APPENDIX D – PIPE AND ANOMALY CONFIGURATION FOR THE PHASE II BENCHMARKING OF EMERGING PIPELINE INSPECTION TECHNOLOGIES

FINAL REPORT

Pipe and Anomaly Configuration for the Phase II Benchmarking of Emerging Pipeline Inspection Technologies

To

Department of Transportation

Pipeline and Hazardous Materials Safety Administration (PHMSA)

DTRS56-05-T-0003 (Milestone 8)

and

Department of Energy

National Energy Technology Laboratory (NETL) DE-AP26-05NT51648

February 2006

Final Report

on

Pipe and Anomaly Configuration for the Phase II Benchmarking of Emerging Pipeline Inspection Technologies

Cofunded by

Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA)
DTRS56-05-T-0003 (Milestone 8)
and
Department of Energy
National Energy Technology Laboratory (NETL)
DE-AP26-05NT51648

by

Stephanie A. Flamberg and Robert C. Gertler

February 2006

BATTELLE
505 King Avenue
Columbus, Ohio 43201-2693

Neither Battelle, nor any person acting on their behalf:

(1) Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of any information contained in this report or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights.

(2) Assumes any liabilities with the respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.

Table of Contents

Page

Table of Contents (continued)

PIPE AND ANOMALY CONFIGURATION FOR THE PHASE II BENCHMARKING OF EMERGING PIPELINE INSPECTION TECHNOLOGIES

This report provides the supporting documentation to assess data obtained by pipeline inspection technology developers participating in an internal inspection benchmarking demonstration held at Battelle's Pipeline Simulation Facility from January 9, 2006 through January 13, 2006. This report is divided into five main sections that document the pipe defect types, sizes, and locations inspected during the demonstration program. Section 1 provides a brief background of the internal inspection benchmarking demonstration program and facilities used. Section 2 provides detailed information on the corrosion defect sets used to benchmark some of the technologies. Section 3 provides detailed information for the mechanical damage defect sets. Section 4 provides detailed information for the Stress Corrosion Cracking (SCC) defect set and Section 5 provides information on the plastic pipe defects used in the benchmarking demonstration.

SECTION 1. BACKGROUND

INTRODUCTION

The Department of Transportation Pipeline and Hazardous Materials Safety Administration (DOT PHMSA) and the Department of Energy National Energy Technology Laboratory (DOE NETL) are improving natural gas delivery safety and reliability by establishing a viable technology foundation for the natural gas transportation and delivery network. This objective is being achieved through development of technologies that enhance the integrity, operational reliability, safety and security of the nation's natural gas infrastructure. DOT PHMSA and DOE NETL are collaborating with National Laboratories and the private sector in developing new inspection technologies. The combined research portfolio includes projects that address corrosion, stress corrosion cracking, mechanical damage, and plastic pipe defects.

Battelle, in association with DOT PHMSA and DOE NETL, have devised a program that will allow each developer to benchmark their sensor technology during a one-week pipeline inspection demonstration at Battelle's Pipeline Simulation Facility (PSF) in Columbus, Ohio. Battelle's PSF has unique facilities and pipe samples with representative defects that are ideal for use in the technology demonstration program. The defect sets include natural and artificial defects with a wide range of types and sizes in pipe segments of various wall thickness and diameters.

A similar benchmark program was successfully completed in September 2004 with the results documented in the DOE NETL report "Pipeline Inspection Technologies – Demonstration

Report”[1]. This demonstration program serves as Phase II in the ongoing process to establish the capabilities of each sensor technology. The Phase II demonstration program was conducted over a one-week time period from January 9, 2006 through January 13, 2006 and attended by the participants listed in Table 1-1.

Table 1-1. Participants in the Internal Inspection Demonstration

Company	Technology	Tool Diameter	Defects Examined
Battelle	Rotating permanent magnet eddy current	8 inch	Corrosion
Gas Technology Institute (GTI)	Small diameter exciter remote field eddy current	8 inch	Corrosion
National Energy Technology Laboratory (NETL)	Plastic pipe sensor	6 inch	Cylindrical pit and saw cut defects in plastic pipe
Oak Ridge National Laboratory (ORNL)	Circumferential EMAT	26 inch	Stress Corrosion Cracking (SCC)
Pacific Northwest National Laboratory (PNNL)	EMAT strain measurement tool	24 inch	Mechanical Damage
Southwest Research Institute (SwRI)	Collapsible coil remote field eddy current	8 inch	Corrosion

As in the previous demonstration program, each participant was contacted directly to discuss the objectives of their sensor development programs and the constraints of current implementation. This information was taken into consideration when developing the demonstration program and associated documentation.

PIPELINE SIMULATION FACILITY

The Pipeline Simulation Facility was designed and built to conduct research and to develop and commercialize pipeline technologies. Its primary focus is in-line inspection technologies. The facility can be used for a wide range of inspection-related studies, from detailed analyses of defects in flat plates under idealized conditions to tests on the same defect geometries in a pressurized line operating under flowing conditions. Collectively, the Pipeline Simulation Facility offers a hierarchy of capabilities for developing and proving technologies.

[1] http://www.netl.doe.gov/technologies/oil-gas/publications/t%26d/Battelle%20Inspection%20Demo%20Final%20Report_111804.pdf

Flow Loop

The flow loop is the largest and most significant part of the Pipeline Simulation Facility. The loop is a simulated operating pipeline in which research, development, and demonstrations can be conducted under realistic conditions. For inspection related developments, tests can be made using test bed vehicles or in-line inspection tools. The loop is approximately 4,700 feet long and 24 inches in diameter, and it allows both pressure and flow velocity to be controlled. It contains a number of typical pipeline features, such as bends, road crossings, underwater sections, and anchors. It can be used to complete the development of pipeline technologies and test the technologies without risking the integrity or throughput of an operating pipeline.

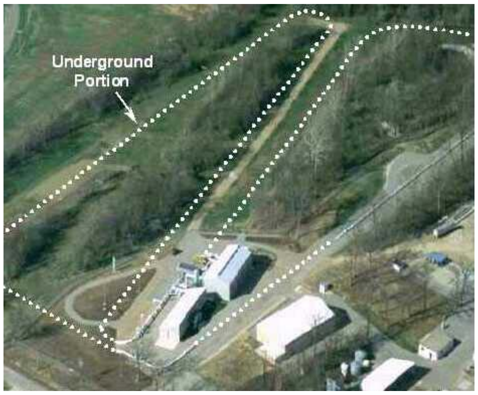


Figure 1-1. PSF Flow Loop

Pull Rig

The pull rig is used for tests of complete inspection systems under unpressurized conditions. It consists of four 300-foot long pipe runs with diameters of 12, 24, 30, and 36 inches. In-line inspection tools and test bed vehicles can be pulled through the pipe sections using the rig's winch. Depending on the tool, pull forces up to 56,000 pounds and speeds up to 25 mph can be achieved.

Figure 1-2. PSF Pull Rig

Sensor Development Sled

The sensor development sled is a moveable platform on which sensors and partial magnetizing or inspection assemblies can be installed and pulled along pipe segments at accurate velocities up to 10 mph. The sensor development sled can be used to measure the effects of velocity and sensor position on defect-to-signal relationships, and it can support virtually any nondestructive evaluation sensor technology.

Figure 1-3. Sensor Development Sled

Test Bed Vehicle

The test bed vehicles are generic in-line inspection platforms upon which inspection hardware can be mounted and tested. Two test bed vehicles are available: the magnetic flux leakage (MFL) vehicle, which is specialized for MFL technology, and the advanced sensor vehicle, which is specialized for high data-rate inspection technologies.

Figure 1-4. Test Bed Vehicle

Defect Sets

A number of existing defect sets are available for evaluation at the PSF. These defect sets provide a common basis for correlating results from each facility component, thereby helping to ensure that the conclusions drawn are valid over a wide range of conditions. Removable mechanical damage defect sets are available for use in 24-inch pipe in the pull rig and flow loop. Similar defects are available in pipe segments for the sensor development sled. Natural and simulated corrosion samples are available in 8- 12- and 24-inch diameter pipe. A stress-corrosion cracking defect set is available for the 30 inch and 26 inch pipe in the pull rig. Additionally, a section of 26 inch pipe that has been re-rounded to 24 inch diameter is also available for pull rig testing. A set of weld-solidification cracks, and a matching set of notches made using electron discharge machining, are available for the flow loop. For development of third party damage inspection tools, over 200 dents and gouges are available in 24 inch diameter pipe.

INTERNAL INSPECTION DEMONSTRATION CONFIGURATION

The following sections provide details on the interface between the PSF test equipment and sensor technology being developed. This is intended as a guide rather than a specification as changes were made throughout the demonstration to meet testing needs.

Pipe Sample Layout

The configuration that was used to benchmark the emerging technologies consisted of the following pipe samples:

- One 8-inch ERW seam welded pipe sample with simulated corrosion defects measuring 30-feet in length with a wall thickness of 0.188 inches. The pipe sample contained two rows of defects spaced 180° apart.
- One 8-inch ERW seam welded pipe sample with simulated corrosion defects measuring 30-feet in length and included a small section of natural corrosion from a pipe pulled from service measuring 5-feet in length. Both the natural and simulated corrosion pipe samples had a wall thickness of 0.188 inches. The complete pipe sample contained two rows of defects spaced 180° apart.
- One 8-inch ERW seam welded pipe sample with simulated corrosion defects measuring 40-feet in length with a wall thickness of 0.188 inches. The pipe sample contained two rows of defects spaced 180° apart.
- One 6-inch Polyethylene Pipe measuring 13 feet in length with a wall thickness of 0.5 inches. The pipe sample contained cylindrical drill holes and saw cut defects for analysis placed along one row on the exterior of the pipe.
- One 24-inch pipe sample with plain dent defects measuring approximately 28-feet in length with a wall thickness of 0.292 inches. The pipe sample contained one row of defects for analysis. Two additional rows of defects were located on this pipe sample spaced 120° apart but were not included in the benchmarking.

- One 24-inch pipe sample with plain dent defects measuring approximately 40-feet in length with a wall thickness of 0.292 inches. The pipe sample contained one row of defects for analysis.
- One 26-inch pipe sample containing natural stress corrosion cracks (SCC) measuring approximately 26-feet in length with a wall thickness of 0.281 inches. The pipe sample contained multiple defect locations requiring several rows for data collection. A separate 26-inch diameter SCC pipe sample was provided for calibration.

Each pipe configuration had the same defect characteristic philosophy; the detection and sizing of the defects ranged from simple to difficult to help define both the current capability and future challenges for each of the inspection technologies.

This benchmarking study was designed to assess the current inspection capability of the sensor technologies prior to full hardware implementation (for pull rig testing or testing on a robotic platform). Therefore, the pipe samples were placed within the pipeline testing lab, which is a 40 foot by 100 foot building with overhead doors. The three 8-inch diameter pipes, one 6-inch diameter plastic pipe, two 24-inch diameter pipes, and two 26-inch diameter pipes were placed parallel to each other with a separation distance between each pipe of approximately 4 feet. All developers brought their own method for pulling their sensor carriage through the pipe samples including a return cable or rope to pull the unit back to the insertion point. The layout of the pipe samples is shown in Figure 1-5 with a photograph of the actual benchmarking set-up shown in Figure 1-6.

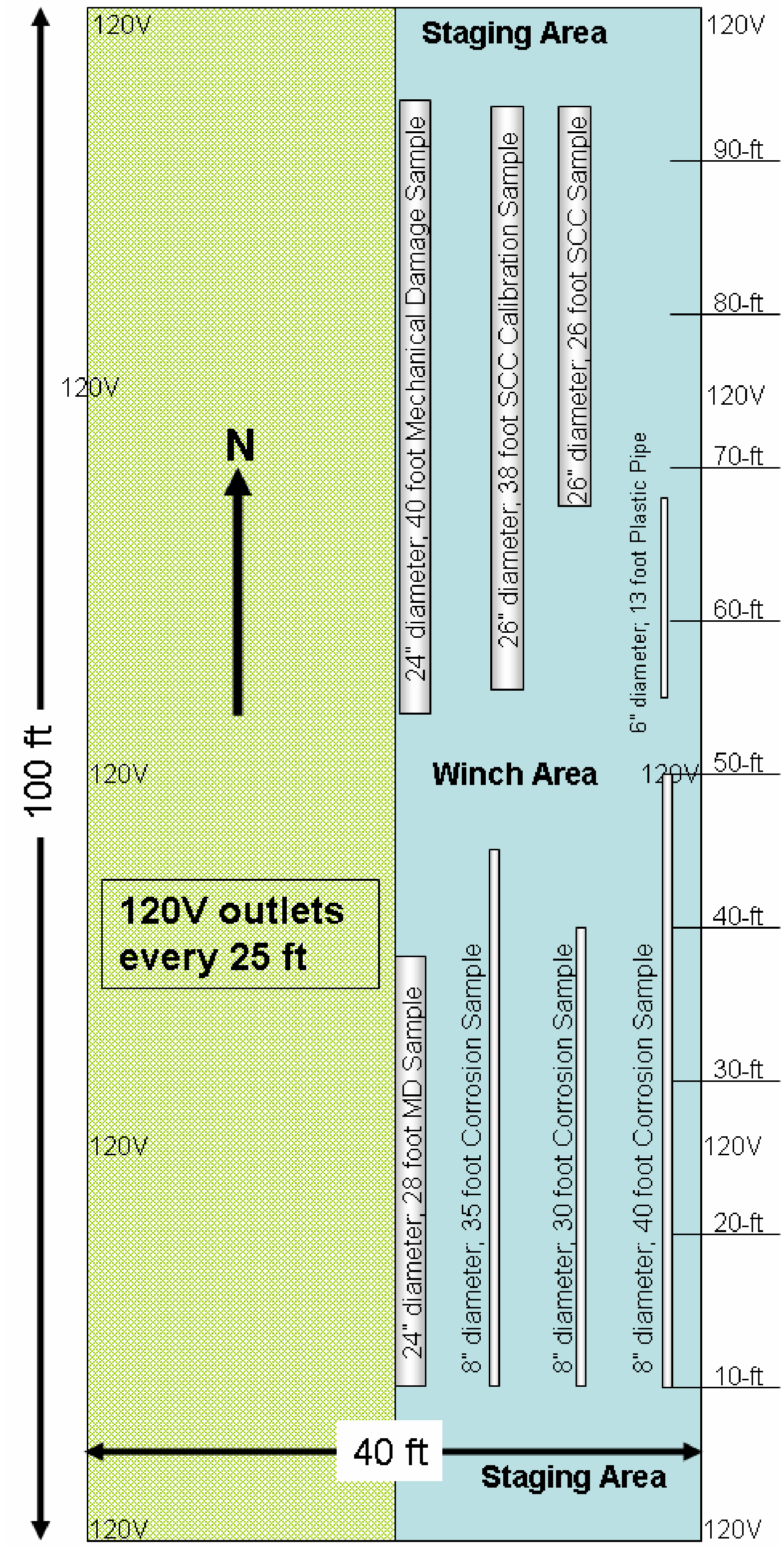


Figure 1-5. Layout of Building and Pipe Samples

Figure 1-6. Benchmarking Demonstration Setup

In developing the internal inspection benchmarking program, the procedures were tailored to the needs of the specific inspection technologies. A general outline of the demonstration program is as follows:

1. The following items were available to attach to the sensor carriage as requested by the sensor developer:
    a. A 100 foot tape measure at the center of the sensor to measure defect position; and
    b. A 115 Volt AC power cord.
2. One light duty winch was available for use to pull the inspection tool through the pipe sample; however each sensor developer brought their own winch or similar device to expedite the testing process.
3. The test schedule was staggered over the week long benchmarking to ensure that each developer had sufficient time to collect data; this schedule was provided approximately 1-month prior to the start of the benchmarking demonstration.
4. Since there were a limited number of test samples, certain technology developers were asked to vacate specific pipe samples to allow other participants an equal opportunity to collect data.

5. After each technology developer had the opportunity to acquire data, the developers were allowed repeat runs to collect additional data, if desired.
6. The facility was open for use from Monday January 9, 2006 to Friday January 13, 2006 from 7 am to 6 pm. After hours access was limited due to safety and security policies at Battelle.
7. The results obtained by each participant were submitted to Battelle for compilation of results.

Similar to the first test program, Battelle established a list of specific distances and positions along the pipe on which each participant is to report. These locations may or may not have had defects, enabling probability of detection and false call rates to be assessed.

Sensor Carriage Configuration

It was expected that each sensor developer provide their own means for transporting their sensors through the pipe samples (wheeled carriage or similar design). Basic requirements included low drag of the wheeled carriage, such that the unit could be pulled by hand or a light duty winch and bidirectional capabilities so that pulling the unit back to the insertion point would not damage the sensor, equipment, or pipe. It was expected that the carriage would have mechanical connection points for the

- Tow cable; and
- Return cable.

It was also anticipated that the sensor carriage would contact the pipe at three or four locations. It was recommended that at least one of the wheels should have an adjustment or spring loading to enable adaptation to pipe mismatch at welds measuring 0.25 inches and at changes in pipe wall thickness and pipe ovality measuring 0.5 inches.

Pipe and Defect Configuration

Pipe samples were welded together to form a complete vessel, though the welds did not have full load carrying capability. The defects were arranged in rows and the sensor developers were informed of which row or rows of defects were included in the benchmarking.

Tool rotation is a significant problem in dented pipe since each dent can easily spin the tool. For the 24-inch pipe, a rail was available 180° from the dents to be evaluated to position the control carriage and prevent rotation. The rail was 1.5” by 1.5” aluminum tubular modular material with a wheel assembly that could be attached to the sensor carriage unit (see Figure 1-7). The clock position of other dent rows within the pipe sample were provided to the sensor developer prior to the benchmarking so that wheels on sensor carriages would not run over defects that were not part of the benchmarking demonstration.

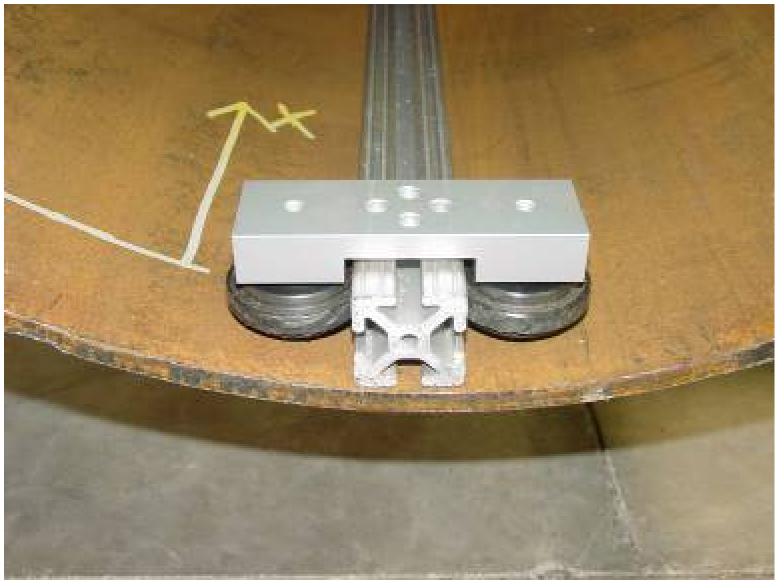


Figure 1-7. Aluminum Rail Guide Assembly

REPORTING

Prior to the demonstration, Battelle selected specific axial locations on which the developers were to report their inspection results. This information was given to each developer for review and comment prior to the start of the demonstration. Following the demonstration, each participant provided their findings to Battelle including any sizing or assessment information. Battelle subsequently tabulated the inspection results and provide these to DOT PHSMA, DOE NETL, and participating organization. Each participant was given the opportunity to assess the results they provided against the measured values and to comment on their own performance. The reported results and the comments provided from the participants are documented in a separate report.

The information provided in Sections 2, 3, 4, and 5 of this report consist of:

- Corrosion Defects: Section 2 documents the maximum pit depths and surface extent for each simulated and natural corrosion defect.
- Mechanical Damage Defects: Section 3 provides the depth of each dent at the center and the axial length as determined by a 0.020 inch departure from a straight edge placed on top of the dent. Section 3 also provides the dent depth and relative severity based on deformation data and previous magnetic flux leakage (MFL) signals. The reporting of dent severity is subjective to the assessment method and assessor.
- SCC Defects: Section 4 provides a magnetic particle map showing the location and length of the natural SCC defects from the test sample.
- Plastic Pipe Defects: Section 5 provides depths, surface extent, and volumes for each cylindrical and saw cut defect from the test sample.

SUMMARY

The PSF has unique facilities and pipes with representative defects to assess the capabilities of a number of inspection technologies. The Phase II benchmarking demonstration program will help to further define sensor technology progress and future direction for research and development efforts.

SECTION 2. CORROSION INSPECTION TECHNOLOGY ASSESSMENT

INTRODUCTION

The current focus of corrosion inspection projects is to develop technologies that can work in unpiggable pipelines. These lines typically have bore restrictions, low pressure or other conditions that make pigging with existing technologies impractical. These new inspection techniques will eventually be mounted on robotic crawlers being developed under separate programs. These crawlers will act as the propulsion units to escort the new sensor technologies through the pipeline. While each technology will have the potential to work in an unpiggable pipeline, the current development is focused only on detecting and sizing corrosion defects. Therefore, the capability of passing bore restrictions was not evaluated at this time.

Each corrosion inspection technology uses electromagnetic energy to interrogate the pipeline for defects. A common requirement for these technologies is that

- a full circumference pipe is needed; the technology will not work on coupons cut from pipe,
- the sending and receiving units need to be separated by 2 to 3 pipe diameters, and
- the defects must be at least four pipe diameters from an open end to avoid end effects that may influence results (end effects are not a problem in actual pipelines).

Although Battelle has a large library of pipe samples containing external corrosion, the smallest diameter samples are 12-inches in diameter. Since the current focus of the demonstration program is for smaller diameter pipe ranging in size from 6-inches to 8-inches in diameter, Battelle procured 8-inch diameter ERW pipe samples and simulated natural corrosion defects using electrochemical etching techniques. Additionally, a small 8-inch diameter pipe sample with natural corrosion was obtained from a pipe segment recently removed from service. A portion of this pipe sample was welded between two simulated corrosion pipe samples (Pipe Sample 1) for the benchmarking.

The donated natural corrosion pipe sample had a field girth weld with corrosion on both sides of the weld. The weld drop through was too large for the inspection tool specifications and as such the pipe was trimmed to include roughly 2 feet of corrosion on one end, 3 feet of full thickness pipe at the other end, and no field welds. The pipe was then sandblasted and welded between two new pipes to comprise Pipe Sample 1. When the pipe was being fully characterized for this report, an additional weld was found in the middle of the corrosion area (see Figure 2-1). This weld was very fine and did not have a significant crown. The natural corrosion defects were intended to be a "stretch goal" of these emerging inspection technologies. While the natural corrosion sample represents a real world problem, this additional weld adds a complex scenario that is most likely new to the technology developers. This should be considered when assessing results.

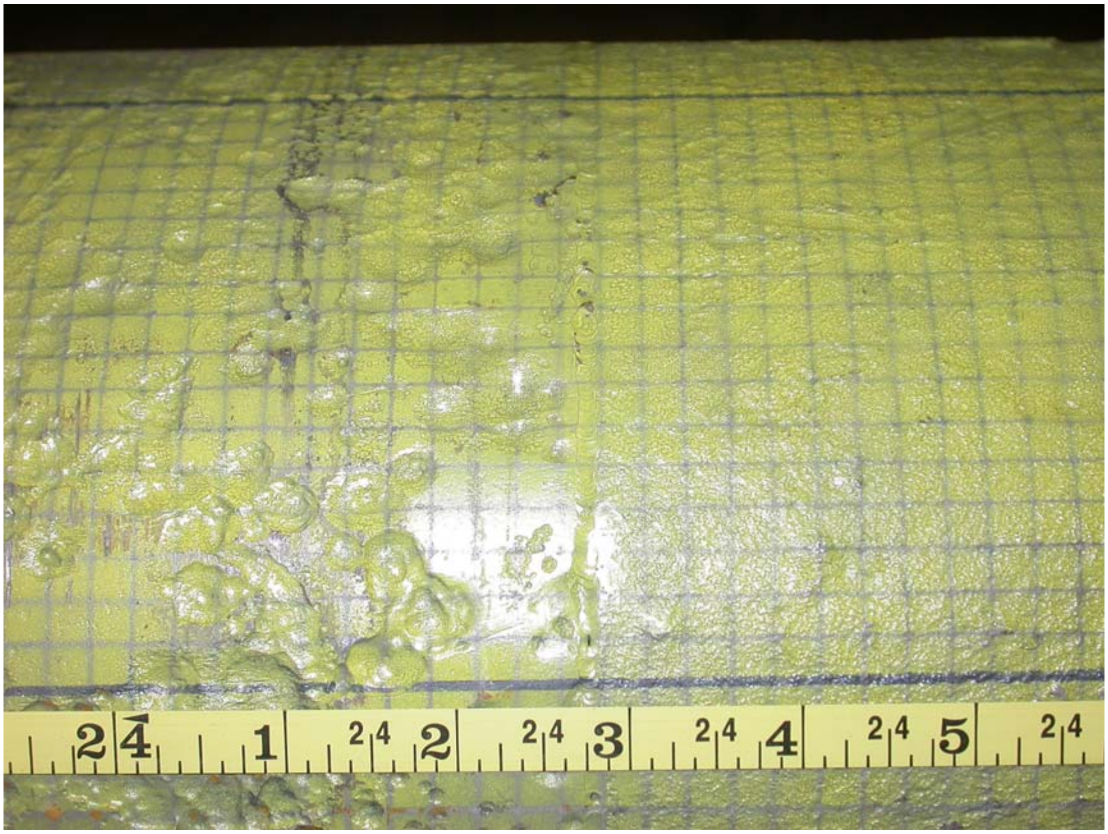


Figure 2-1. Fine Weld in Natural Corrosion Sample; Test Line 2 in Pipe Sample 1

The report sections below discuss the demonstration plan for the corrosion inspection tools and provides an “answer key” (Table 2-1) for the data sheets filled out by the corrosion inspection tool developers during the demonstration. Additional information and photographs are provided in Figures 2-2 through 2-42 describing the maximum depths, surface extent, and locations for all of the corrosion defects. This information will be used as the guide to assess the performance of the specific sensor technology developers.

8-INCH CORROSION DEFECT DEMONSTRATION PLAN

The demonstration plan for the 8-inch corrosion defect test configuration is as follows:

1. The technologies for benchmarking include:
   1.1. SwRI: Collapsible coil remote field eddy current
   1.2. GTI: Small diameter exciter remote field eddy current
   1.3. Battelle: Moving permanent magnet eddy current
2. The pipe is 8-inch inside diameter
3. The demonstration samples are comprised of three pipes:
   3.1. Pipe 1 specifications are as follows:

3.1.1. The length is 35 feet long, Schedule 10, ERW

3.1.2. A small portion of the pipe sample contains pipe pulled from service with natural corrosion; the pipe properties are unknown.

3.1.3. The nominal wall thickness is 0.188 inches

3.1.4. The pipe has 11 simulated corrosion defects plus natural corrosion.

3.1.5. The defects were placed along 2 rows separated by 180°

3.1.6. The angular coverage area for each sensor technology should have been designed to cover +/- 2 inches on either side of the centerline (~60° angular coverage)

3.1.7. The defects had the following dimensions:

3.1.7.1. Length (in): >= 1 inch and <= 4 inches

3.1.7.2. Width (in): >= 1 inch and <= 4 inches

3.1.7.3. Depth (% wall thickness): >= 30% and <=80%

3.1.8. The simulated defects were aligned in two rows with the separation between defects nominally 3 pipe diameters.

3.1.9. Each defect consisted of a generally corroded area and anywhere from 1 to 8 individual pits within the general corrosion area.

3.1.10. All defects, except the calibration defect, were covered with a heavy material to prevent sensor developers from viewing the defects. One defect near end A of the pipe remained uncovered for system check-out and calibration.

3.2. Pipe 2 specifications are as follows:

3.2.1. The length is 30 feet long, Schedule 10, ERW

3.2.2. The nominal wall thickness is 0.188 inches

3.2.3. The pipe has 11 simulated corrosion defects.

3.2.4. The defects were placed along 2 rows separated by 180°

3.2.5. The angular coverage area for each sensor technology should have been designed to cover +/- 2 inches on either side of the centerline (~60° angular coverage)

3.2.6. The defects had the following dimensions:

3.2.6.1. Length (in): >= 1 inch and <= 4 inches

3.2.6.2. Width (in): >= 1 inch and <= 4 inches

3.2.6.3. Depth (% wall thickness): >= 30% and <=100%

3.2.7. The simulated defects were aligned in two rows with the separation between defects nominally 3 pipe diameters.

3.2.8. Each defect consisted of a generally corroded area and anywhere from 1 to 8 individual pits within the general corrosion area.

3.2.9. All defects, except the calibration defects, were covered with a heavy material to prevent sensor developers from viewing the defects. Two defects near End A of the pipe remained uncovered for system check-out and calibration.

3.3. Pipe 3 specifications are as follows:

3.3.1. The length is 40 feet long, Schedule 10, ERW

3.3.2. The nominal wall thickness is 0.188 inches

3.3.3. The pipe has 14 simulated corrosion defects.

3.3.4. The defects were placed along 2 rows separated by 180°

3.3.5. The angular coverage area for each sensor technology should have been designed to cover +/- 2 inches on either side of the centerline (~60° angular coverage)

3.3.6. The defects had the following dimensions:

3.3.6.1. Length (in): >= 1 inch and <= 4 inches

3.3.6.2. Width (in): >= 1 inch and <= 4 inches

3.3.6.3. Depth (% wall thickness): >= 30% and <=80%

3.3.7. The simulated defects were aligned in two rows with the separation between defects nominally 3 pipe diameters.

3.3.8. Each defect consisted of a generally corroded area and anywhere from 1 to 8 individual pits within the general corrosion area.

3.3.9. All defects, except the calibration defects, were covered with a heavy material to prevent sensor developers from viewing the defects. One defect near End A of the pipe remained uncovered for system check-out and calibration.

This page intentionally blank.

