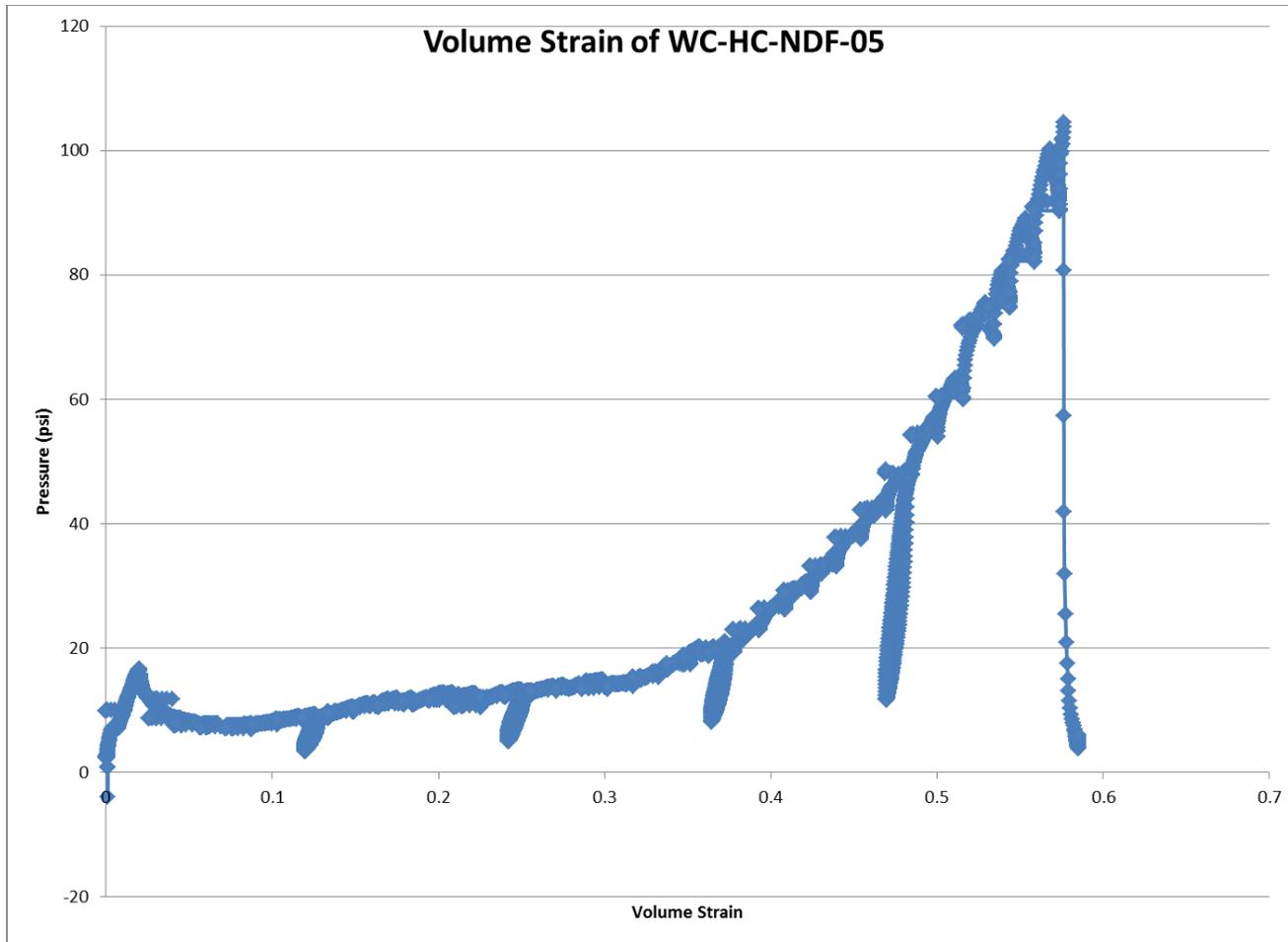


Figure 10: Volume Strain Calculated during Hydrostatic Testing of WC-HC-NDF-05



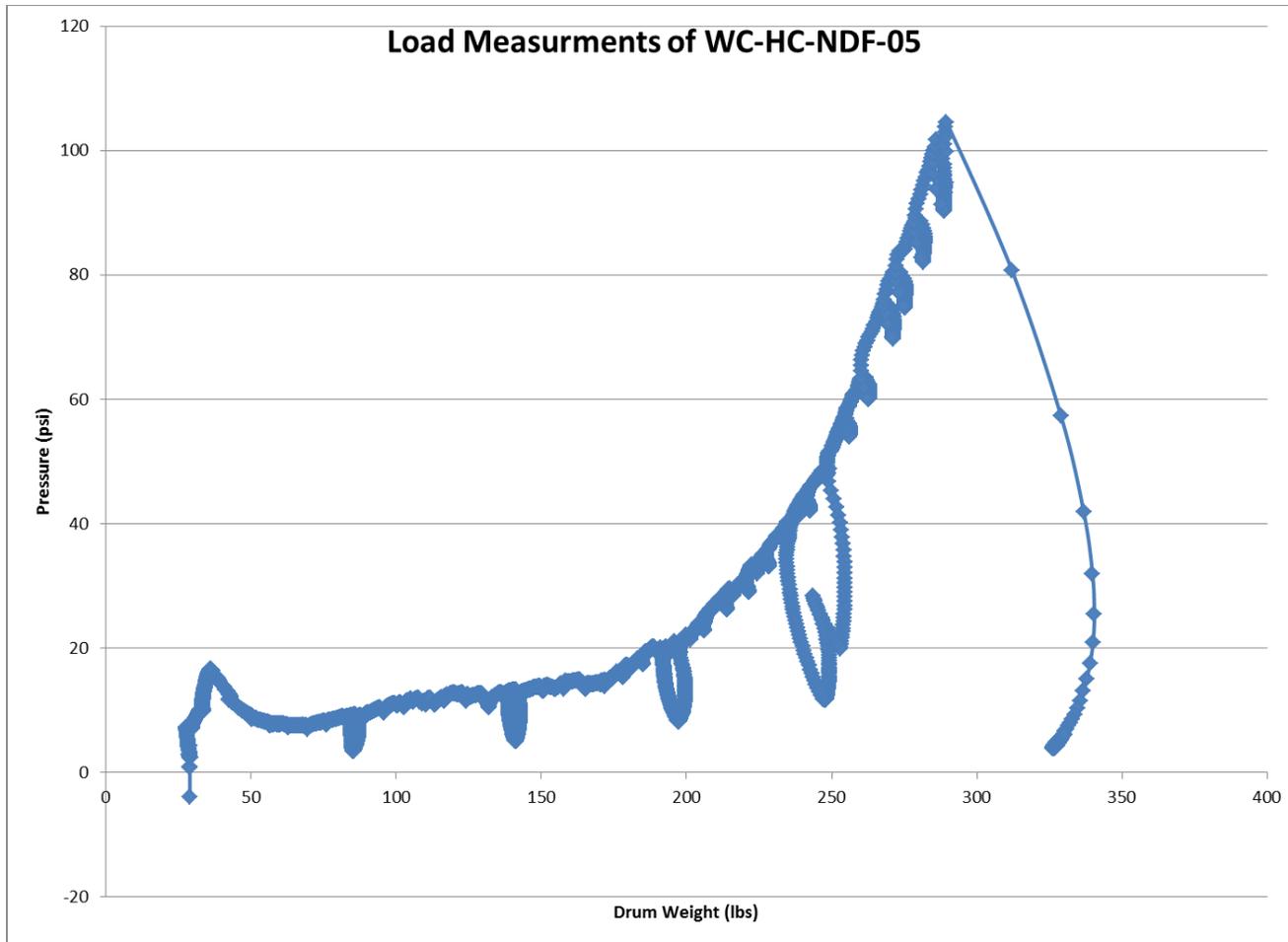


Figure 11: Buoyancy Reduction during Hydrostatic Testing of WC-HC-NDF-05



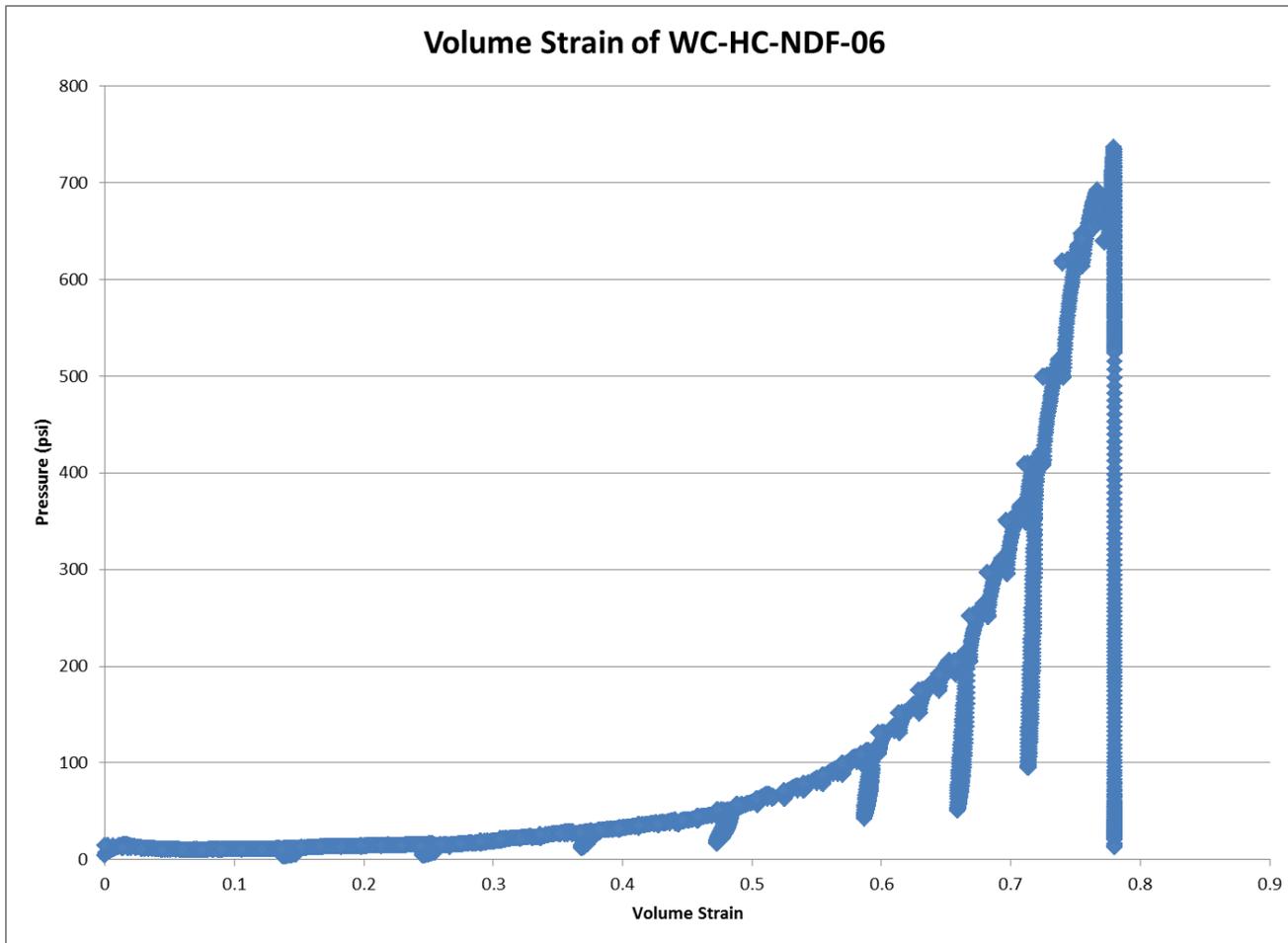


Figure 12: Volume Strain Calculated during Hydrostatic Testing of WC-HC-NDF-06



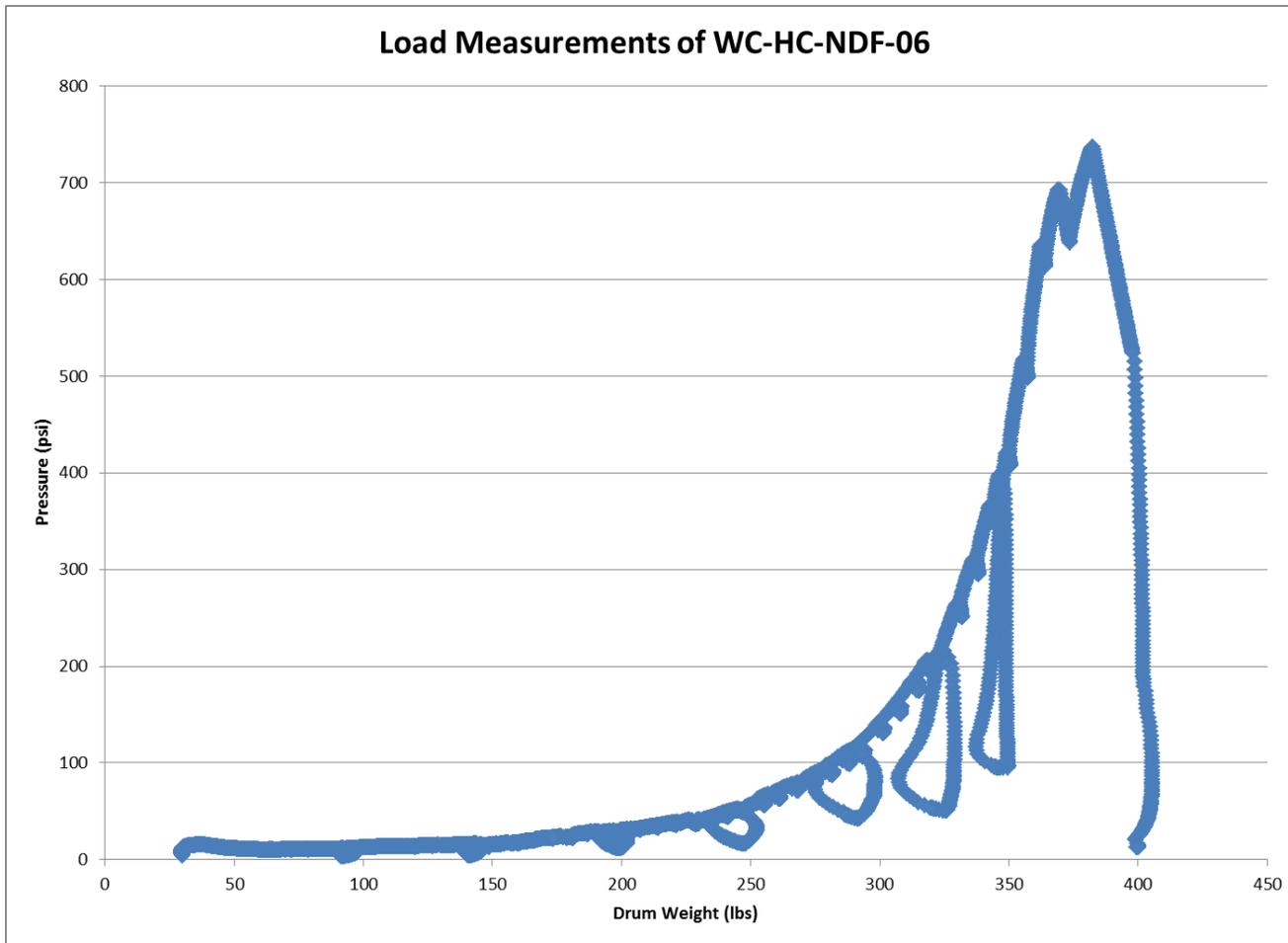


Figure 13: Buoyancy Reduction during Hydrostatic Testing of WC-HC-NDF-06



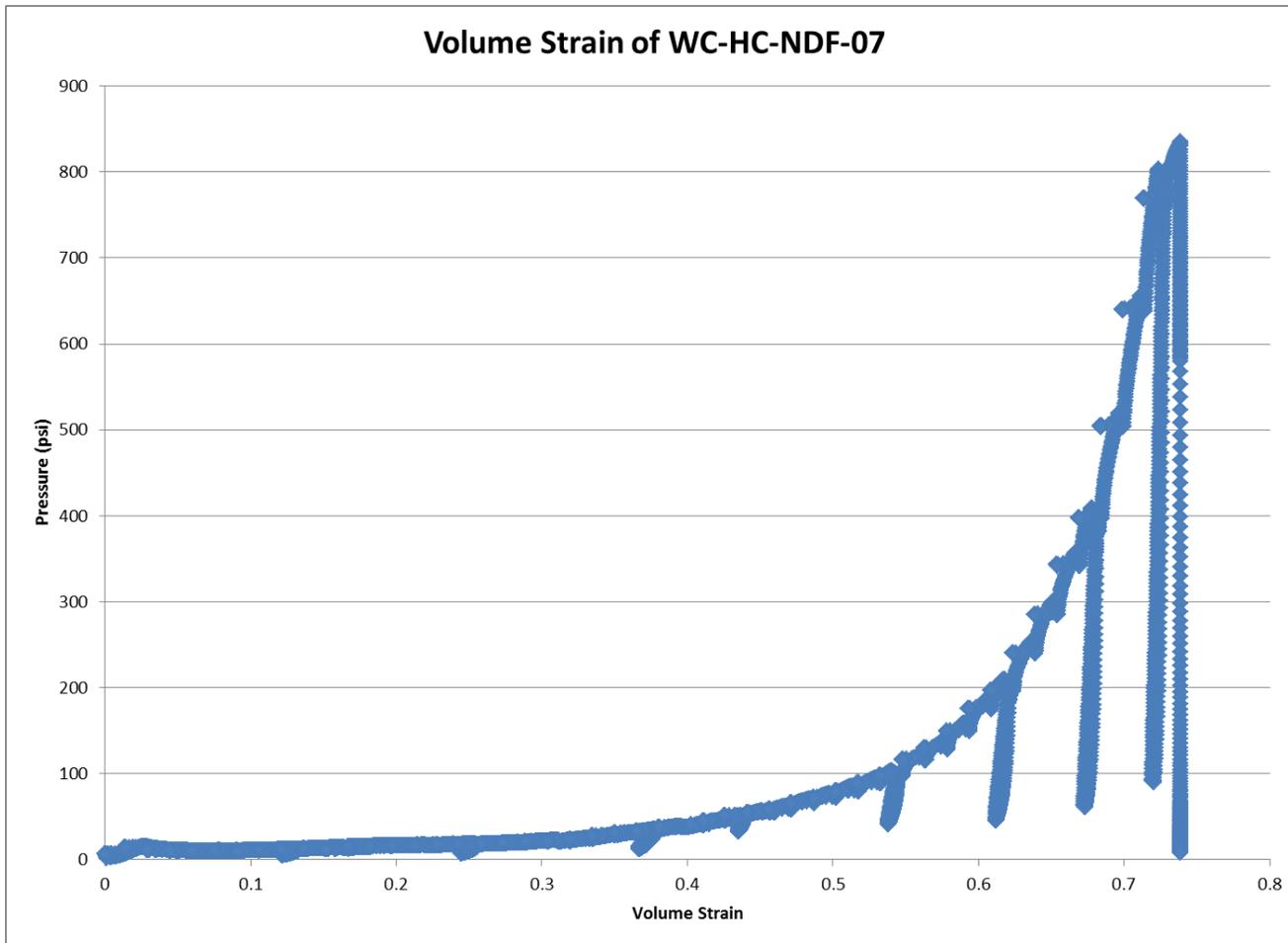


Figure 14: Volume Strain Calculated during Hydrostatic Testing of WC-HC-NDF-07



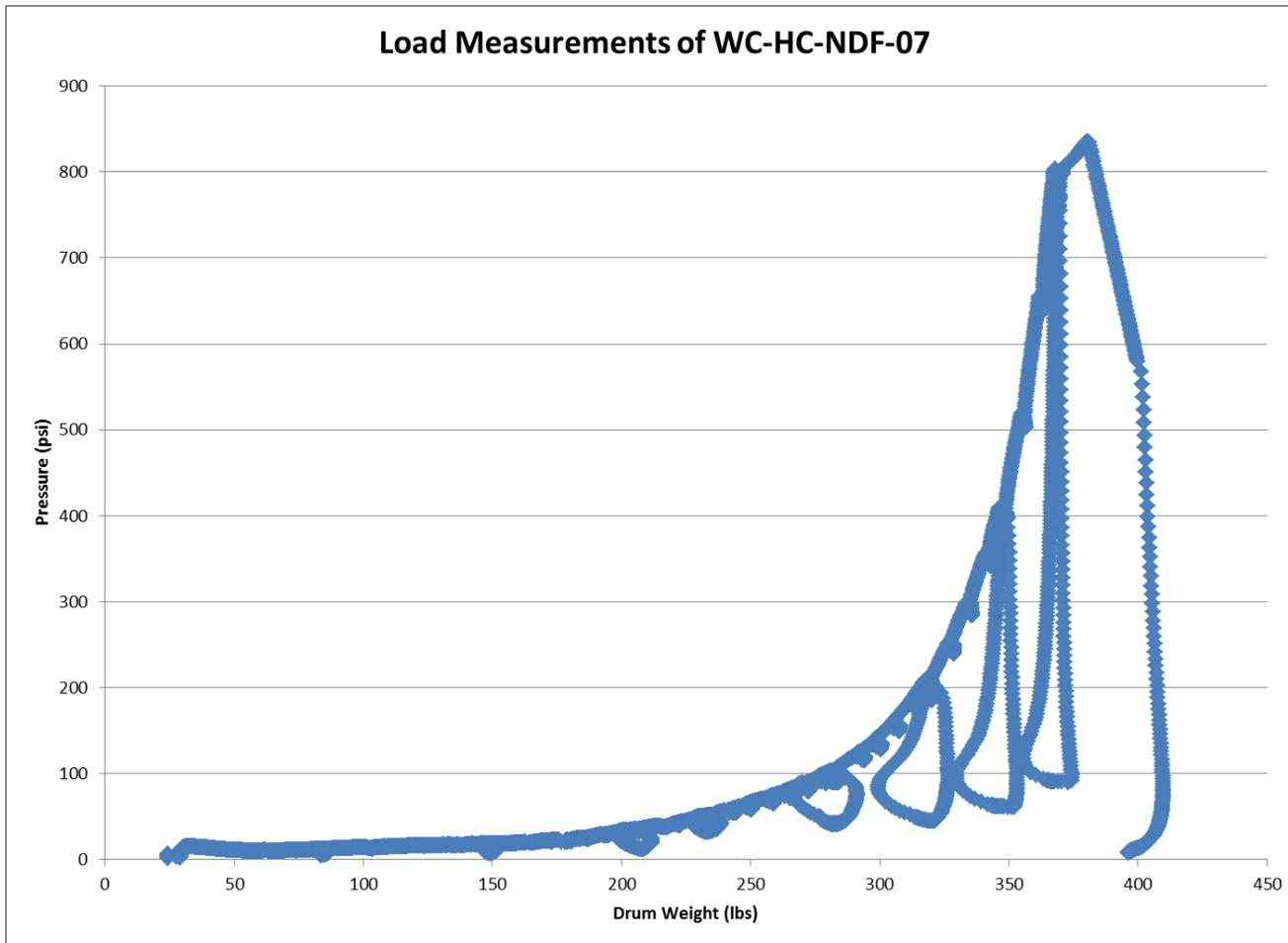


Figure 15: Buoyancy Reduction during Hydrostatic Testing of WC-HC-NDF-07