8-INCH DIAMETER CORROSION DEFECT ASSESSMENT DATA

Detection of Metal Loss - Page 1

Name:	
Date:	
Company:	
Sensor Design:	

CALIBRATION DATA

Pipe Sample	Calibration Metal Loss Location	Metal Loss Length & Width	Depth of Metal Loss	Measured Length & Width of Defect	Measured Max. Depth of Defect	Comments
	inches from End B to center of defect	inches	inches			
PIPE SAMPLE 1:						
Calibration P1-1:	361" (59" from End A)	2 x 2	See profile			

TEST DATA

Pipe Sample:	**PIPE SAMPLE 1**
Defect Set:	8" Diameter, 0.188" Wall Thickness Pipe Sample; Schedule 10; Length = 34' 11.75"

TEST LINE 1

Defect Number	Search Region (Distance from End B)	Start of Metal Loss Region from Side B	End of Metal Loss Region from Side B	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region	Additional Data Attached?	Comments
	inches	inches	inches	inches	inches	inches	Y/N	
P1-12	52" to 64"	**56.75"**	**60.875"**	**4.125"**	**2"**	**0.122"**	**Y**	**Defect 6**
P1-11	76" to 88"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 6**
P1-10	100" to 112"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 5**
WELD	120"							
P1-9	120" to 144"	**120"**	**140.25"**	**20.25"**	**Full Circumference**	**0.146"**	**Y**	**P1-NC1**
P1-8	160" to 172"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 4 (natural corrosion pipe segment)**
WELD	180"							
P1-7	184" to 196"	**190.625"**	**192.75"**	**2.125"**	**2"**	**0.147"**	**Y**	**Defect 5**
P1-6	208" to 220"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 3**
P1-5	232" to 244"	**232.75"**	**235.75"**	**3"**	**1"**	**0.081"**	**Y**	**Defect 4**
P1-4	256" to 268"	**259.625"**	**263.625"**	**4"**	**2"**	**0.063"**	**Y**	**Defect 3**
P1-3	280" to 292"	**287.75"**	**290.875"**	**3.125"**	**2"**	**0.096"**	**Y**	**Defect 2**
P1-2	304" to 316"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 2**
P1-1	328" to 340"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 1**

TEST LINE 2

Defect Number	Search Region (Distance from End B)	Start of Metal Loss Region from Side B	End of Metal Loss Region from Side B	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region	Additional Data Attached?	Comments
	inches	inches	inches	inches	inches	inches	Y/N	
P1-23	74" to 86"	**79.75"**	**83.75"**	**4"**	**2"**	**0.097"**	**Y**	**Defect 11**
P1-22	98" to 110"	**108"**	**110"**	**2"**	**2"**	**0.12"**	**Y**	**Defect 10**
WELD	120"							
P1-21	120" to 144"	**120"**	**140.75"**	**20.75"**	**Full Circumference**	**0.127"**	**Y**	**P1-NC2**
P1-20	160" to 172"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 11 (natural corrosion pipe segment)**
WELD	180"							
P1-19	186" to 198"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 10**
P1-18	210" to 222"	**213.625"**	**217.875"**	**4.25"**	**2"**	**0.145"**	**Y**	**Defect 9**
P1-17	234" to 246"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 9**
P1-16	258" to 270"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 8**
P1-15	282" to 294"	**---**	**---**	**---**	**---**	**---**	**N**	**BLANK 7**
P1-14	306" to 318"	**308.875"**	**312"**	**3.125"**	**1"**	**0.115"**	**Y**	**Defect 8**
P1-13	330" to 342"	**335.75"**	**339.625"**	**3.875"**	**1.75"**	**0.095"**	**Y**	**Defect 7**

Table 2-1. 8-inch Corrosion Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies Detection of Metal Loss - Page 2								
Name:								
Date:								
Company:								
Sensor Design:								
CALIBRATION DATA								
Pipe Sample		Calibration Metal Loss Location	Metal Loss Length & Width		Depth of Metal Loss	Measured Length & Width of Defect	Measured Max. Depth of Defect	Comments
		inches from End B to center of defect	inches		inches			
PIPE SAMPLE 2:								
Calibration P2-1:		301.5" (58.5" from End A)	3 x 1		See profile			
Calibration P2-2:		275" (85" from End A)	2 x 2		See profile			

TEST DATA								
Pipe Sample:		PIPE SAMPLE 2						
Defect Set:		8" Diameter, 0.188" Wall Thickness Pipe Sample; Schedule 10; Length = 30' 0.375"						
		TEST LINE 1						
Defect Number	Search Region (Distance from End B)	Start of Metal Loss Region from Side B	End of Metal Loss Region from Side B	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region	Additional Data Attached?	Comments
	inches	inches	inches	inches	inches	inches	Y/N	
P2-11	54" to 66"	---	---	---	---	---	N	BLANK 6
P2-10	78" to 90"	80.125"	84.5"	4.375"	2"	0.147"	Y	Defect 5
P2-9	102" to 114"	108.125"	112.25"	4.125"	2"	0.158"	Y	Defect 4
WELD	120"							
P2-8	126" to 138"	---	---	---	---	---	N	BLANK 5
P2-7	150" to 162"	153.125"	156.375"	3.25"	1"	0.085"	Y	Defect 3
P2-6	174" to 186"	180.25"	183.375"	3.125"	1"	0.114"	Y	Defect 2
P2-5	198" to 210"	---	---	---	---	---	N	BLANK 4
P2-4	222" to 234"	227.25"	229.375"	2.125"	2"	0.079"	Y	Defect 1
P2-3	246" to 258"	---	---	---	---	---	N	BLANK 3
P2-2	270" to 282"	---	---	---	---	---	N	BLANK 2
P2-1	294" to 306"	---	---	---	---	---	N	BLANK 1

		TEST LINE 2						
Defect Number	Search Region (Distance from End B)	Start of Metal Loss Region from Side B	End of Metal Loss Region from Side B	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region	Additional Data Attached?	Comments
	inches	inches	inches	inches	inches	inches	Y/N	
P2-20	54" to 66"	57.75"	60.875"	3.125"	1"	0.188"	Y	Defect 11; through hole
P2-19	78" to 90"	---	---	---	---	---	N	BLANK 11
P2-18	102" to 114"	---	---	---	---	---	N	BLANK 10
WELD	120"							
P2-17	126" to 138"	130"	134.125"	4.125"	2"	0.112"	Y	Defect 10
P2-16	150" to 162"	---	---	---	---	---	N	BLANK 9
P2-15	174" to 186"	---	---	---	---	---	N	BLANK 8
P2-14	198" to 210"	202.625"	205.75"	3.125"	1"	0.105"	Y	Defect 9
P2-13	222" to 234"	---	---	---	---	---	N	BLANK 7
P2-12	246" to 258"	248.125"	250.25"	2.125"	2"	0.14"	Y	Defect 8

Table 2-1 (cont). 8-inch Corrosion Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies
Detection of Metal Loss - Page 3

Name:	
Date:	
Company:	
Sensor Design:	

CALIBRATION DATA

Pipe Sample	Calibration Metal Loss Location	Metal Loss Length & Width	Depth of Metal Loss	Measured Length & Width of Defect	Measured Max. Depth of Defect	Comments
	inches from End B to center of defect	inches	inches			
PIPE SAMPLE 3:						
Calibration P3-1:	421" (59" from End A)	2 x 2	See profile			

TEST DATA

Pipe Sample:	**PIPE SAMPLE 3**
Defect Set:	8" Diameter, 0.188" Wall Thickness Pipe Sample; Schedule 10; Length = 40' 0.25"

TEST LINE 1

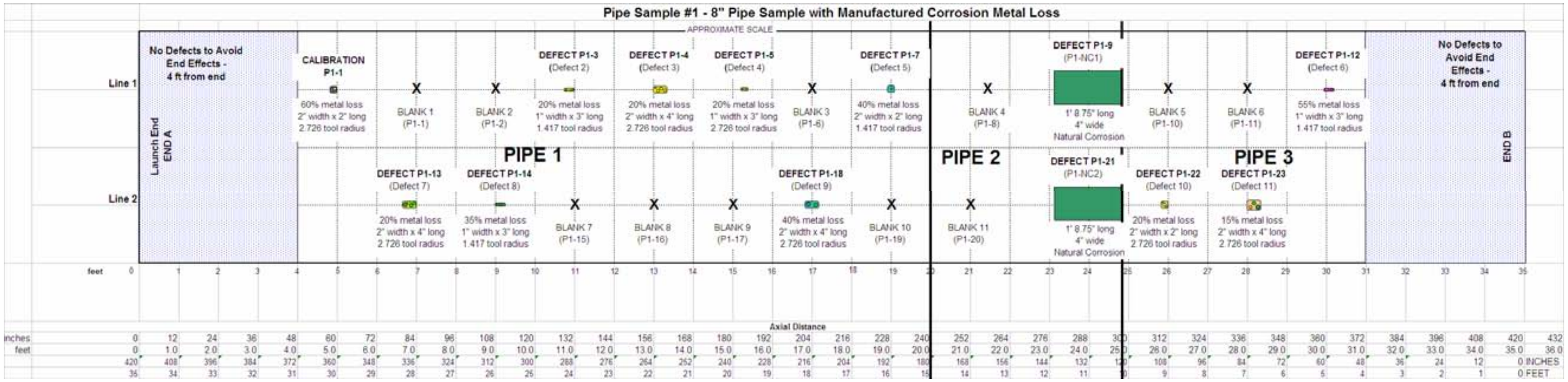
Defect Number	Search Region (Distance from End B)	Start of Metal Loss Region from Side B	End of Metal Loss Region from Side B	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region	Additional Data Attached?	Comments
	inches	inches	inches	inches	inches	inches	Y/N	
P3-11	66" to 78"	---	---	---	---	---	N	BLANK 5
P3-10	102" to 114"	106.375"	109.625"	3.25"	1"	0.156"	Y	Defect 7
P3-9	138" to 150"	143.665"	144.335"	0.67"	0.67"	0.120"	N	Defect 6; machined defect
P3-8	162" to 174"	---	---	---	---	---	N	BLANK 4
P3-7	186" to 198"	189.875"	194"	4.125"	2"	0.115"	Y	Defect 5
P3-6	222" to 234"	---	---	---	---	---	N	BLANK 3
WELD	240"							
P3-5	270" to 282"	275"	277.25"	2.25"	2"	0.103"	Y	Defect 4
P3-4	300" to 312"	305.625"	306.375"	0.75"	0.75"	0.148"	N	Defect 3; machined defect
P3-3	330" to 342"	335"	337.25"	2.25"	2"	0.133"	Y	Defect 2
P3-2	360" to 372"	---	---	---	---	---	N	BLANK 2
P3-1	384" to 396"	---	---	---	---	---	N	BLANK 1

TEST LINE 2

Defect Number	Search Region (Distance from End B)	Start of Metal Loss Region from Side B	End of Metal Loss Region from Side B	Total Length of Metal Loss Region	Width of Metal Loss Region	Maximum Depth of Metal Loss Region	Additional Data Attached?	Comments
	inches	inches	inches	inches	inches	inches	Y/N	
P3-23	66" to 78"	69.5"	73.625"	4.125"	2"	0.088"	Y	Defect 14
P3-22	102" to 114"	---	---	---	---	---	N	BLANK 10
P3-21	126" to 138"	130"	134.125"	4.125"	2"	0.103"	Y	Defect 13
P3-20	156" to 168"	---	---	---	---	---	N	BLANK 9
P3-19	180" to 192"	185.765"	186.485"	0.72"	0.72"	0.139"	N	Defect 12; machined defect
P3-18	210" to 222"	214.5"	217.625"	3.125"	1"	0.091"	Y	Defect 11
WELD	240"							
P3-17	248" to 260"	250.625"	253.75"	3.125"	1"	0.07"	Y	Defect 10
P3-16	282" to 294"	---	---	---	---	---	N	BLANK 8
P3-15	306" to 318"	---	---	---	---	---	N	BLANK 7
P3-14	330" to 342"	335.875"	336.625"	0.75"	0.75"	0.154"	N	Defect 9; machined defect
P3-13	356" to 368"	---	---	---	---	---	N	BLANK 6
P3-12	390" to 402"	392.25"	396.375"	4.125"	2"	0.094"	Y	Defect 8

Table 2-1 (cont). 8-inch Corrosion Inspection Technology Data Sheet "Answer Key"

8 INCH PIPE SAMPLE 1 DOCUMENTATION



Defect Number	Distance from End A to Defect Center (inches)	Distance from End A to Defect Center (feet)	Length of Defect (in)	Width of Defect (in)	Max Depth of Metal Removed (in)	% Metal Loss	Radius of End Mill Tool
PIPE 1 Line 1							
Calibration P1-1	59.0	4.916667	2	2	0.151	80%	2.726
Blank 1 (P1-1)	84.0	7	-	-	0.00	0%	-
Blank 2 (P1-2)	108.0	9	-	-	0.00	0%	-
Defect P1-3 (Defect 2)	130.5	10.875	3	1	0.096	51%	1.417
Defect P1-4 (Defect 3)	158.0	13.16667	4	2	0.063	34%	2.726
Defect P1-5 (Defect 4)	185.5	15.45833	3	1	0.081	43%	2.726
Blank 3 (P1-6)	204.0	17	-	-	0.00	0%	-
Defect P1-7 (Defect 5)	228.0	19	2	2	0.147	78%	1.417
PIPE 2 Line 1							
Blank 4 (P1-8)	252.0	21	-	-	0.00	0%	-
Defect P1-NC1 (P1-9)	289.5	24.125	20.25	4	0.146	78%	
PIPE 3 Line 1							
Blank 5 (P1-10)	312.0	26	-	-	0.00	0%	-
Blank 6 (P1-11)	336.0	28	-	-	0.00	0%	-
Defect P1-12 (Defect 6)	361.5	30.125	3	1	0.122	65%	1.417
PIPE 1 Line 2							
Defect P1-13 (Defect 7)	82.0	6.833333	4	2	0.095	51%	2.726
Defect P1-14 (Defect 8)	109.5	9.125	3	1	0.115	61%	1.417
Blank 7 (P1-15)	132.0	11	-	-	0.00	0%	-
Blank 8 (P1-16)	156.0	13	-	-	0.00	0%	-
Blank 9 (P1-17)	180.0	15	-	-	0.00	0%	-
Defect P1-18 (Defect 9)	204.0	17	4	2	0.145	77%	2.726
Blank 10 (P1-19)	228.0	19	-	-	0.00	0%	-
PIPE 2 Line 2							
Blank 10 (P1-20)	252.0	21	-	-	0.00	0%	2.726
Defect P1-NC2 (P1-21)	289.0	24.08333	20.75	4	0.127	68%	
PIPE 3 Line 2							
Defect P1-22 (Defect 10)	311.0	25.91667	2	2	0.120	64%	2.726
Defect P1-23 (Defect 11)	338.0	28.16667	4	2	0.097	52%	2.726

Figure 2-2. 8-inch Pipe Sample 1 Defect Map

Pipe Sample 1 Simulated Corrosion Defect Photos

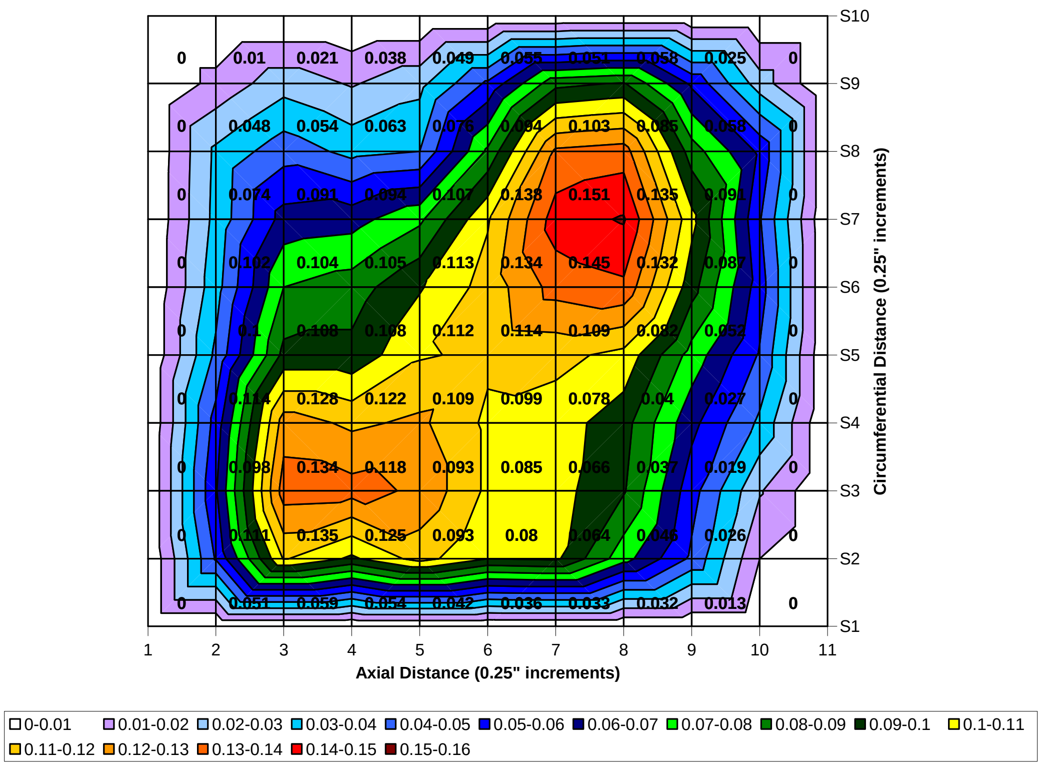
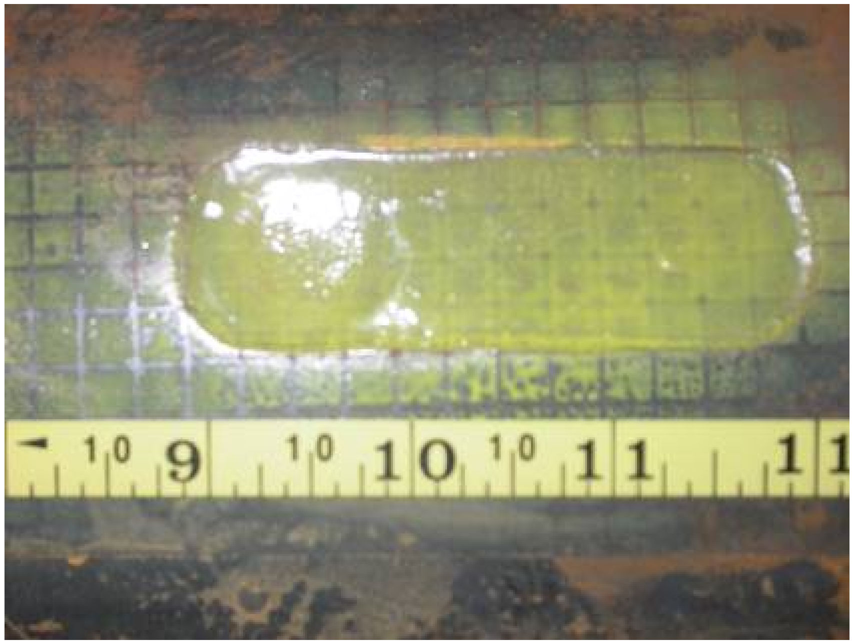


Figure 2-3. Calibration Defect P1-1 (Defect 1)



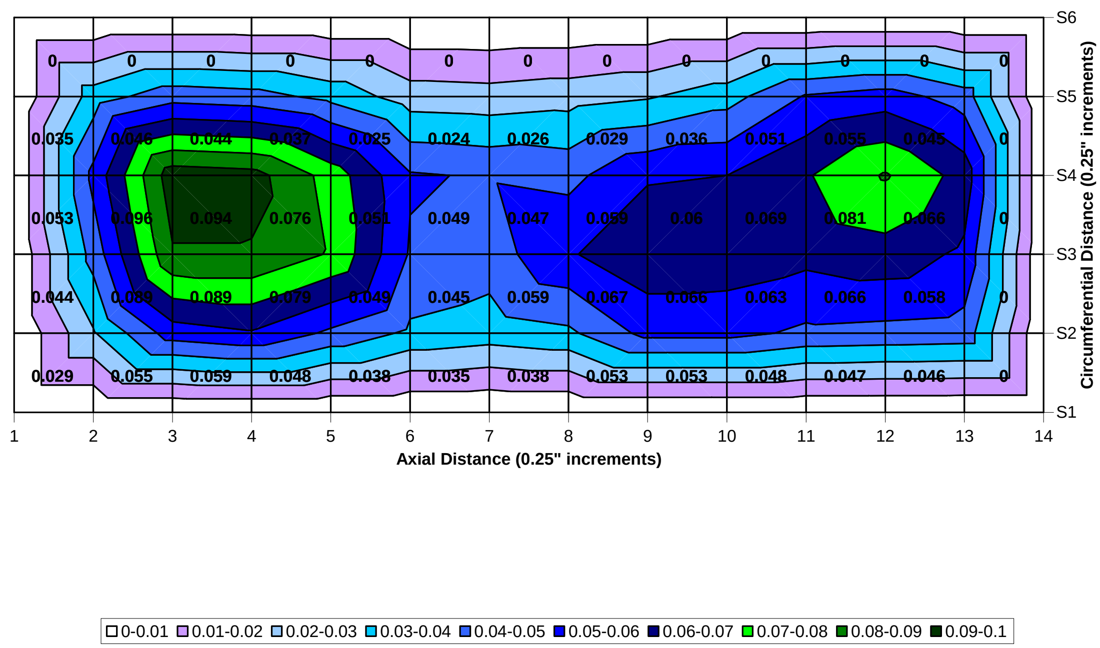
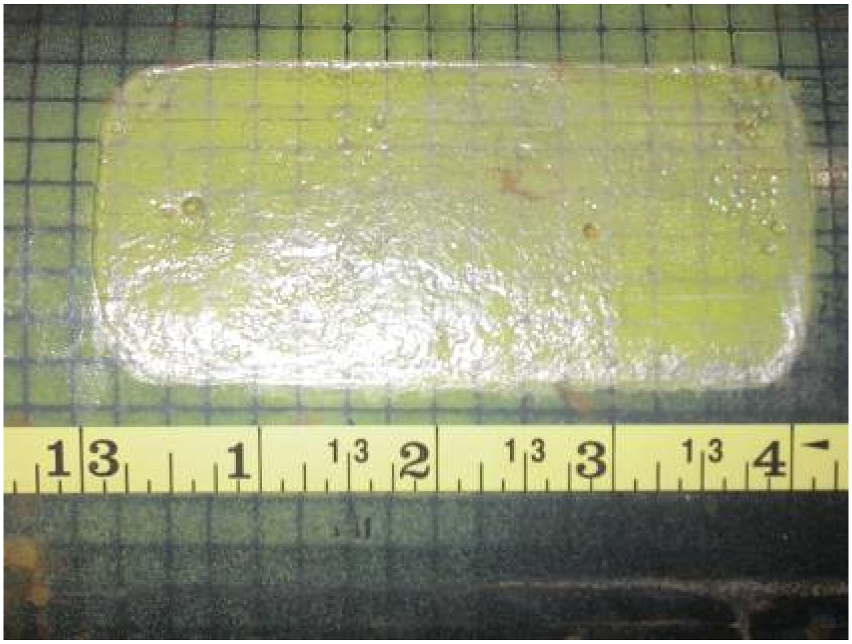


Figure 2-4. Defect P1-3 (Defect 2)



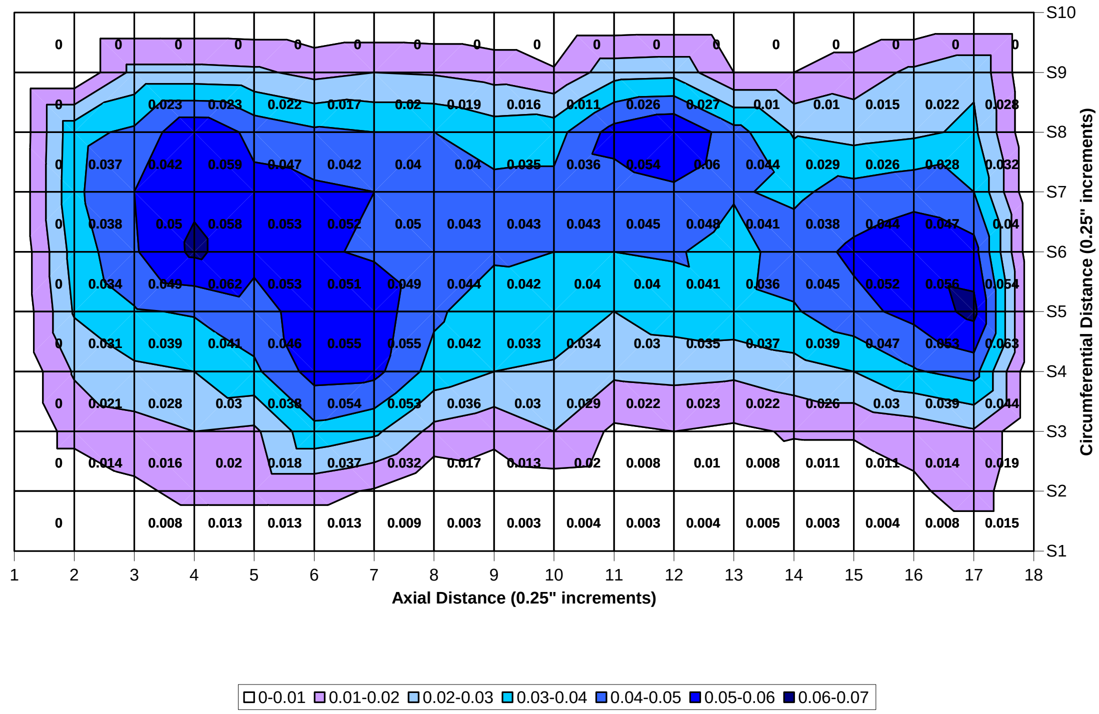
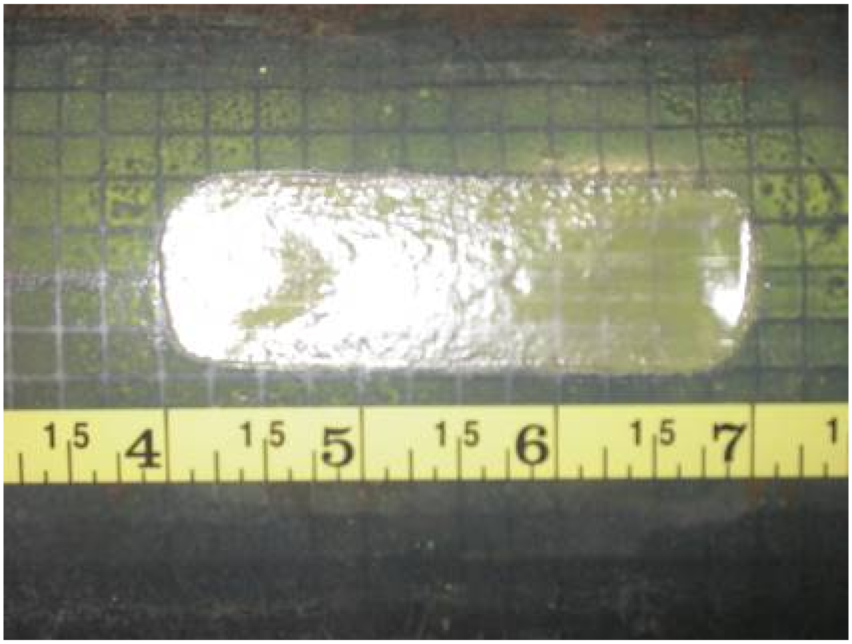


Figure 2-5. Defect P1-4 (Defect 3)



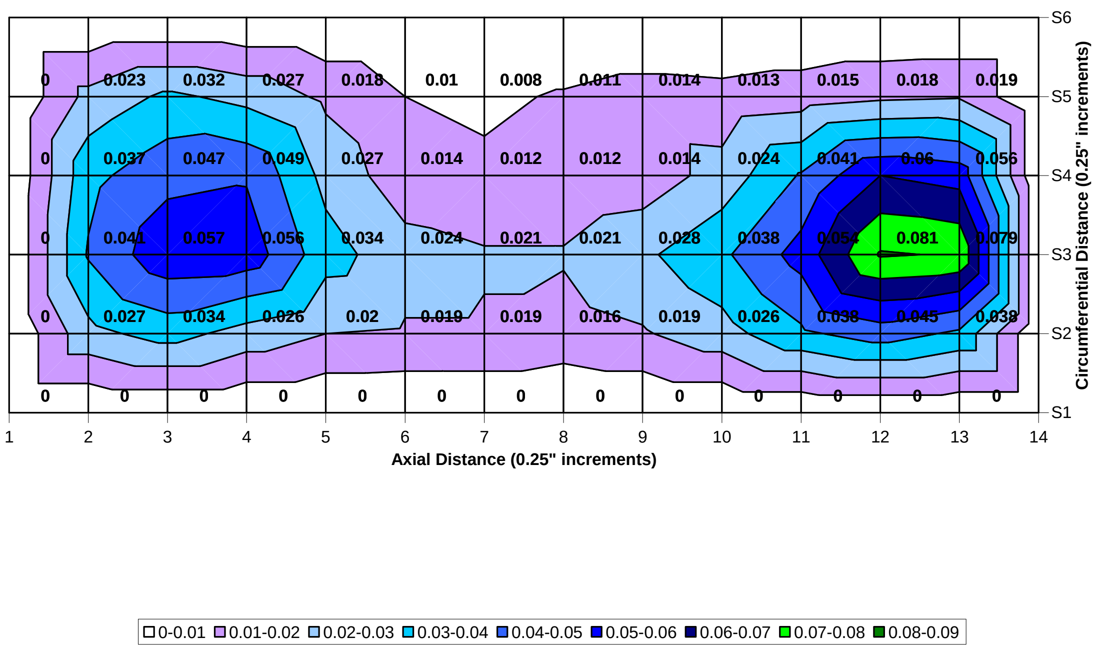
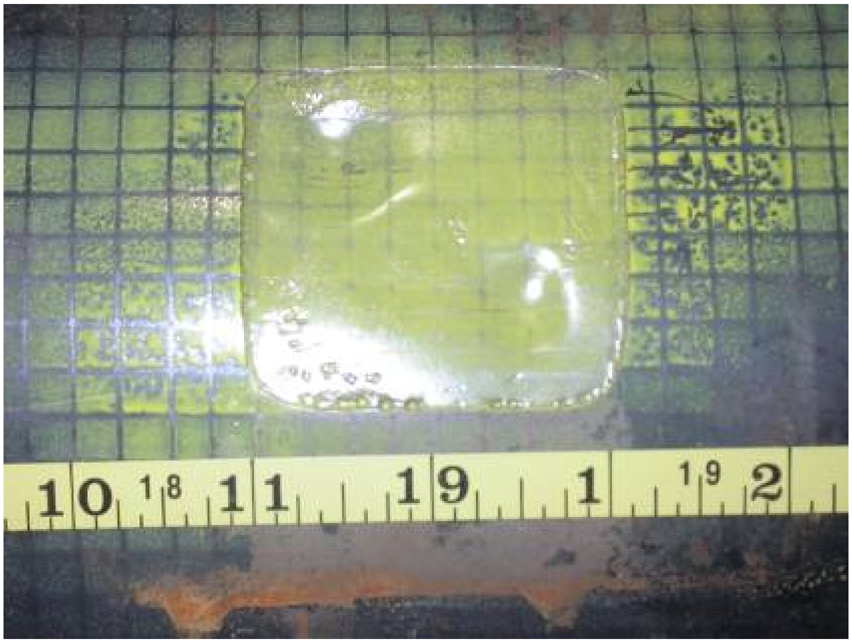


Figure 2-6. Defect P1-5 (Defect 4)



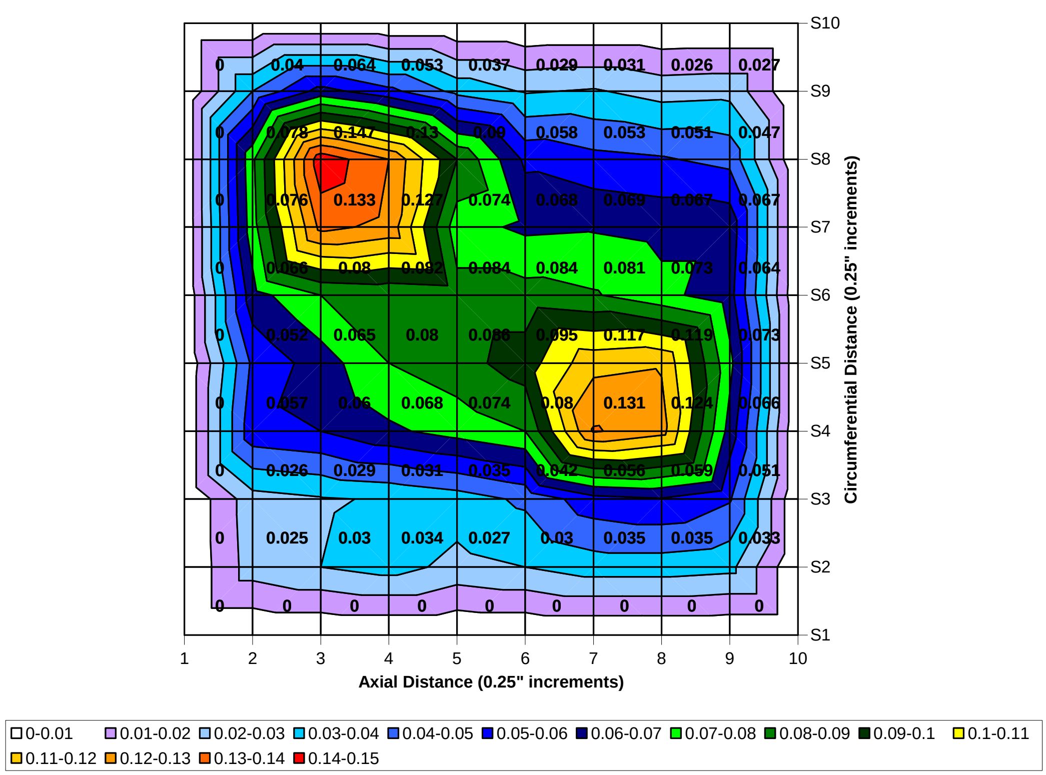


Figure 2-7. Defect P1-7 (Defect 5)

This page intentionally blank.

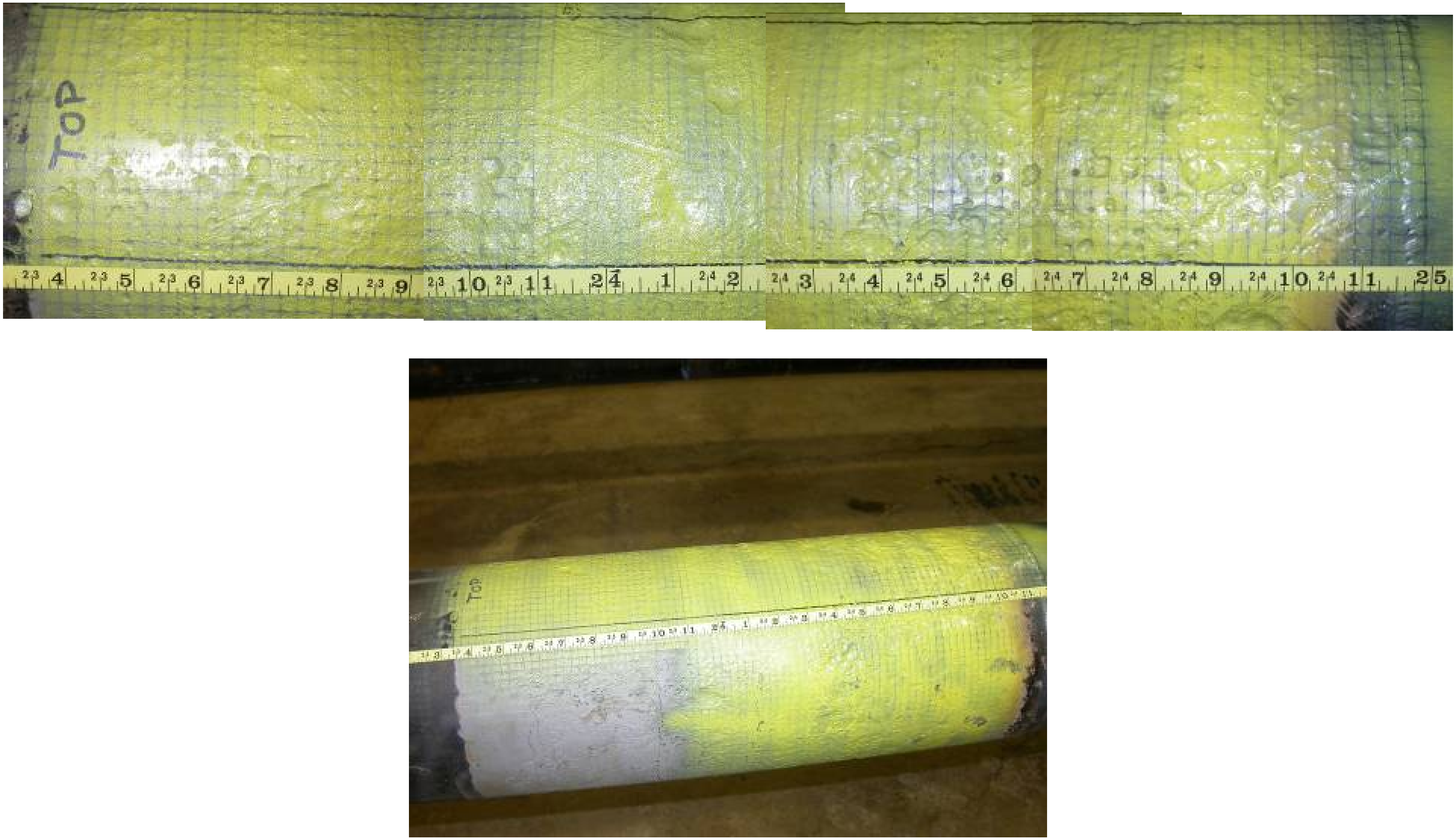


Figure 2-8. Defect P1-9 (P1-NC1)

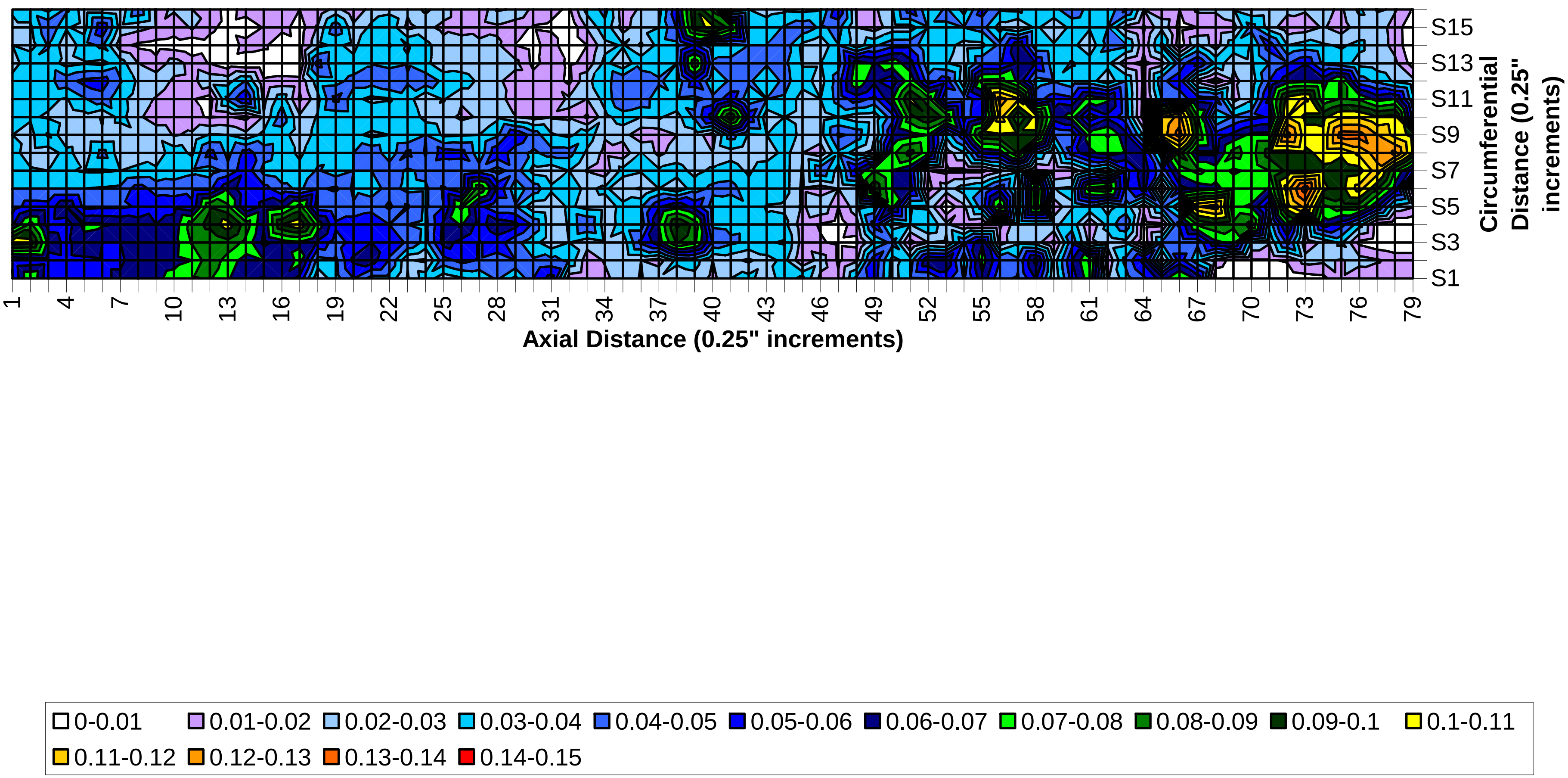
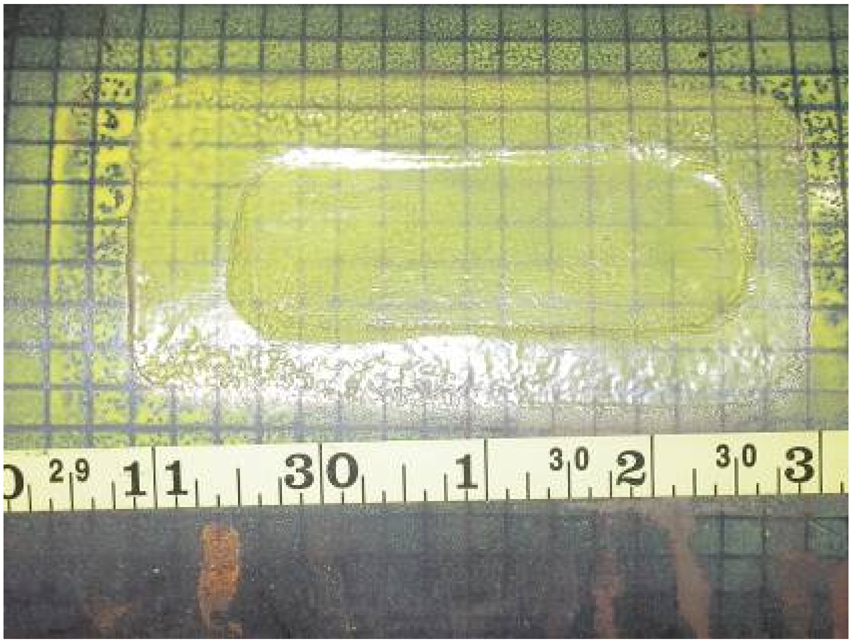


Figure 2-8 (cont). Defect P1-9 (P1-NC1)



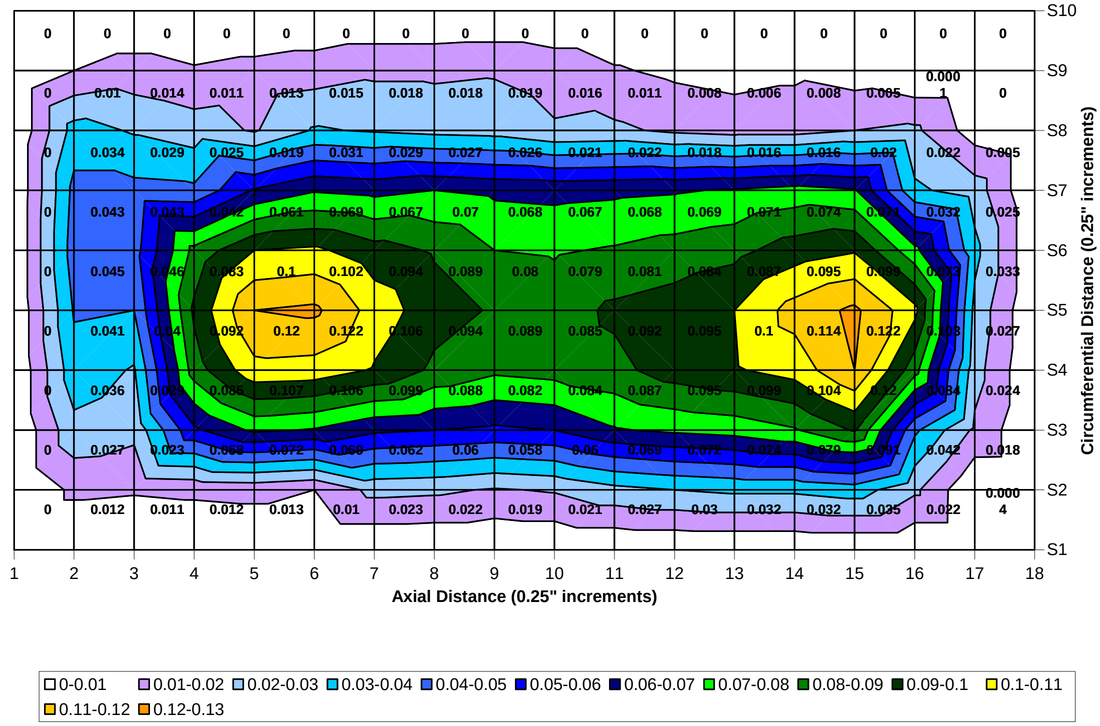
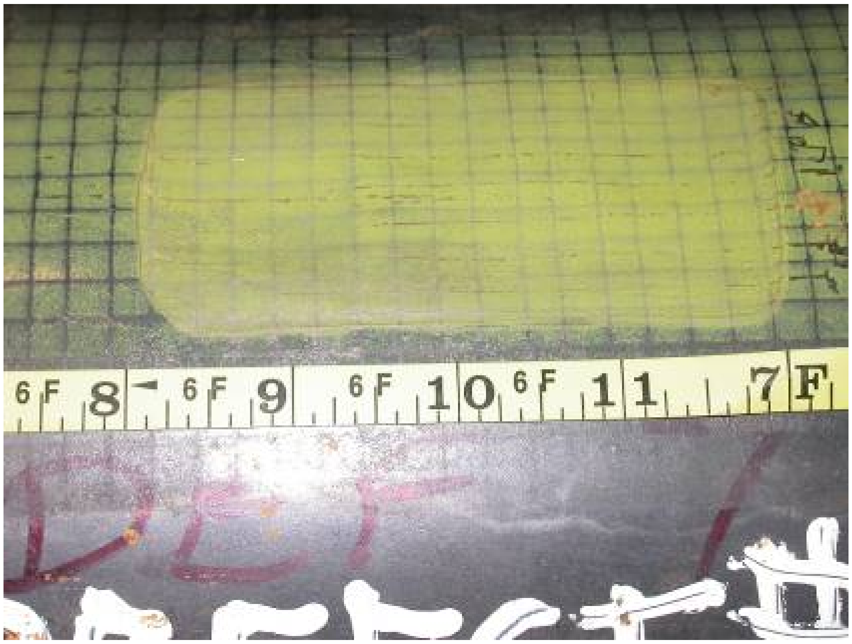


Figure 2-9. Defect P1-12 (Defect 6)



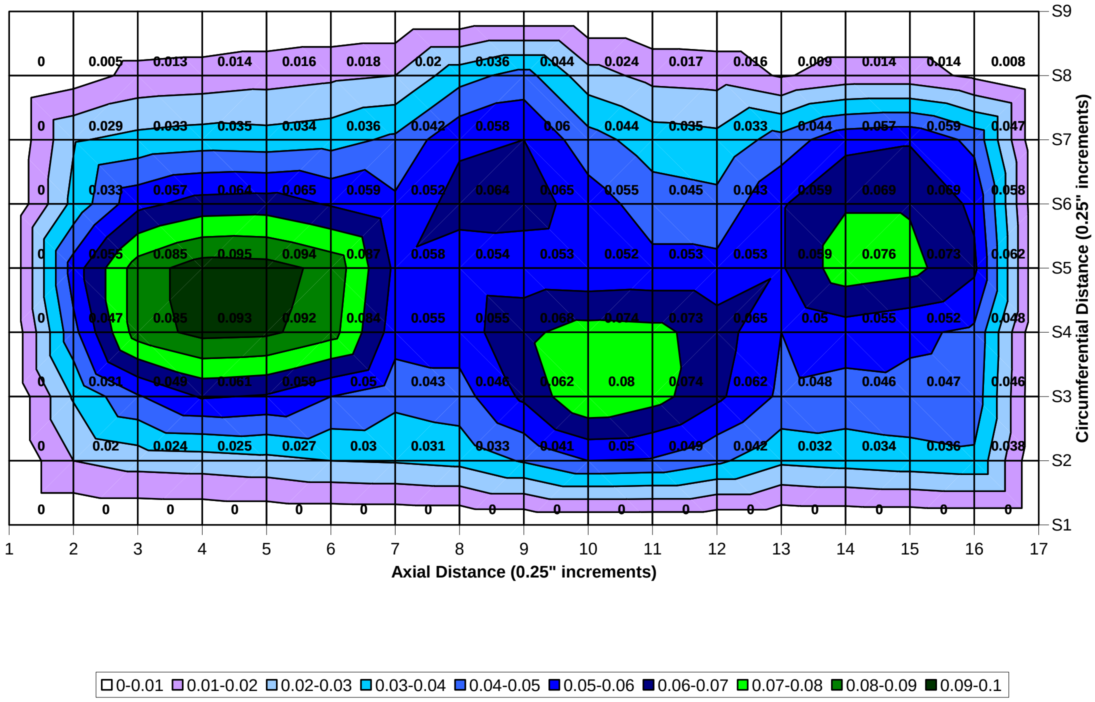


Figure 2-10. Defect P1-13 (Defect 7)

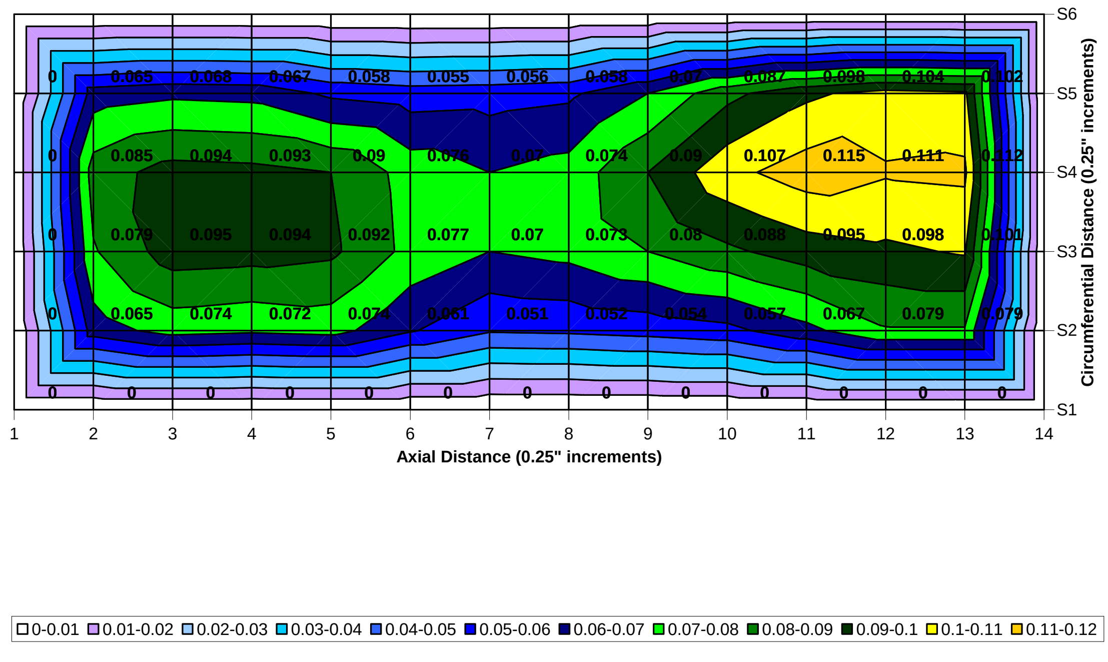


Figure 2-11. Defect P1-14 (Defect 8)

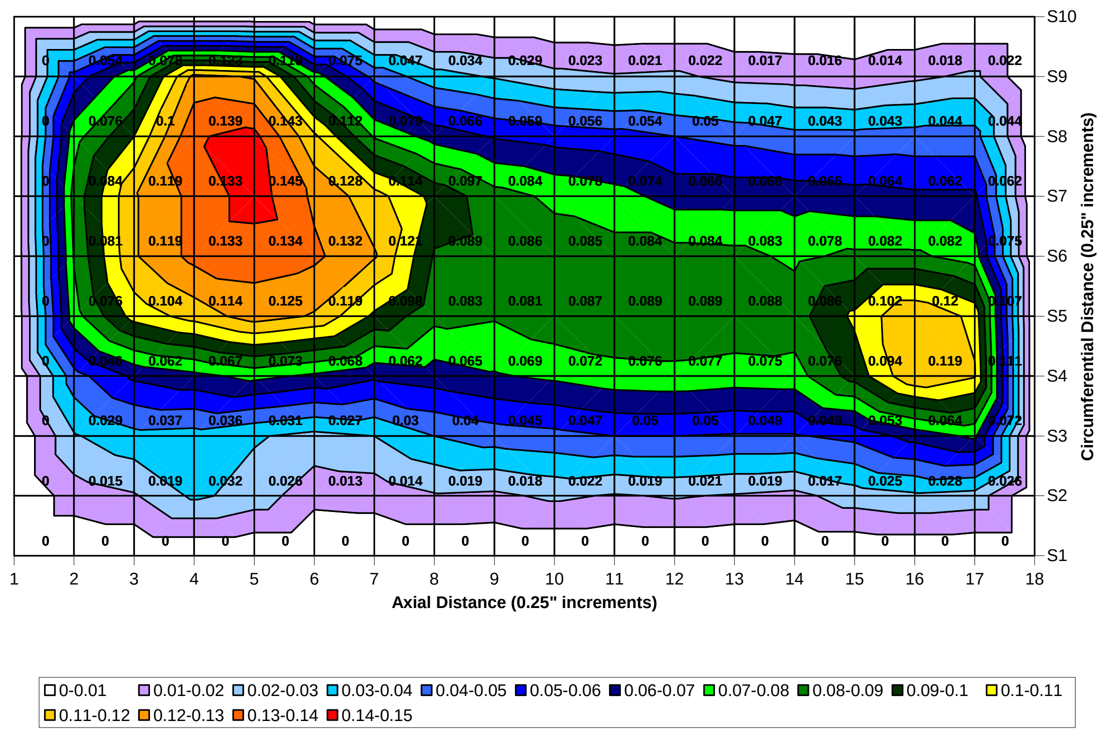


Figure 2-12. Defect P1-18 (Defect 9)

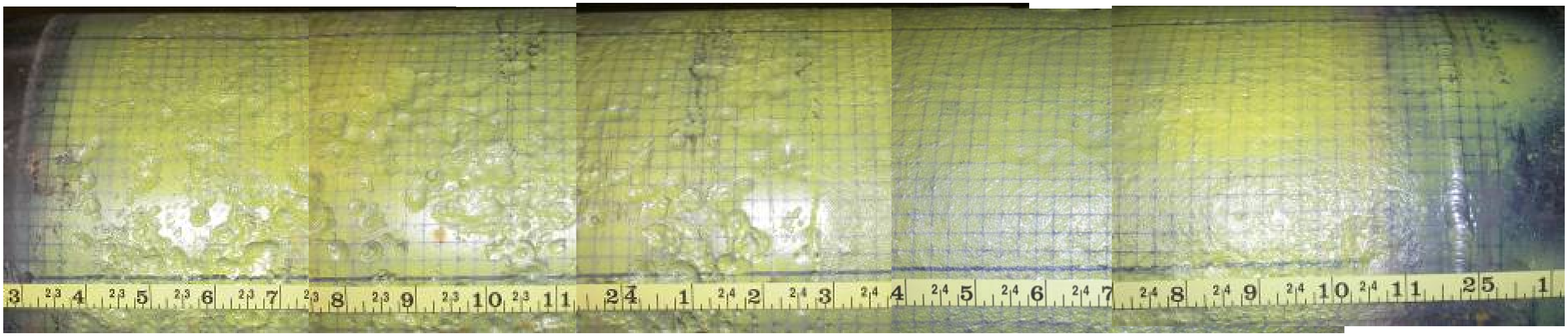


Figure 2-13. Defect P1-21 (P1-NC2)

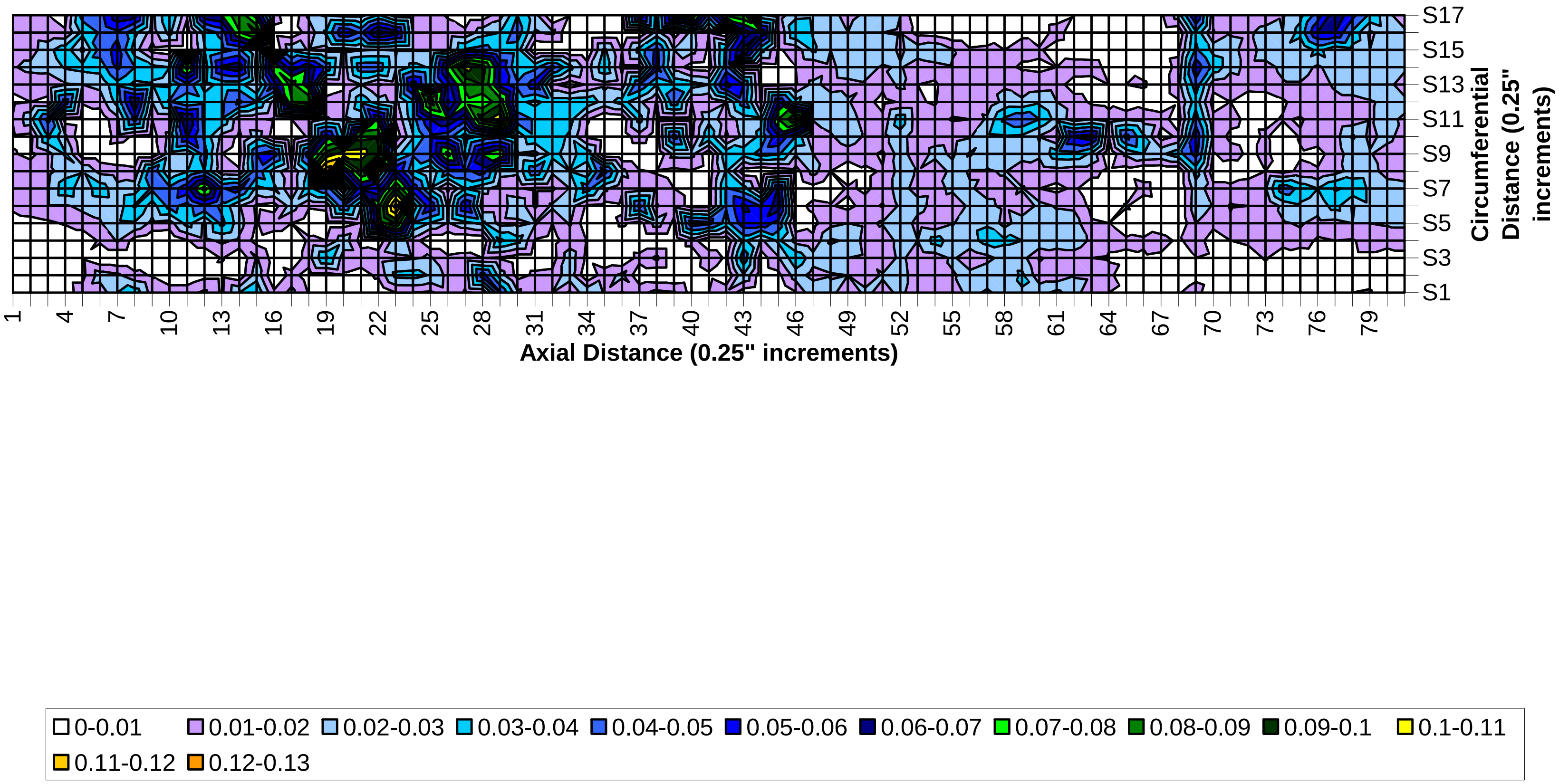


Figure 2-13 (cont). Defect P1-21 (P1-NC2)

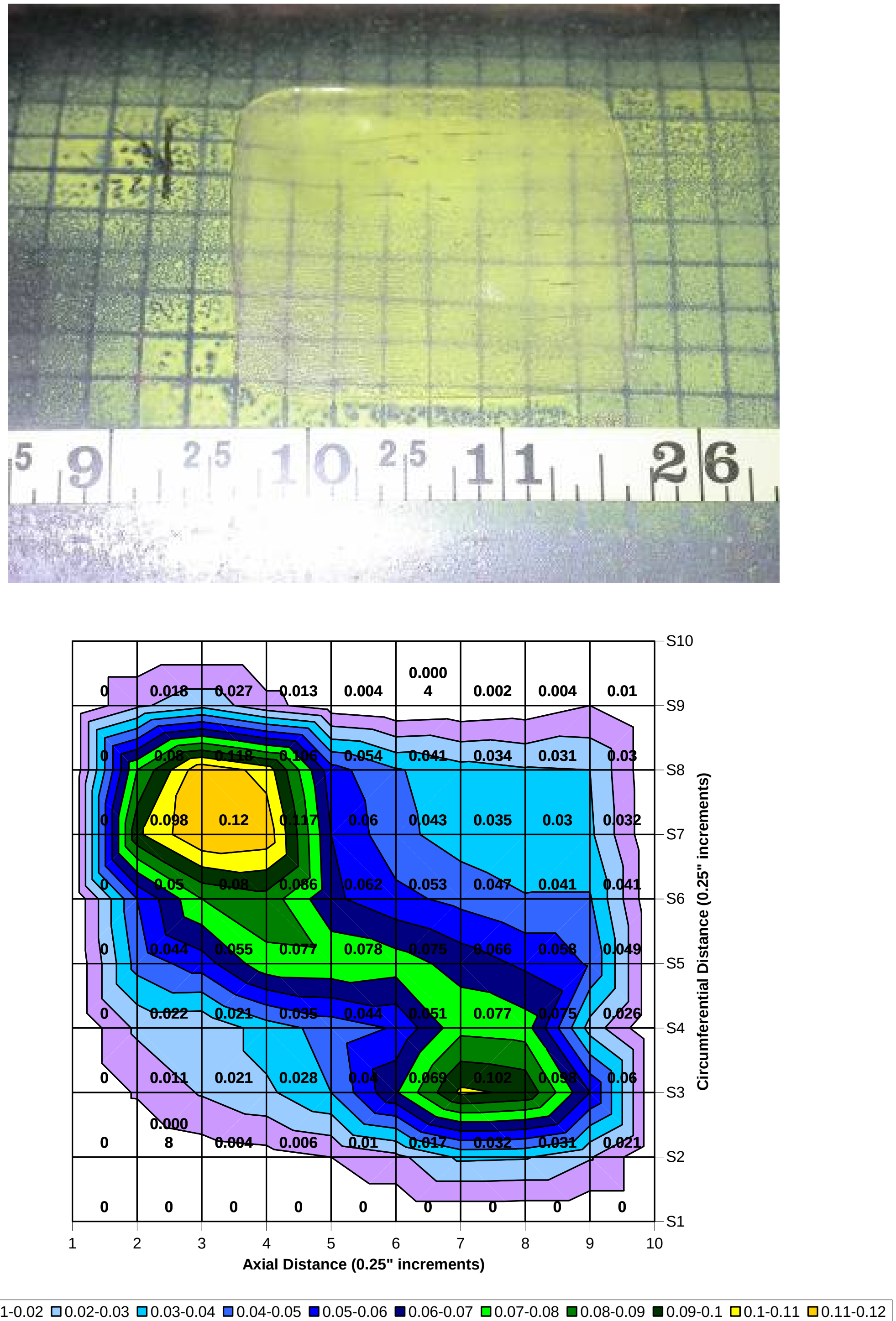
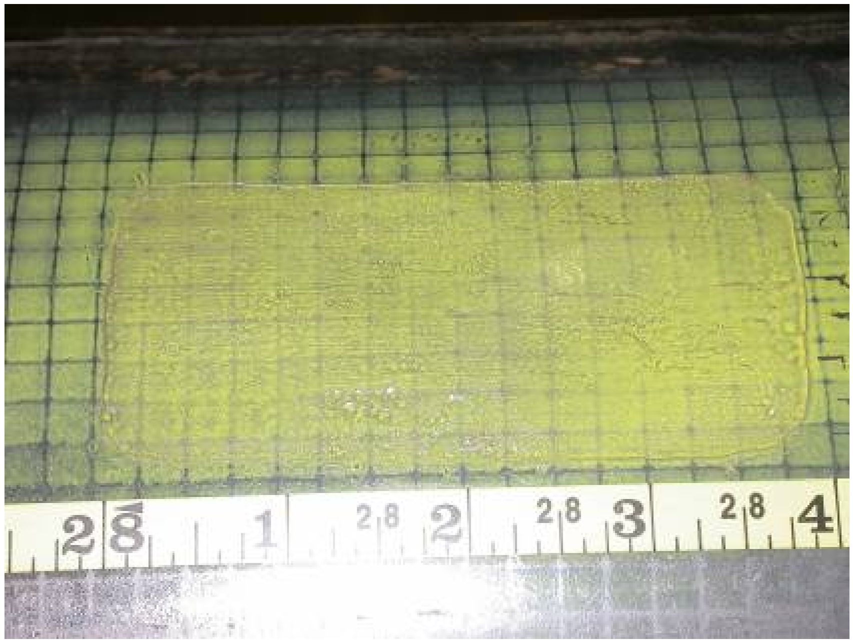


Figure 2-14. Defect P1-22 (Defect 10)