Appendix II
Quality Program Documentation



Distributed: February 13, 2015

Quality Plan (QP)

DISTRIBUTION LIST

QP 18.18197.03.103

Revision 0

Hyperbaric Testing for Four 55 Gallon Drums

M. Orłowski (18)	Copy No. 1
M. Lewis (CC30)	Copy No. 2
C. Hobson (CC30)	Copy No. 3
M. Ehnstrom (CC30)	Copy No. 4
P. Rodriguez (CC30)	Copy No. 5
IQS Records	Original

Note: A return receipt to Institute Quality Systems will not be required, as it is the responsibility of the holder of a controlled document to maintain that document and to ensure the most recent revision/change to that document has been retained.





**SOUTHWEST RESEARCH INSTITUTE®
INSTITUTE QUALITY SYSTEMS
CONTRACT REVIEW RECORD AND QUALITY PLAN**

(If Applicable) Quality Plan Number: 18197.03.103

PROJECT INFORMATION

- | | |
|--|--|
| 1. Project Number: 18197.03.103 | 2. SwRI® Project Manager: Mark Orłowski |
| 3. Project Title/Description: Hyperbaric Testing of Four 55 Gallon Drums | |
| 4. Proposal Reference #: N/A | 5. SwRI® Contract Admin: Vera Elizondo |
| 6. Start Date: 2/02/15 | 7. Est. Completion Date: 5/08/15 |
| 8. Key Project Activities | |
| <input type="checkbox"/> Design/Design Analysis | <input type="checkbox"/> Software Development |
| <input checked="" type="checkbox"/> Testing | <input type="checkbox"/> Numerical Analysis |
| <input type="checkbox"/> Fabrication | <input type="checkbox"/> Laboratory Testing/Analysis |
| <input type="checkbox"/> Field/Fleet Testing | <input type="checkbox"/> Literature/Data Review |
| <input type="checkbox"/> Inspection/Evaluation | <input type="checkbox"/> Prototype Development |
| <input type="checkbox"/> Other _____ | |

CUSTOMER INFORMATION

- | | |
|---|--|
| 9. Customer: Sandia National Laboratories | 10. Location: Albuquerque, NM |
| 11. Contract Number: 1493421 | 12. Customer Contact: Christina Vallejos |

CONTRACT REQUIREMENTS

13. Quality System Requirement: QSM, Rev. 4;
14. Applicable Specifications: ISO 9001:2008
15. Additional Requirements: Testing in accordance with client supplied test procedure.