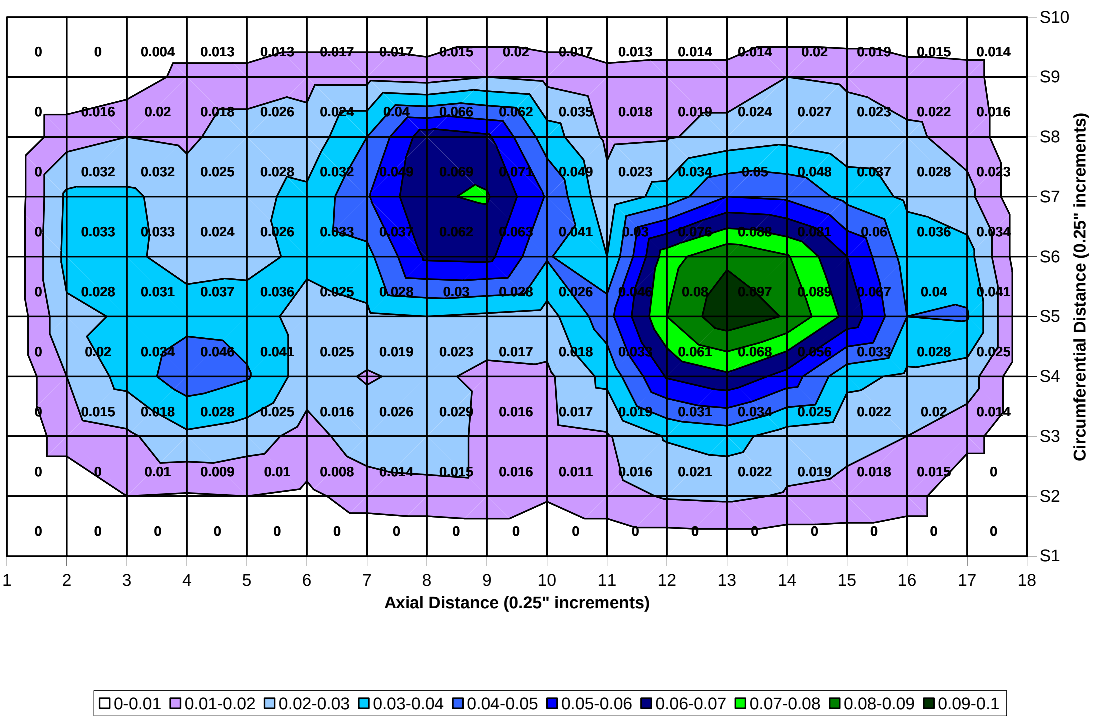
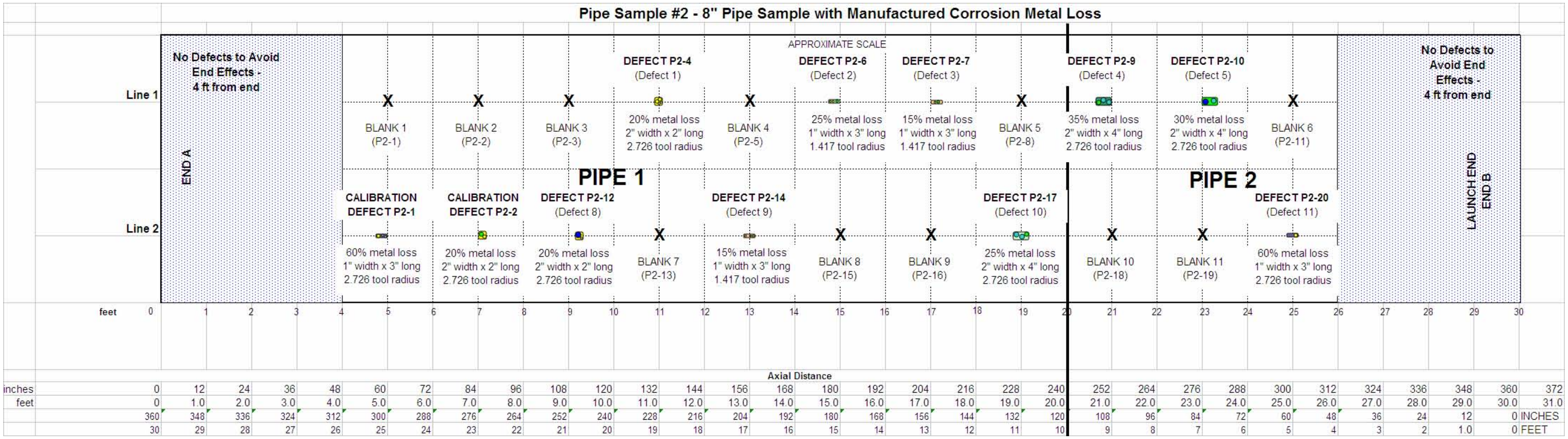


Figure 2-15. Defect P1-23 (Defect 11)

8 INCH PIPE SAMPLE 2 DOCUMENTATION

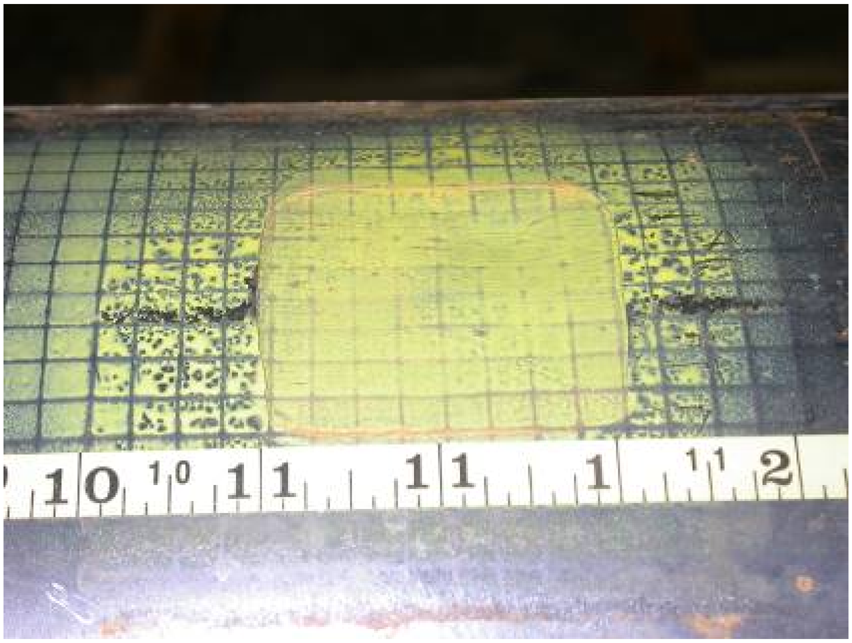


Defect Number	Distance from End A to Defect Center (inches)	Distance from End A to Defect Center (feet)	Length of Defect (in)	Width of Defect (in)	Max Depth of Metal Removed (in)	% Metal Loss	Radius of End Mill Tool
		PIPE 1 Line 1					
Blank 1 (P2-1)	60.0	5	-	-	0.00	0%	-
Blank 2 (P2-2)	84.0	7	-	-	0.00	0%	-
Blank 3 (P2-3)	108.0	9	-	-	0.00	0%	-
Defect P2-4 (Defect 1)	132.0	11	2	2	0.079	42%	2.726
Blank 4 (P2-5)	156.0	13	-	-	0.00	0%	-
Defect P2-6 (Defect 2)	178.5	14.875	3	1	0.114	61%	1.417
Defect P2-7 (Defect 3)	205.5	17.125	3	1	0.085	45%	1.417
Blank 5 (P2-8)	228.0	19	-	-	0.00	0%	-
		PIPE 2 Line 1					
Defect P2-9 (Defect 4)	250.0	20.83333	4	2	0.158	84%	2.726
Defect P2-10 (Defect 5)	278.0	23.16667	4	2	0.147	78%	2.726
Blank 6 (P2-11)	300.0	25	-	-	0.00	0%	-
		PIPE 1 Line 2					
Calibration Defect P2-1	58.5	4.875	3	1	0.188	100%	2.726
Calibration Defect P2-2	85.0	7.083333	2	2	0.077	41%	2.726
Defect P2-12 (Defect 8)	111.0	9.25	2	2	0.140	74%	2.726
Blank 7 (P2-13)	132.0	11	-	-	0.00	0%	-
Defect P2-14 (Defect 9)	156.0	13	3	1	0.105	56%	1.417
Blank 8 (P2-15)	180.0	15	-	-	0.00	0%	-
Blank 9 (P2-16)	204.0	17	-	-	0.00	0%	-
Defect P2-17 (Defect 10)	228.0	19	4	2	0.112	60%	2.726
		PIPE 2 Line 2					
Blank 10 (P2-18)	252	21	-	-	0.00	0%	-
Blank 11 (P2-19)	276	23	-	-	0.00	0%	-
Defect P2-20 (Defect 11)	300	25	3	1	0.188	100%	2.726

Figure 2-16. 8-inch Pipe Sample 2 Defect Map

This page intentionally blank.

Pipe Sample 2 Simulated Corrosion Defect Photos



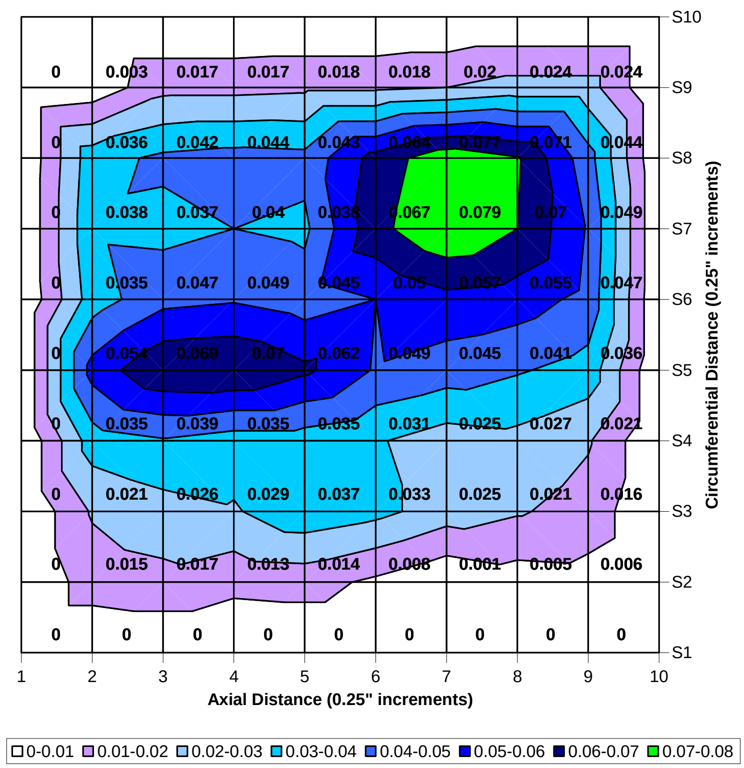
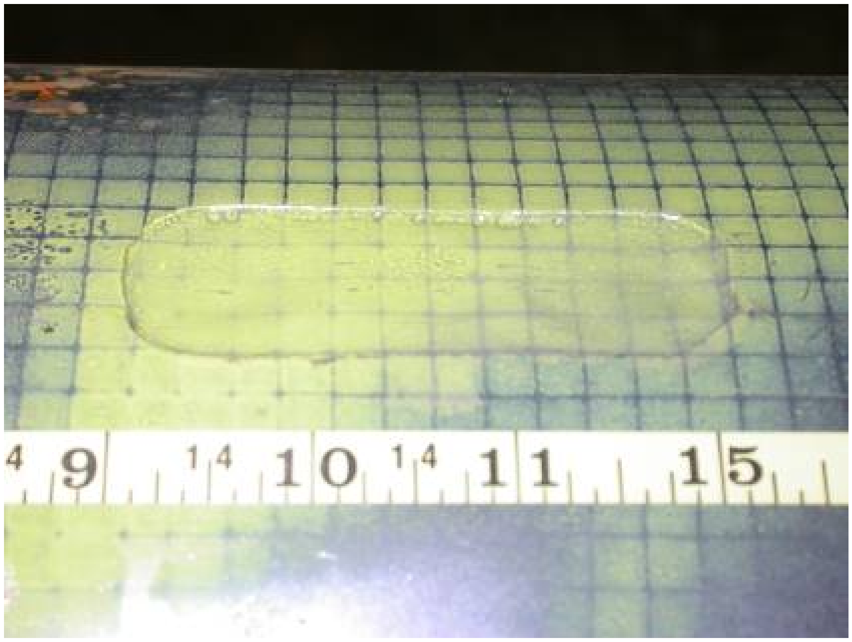


Figure 2-17. Defect P2-4 (Defect 1)



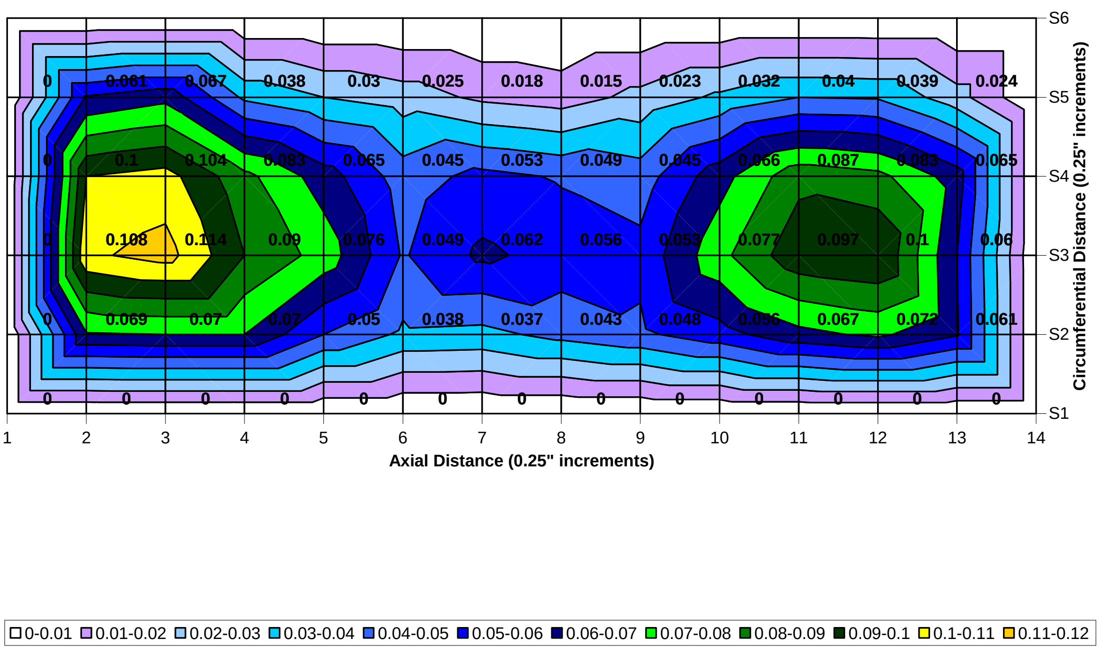
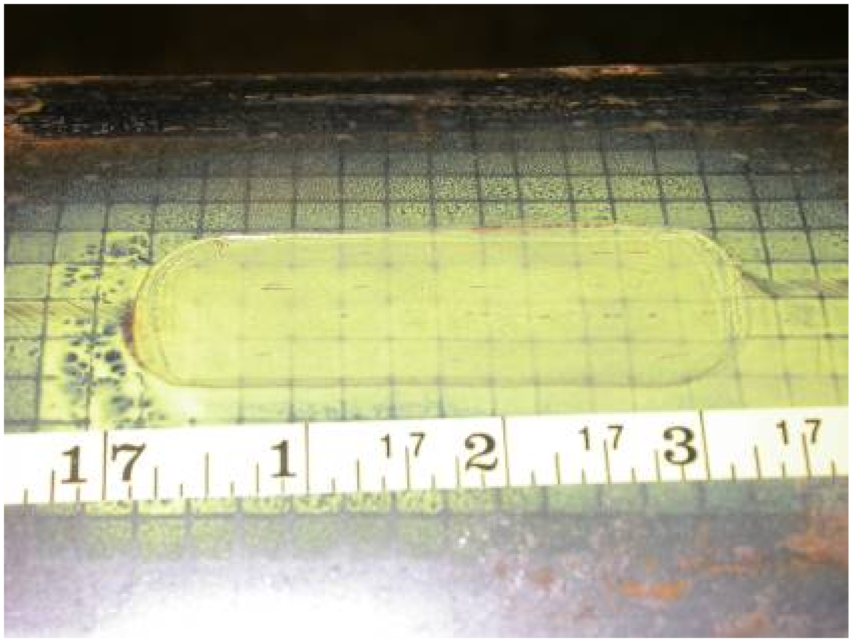


Figure 2-18. Defect P2-6 (Defect 2)



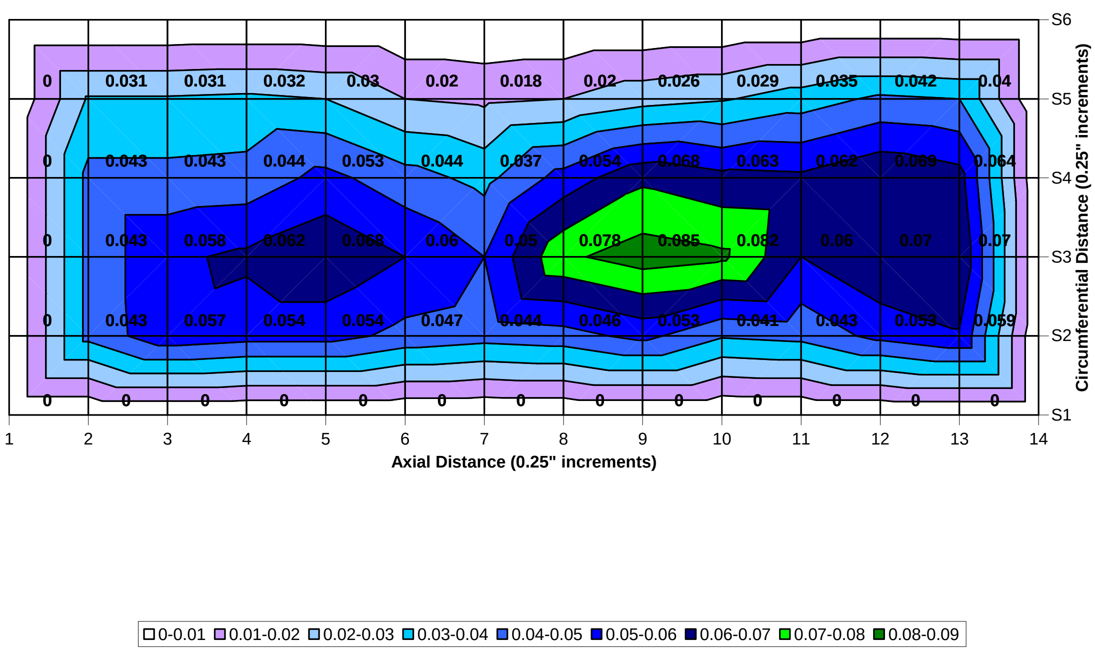


Figure 2-19. Defect P2-7 (Defect 3)

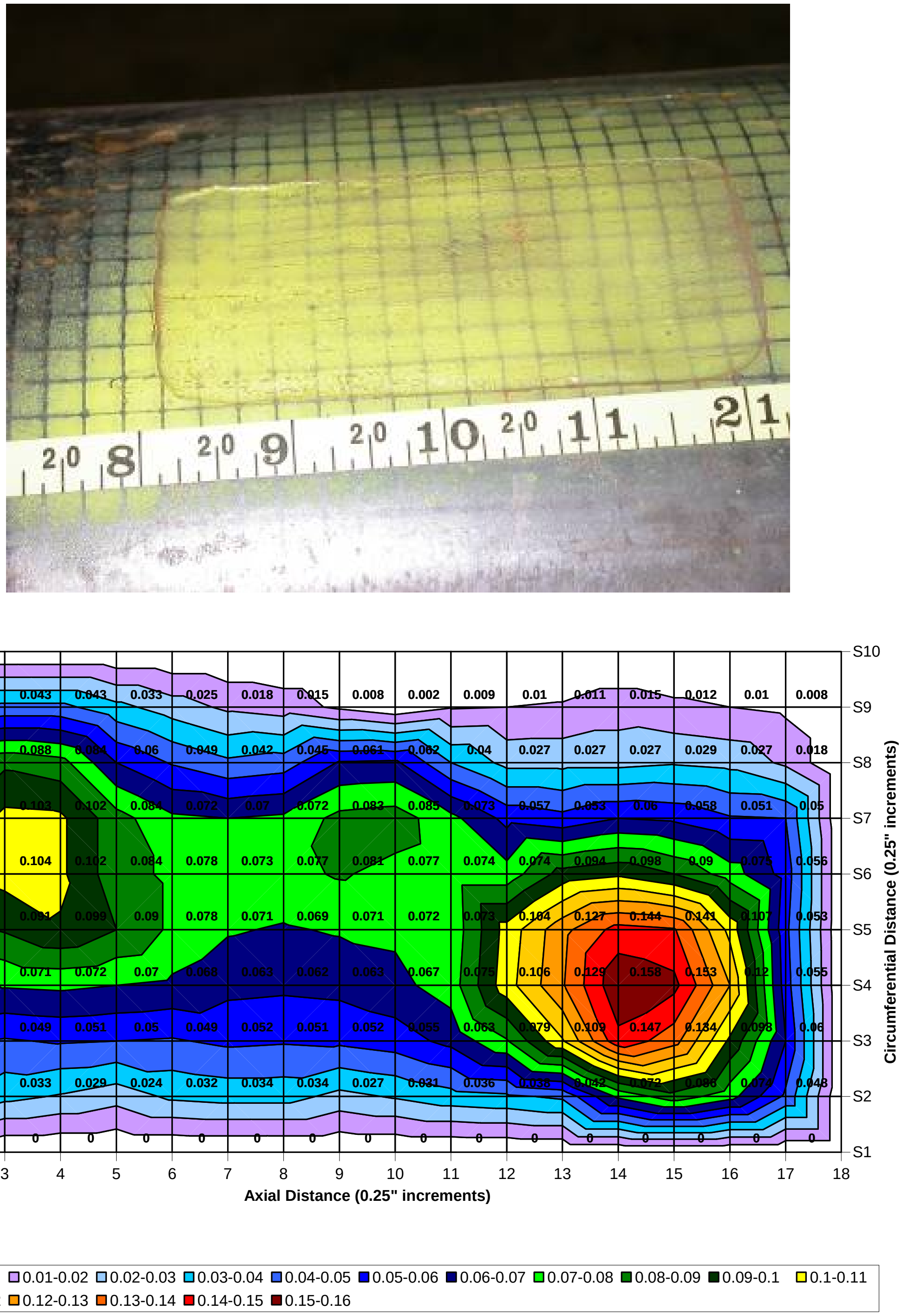
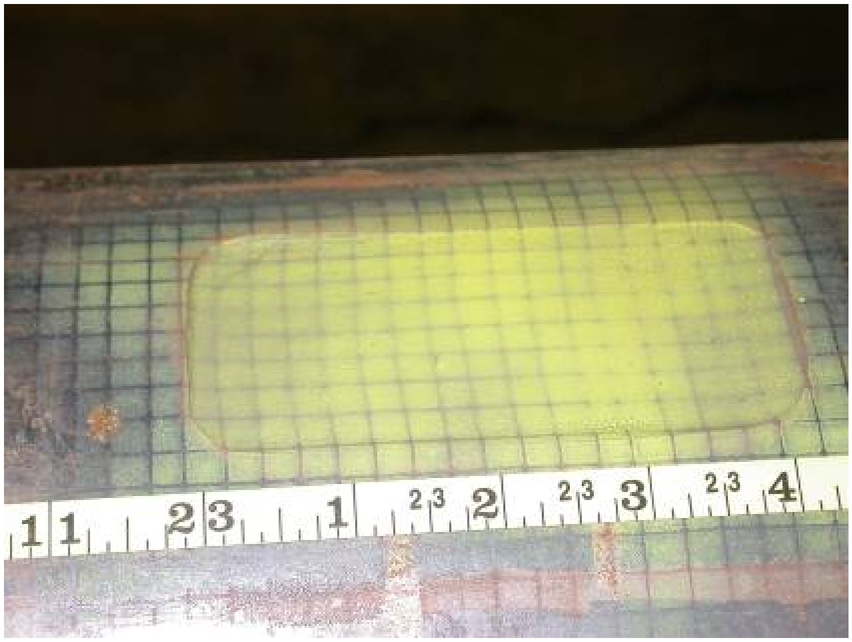


Figure 2-20. Defect P2-9 (Defect 4)



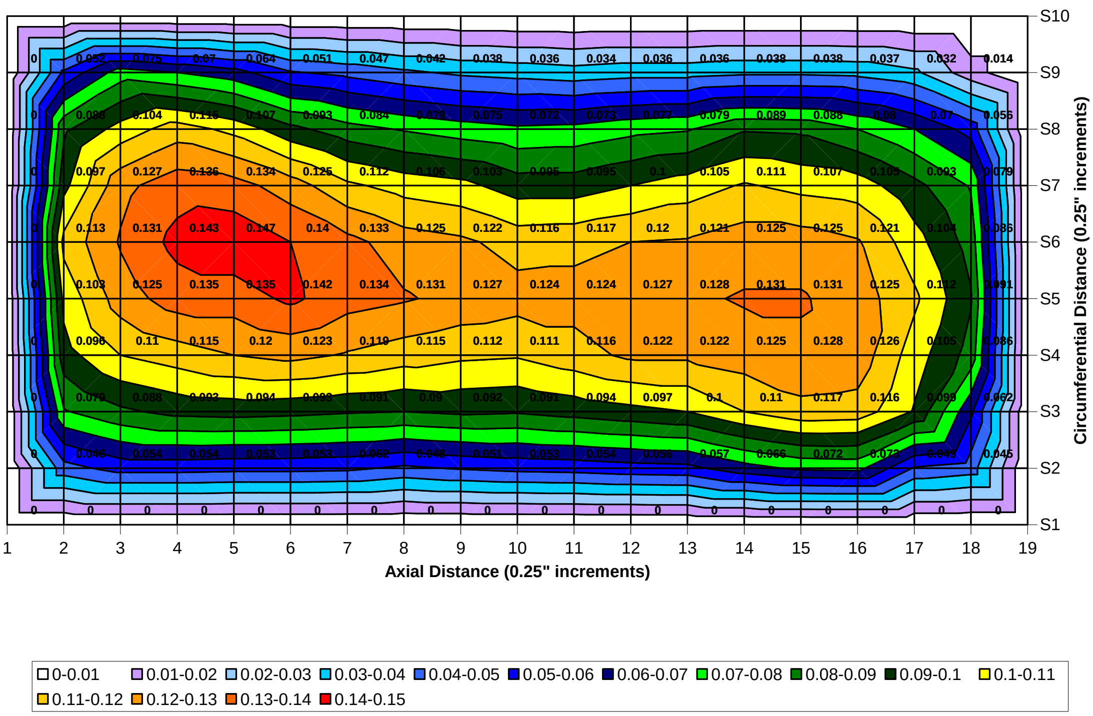


Figure 2-21. Defect P2-10 (Defect 5)

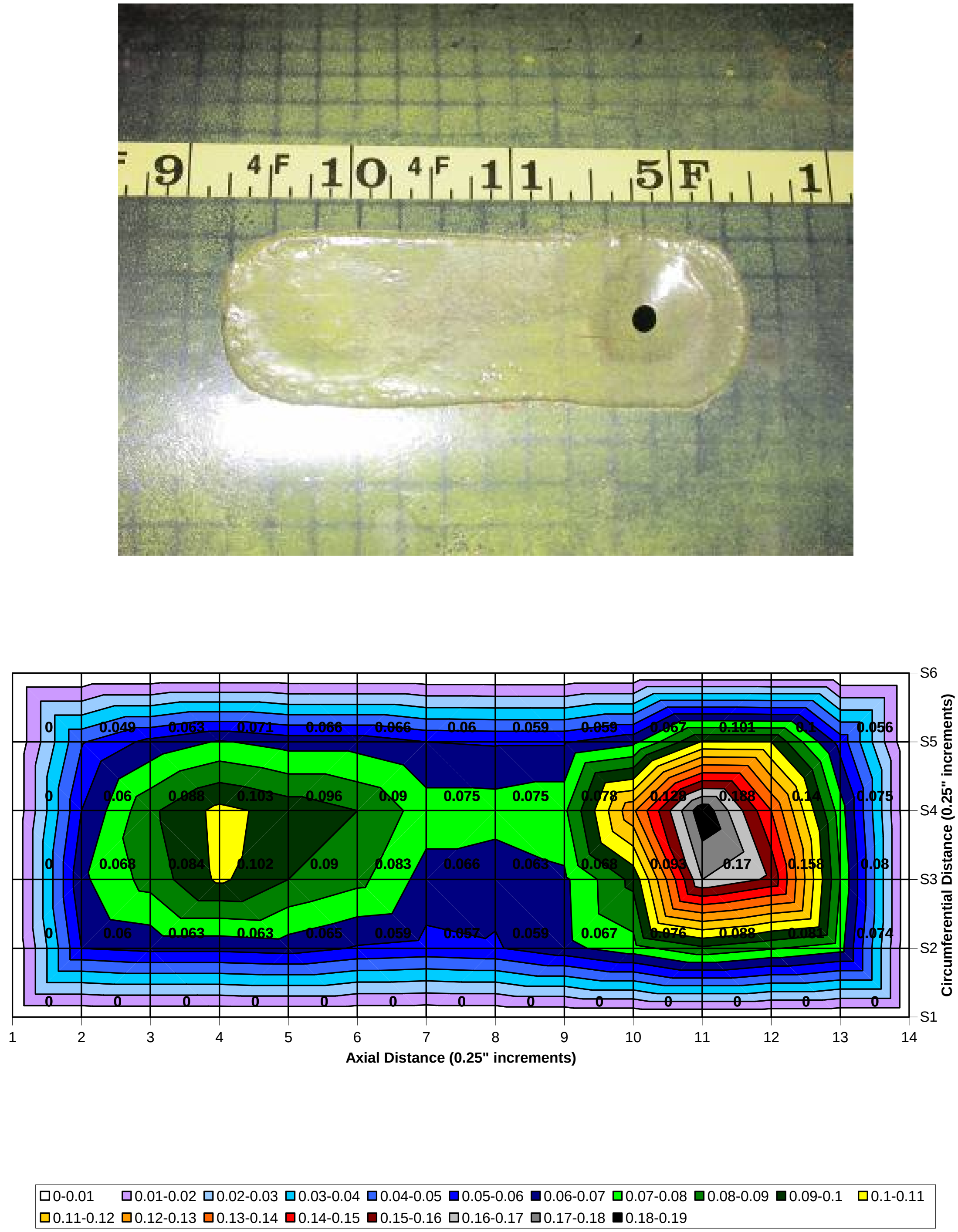


Figure 2-22. Calibration Defect P2-1 (Defect 6)

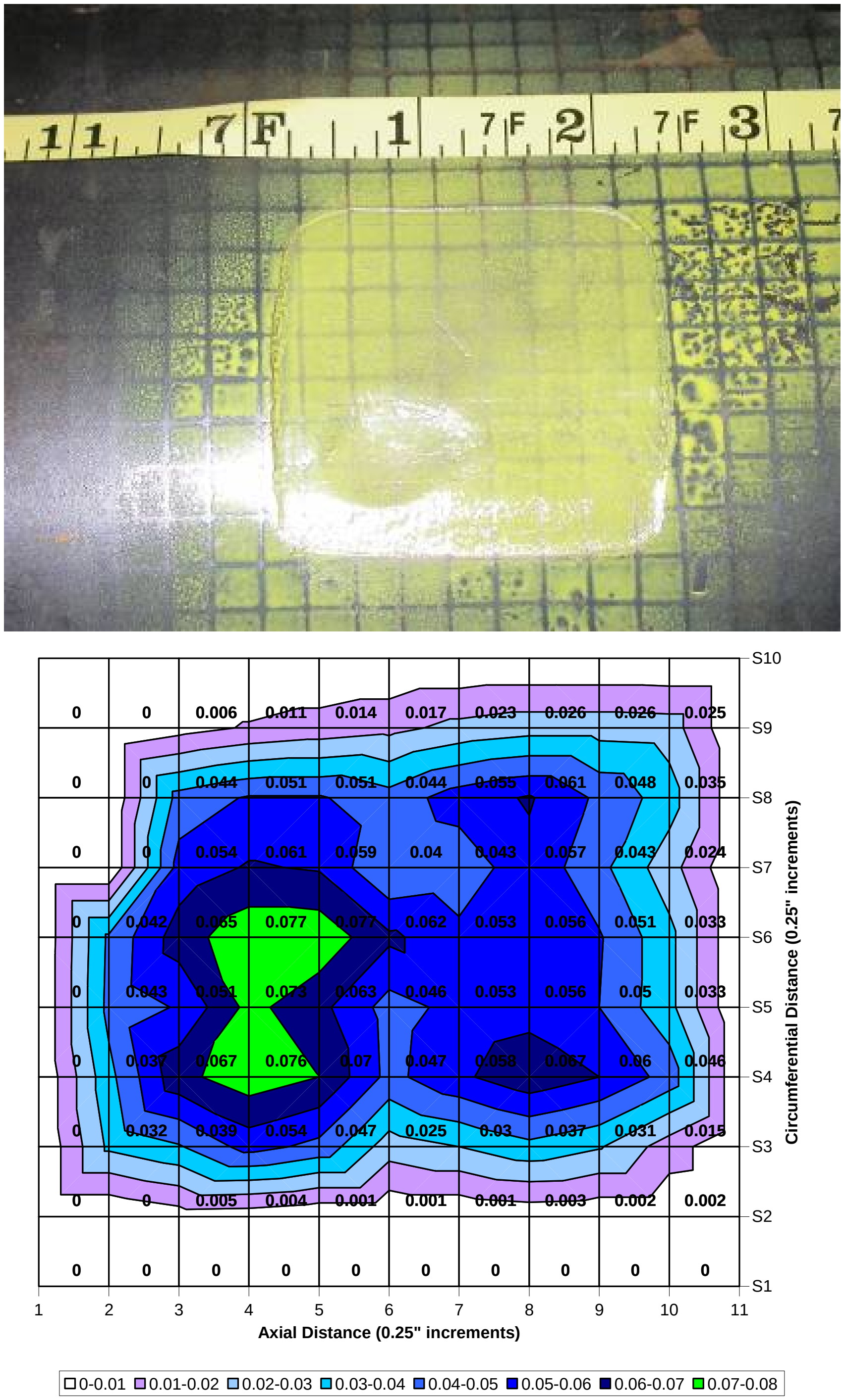


Figure 2-23. Calibration Defect P2-2 (Defect 7)

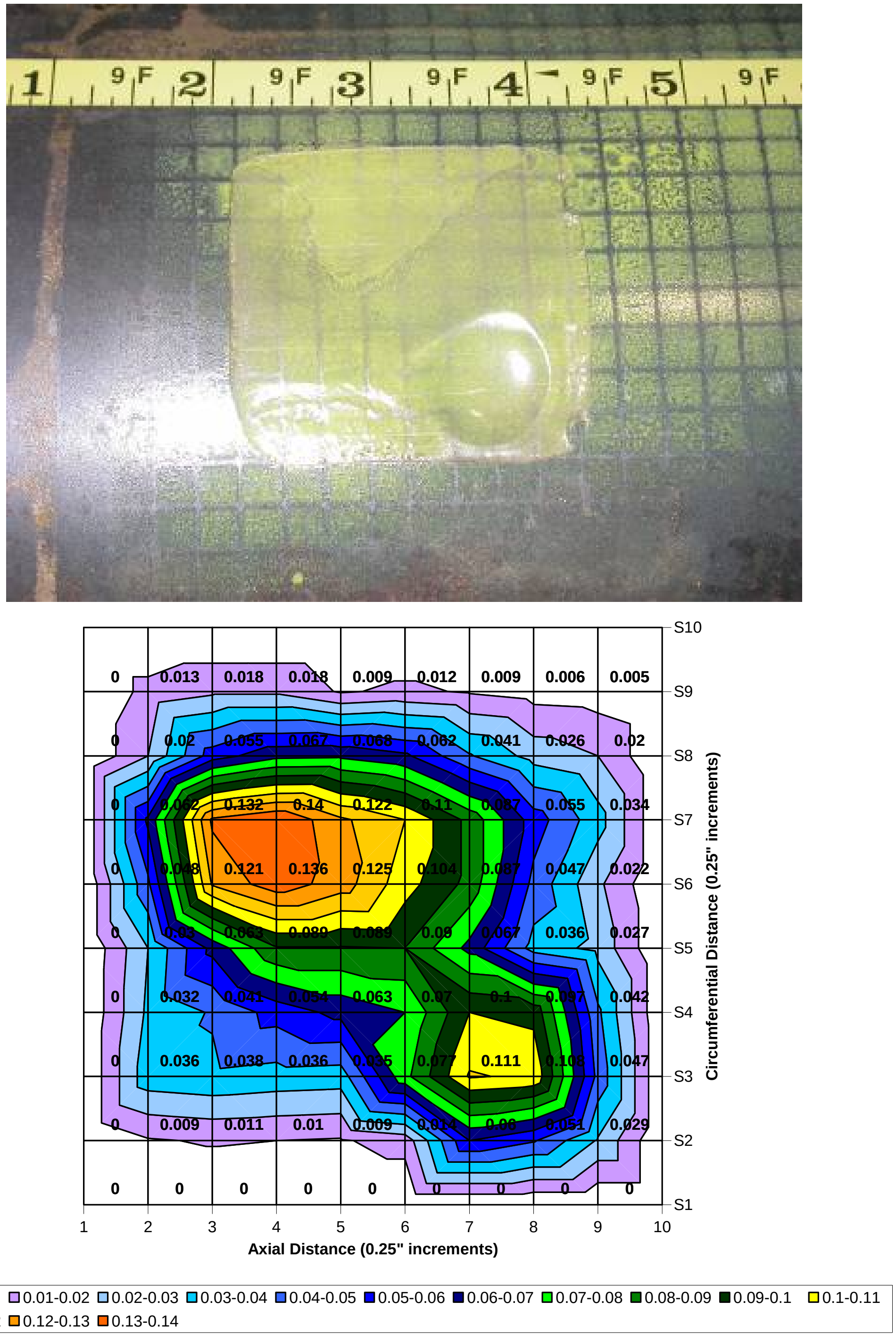
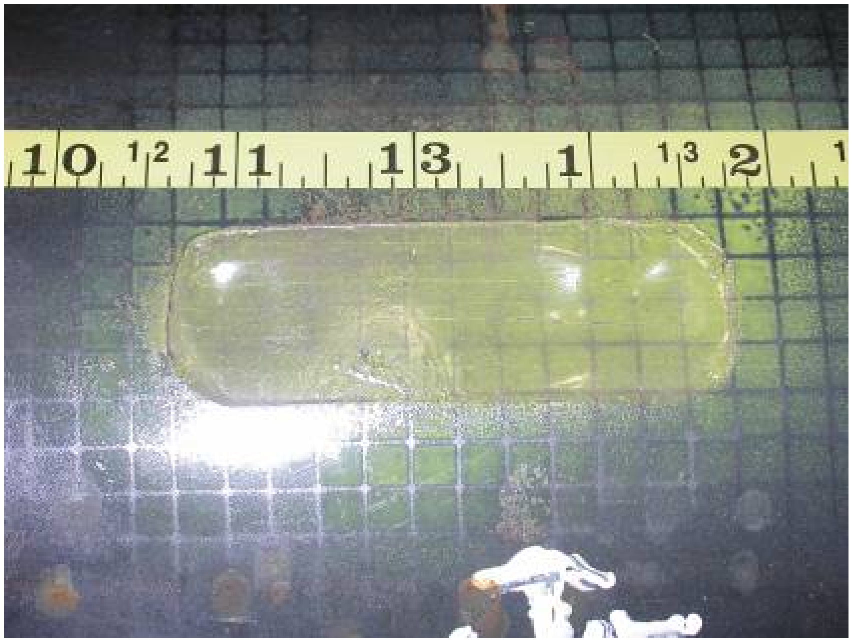


Figure 2-24. Defect P2-12 (Defect 8)



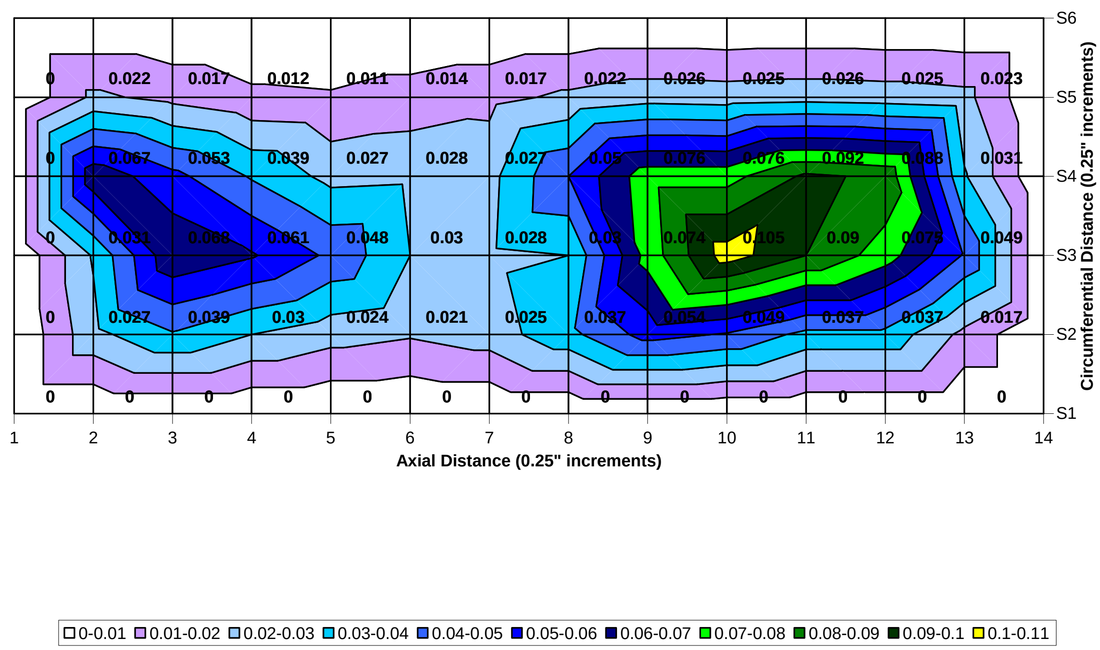
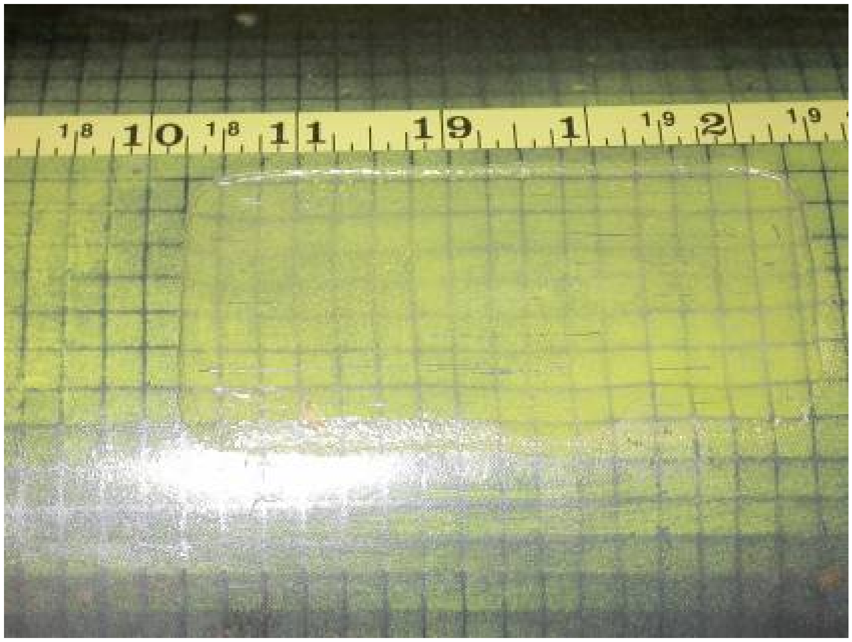


Figure 2-25. Defect P2-14 (Defect 9)



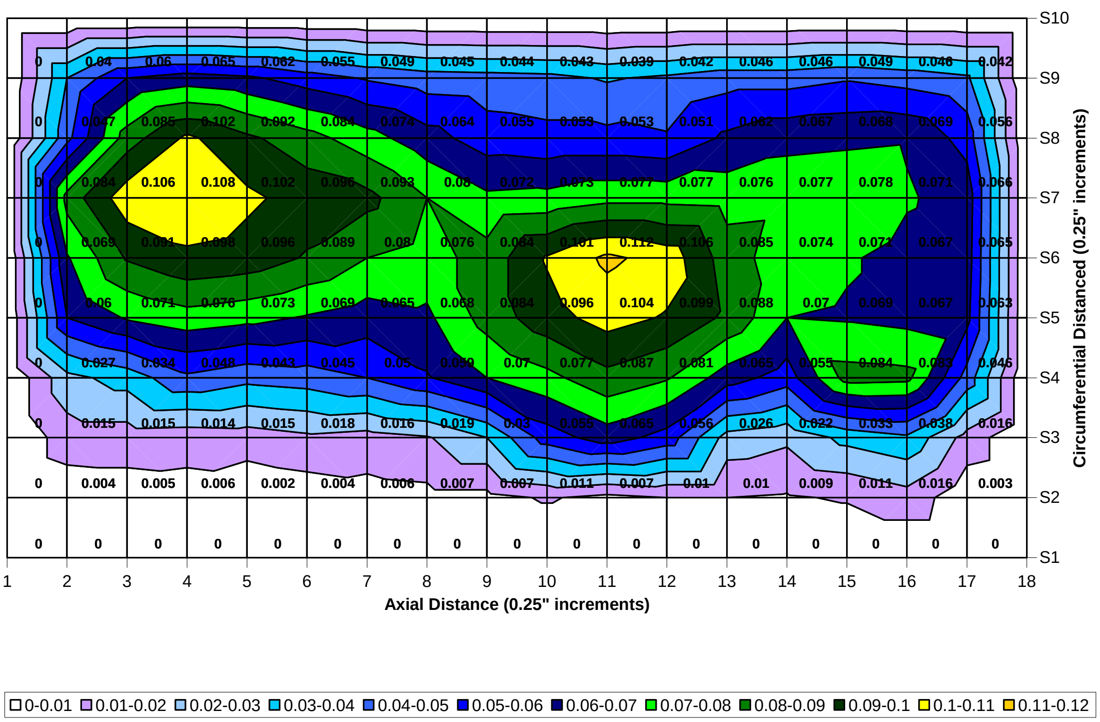
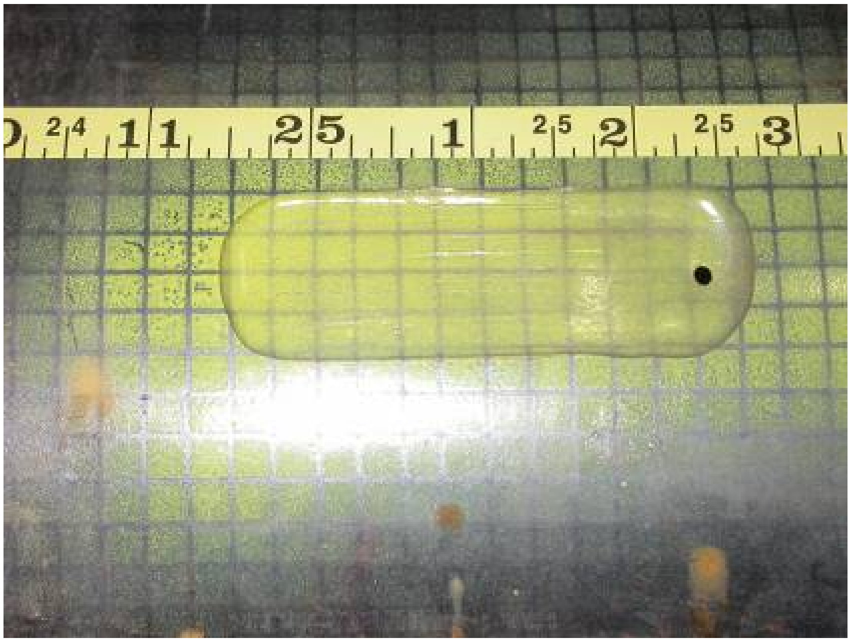


Figure 2-26. Defect P2-17 (Defect 10)



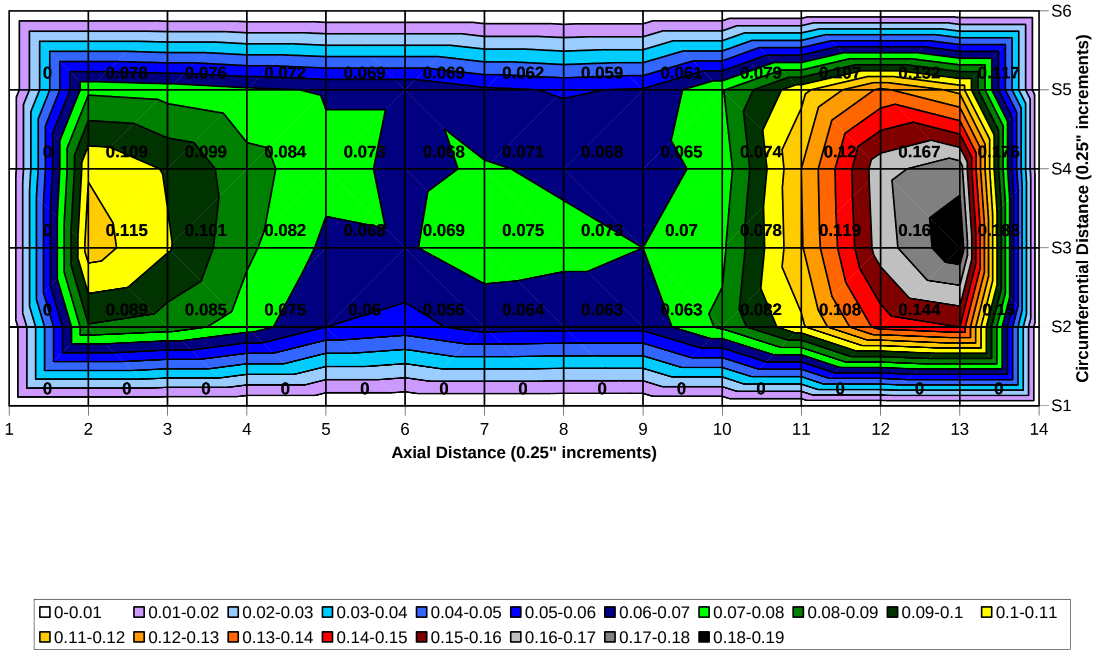
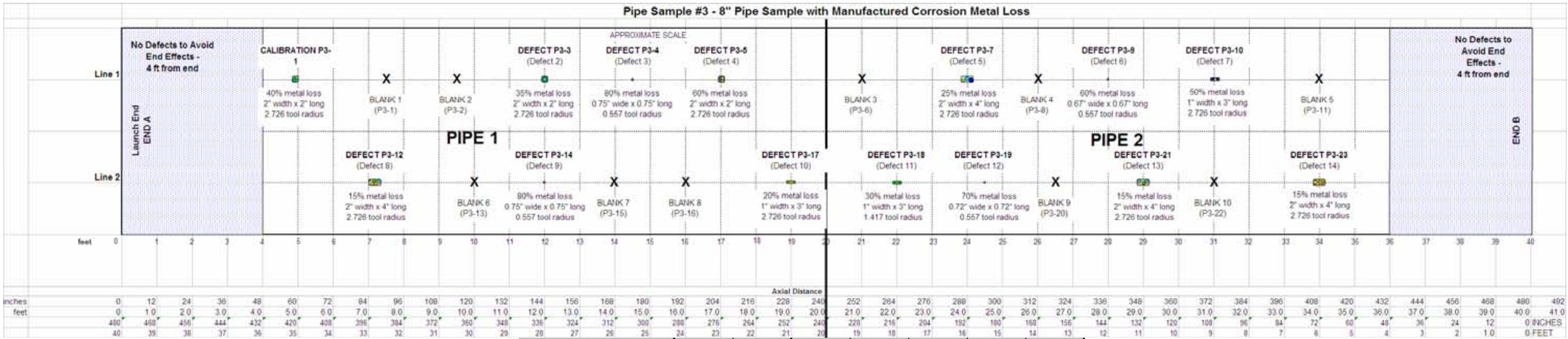


Figure 2-27. Defect P2-20 (Defect 11)

This page intentionally blank.

8 INCH PIPE SAMPLE 3 DOCUMENTATION

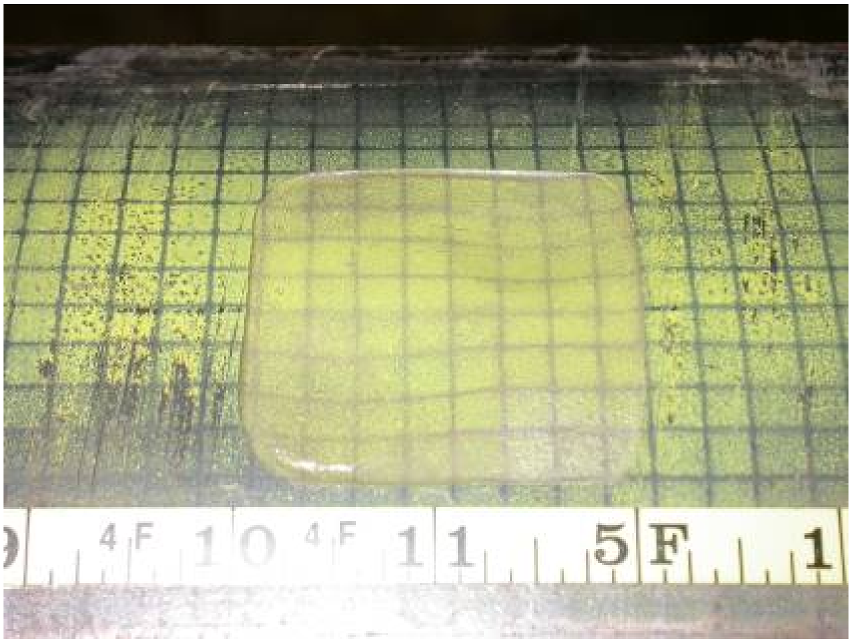


Defect Number	Distance from End A to Defect Center (inches)	Distance from End A to Defect Center (feet)	Length of Defect (in)	Width of Defect (in)	Max Depth of Metal Removed (in)	% Metal Loss	Radius of End Mill Tool
PIPE 1 Line 1							
Calibration P3-1	59	4.916667	2	2	0.00	0%	2.726
Blank 1 (P3-1)	90	7.5	-	-	0.00	0%	-
Blank 2 (P3-2)	114	9.5	-	-	0.00	0%	-
Defect P3-3 (Defect 2)	144	12	2	2	0.133	71%	2.726
Defect P3-4 (Defect 3)	174	14.5	0.75	0.75	0.148	79%	0.557
Defect P3-5 (Defect 4)	204	17	2	2	0.103	55%	2.726
PIPE 2 Line 1							
Blank 3 (P3-6)	252	21	-	-	0.00	0%	-
Defect P3-7 (Defect 5)	288	24	4	2	0.115	61%	2.726
Blank 4 (P3-8)	312	26	-	-	0.00	0%	-
Defect P3-9 (Defect 6)	336	28	0.67	0.67	0.120	64%	0.557
Defect P3-10 (Defect 7)	372	31	3	1	0.156	83%	2.726
Blank 5 (P3-11)	408	34	-	-	0.00	0%	-
PIPE 1 Line 2							
Defect P3-12 (Defect 8)	86	7.166667	4	2	0.094	50%	2.726
Blank 6 (P3-13)	120	10	-	-	0.00	0%	-
Defect P3-14 (Defect 9)	144	12	0.75	0.75	0.154	82%	0.557
Blank 7 (P3-15)	168	14	-	-	0.00	0%	-
Blank 8 (P3-16)	192	16	-	-	0.00	0%	-
Defect P3-17 (Defect 10)	228	19	3	1	0.070	37%	2.726
PIPE 2 Line 2							
Defect P3-18 (Defect 11)	264	22	3	1	0.091	48%	1.417
Defect P3-19 (Defect 12)	294	24.5	0.72	0.72	0.139	74%	0.557
Blank 9 (P3-20)	318	26.5	-	-	0.00	0%	-
Defect P3-21 (Defect 13)	348	29	4	2	0.103	55%	2.726
Blank 10 (P3-22)	372	31	-	-	0.00	0%	-
Defect P3-23 (Defect 14)	408	34	4	2	0.088	47%	2.726

Figure 2-28. 8-inch Pipe Sample 3 Defect Map

This page intentionally blank.

Pipe Sample 3 Simulated Corrosion Defect Photos



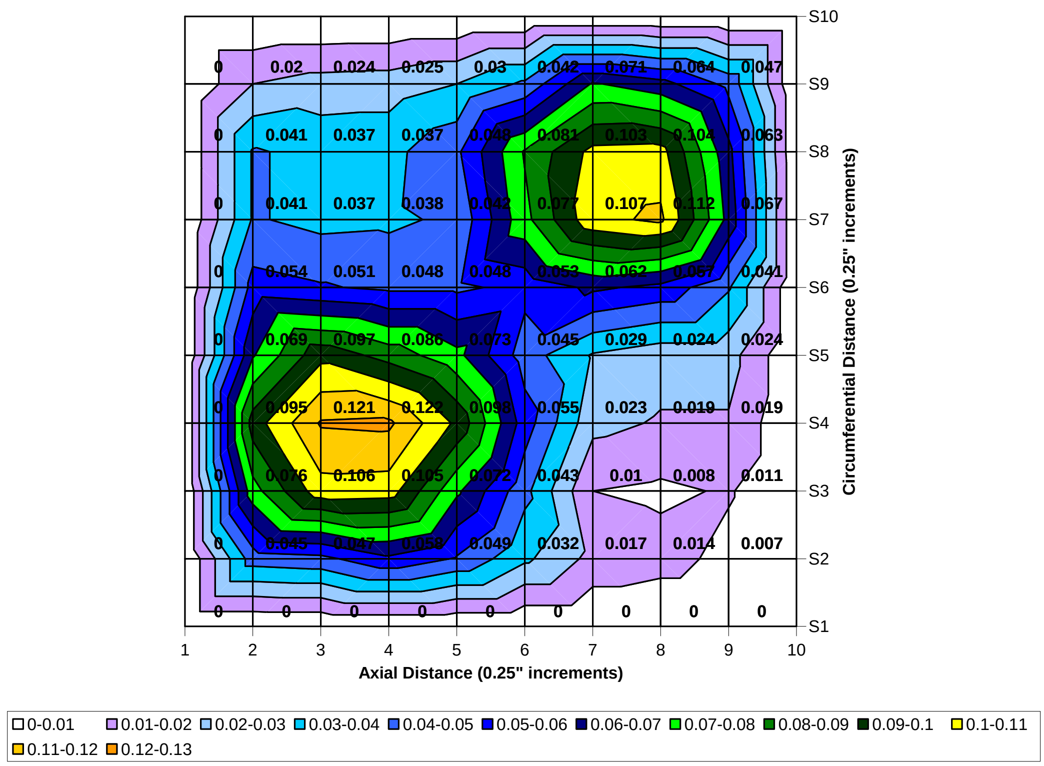
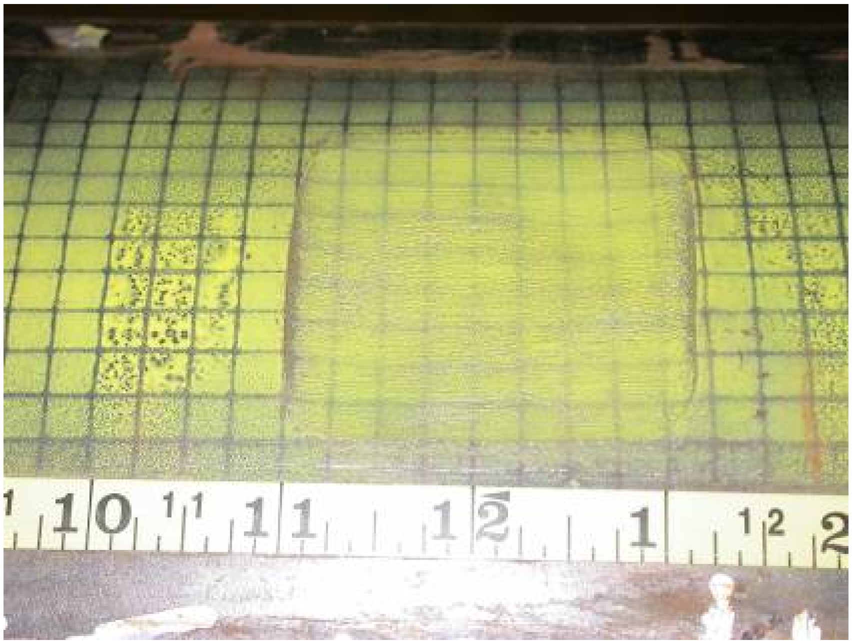


Figure 2-29. Calibration Defect P3-1 (Defect 1)



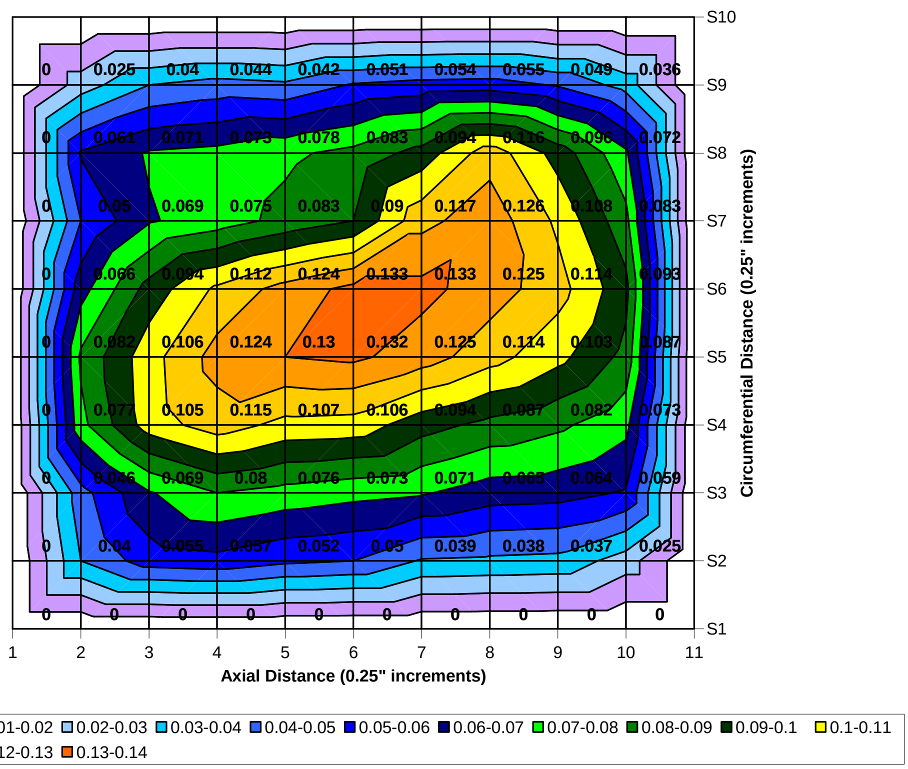


Figure 2-30. Defect P3-3 (Defect 2)

Figure 2-31. Defect P3-4 (Defect 3)