(For DoD/NASA Contracts)

- | | | |
|--------------------------|---------------------------------|--------------------------------------|
| 16. Administered by: N/A | | |
| 17. Inspection Point | <input type="checkbox"/> Source | <input type="checkbox"/> Destination |
| 18. Acceptance Point | <input type="checkbox"/> Source | <input type="checkbox"/> Destination |
| 19. DD-250/DD-1149 | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 20. MRB Authority | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 21. DCMA Delegation | <input type="checkbox"/> Yes | <input type="checkbox"/> No |

SwRI® Form QA-181-3 (Front)



QSM APPLICABILITY MATRIX		
QSM SECTION	APPLICABLE	APPLICABLE PROCEDURES
Section 4.0 Quality Management System 4.1 General Requirements 4.2 Documentation Requirements	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	Applicable Sections of the QSM Rev.4; SOP-410-01 Rev.10
Section 5.0 Management Responsibility 5.1 Management Commitment 5.2 Customer Focus 5.3 Quality Policy 5.4 Planning 5.5 Responsibility, Authority and Communication 5.6 Management Review	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	QSM 5 QSM 5.1 QSM 5.2 QSM 5.3 QSM 5.4 QSM 5.5 QSM 5.6
Section 6.0 Resource Management 6.1 Provision of Resources 6.2 Human Resources 6.3 Infrastructure 6.4 Work Environment	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	SOP-600-01 Rev. 1 QSM 6.1; QSM 6.2; QSM 6.3; QSM 6.4
Section 7.0 Product Realization 7.1 Planning of Product Realization 7.2 Customer-Related Processes 7.3 Design and Development 7.4 Purchasing 7.5 Production and Service Provision 7.6 Control of Monitoring and Measuring Equipment	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	SOP-750-01 Rev. 5 SOP-750-01 Rev. 5 SOP-750-01 Rev. 5 N/A SOP-740-01 Rev. 2 N/A QSM 7.6; SOP-760-01 Rev.7 Control or Monitoring and Measuring Devices
Section 8.0 Measurement, Analysis and Improvement 8.1 General 8.2 Measuring and Monitoring 8.3 Control of Nonconforming Product 8.4 Analysis of Data 8.5 Improvement	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	QSM 8 SOP-840-01 Rev. 3 SOP-840-01 Rev. 3 QSM 8.3, SOP-830-01, Rev.4 SOP-710-01, Rev.2 SOP-821-01, Customer Satisfaction Rev.6

List Attachments: None

APPROVALS:

Mark R. Ehnstom
 Institute Quality Systems

2/2/15
 Date

Mark Orlovski
 Project Manager

2/2/15
 Date

SwRI® Form QA-181-3 (Back)





RECEIVING INSPECTION REPORT

Supplier Name: <i>Dandia National Laboratories</i>		Supplier Code: <i>N/A</i>	P.O. # <i>1493421</i>	Project # <i>18171.03.103</i>	QAE <i>MLB</i>	Date <i>2/9/15</i>
Inspection Criteria: <input checked="" type="checkbox"/> None Required		<input type="checkbox"/> C of C	<input type="checkbox"/> Material Cert	<input type="checkbox"/> Mill Certs	<input type="checkbox"/> Inspection Data	<input type="checkbox"/> Other
Item #	Part #/Serial #	Description	Date Code/Lot # Batch #/Heat #	Quantity Accepted	Reject Tag #	Quantity Rejected
<i>N/A</i>	<i>WC-HC-NDF-01 02 03 04</i>	<i>USA DOT 7A Type A 55 gal Storage Drums/ Containers (Non jacketed)</i>	<i>N/A</i>	<i>4</i>	<i>N/A</i>	<i>0</i>
<i>A</i>	<i>WC-HC-NDF-05 06 07</i>	<i>USA DOT 7A Type A 55 gal Storage Drums/ Containers (Jacketed)</i>	<i>A</i>	<i>3</i>	<i>A</i>	<i>0</i>
Comments/Discrepancies: <i>None</i>						
Damaged/Photos taken/photo directory: <i>N/A</i>						
Disposition		NCR No. <i>N/A</i>		Inspected by: <i>Mark R. Edmiston</i>		
<input checked="" type="checkbox"/> Accepted	<input type="checkbox"/> Scrapped	<input type="checkbox"/> Return to Vendor (RMA #)	<input type="checkbox"/> Other (Specify)			



**Southwest Research Institute®
Surveillance Report**



IDENTIFICATION		
Submitted By: Ehnstrom, Mark R.	Date: 23-FEB-15	Report Number: SR Draft
Division: 30 - INSTITUTE QUALITY SYSTEMS		Project Number: 18197.03.103
Quality Program: 10CFR50, App. B,PQP - Nuclear		Project Title: QA SURVEILLANCE
Surveillance Organization: 18 - MECHANICAL ENGINEERING 05.00: STRUCTURAL ENGINEERING		
Associated Report: N/A		
Surveillance Scope: Surveillance activities were performed during hydrostatic compression testing on full-scale waste packages for Sandia National Laboratories.		
References: Sandia National Laboratories Purchase Order 1493421; Sandia National Laboratories Test Procedure "Full Scale Hydrostatic Test Procedure"; SwRI Project Quality Plan 18.18197.03.103; SwRI Program Quality Plan-Nuclear Revision 3; SwRI QMS Revision 4.		
Starting Date: 09-FEB-15		Ending Date: 12-FEB-15
Interviewee(s)/Person(s) performing tests/procedure: Mark Orlowski		
Satisfactory Findings: Surveillance activities were performed during hydrostatic testing on full-scale waste packages for Sandia National Laboratories. Receiving inspection were performed on the three (3)jacketed and the four (4)un-jacketed packages. Reviews were performed on SwRI supplied test equipment prior to the start of testing. The equipment was determined to be within certification and appropriate for use. Sandia personnel were observed advising SwRI personnel on the rate of injection of the confining liquid during the test in accordance with paragraph 4.c of the test procedure. Surveillance confirmed the package configuration in the pressure vessel as required/described in the test procedure. The data acquisition system used a Lab-View program, Sandia Barrel Crush V0, written to collect data specific for this test. Surveillance activities confirmed that testing activities were being performed in accordance with test procedure requirements and no unsatisfactory items were identified.		
Unsatisfactory Findings: None		
Recommendations/Actions: None		
Equipment Calibration: Load Cell Asset# 020800 Calibration Date 11/26/14, Calibration Due 5/26/15 Thermocouple Calibrator Asset# 016644 Calibration Date 2/21/14, Calibration Due 2/21/15		

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Appendix III
Calibration Sheets





Southwest Research Institute Calibration Certificate



Cost Center:	18 MECHANICAL & MATERIALS ENGINEERING	Certificate Number:	1833
Asset Number:	016644	Calibrated:	2/21/2014
Description:	THERMOCOUPLE CALIBRATOR	Calibration Due:	2/21/2015
Manufacturer:	FLUKE	Data Type:	FOUND / LEFT
Model Number:	714	Temp./RH:	74 F / 38
Serial Number:	1131008	Work Order #	403121584
Calibration Procedure:	FLUKE 71x SERIES		

This certificate documents traceability to the International System of Units (SI) through the National Institute of Standards and Technology (NIST) or other national metrology institute. The laboratory quality system is compliant to ISO/IEC 17025:2005, ANSI/NCSL Z540-1-1994 and relevant requirements of ISO 9001-2008. This certificate shall not be reproduced, except in full, without written approval of Southwest Research Institute Calibration Laboratory and shall not be used to claim product endorsement by SwRI® or any agency of the U.S. Government.

Results of this calibration relate only to the instrument described above at the time of calibration and does not imply any long term stability. Date due for recalibration is determined by the customer and does not imply the instrument will remain within limits, as any number of factors may cause an out of tolerance condition before this date.

Data type shall be interpreted as follows: Found-left - data recorded and no adjustment or repair was performed. As-left - data recorded after adjustment or repair was performed. As-found data are reviewed and the customer notified when the as-found results are other than pass and/or greater than 70 percent of the test limit. Pass? or Fail? indicate the measured value, plus or minus the expanded uncertainty, overlap the test limit and it is not possible to state Pass or Fail with a 95% confidence level. No statement of compliance with manufacturer or other specification is made or implied by this certificate. The customer has sole responsibility for determination of in/out-of-tolerance or compliance/noncompliance for the intended use of the instrument.

Measurement uncertainties are calculated in accordance with the methods described in the ISO "Guide to the Expression of Uncertainty in Measurement" (GUM), and reported in the attached measurement report as an expanded uncertainty with a coverage factor of $k = 2$ to approximately a 95% level of confidence.

Remarks:

Standards Used To Calibrate Equipment

Asset	Manufacturer	Model	Description	Cal. Due Date
001505	AGILENT-HP	3458A OPT 002	MULTIMETER	5/13/2014
004164	FLUKE	5500A/SC300	CALIBRATOR MULTI - PRODUCT	2/14/2015

Reviewed By

Calibrated By: CER
Metrology Technician

Institute Calibration Laboratory, Bldg. 64, San Antonio, TX 78227, ext. 5215

Page 1 of 1



Southwest Research Institute
Calibration Laboratory
Measurement Report

Work Order:	403121584	Mfr.	Fluke	Technician:	CER
Asset No.	016644	Model	714	Type Data:	Found-left
Serial No.	1131008	Type	Thermocouple Calibrator	Cal Date:	21-Feb-14
Remarks:					

Function/Range	Test Point	TI Reading	Difference	± Limit	± Uncertainty	Result	% Limit	
Type J Read	°C	°C	°C	°C	°C			
	-200.0	-200.3	-0.3	0.6	0.44	Pass	50%	
	0.0	-0.2	-0.2	0.4	0.18	Pass	50%	
	800.0	799.9	-0.1	0.4	0.29	Pass	25%	
	1200.0	1199.9	-0.1	0.5	0.29	Pass	20%	
	°F	°F	°F	°F	°F			
	-320.0	-320.5	-0.5	1.4	0.7	Pass	36%	
	32.0	31.7	-0.3	0.9	0.3	Pass	33%	
	2000.0	1999.9	-0.1	0.9	0.5	Pass	11%	
	Type K Read	°C	°C	°C	°C	°C		
-190.0		-190.1	-0.1	0.9	0.49	Pass	11%	
0.0		-0.1	-0.1	0.6	0.21	Pass	17%	
1300.0		1299.9	-0.1	0.6	0.47	Pass	17%	
°F		°F	°F	°F	°F			
-300.0		-300.4	-0.4	1.6	0.71	Pass	25%	
32.0		31.8	-0.2	1.0	0.36	Pass	20%	
2300.0		2299.8	-0.2	1.0	0.84	Pass	20%	
mV Read		mVolts	mVolts	mVolts	mVolts	mVolts		
		-10.000	-10.000	0.000	0.012	0.015	Pass	0%
	30.000	30.000	0.000	0.025	0.015	Pass	0%	
mV Source	mVolts	mVolts	mVolts	mVolts	mVolts			
	-10.000	-9.998	0.002	0.012	0.001	Pass	17%	
	30.000	30.003	0.003	0.025	0.001	Pass	11%	
Type J Source	°C	°C	°C	°C	°C			
	-200.00	-199.60	0.40	0.60	0.33	Pass	67%	
	0.00	0.23	0.23	0.40	0.17	Pass	58%	
	800.00	800.15	0.15	0.40	0.27	Pass	37%	
	1200.00	1200.14	0.14	0.50	0.27	Pass	28%	

END OF REPORT





Southwest Research Institute Calibration Certificate



Cost Center:	18 MECHANICAL & MATERIALS ENGINEERING	Certificate Number:	20844
Asset Number:	020800	Calibrated:	11/26/2014
Description:	LOAD CELL	Calibration Due:	5/26/2015
Manufacturer:	STELLAR TECHNOLOGY	Data Type:	FOUND / LEFT
Model Number:	PNC710-500LBTN-159	Temp./RH:	68 °F / 40 %
Serial Number:	1110923	Work Order #	403127714
Calibration Procedure:	LOAD CELLS		

This certificate documents traceability to the International System of Units (SI) through the National Institute of Standards and Technology (NIST) or other national metrology institute. The laboratory quality system is compliant to ISO/IEC 17025:2005, ANSI/NCSL Z540-1-1994 and relevant requirements of ISO 9001-2008. This certificate shall not be reproduced, except in full, without written approval of Southwest Research Institute Calibration Laboratory and shall not be used to claim product endorsement by SwRI® or any agency of the U.S. Government.

Results of this calibration relate only to the instrument described above at the time of calibration and does not imply any long term stability. Date due for recalibration is determined by the customer and does not imply the instrument will remain within limits, as any number of factors may cause an out of tolerance condition before this date.

Datatype shall be interpreted as follows: Found-left - data recorded and no adjustment or repair was performed. As-left - data recorded after adjustment or repair was performed. As-found data are reviewed and the customer notified when the as-found results are other than pass and/or greater than 70 percent of the test limit. Pass? or Fail? indicate the measured value, plus or minus the expanded uncertainty, overlap the test limit and it is not possible to state Pass or Fail with a 95% confidence level. No statement of compliance with manufacturer or other specification is made or implied by this certificate. The customer has sole responsibility for determination of in/out-of-tolerance or compliance/noncompliance for the intended use of the instrument.

Measurement uncertainties are calculated in accordance with the methods described in the ISO "Guide to the Expression of Uncertainty in Measurement" (GUM) as an expanded uncertainty with a coverage factor of $k = 2$ to approximately a 95% level of confidence. See Remarks or attached Measurement Report with the same Work Order number for data.