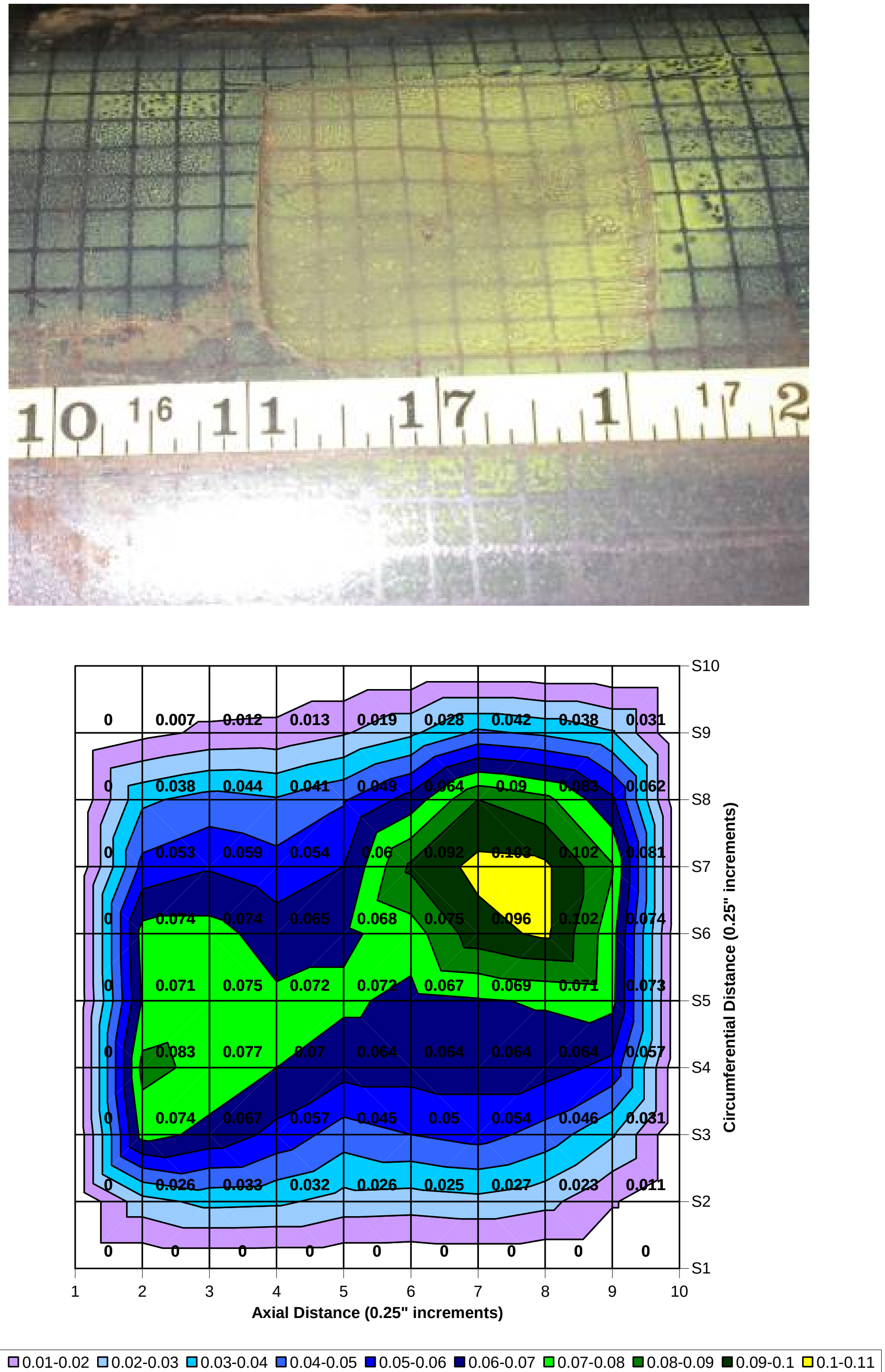
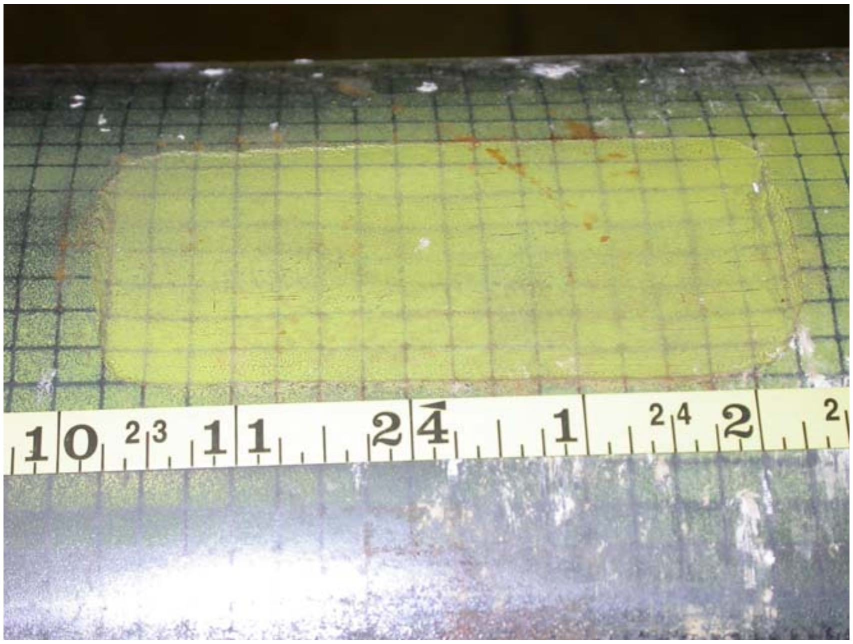


Figure 2-32. Defect P3-5 (Defect 4)



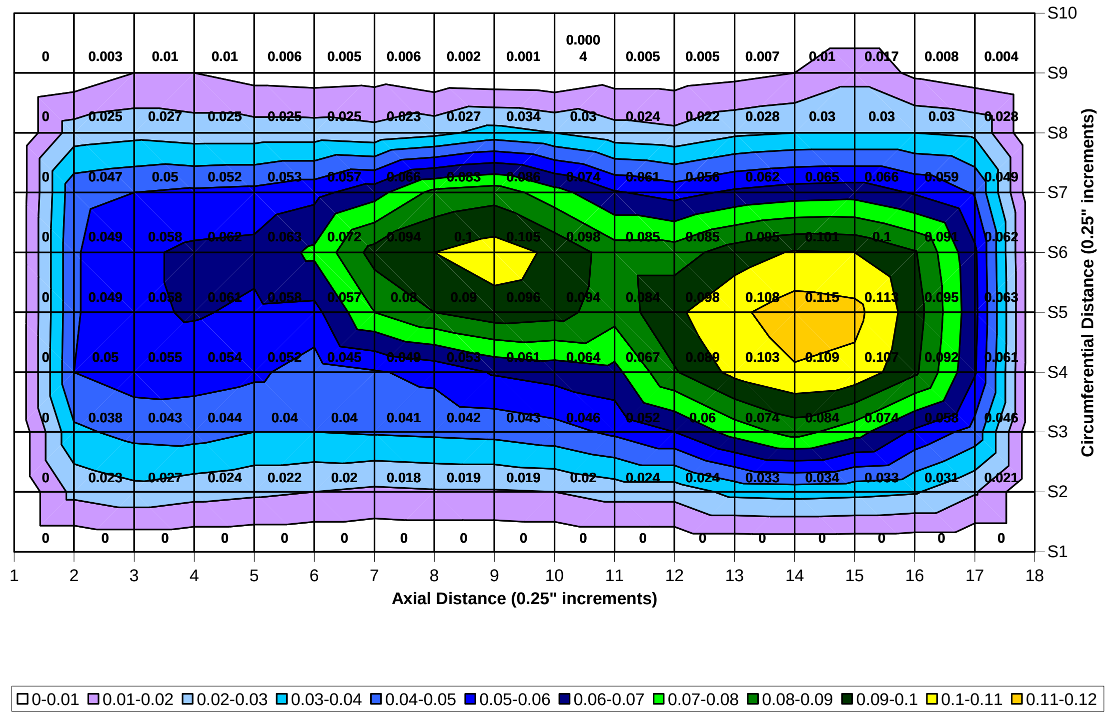
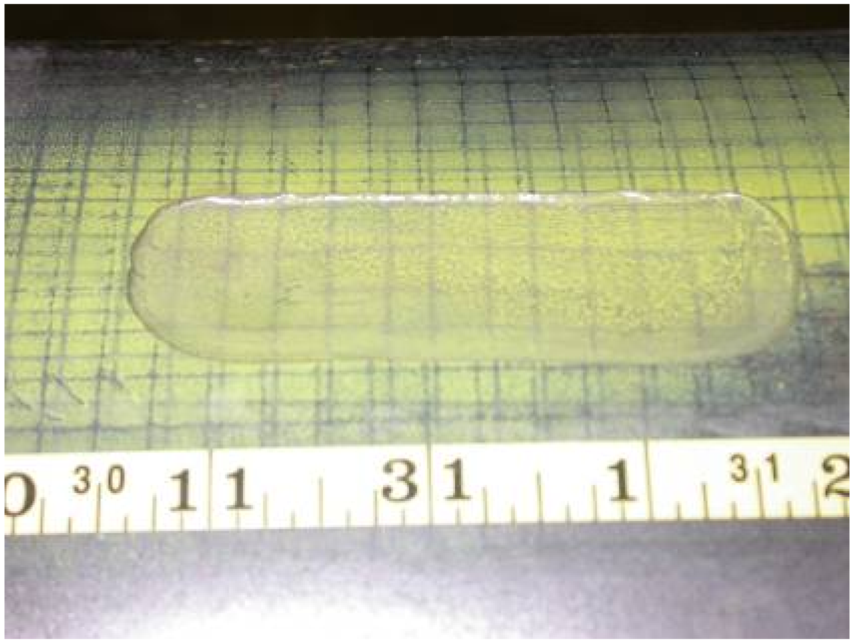


Figure 2-33. Defect P3-7 (Defect 5)

Figure 2-34. Defect P3-9 (Defect 6)



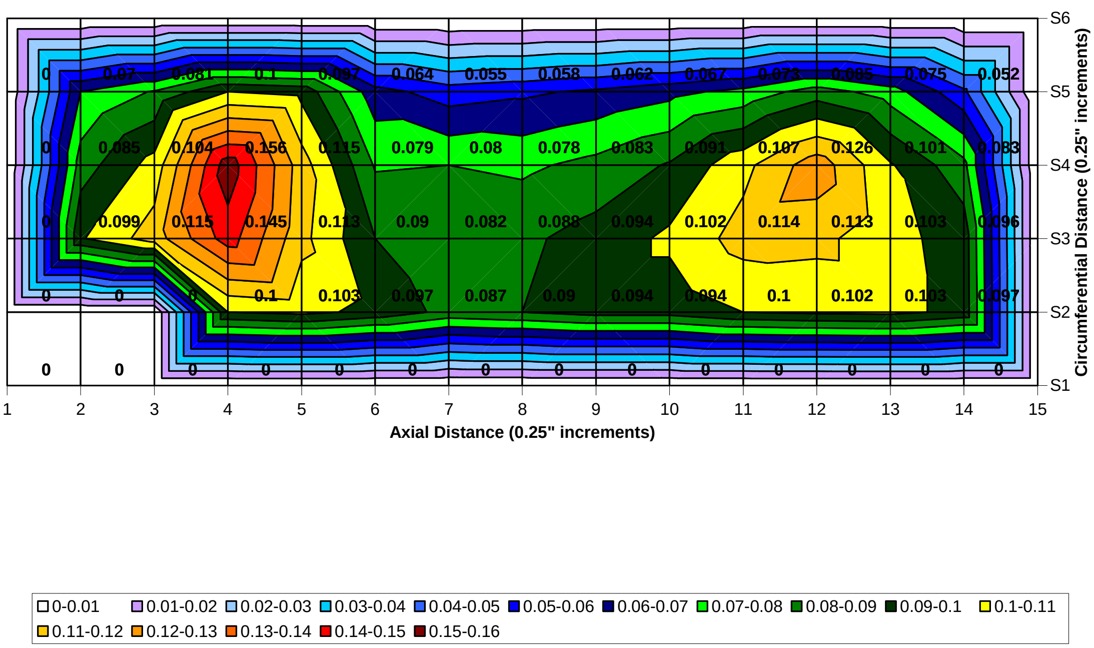
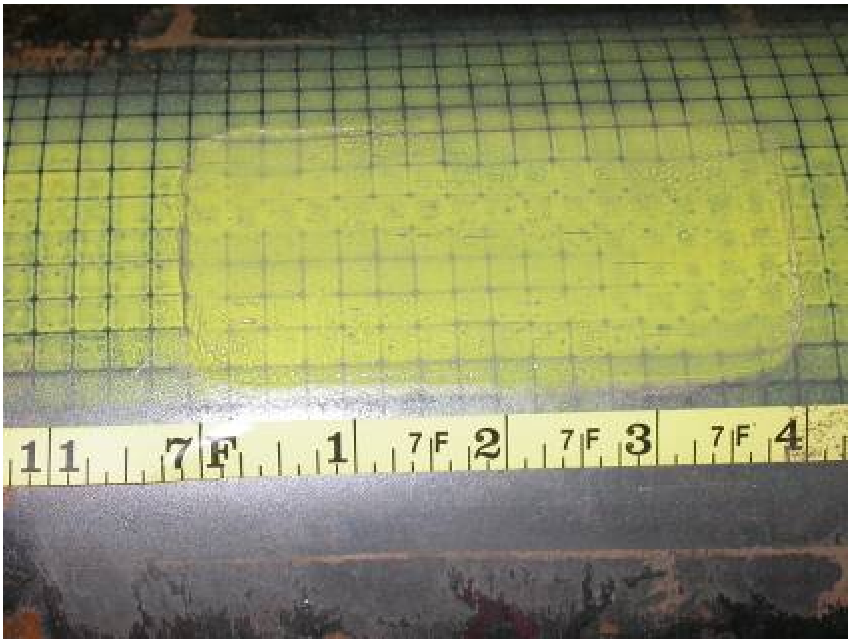


Figure 2-35. Defect P3-10 (Defect 7)



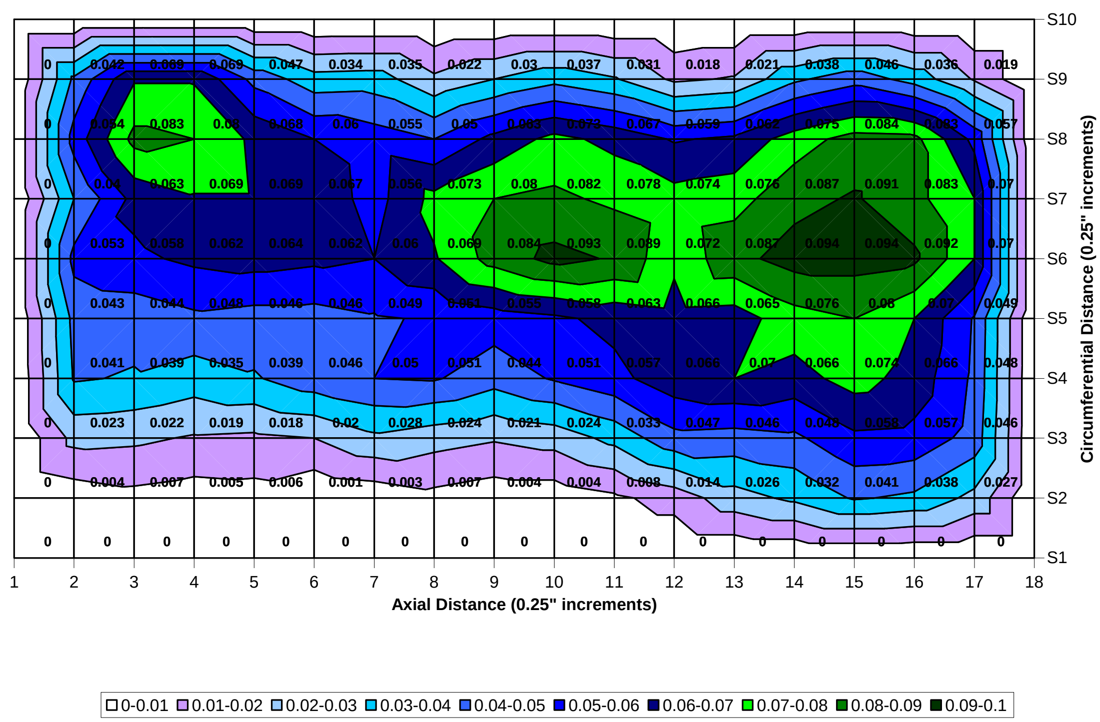
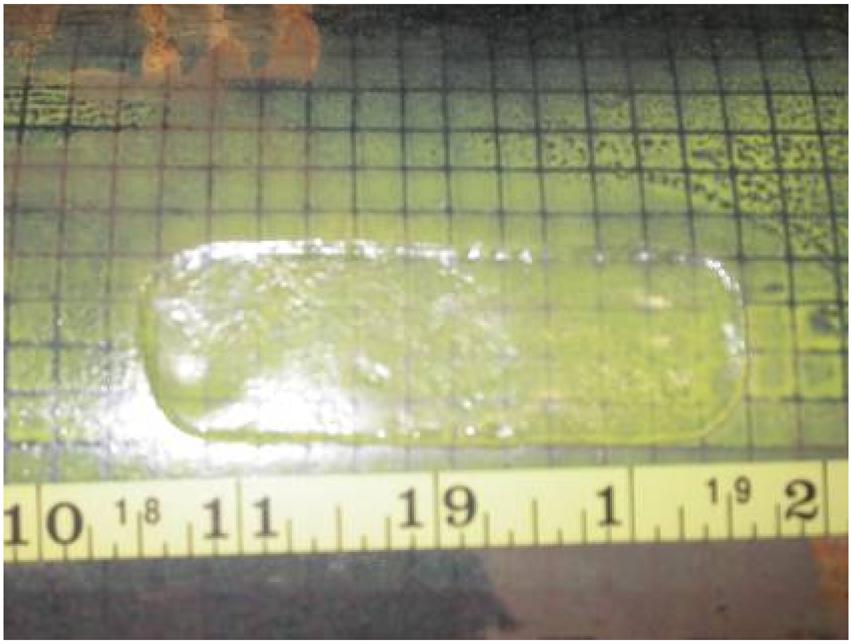


Figure 2-36. Defect P3-12 (Defect 8)

Figure 2-37. Defect P3-14 (Defect 9)



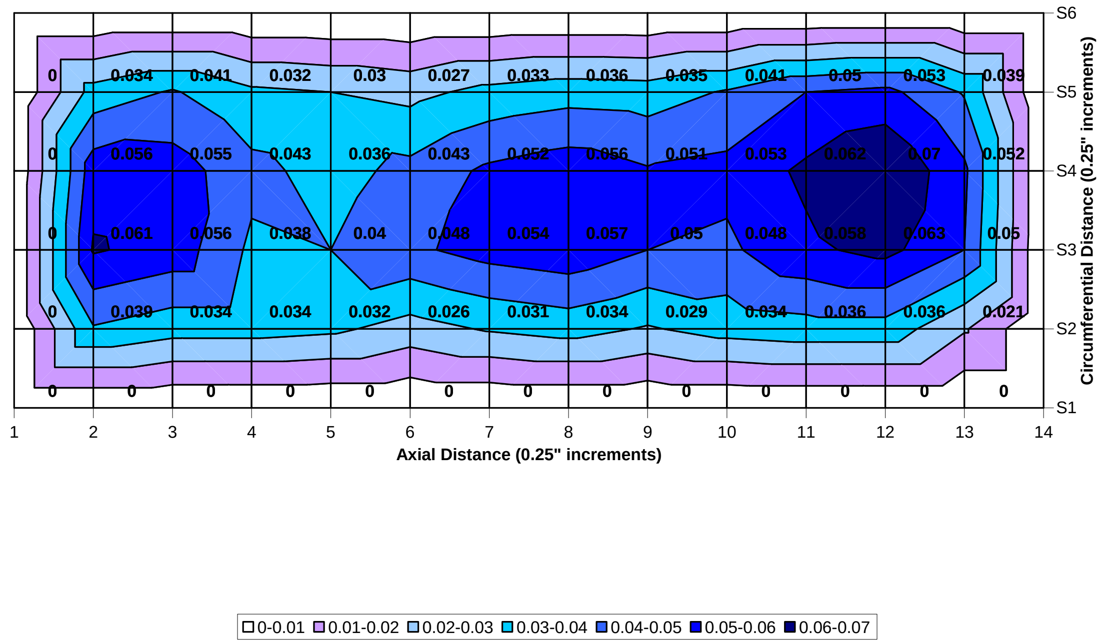
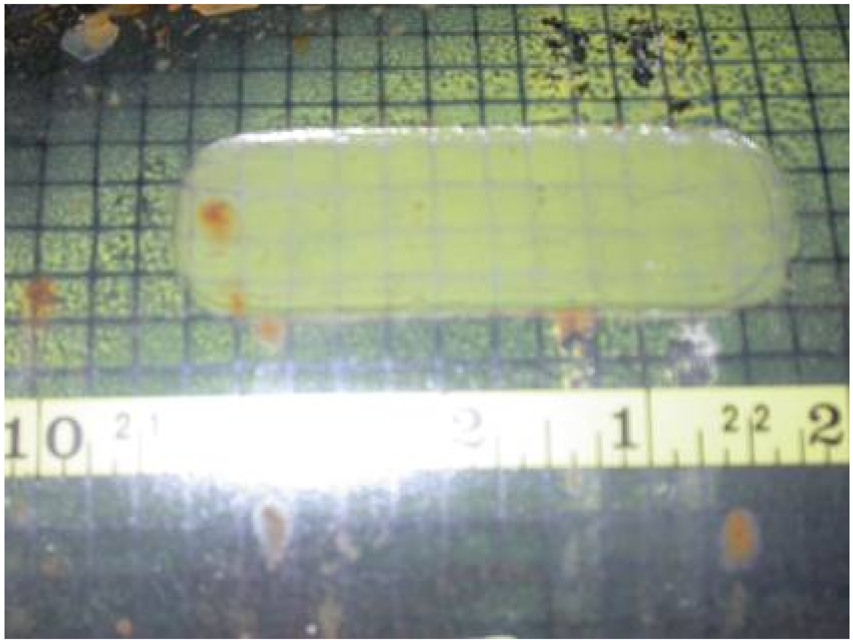


Figure 2-38. Defect P3-17 (Defect 10)



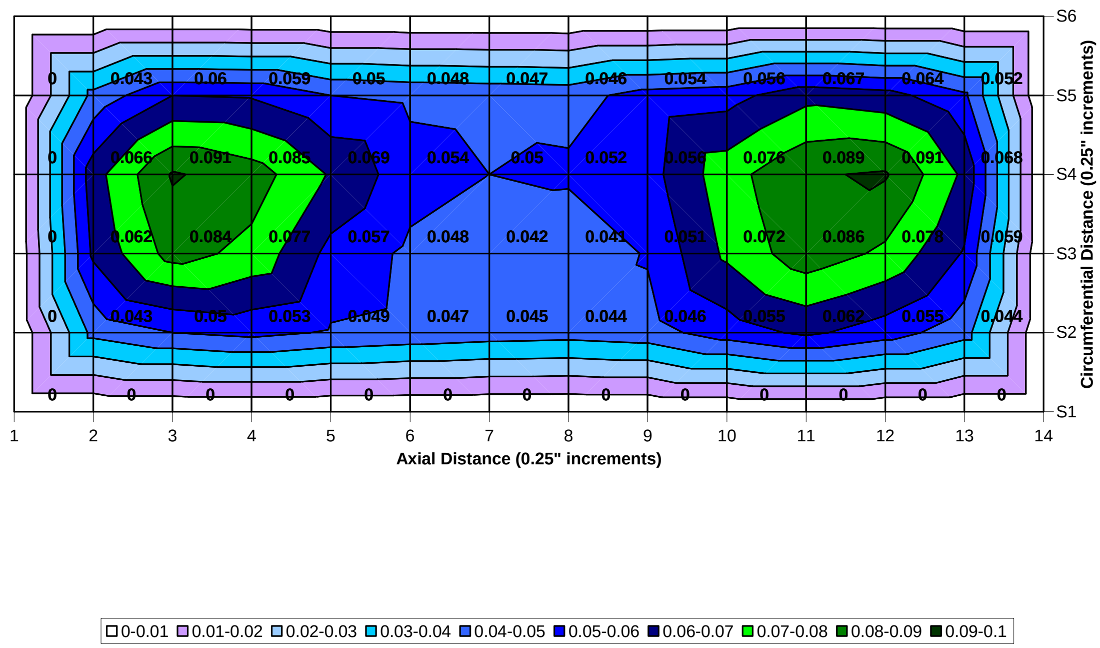
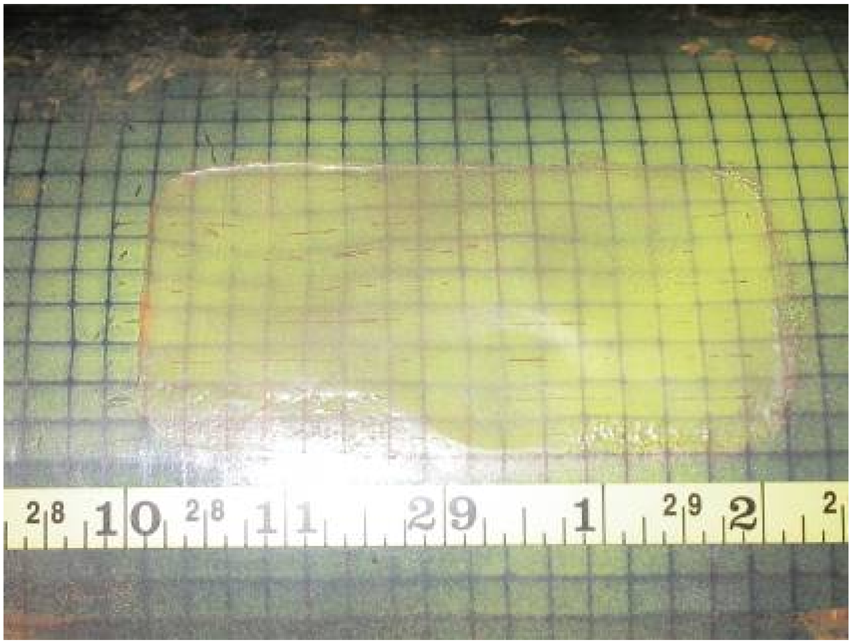


Figure 2-39. Defect P3-18 (Defect 11)

Figure 2-40. Defect P3-19 (Defect 12)



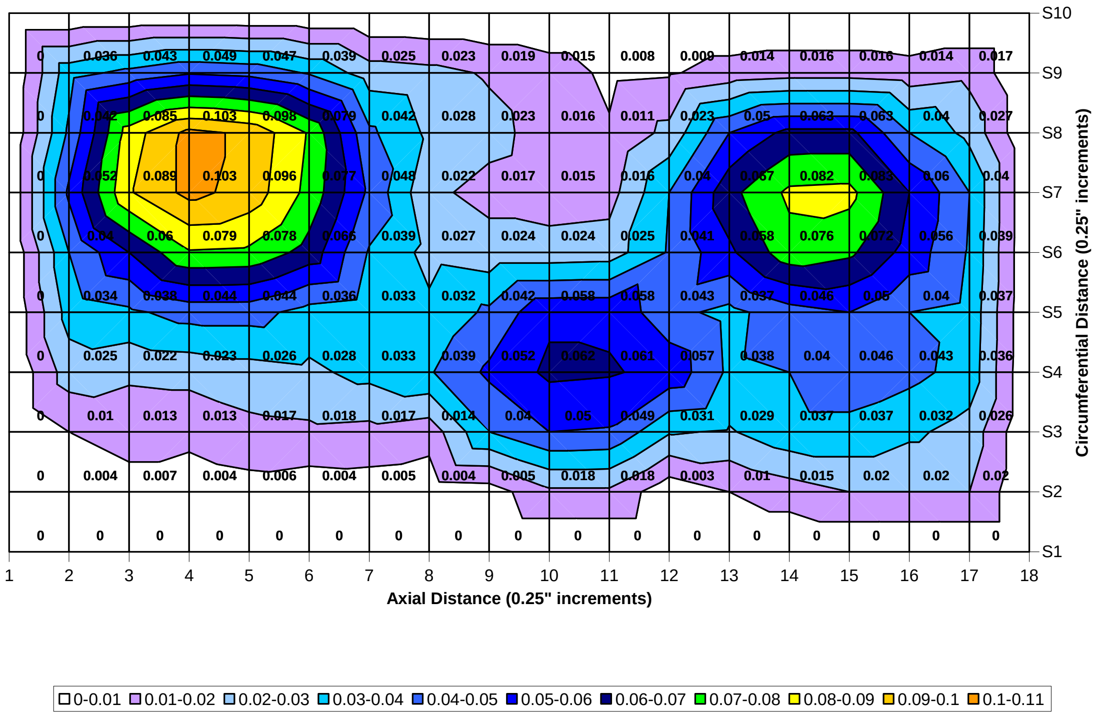
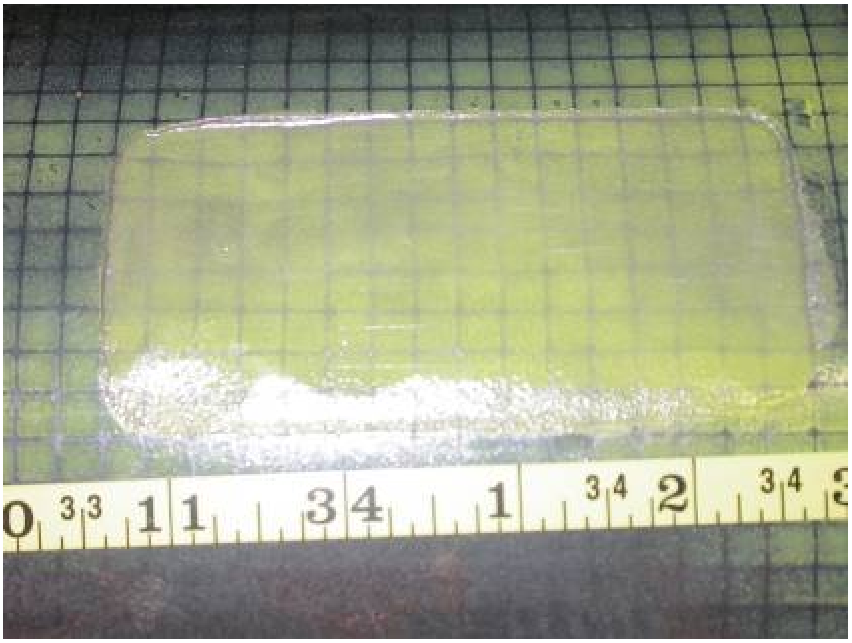


Figure 2-41. Defect P3-21 (Defect 13)



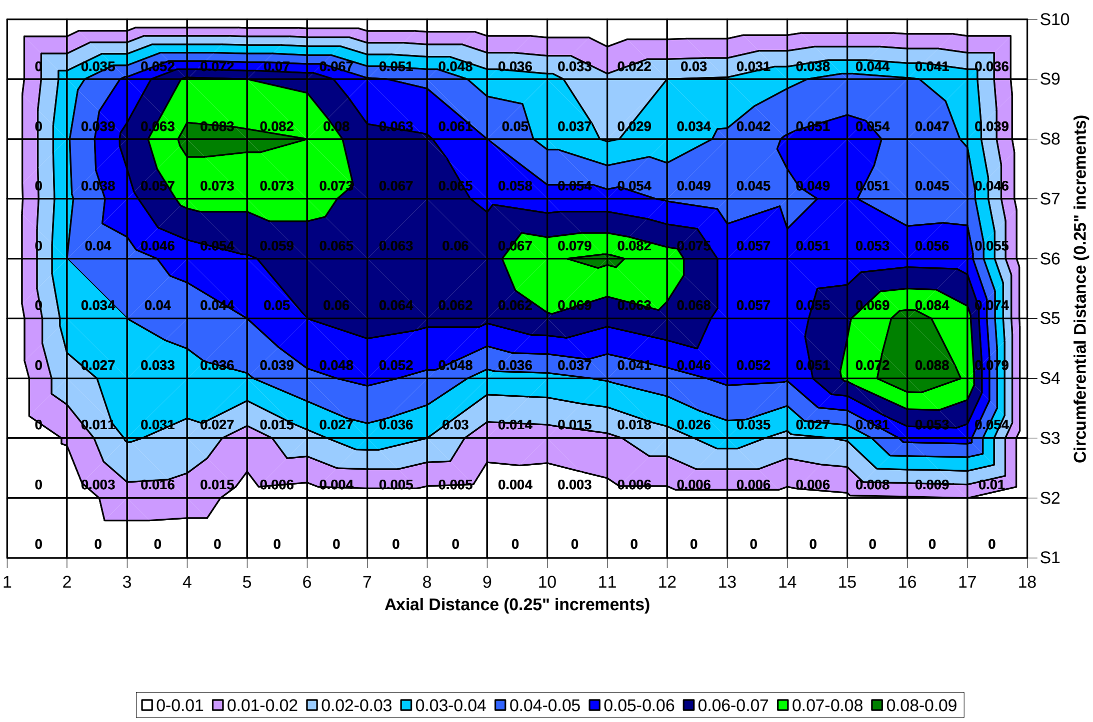


Figure 2-42. Defect P3-23 (Defect 14)

SECTION 3. MECHANICAL DAMAGE INSPECTION TECHNOLOGY ASSESSMENT

INTRODUCTION

The current DOT PHMSA and DOE NETL developments for mechanical damage inspection technologies are not restrictive of pipe diameter. However, prior DOT PHMSA projects involved fabricating defect sets in 24 inch diameter pipe. Therefore when selecting the specimens and data for the mechanical damage defect set the use of the existing 24 inch diameter pipe samples was the most practical. An additional advantage of using the existing 24 inch defect sets is that they have already been inspected using MFL technology under a DOT contract. As such, magnetic flux leakage signals from these defects can be made available upon request.

The technology developer examining mechanical damage anomalies has requested only smooth dents without gouges on the external surface. One pipe sample exists that meets the smooth dent requirement; however another defect set with dents fabricated with a track hoe are also included in the demonstration to assess the future potential of this technology. These defects have minimal gouging and therefore are the most appropriate for this demonstration.

The following report sections discuss the demonstration plan for the mechanical damage inspection tools and provides an "answer key" (Table 3-1) for the data sheets given to the developer during the demonstration. Additional information and photographs are provided in Figures 3-1 through 3-40 describing how the dents were manufactured, the dent depths, dent lengths, and locations for all of the mechanical damage defects.