Remarks:
Sensitivity 2.961 mV/V

Standards Used To Calibrate Equipment

Asset	Manufacturer	Model	Description	Cal. Due Date
005090	RICE LAKE	50 LB	WEIGHT CLASS F	8/21/2015
005093	RICE LAKE	50 LB	WEIGHT CLASS F	12/12/2015
007001	AGILENT-HP	3458A OPT 002	MULTIMETER	5/16/2015
007514	CDI	50 LB	WEIGHT HANGER CLASS F	5/9/2015
008188	RICE LAKE	50 LB	WEIGHT CLASS 6	7/18/2015
015274	RICE LAKE	50 LB	WEIGHT CLASS F	11/17/2016

Approved By

Calibrated By: SRK
Metrology Technician





Southwest Research Institute Calibration Certificate



015276	RICE LAKE	50 LB	WEIGHT CLASS F	11/17/2016
015278	RICE LAKE	50 LB	WEIGHT CLASS F	11/20/2016
015279	RICE LAKE	50 LB	WEIGHT CLASS F	11/20/2016
015280	RICE LAKE	50 LB	WEIGHT CLASS F	11/20/2016
015281	RICE LAKE	50 LB	WEIGHT CLASS F	11/20/2016

Approved By

Calibrated By: SRK
Metrology Technician

Institute Calibration Laboratory, Bldg. 64, San Antonio, TX 78227, ext. 5215

Page 2 of 2



Southwest Research Institute
Calibration Laboratory
Measurement Report

Work Order:	403127714	Mfr:	Stellar Technology	Technician:	SRK
Asset No.:	020800	Model:	PNC710-500LBTN-159	Type Data:	Found-left
Serial No.:	1110923	Type:	Load Cell	Cal Date:	26-Nov-14
Remarks: Applied weight corrected for local gravity.					
Sensitivity:			2.961 mV/V	Excitation Voltage: 10.0 V	

Function/Range	Test Point	TI Read	Difference	± Limit	± Uncertainty	Result	% Limit
Tension (lbf)	mV	mV	mV	mV	mV		
49.9	2.96	2.93	-0.03	0.75	0.077	Pass	4%
99.8	5.91	5.88	-0.03			Pass	4%
149.8	8.87	8.83	-0.04			Pass	5%
199.7	11.83	11.78	-0.05			Pass	6%
249.6	14.78	14.74	-0.05			Pass	6%
299.5	17.74	17.68	-0.06			Pass	7%
349.5	20.70	20.64	-0.05			Pass	7%
399.4	23.65	23.59	-0.06			Pass	9%
449.3	26.61	26.55	-0.05			Pass	7%
499.2	29.57	29.50	-0.07			Pass	9%

END OF REPORT



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LABORATORY**

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665



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Calibration Certificate

Document #: 6662865_11638925

Item Identification

Asset Number	6662865
Description	Transducer, Pressure
Model	PX309-3KGV
Serial #	050109D060
Manufacturer	Omega Engineering, Inc.
Customer Asset Id	
Purchase Order	
Customer	Geomechanics 06914
Custodian	Flint, Gregory Mark
Location	SNLNM/TA1/849/1
Date of Receipt	November 19, 2014
Dates Tested (Start – End)	November 28, 2014 - November 28, 2014
Date Approved	December 09, 2014
Calibration Expiration Date	December 09, 2015

Calibration Description

Calibration Lab	PSL-PRESSURE
Calibration Procedure, rev.	PSL-PVL-CP-6210-001-V01, 10K Bench, High Pressure Calibration System
Temperature	23 deg C
Humidity	40 %RH
Barometric Pressure	N/A mmHg
As Found Condition	PASS
As Left Condition	PASS
Software Used	None
Tamper Seal	None

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Calibration Results

As Found / As Left

DUT Full Scale Pressure (psi)	3000	New Sensitivity Coefficient ((V-zero)/psi)	0.001679
DUT Full Scale Output Signal (V)	5.04248		
Assigned Tolerance (%FS)	0.25	New Inverse Sensitivity Coeff. (Sen ⁻¹)	595.4449
Measured Zero (V)	0.0046		

$$\text{psi} = (\text{Inverse Sensitivity}) * (\text{V} - \text{Zero})$$

$$\text{V} = (\text{Sensitivity} * \text{psi}) + \text{Zero}$$

Gauge Pressure						
Reference Pressure	DUT Raw	Excitation	DUT Corrected using new fit	Error	Assigned Tolerance ±	Status
psi	V	V	psi	% Full Scale	% Full Scale	Pass/Fail
300.0500	0.5084	9.9955	299.9613	-0.003	0.25	Pass
600.0300	1.0121	9.9955	599.9167	-0.004	0.25	Pass
899.9800	1.5159	9.9955	899.9077	-0.002	0.25	Pass
1200.0000	2.0199	9.9955	1199.9584	-0.001	0.25	Pass
1499.9900	2.5237	9.9955	1499.9971	0.000	0.25	Pass
1799.9900	3.0275	9.9955	1799.9703	-0.001	0.25	Pass
2100.0200	3.5313	9.9955	2099.9614	-0.002	0.25	Pass
2400.0200	4.0353	9.9956	2400.0358	0.001	0.25	Pass
2699.9900	4.5390	9.9955	2699.9436	-0.002	0.25	Pass
2999.9500	5.0425	9.9955	2999.7679	-0.006	0.25	Pass
2999.9400	5.0425	9.9955	2999.7679	-0.006	0.25	Pass
2699.9800	4.5388	9.9955	2699.8781	-0.003	0.25	Pass
2399.9600	4.0351	9.9955	2399.9525	0.000	0.25	Pass
2099.9800	3.5317	9.9955	2100.1758	0.007	0.25	Pass
1799.9800	3.0279	9.9955	1800.2204	0.008	0.25	Pass
1500.0000	2.5242	9.9955	1500.2531	0.008	0.25	Pass
1199.9800	2.0203	9.9955	1200.2085	0.008	0.25	Pass
899.9900	1.5164	9.9956	900.1936	0.007	0.25	Pass
599.9500	1.0124	9.9955	600.0774	0.004	0.25	Pass
299.9300	0.5086	9.9955	300.0744	0.005	0.25	Pass