24-INCH MECHANICAL DAMAGE DEMONSTRATION PLAN

The test plan for the 24-inch mechanical damage defect test configuration is as follows:

1. The technologies to be benchmarked include:
   1.1. PNNL: Strain measurement tool
2. The pipe is 24-inch outside diameter
3. A guide rail was installed on the interior of each pipe to minimize rotation
4. The demonstration samples were comprised of two pipes:
   4.1. Pipe 1 specifications are as follows:
      4.1.1. The length is approximately 28 feet; seam welded pipe
      4.1.2. The nominal wall thickness is 0.290 inches
      4.1.3. The pipe contained 17 mechanical damage defects created by direct impact with a 57,000 pound track hoe.

4.1.4. The defects were placed along 1 row with the guide rail located 180° away from the defects (or in a location determined by the sensor developer prior to the demonstration).

4.1.5. The angular coverage area for each sensor technology should have been designed to cover +/- 6 inches on either side of the centerline (~60° angular coverage).

4.1.6. All defects (except the calibration defects) were covered with a heavy material to prevent the sensor developer from viewing the defects. One defect near End A of the pipe sample remained uncovered for system check-out and calibration.

4.2. Pipe 2 specifications are as follows:

4.2.1. The length is 40 feet of seam welded pipe

4.2.2. The nominal wall thickness is 0.280 inches

4.2.3. The pipe contained 10 smooth dents without gouges

4.2.4. The defects were placed along 1 row with the guide rail located 180° away from the defects.

4.2.5. The angular coverage area for each sensor technology should have been designed to cover +/- 6 inches on either side of the centerline (~60° angular coverage).

4.2.6. All defects (except the calibration defects) were covered with a heavy material to prevent the sensor developer from viewing the defects. Two defects near End A of the pipe sample remained uncovered for system check-out and calibration.

24 INCH MECHANICAL DAMAGE DEFECT ASSESSMENT DATA

Table 3-1. 24 inch Mechanical Damage Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies
Detection of Mechanical Damage - Page 1

Name:	
Date:	
Company:	
Sensor Design:	

CALIBRATION DATA

	Dent Locations	Total Length of Dent Region	Maximum Depth of Dent Region	Relative Dent Severity	Comments
	inches from end A to center of dents	inches	Depth measured with deformation sensor (in)	0 = No damage 1 = Least Severe 2 = Moderately Severe 3 = Severe 4 = Most Severe	Dent severity is relative to the pipe sample being evaluated. Do NOT interpret dent severity between Pipe Sample 1 and Pipe Sample 2; only evaluate the relative severity between dents in the same pipe sample.
Mechanical Damage Pipe SAMPLE 1 (~28 feet)					
Calibration Dent P06dTH1:	1' 8"	20	-.025"	0	
	1' 11"	20	.075"	1	
	2' 2"	20	.325"	3	
	2' 5"	20	.150"	2	
	2' 8"	20	.200"	3	
	2' 11"	20	0	0	
	3' 2"	20	.325"	3	
	3' 5"	20	0.75"	1	
Mechanical Damage Pipe SAMPLE 2 (40' 1.5")					
Calibration Dent R01:	42.25"	3.5	1.2%	1	
Calibration Dent R02:	73.25"	8.5	0.8%	2	

TEST DATA

Pipe Sample:	**SAMPLE 1**
Defect Set:	24" Diameter Pipe with Mechanical Damage; Length =~28'

Defect Number	Search Region (Distance from End A to Center of Dent)	Dent Severity	Commments
	feet & inches	0 = No damage 1 = Least Severe 2 = Moderately Severe 3 = Severe 4 = Most Severe	
D1	5' 4.5"	2	Deformation data indicates max dent depth of 0.225 inches
D2	5' 8.5"	2	Deformation data indicates max dent depth of 0.24 inches
D3	6' 5.5"	2	
D4	8' 9"	2	Deformation data indicates max dent depth of 0.15 inches
D5	9' 6"	1	Deformation data indicates max dent depth of 0.075 inches
WELD	10' 5.5"		
D6	13' 6"	4	GOUGE NOT PART OF DEMONSTRATION; Deformation data indicates max dent depth of 0.42 inches
D7	19' 2"	2	Deformation data indicates max dent depth of 0.28 inches
D8	20'	1	Deformation data indicates max dent depth of 0.125 inches
D9	20' 6"	1	Deformation data indicates max dent depth of 0.10 inches
D10	22' 3.5"	4	Deformation data indicates max dent depth of 0.48 inches
D11	22' 10"	2	Deformation data indicates max dent depth of 0.20 inches
D12	23' 4.5"	3	Deformation data indicates max dent depth of 0.30 inches
D13	25' 5.5"	4	Deformation data indicates max dent depth of 0.48 inches
D14	25' 10"	4	Deformation data indicates max dent depth of 0.48 inches
D15	26' 1"	3	Deformation data indicates max dent depth of 0.30 inches

Table 3-1 (cont). 24 inch Mechanical Damage Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies Detection of Mechanical Damage - Page 2			
Name:			
Date:			
Company:			
Sensor Design:			
TEST DATA			
Pipe Sample:	SAMPLE 2		
Defect Set:	24" Diameter Pipe with Mechanical Damage; Length = 40' 1.5"		
Defect Number	Search Region (Distance from End A to Center of Dent)	Dent Severity	Comments
	inches	0 = No damage 1 = Least Severe 2 = Moderate Severity 3 = Most Severe	
R03	109.25"	1	R03 = Calibration Dent R01 = R06
R04	144"	3	R04 = R08 = R10
R05	183"	2	R05 = Calibration Dent R02 = R07 = R09
R06	217"	1	R03 = Calibration Dent R01 = R06
R07	253"	2	R05 = Calibration Dent R02 = R07 = R09
R08	289.5"	3	R04 = R08 = R10
R09	325"	2	R05 = Calibration Dent R02 = R07 = R09
R10	360.5"	3	R04 = R08 = R10
R11	397"	0	Blank

24 INCH MECHANICAL DAMAGE PIPE SAMPLE 1 DOCUMENTATION

Pipe sample 1 was created from two sections of 24-inch diameter pipe with a wall thickness of 0.29-inches welded together to produce one longer length of pipe measuring approximately 28 feet in length. Pipe sample 1 was subsequently fitted with end caps containing nipples to allow water to pass into and out of the pipe to facilitate pipe pressurization during defect installation. The specifications for the individual pipe segments are provided in Table 1. For pipe sample 1, many magnetic, mechanical and chemical properties had been measured on a previous project; selected properties are included in Table 1.

Table 3-2. Material and Mechanical Properties of Pipe Sample 1.

	Thin Wall Pipe Sample	
Property:	**PSF 24-06**	**PSF 24-28**
Diameter, in.	24	24
Wall Thickness, in.	0.292	0.293
Yield Stress, ksi	66	55
Ultimate Stress, ksi	84	73
Toughness, ft-lb	22	38
Remnant Magnetism, G	12,100	9,900
Carbon, %	0.11	0.23

Defect Installation

Pipe Sample 1 contained three rows of mechanical damage defects, two rows were created with the dent and gouge machine and a third row was created with a 50-ton track hoe. Only the row of mechanical damage defects created by the track hoe was used for the benchmarking demonstration. However, to avoid possible mechanical and magnetic signal interaction, the other defect rows were spaced circumferentially by 120° increments and the defects were staggered axially by approximately a pipe diameter.

During installation of each dent and gouge defect, the pressure in the pipe was held near 60 percent of the specified minimum yield stress (SMYS) of the weakest pipe. During installation of the track hoe defects, the pressure in the pipe was held near 15 percent of SMYS (200 psig). Prior experience has shown that even this relatively small amount of internal pressure adds significant stiffness to the pipe and causes defects to reround to nearly the same extent as defects made under fully pressurized conditions.

Installing multiple defects in one pipe section necessitated moving the pipe axially and rotating it in the dent-and-gouge machine. The pressure in the pipe was reduced each time the pipe was moved to reduce the likelihood of damage growth or an accident. Therefore, defects installed early in the sequence were subjected to a number of pressure cycles of roughly 30 percent of the yield stress.

For defects made using the track hoe, a trench was excavated so that the pipe samples would fit securely within. The depth of the trench was slightly less than the pipe diameter so that the crown if the pipe was an inch or so above grade. The track hoe was able to straddle the trench so that the bucket could impact the crown of the pipe, parallel to the pipe direction, to produce the mechanical damage defects. The track hoe was also moved to the side of the trench so that defects could be produced that were transverse to the pipe direction. The location of mechanical damage defects are shown in Figure 3-1.

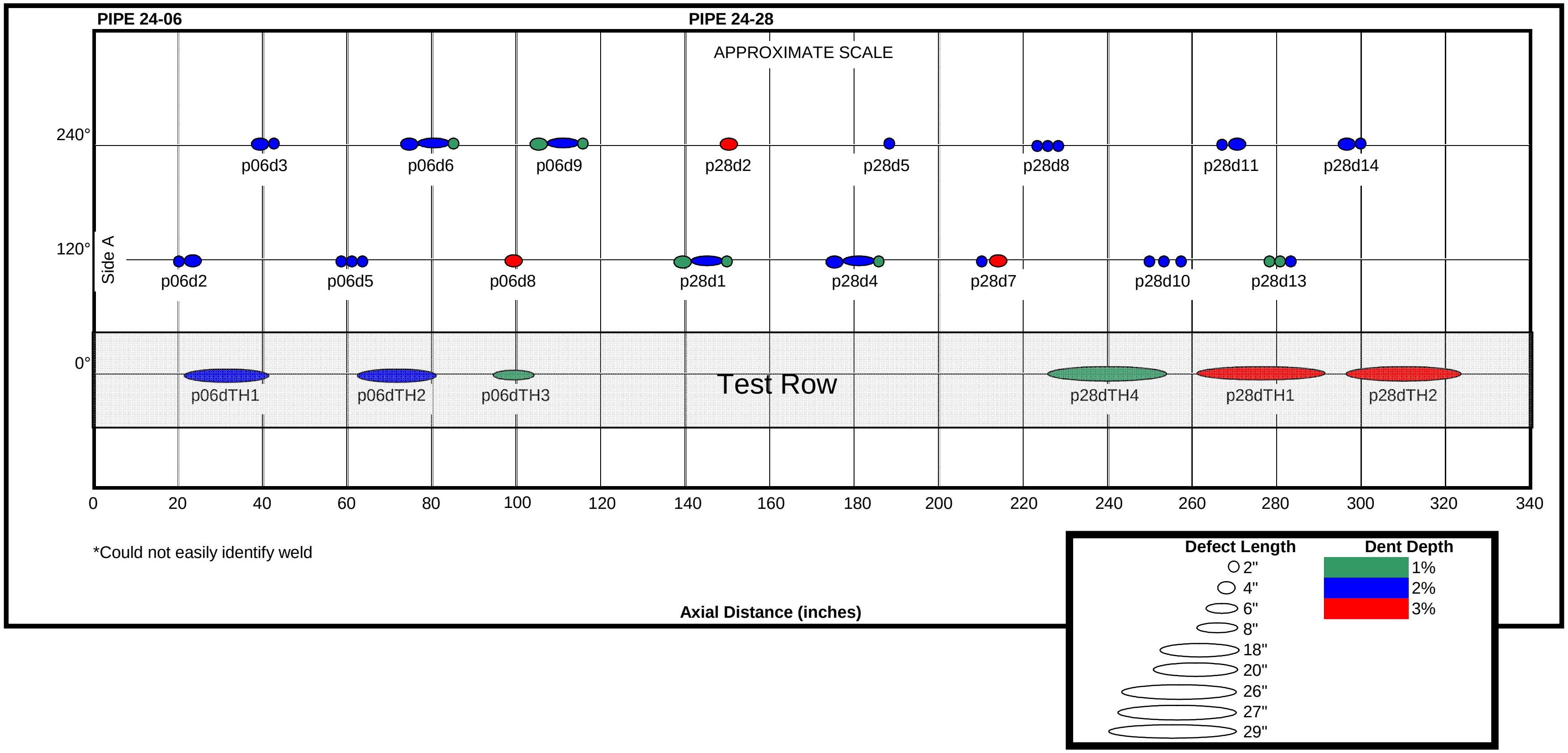


Figure 3-1. 24 inch Mechanical Damage Pipe Sample 1 Defect Map

This page intentionally blank.

Simulating Dents and Gouges with the Track Hoe

The mechanical damage defect row used for the benchmarking demonstration was installed using a Kobelco Mark SK200 track hoe (see Figure 3-2). This particular track hoe is capable of producing a load of nearly 47,000 pounds. To the extent practical, the simulation was set-up to reflect actual conditions along the pipeline right-of-way. A trench slightly less than the pipe diameter was excavated so that the pipe samples would fit securely within. The pipe was placed within the trench and pressurized to approximately 200 psig. The track hoe was able to straddle the trench so that the bucket could impact the crown of the pipe, parallel to the pipe direction, to produce the mechanical damage defects. The track hoe was also moved to the side of the trench so that additional defects could be produced that were transverse to the pipe direction.

Figure 3-2. Kobelco Mark SK200 Track Hoe.

The track hoe bucket consisted of six teeth measuring approximately 6 inches in width and 1 inch in depth. Close-up photos of the track-hoe bucket and teeth are shown in Figure 3-3.

Figure 3-3. Close-Up of Bucket and Teeth from the Kobelco Mark SK200 Track Hoe.

Additionally, the track hoe bucket was positioned in two different configurations during defect installation. The first configuration allowed the teeth of the bucket to directly impact the crown of the pipe. The second configuration allowed two teeth to straddle the crown of the pipe when impact was made. Various track hoe defect parameters for each pipe sample are provided in Table 3-3. For the track hoe defects, dent depth range refers to the maximum depth measured after defect installation and possible re-rounding.

Table 3-3. Parameters for pipe sample 1 track hoe mechanical damage defects.

<table>
<tr><td colspan="13">Pipe 24-28, Internal Pressure of 200 psig</td></tr>
<tr><td>Defect</td><td>Description</td><td>Tool</td><td>Number of Strikes</td><td>Strike Direction</td><td>Bucket Tooth Position</td><td colspan="6">Dent Depth Range (inches)</td><td>Dent Length, in.</td></tr>
<tr><td>D13, D14, D15 (p28dTH1)</td><td>Parallel, direct</td><td>TH</td><td>3</td><td>parallel</td><td>direct</td><td colspan="2">0.62</td><td colspan="2">0.59</td><td colspan="2">0.58</td><td>29</td></tr>
<tr><td>D10, D11, D12, (p28dTH2)</td><td>Parallel, straddle</td><td>TH</td><td>3</td><td>parallel</td><td>straddle</td><td>0.51</td><td>0.35</td><td>0.60</td><td>0.29</td><td>0.60</td><td>0.28</td><td>26</td></tr>
<tr><td>D7, D8, D9 (p28dTH4)</td><td>Transverse, direct</td><td>TH</td><td>2</td><td>transverse</td><td>direct</td><td colspan="2">0.32</td><td colspan="2">0.25</td><td colspan="2">0.10</td><td>27</td></tr>
<tr><td colspan="13">Pipe 24-06, Internal Pressure of 200 psig</td></tr>
<tr><td>Defect</td><td>Description</td><td>Tool</td><td>Number of Strikes</td><td>Strike Direction</td><td>Bucket Tooth Position</td><td colspan="6">Dent Depth Range (inches)</td><td>Dent Length, in.</td></tr>
<tr><td>Calibration Defect (p06dTH1)</td><td>Parallel, direct</td><td>TH</td><td>3</td><td>parallel</td><td>direst</td><td colspan="2">0.51</td><td colspan="2">0.52</td><td colspan="2">0.50</td><td>20</td></tr>
<tr><td>D1, D2, D3 (p06dTH2)</td><td>Parallel, straddle</td><td>TH</td><td>3</td><td>parallel</td><td>straddle</td><td>0.30</td><td>0.30</td><td>0.24</td><td>0.41</td><td>0.20</td><td>0.40</td><td>18</td></tr>
<tr><td>D4, D5 (p06dTH3)</td><td>Transverse, direct</td><td>TH</td><td>1</td><td>transverse</td><td>direct</td><td colspan="3">0.20</td><td colspan="3">0.11</td><td>8</td></tr>
</table>

Mechanical Damage Pipe Sample 1 Defect Photos

Figure 3-4. Calibration Defect p06dTH1

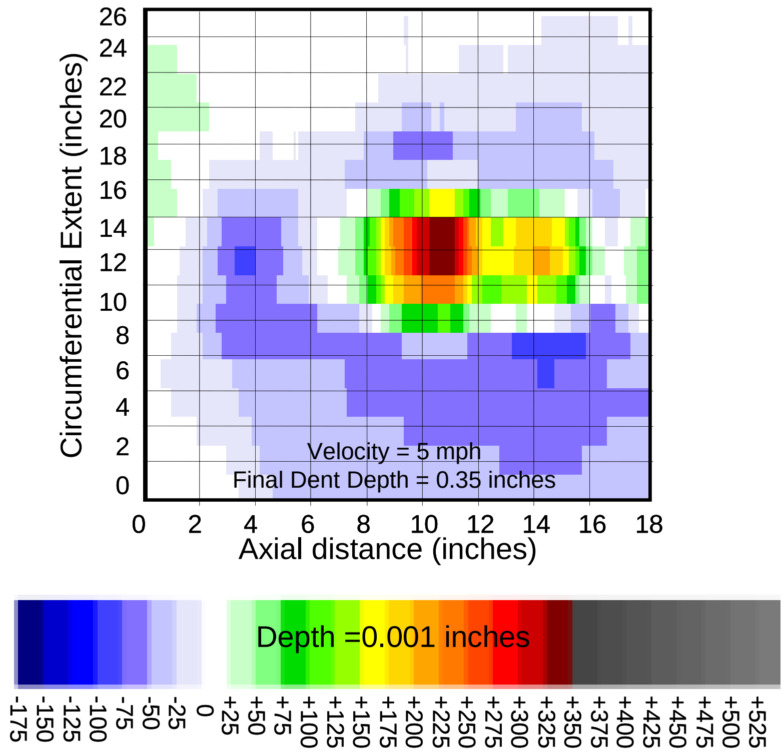


Figure 3-5. Deformation Data for Calibration Defect p06dTH1

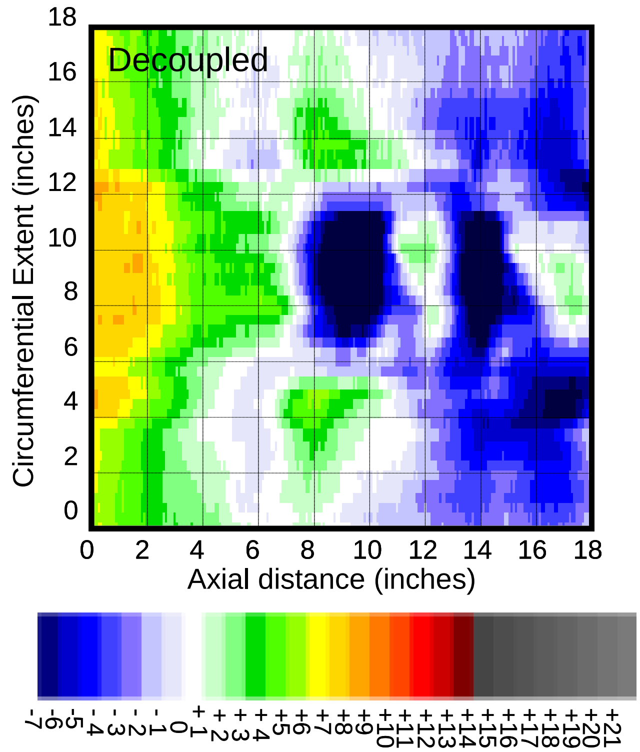


Figure 3-6. MFL Signal for Calibration Defect p06dTH1

Figure 3-7. Defects D1, D2, and D3 (p06dTH2)

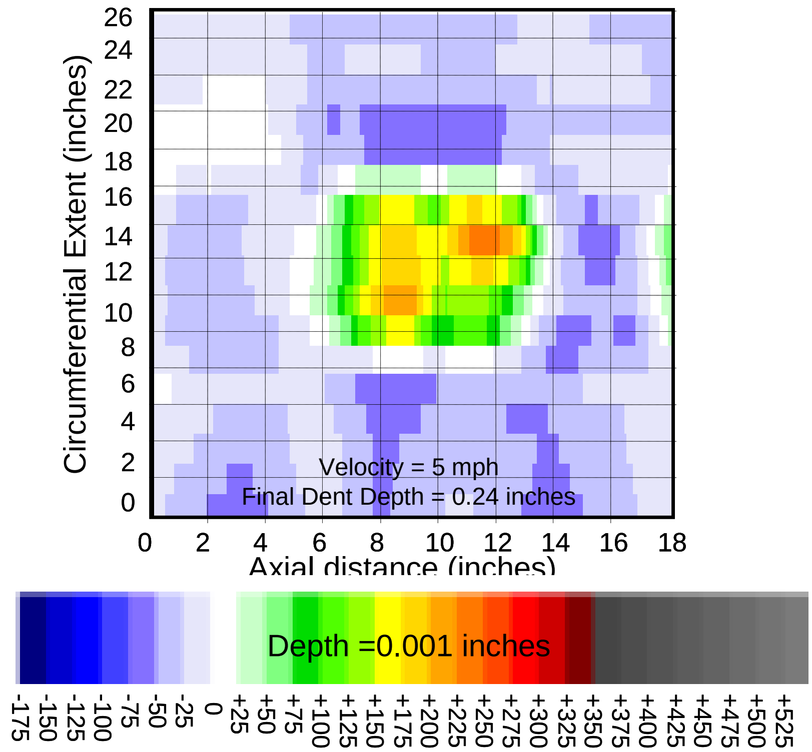


Figure 3-8. Deformation Data for Defects D1, D2, and D3 (p06dTH2)

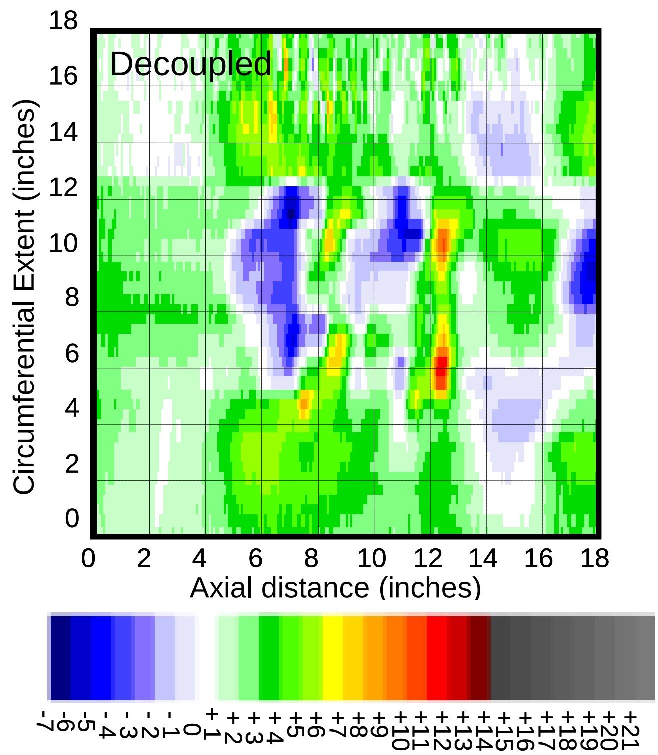


Figure 3-9. MFL Signal Data for Defects D1, D2, and D3 (p06dTH2)

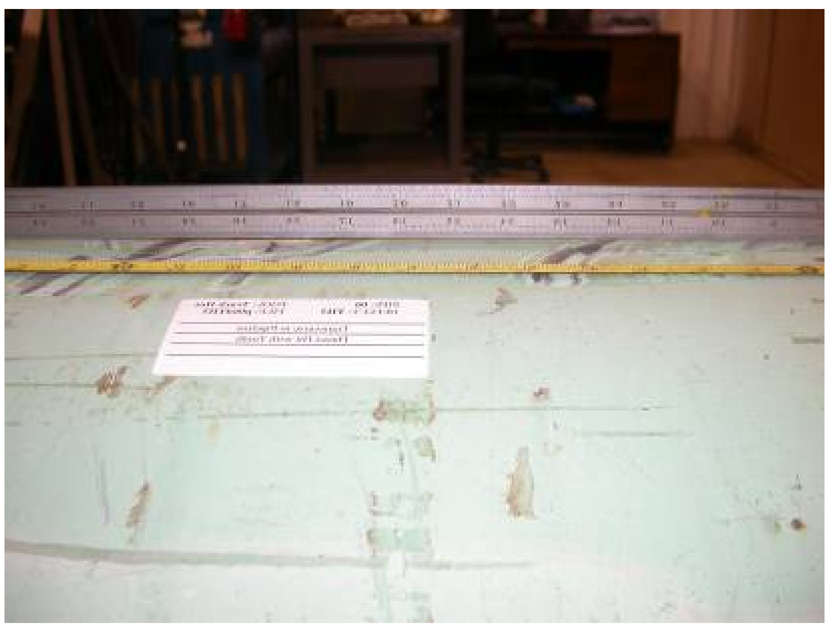


Figure 3-10. Defects D4 and D5 (p06dTH3)

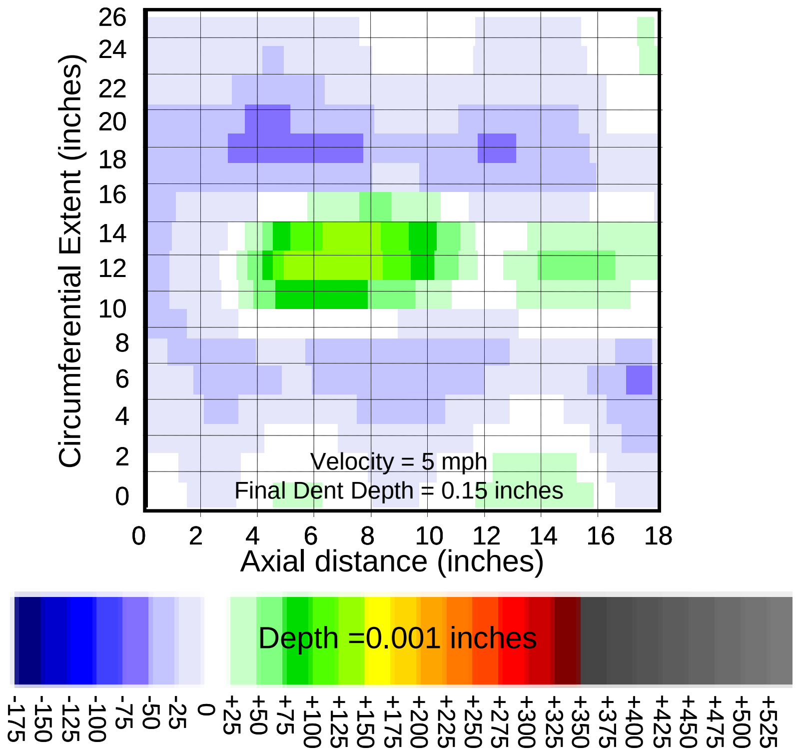


Figure 3-11. Deformation Data for Defects D4 and D5 (p06dTH3)

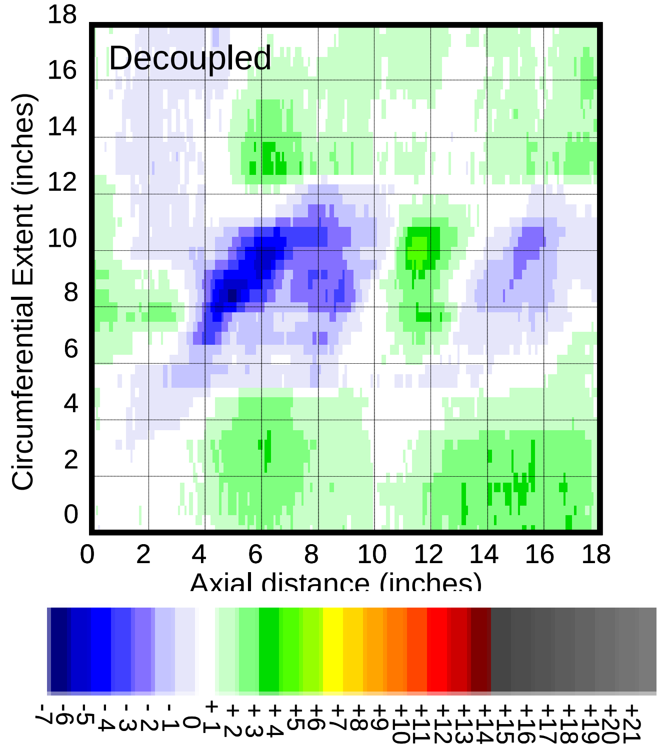


Figure 3-12. MFL Signal Data for Defects D4 and D5 (p06dTH3)

Figure 3-13. Defect D6 (Dent with Gouge; Not Part of Benchmarking)

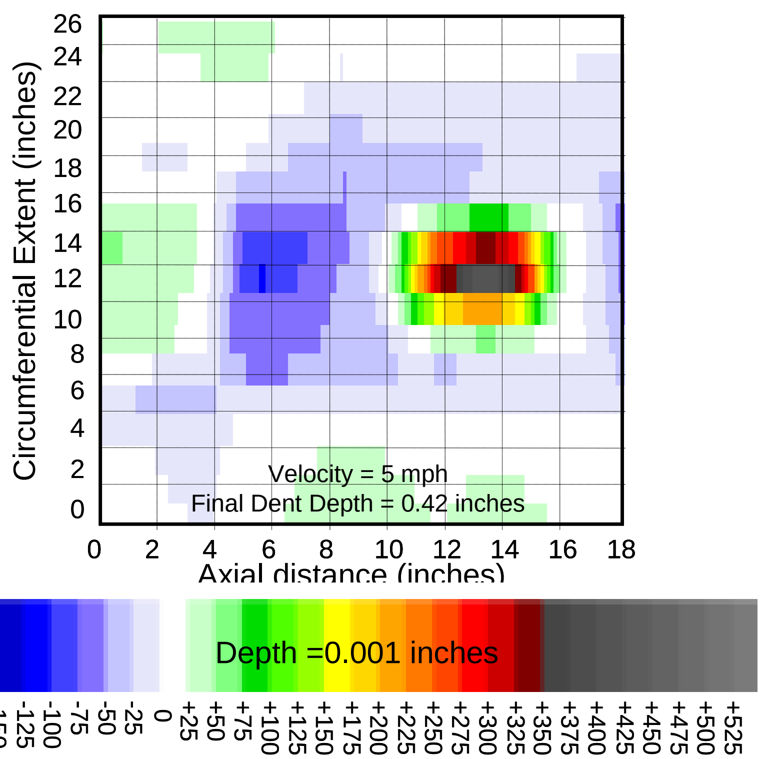


Figure 3-14. Deformation Data for Defect D6 (Dent with Gouge; Not Part of Benchmarking)

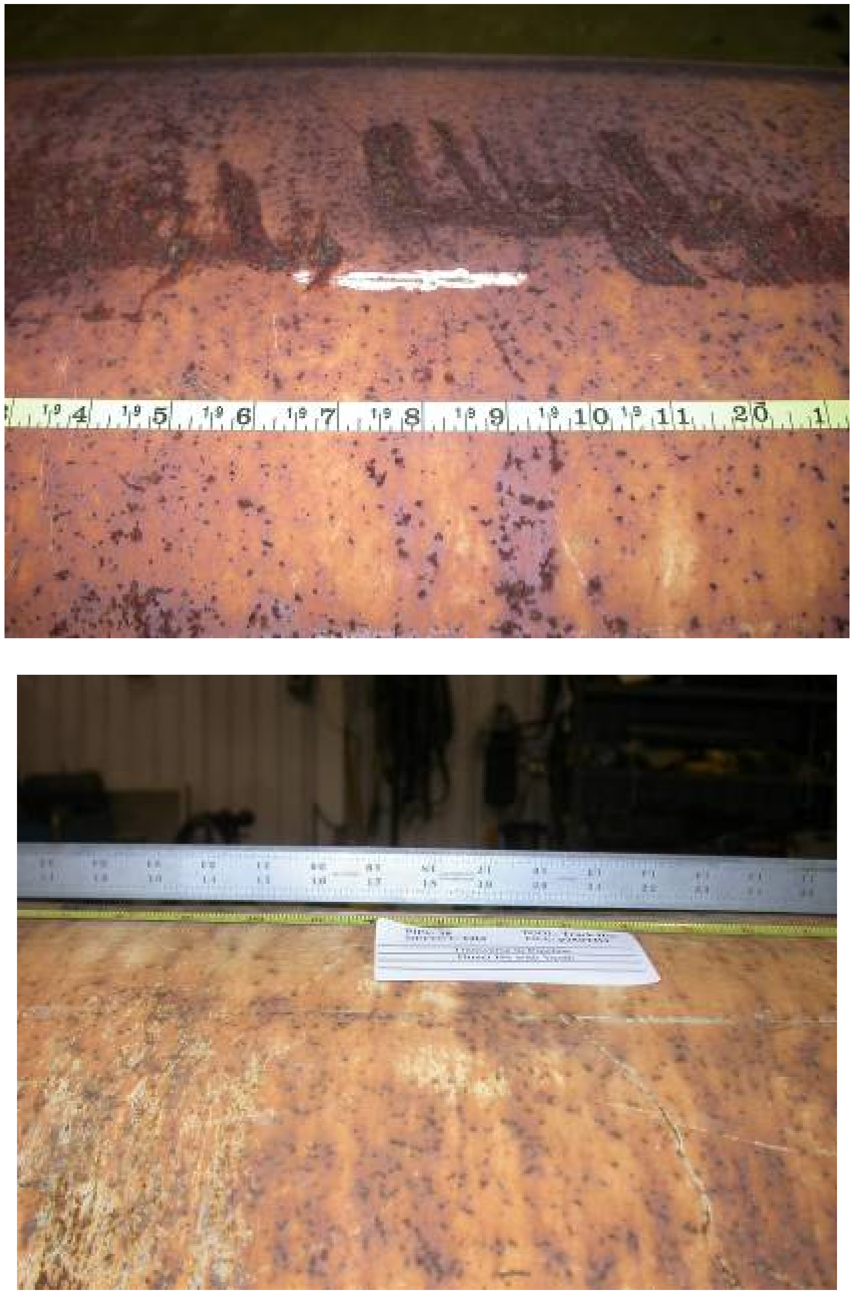


Figure 3-15. Defects D7, D8, D9 (p28dTH4)

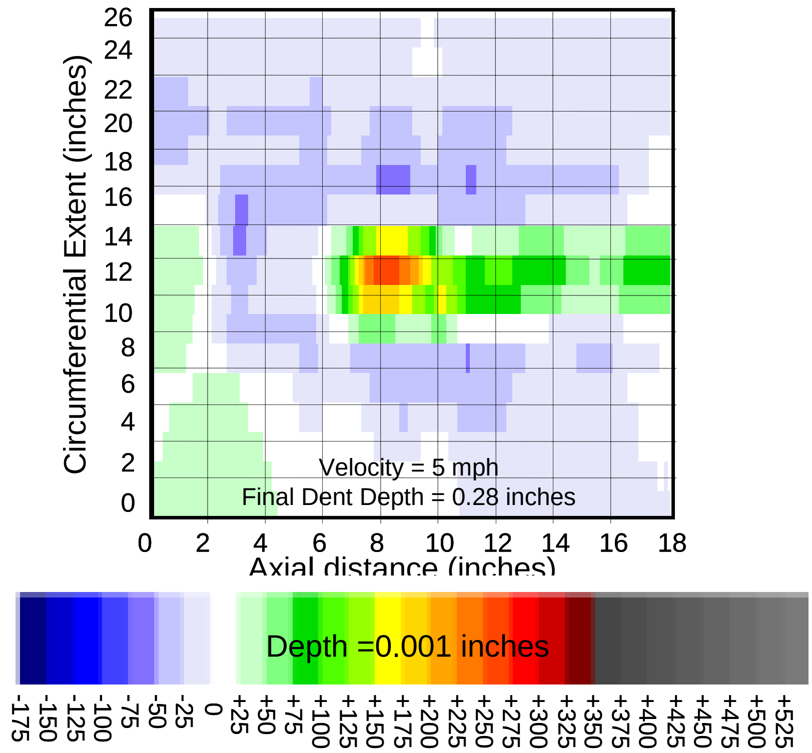


Figure 3-16. Deformation Data for Defects D7, D8, D9 (p28dTH4)

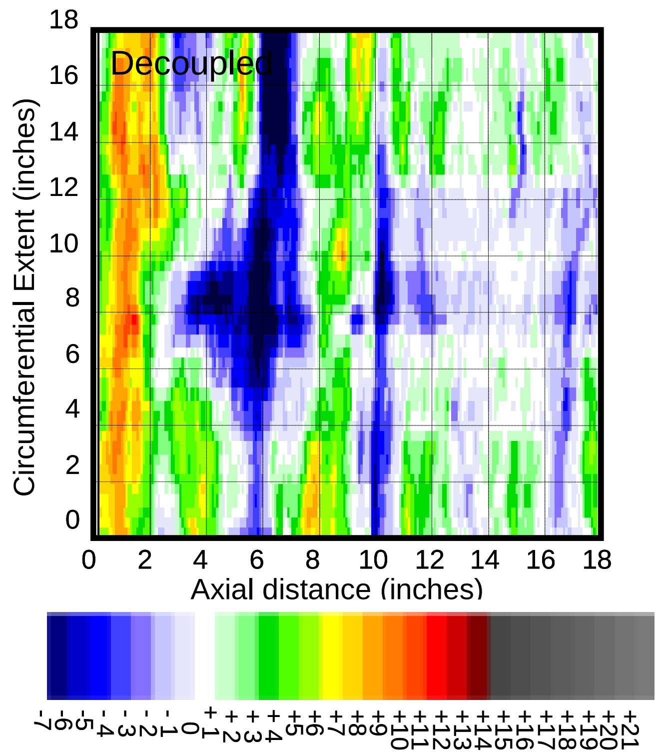


Figure 3-17. MFL Signal Data for Defects D7, D8, D9 (p28dTH4)

Figure 3-18. Defects D10, D11, D12 (p28dTH1)

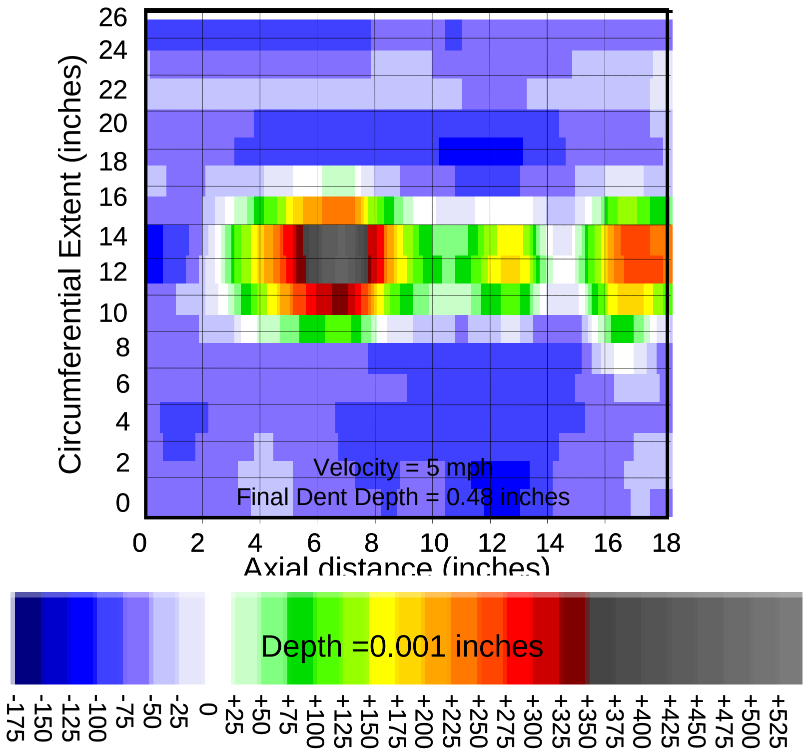


Figure 3-19. Deformation Data for Defects D10, D11, D12 (p28dTH1)

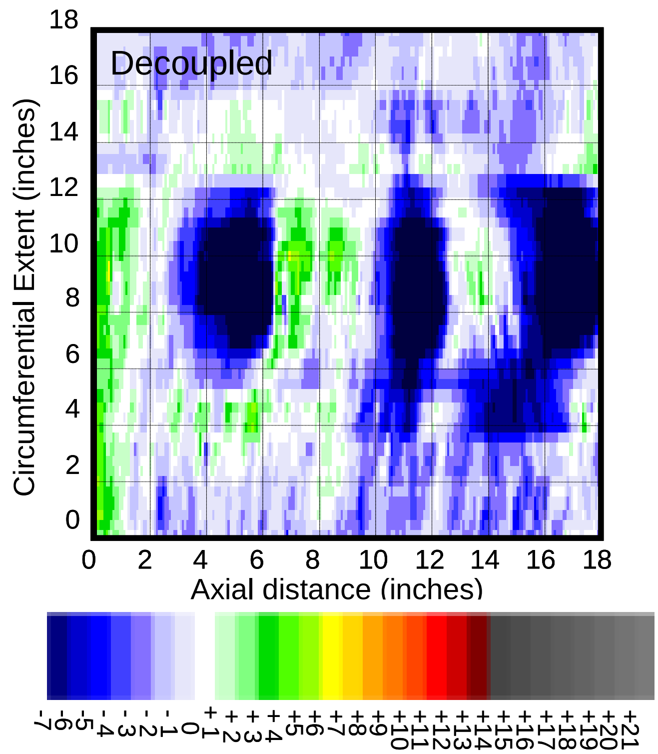


Figure 3-20. MFL Signal Data for Defects D10, D11, D12 (p28dTH1)

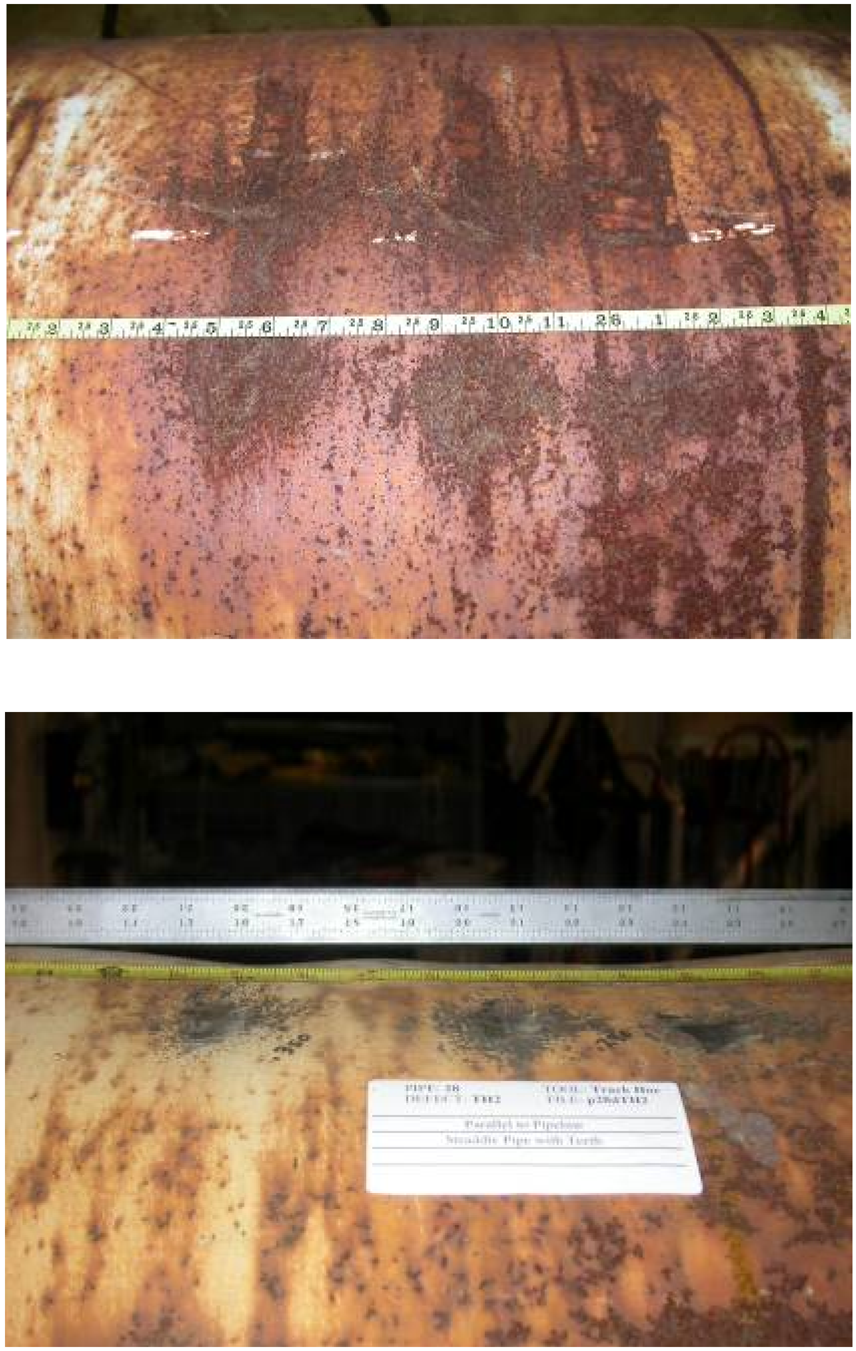


Figure 3-21. Defects D13, D14, D15 (p28dTH2)

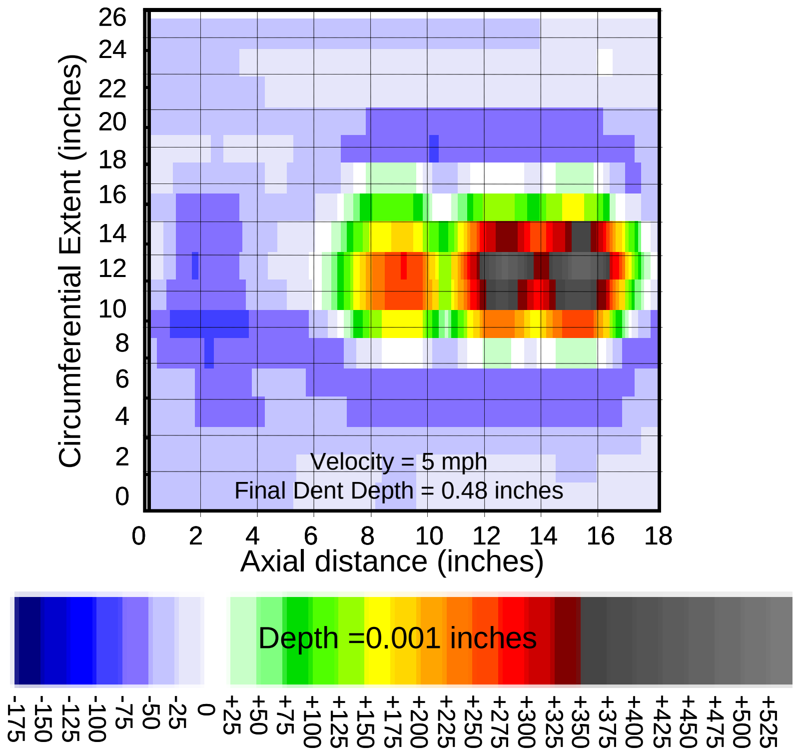


Figure 3-22. Deformation Data for Defects D13, D14, D15 (p28dTH2)

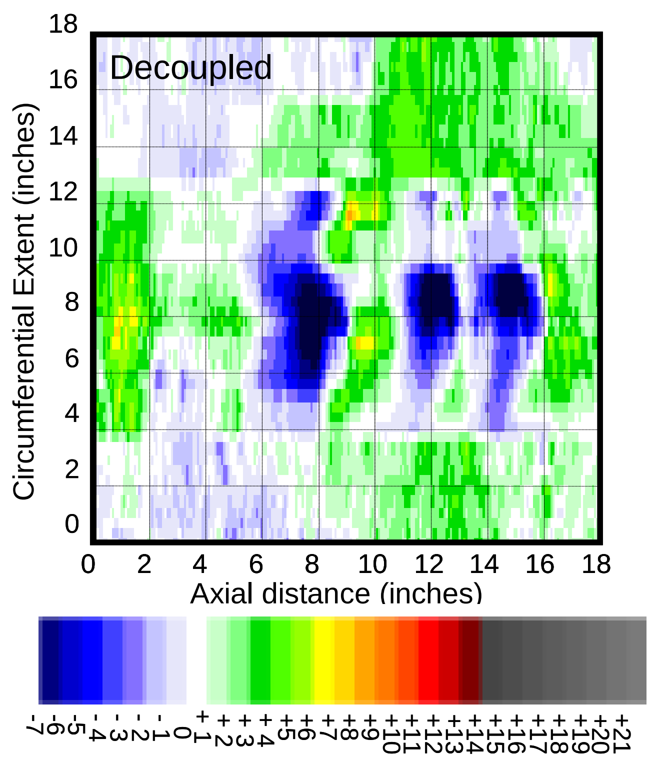


Figure 3-23. MFL Signal Data for Defects D13, D14, D15 (p28dTH2)

24 INCH MECHANICAL DAMAGE PIPE SAMPLE 2 DOCUMENTATION

Plain dents represent the other fundamental part of mechanical damage where the natural cylindrical shape of the pipe is distorted. The dents in mechanical damage Pipe Sample 2 were made without gouging, so that the response of inspection systems to dents could be examined without compensation for the geometry changes, such as removed metal, and stresses caused by the gouge process.

This section describes the methods and equipment used to fabricate the dent-only defects. The description is followed by detailed information of each dent and photographs.

Data Collection Procedure

The procedure for the incremental denting and data collection was a follows:

1. Pressurize the 24-inch diameter, 0.280-inch wall pipe to 600 psi, or about 40 percent of specified minimum yield stress (SMYS) of the this X60 pipe
2. Acquire baseline MFL data prior to denting, but with denting apparatus positioned (about one percent of maximum dent load was applied to hold reaction frame in place)
3. Apply hydraulic pressure to indent the pipe in increments of 0.5 percent of the pipe diameter (0.120 inches)
4. Acquire axial MFL data with the indenter in place to keep the dent from rebounding
5. Repeat steps 3 and 4 until a maximum dent depth of 2 percent is a attained
6. Allow the dent to rebound 0.5 percent of the pipe diameter, matching the indenting steps
7. Acquire MFL with the indenter in place to keep the dent from further rebounding
8. Repeat steps 6 and 7 until the denting load is zero indicating the dent has finished rebounding.

The equipment for the experiments is described in two subsections that follow. The first subsection describes a denting apparatus with a hydraulic actuator and reaction frame. The second subsection describes the flanged pipe sample with components that enable a MFL inspection pig to be launched, pulled back and forth during the dent forming process, and accessed between inspections.

Denting Apparatus

The apparatus used to dent the pipe in a controlled manner is illustrated in Figure 3-24. The operation of the equipment is simple. A hydraulic cylinder is extended between a pipe sample and a stiff reaction frame. The reaction frame was a previously used I-beam with the web reinforced to minimize deformation during the application of the denting load. A 1-inch thick plate was welded to the beam for support of the hydraulic cylinder. The weakest component of the apparatus is the pipe wall that is in contact with the indenter. As the hydraulic load increases, the pipe deforms.

To determine the amount of deformation, two measurements are made by linear cable extension transducers, commonly referred to as “string pots.” The first string pot measures the extension of indenting tool. The second string pot measures the separation between the pipe and the reaction frame, which increases during the formation of the dents since the many components elastically bend and extend. The depth of the dent is established by the difference between the

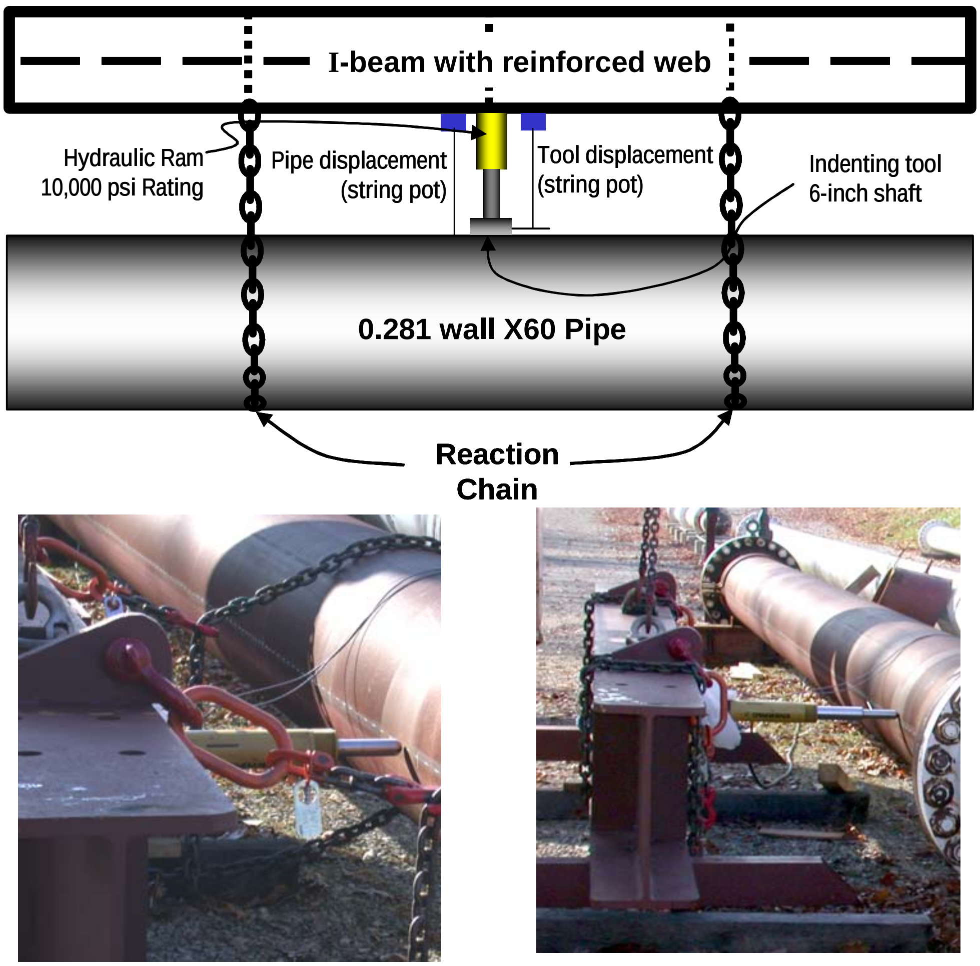


Figure 3-24.   Denting apparatus configuration including reaction frame, hydraulic actuator displacement transducers, pipe sample and load reaction chains.

two measurements. The dents were formed by slowly increasing the pressure until depth was attained. The denting process took between 2 and 3 minutes. Since the pipe was pressured to 600 psi, the pump was located 150 feet from the actuator for safety concerns.

Pressurized Pull Rig

To evaluate leakage signals from dents as they form and rebound under internal pressure, a method was established to acquire flux leakage at multiple pressures repeatedly at multiple magnetization levels. The experimental configuration, shown in Figure 3-25, is essentially a pressurized version of a pull rig. The components include:

- A new pipe sample configured with flanges on either end. This was a 0.281-inch wall thickness, 24-inch diameter, 60 ksi yield pipe.
- A pig launching barrel for insertion of the circumferential magnetizer and data recorder. This was a 0.5-inch wall thickness, 24-inch diameter, 60 ksi yield pipe from existing pipe inventory.
- A hinged pressure door for insertion and access to the magnetizer and data recording equipment.
- Two rods for pulling the magnetizer and data recording equipment in either direction.
- Rod seals to hold pressure as the equipment is pulled. These seals are commonly used in oil well pumping operations.
- A pressure relief valve to prevent over pressurizing. This was required to adequately address safety concerns.

After each increment of dent depth, the MFL inspection pig was pulled from one end of the pipe sample and back to the return position. During the pulling of the pig, leakage in the rod seals would cause a drop in internal pressure in the pipe. Lubricating the rod with light oil reduced wear on the seal, minimizing pressure losses to less than 5 psi or 1 percent on each pull.

Three indenters were used to dent the pipe. Each indenter was made from a non-ferromagnetic 300 series stainless steel. Each shaft was 6 inches long to keep the ferromagnetic hydraulic actuator sufficiently away from the pipe to minimize interference with the flux leakage inspection equipment. Figure 3-26 shows a spherical indenter made from 1.5-inch diameter rod, photographed during the denting process. Figure 3-27 shows the two longer indenters. The radius of the rounded indenter matches the spherical indenter radius of 0.75 inches. The sharp indenter is rounded to a radius of 0.125 inches to provide a more concentrated load, but avoid piercing. The length of the long rounded indenter and the long sharp indenter is 4.5 inches. The shape changes were chosen to facilitate comparison of results. For the spherical and long rounded indenter, the radius is the same but the contact shape is changed from a sphere to a cylinder. For the two longer indenters, the length was the same, but the contact shape is changed from gradual to abrupt.

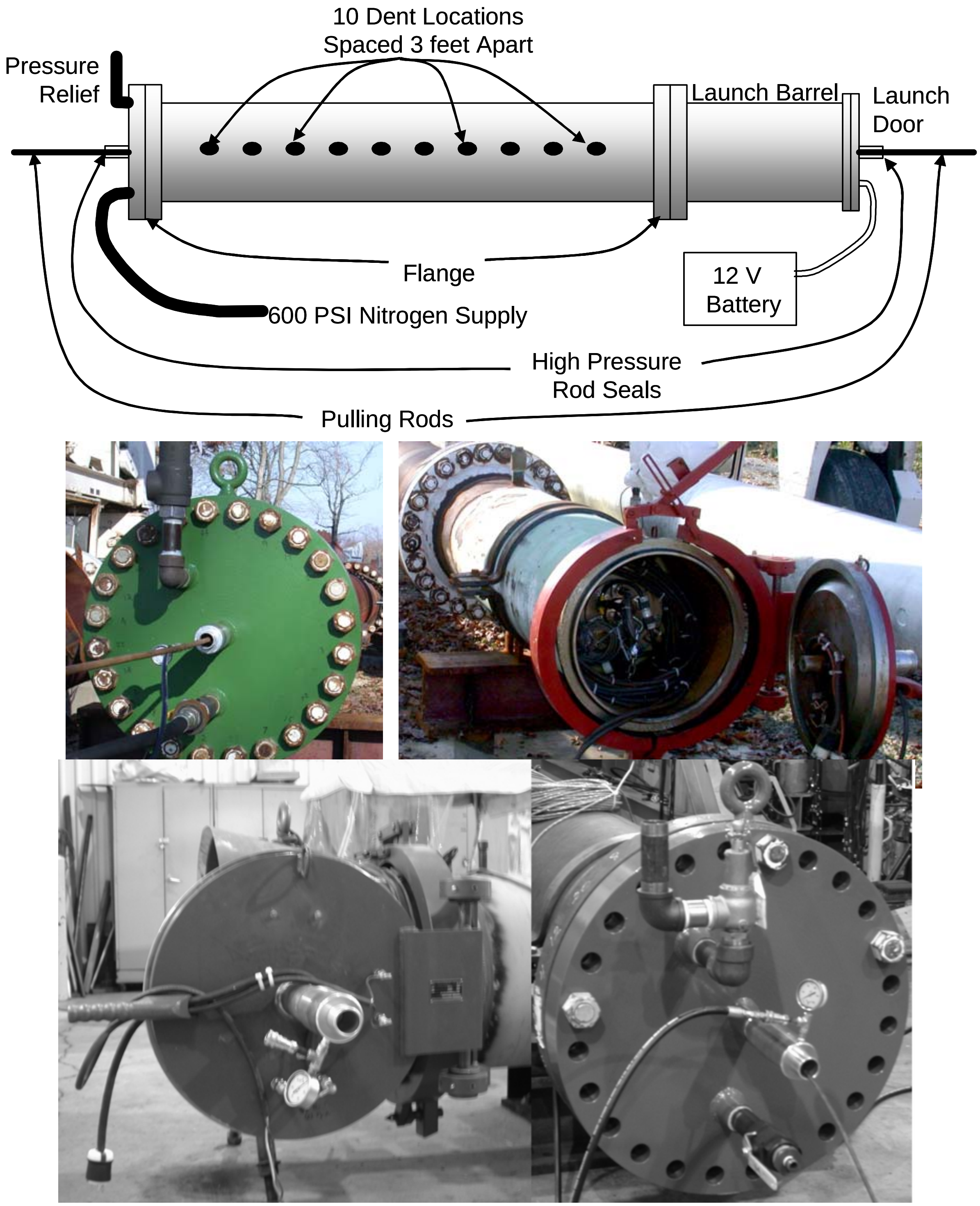


Figure 3-25. Pressurized pull rig for acquisition of MFL data during incremental denting and rebounding.

Figure 3-26. The spherical indenter, made from a non-ferromagnetic material, photographed while holding a 2 percent dent.

Note the connections for the two linear cable extension transducers.

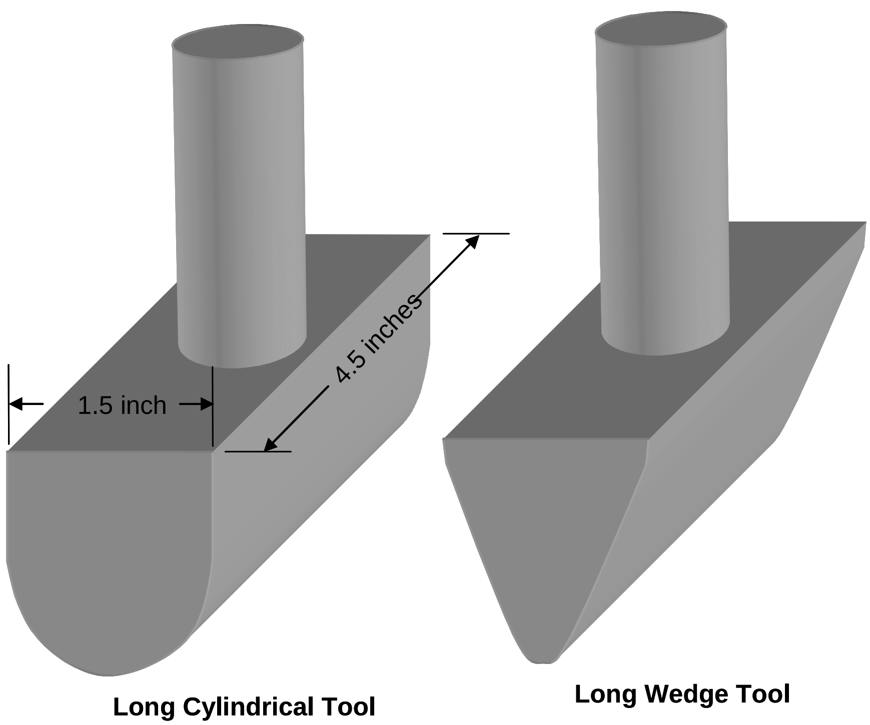


Figure 3-27. Diagram of two other indenters used in incremental denting and data recording experiments.

Plain Dent Defects

A total of 10 defects were made with three indenters at two magnetization levels, as shown in Table 3-4.

Table 3-4. Incremental dent defects

Defect #	Indenter
Calibration Dent R01	Spherical
Calibration Dent R02	Long Cylindrical
R03	Spherical
R04	Long Wedge
R05	Long Cylindrical
R06	Spherical
R07	Long Cylindrical
R08	Long Wedge
R09	Long Cylindrical
R10	Long Wedge

Table 3-5 shows the final dimensions of the dents used for evaluation. Since dents do not have distinct start and end points, measurements can be subjective; the length measurements for Defect R05 are illustrated in Figure 3-28. The total length and width were defined by a 0.025-inch departure from the nominal shape of the pipe. The reround lengths were defined by a more abrupt departure from the nominal shape of the pipe. The surface length is the length that the indenter was in hard contact with the pipe. Because of irregularities of the pipe shape itself, the accuracy of the length and width measurements is ±0.5 inch and the accuracy of the depth measurement is ±0.010 inch. The defect map for pipe sample 2 is presented in Figure 3-29.

Table 3-5. Dimensions of the dents used for the primary comparisons of the high and low magnetization signals.

#	Indenter	Signal	Dent Dimension (inches)					% W.T. Depth
			Total Length	Reround Length	Surface Length	Width	Depth	
R01	Spherical	High	6.5	3.5	1.5	5.0	0.290	1.21%
R02	Long Cylindrical	High	12.0	8.5	4.5	6.0	0.200	0.83%
R03	Spherical	High	6.5	3.5	1.5	5.0	0.290	1.21%
R04	Long Wedge	High	13.5	9.5	4.5	5.5	0.200	0.83%
R05	Long Cylindrical	High	12.0	8.5	4.5	6.0	0.200	0.83%
R06	Spherical	Low	7.5	4.3	1.5	5.0	0.290	1.21%
R07	Long Cylindrical	