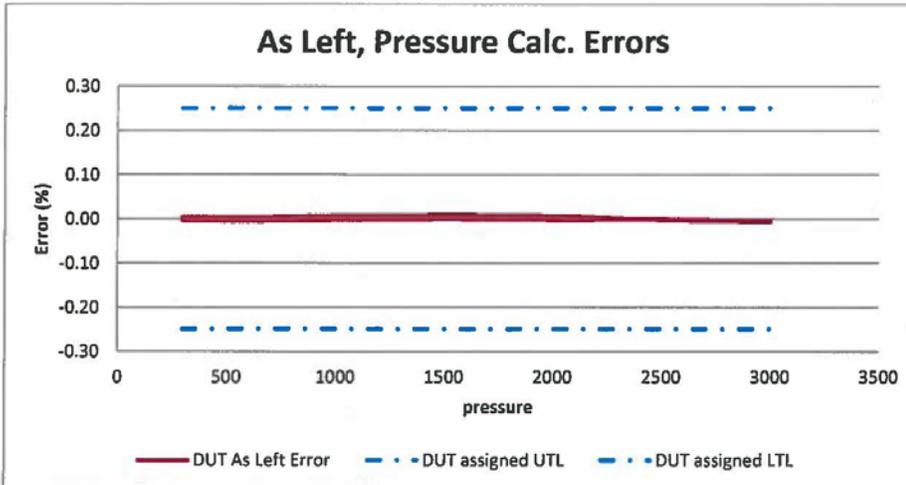


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Calibration Method

This gauge was tested using a comparison technique. The standard used to determine the reference pressure was a Quartz Reference Pressure Transducer (Q-RPT) Pressure Controller/Calibrator. This standard was calibrated by Sandia National Laboratories Primary Standards Lab using Dead Weight Piston Gauges using a coverage factor at k=2.

Calibration Note

Meets customer requested tolerance of $\pm 0.25\%$ of full scale from 300 psig to 3000 psig with a Test Accuracy Ratio (TAR) of $> 4:1$.

This device is expected to remain within the stated measurement tolerance through the calibration interval.

Equipment (Standard) Used

Asset #	Description	Model	Expires
6651361	System,Data,Acquisition	34970A	April 21, 2015
6651346	Supply,Power,DC	6633B	June 09, 2015
6652763	Calibrator,Pressure	PPC4 A700K/A100K	January 14, 2015



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2. Reference standards whose values are disseminated by a laboratory that has demonstrated competence, measurement capability, and traceability for those values;
3. The accepted value(s) of fundamental physical phenomena (intrinsic standards);
4. Ratio(s) or other non-maintained standards established by either a self-calibration and/or a direct calibration technique;
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Authorization

Calibrated By:

Sandoval, Ronald Steven
Metrologist

Approved By:

Benner, Mark S.
Technical Project Leader

End-of-Document

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LVDT Calibration Data by Comparison Method

For: 849 Geolab **Did UUT Pass Acceptance Criteria per** Yes **Expiration Date** 5/8/2015
 UUT Model#: MHR-1000
 UUT s/n: 706 **Cal Date** 5/8/2014
 Conditioner: NI-SCXI-1315 settings: analog system output= +/- 5 VDC **By** GF
 Sensitivity 0.77 mV/V/in **Excitation (vex)** 3 **Org** 6914
 Max 1000m **Excitation** 10k
 Min -1000m **Frequency**

Temp 24.8°C **Standards used:** LVDT calibrator, File SNL-7716, exp 8/20/15
 RH% 18.5 Multimeter, HP 34401A s/n US36034147, exp 2/5/15
 Temp/Hum, Rotronic s/n 60189152/150014, exp 2/24/15

UUT Sensitivity 0.221474 in/v **Std. Sensitivity 0.050162 in/v**

Offset: 0.00165 in

Standard output V	measured output v		Gage Block Used inch	Calculated Standard Displ in	Calculated displ in	Deviation: % full scale
0.000	0.0000 (center)		0.5000	0.00002	0.00165	0.16
2.001	0.4662		0.5000	0.10035	0.10491	0.45
4.001	0.9251		0.5000	0.20068	0.20653	0.58
6.001	1.3746		0.5000	0.30101	0.30609	0.51
8.000	1.8170		0.5000	0.40131	0.40407	0.28
10.000	2.2601		0.5000	0.50164	0.50220	0.06
0.007	2.2604 (block chg)		0.0000	0.50036	0.50227	0.19
2.001	2.7060		0.0000	0.60036	0.60096	0.06
4.000	3.1492		0.0000	0.70065	0.69911	-0.15
6.001	3.5914		0.0000	0.80100	0.79705	-0.39
8.000	4.0389		0.0000	0.90130	0.89616	-0.51
10.001	4.4833		0.0000	1.00165	0.99458	-0.71
8.001	4.0399		0.0000	0.90133	0.89638	-0.49
6.000	3.5924		0.0000	0.80097	0.79727	-0.37
4.001	3.1509		0.0000	0.70068	0.69949	-0.12
2.000	2.7077		0.0000	0.60033	0.60133	0.10
0.000	2.2609		0.0000	0.50002	0.50238	0.24
9.995	2.2605 (block chg)		0.5000	0.50135	0.50229	0.09
8.000	1.8184		0.5000	0.40130	0.40438	0.31
6.000	1.3757		0.5000	0.30098	0.30633	0.53
4.001	0.9260		0.5000	0.20067	0.20672	0.60
2.000	0.4685		0.5000	0.10034	0.10495	0.46
0.001	0.0003 (center)		0.5000	0.00004	0.00171	0.17
-2.000	-0.4604		0.5000	-0.10034	-0.10031	0.00
-4.001	-0.9188		0.5000	-0.20068	-0.20185	-0.12
-6.000	-1.3747		0.5000	-0.30098	-0.30281	-0.18
-8.000	-1.8318		0.5000	-0.40132	-0.40405	-0.27



-10.000	-2.2849		0.5000	-0.50162	-0.50440	-0.28
-0.086	-2.2852 (block chg)		1.0000	-0.50431	-0.50446	-0.02
-2.000	-2.7203		1.0000	-0.60032	-0.60083	-0.05
-4.001	-3.1706		1.0000	-0.70069	-0.70056	0.01
-6.001	-3.6267		1.0000	-0.80101	-0.80157	-0.06
-8.001	-4.0876		1.0000	-0.90134	-0.90365	-0.23
-10.001	-4.5292		1.0000	-1.00167	-1.00145	0.02
-8.000	-4.0867		1.0000	-0.90131	-0.90345	-0.21
-6.000	-3.6260		1.0000	-0.80099	-0.80142	-0.04
-4.000	-3.1697		1.0000	-0.70066	-0.70036	0.03
-2.000	-2.7196		1.0000	-0.60033	-0.60067	-0.03
0.000	-2.2849		1.0000	-0.50000	-0.49997	0.00
-9.911	-2.2647 (block chg)		0.5000	-0.49717	-0.49992	-0.28
-8.000	-1.8308		0.5000	-0.40130	-0.40383	-0.25
-6.001	-1.3741		0.5000	-0.30100	-0.30268	-0.17
-4.000	-0.9182		0.5000	-0.20065	-0.20171	-0.11
-2.000	-0.4600		0.5000	-0.10034	-0.10022	0.01
0.001	0.0004 (center)		0.5000	0.00003	0.00174	0.17

UUT Model#: MHR-1000
 UUT s/n: 706

Cal Date 5/8/2014
 By GF
 Org 6914

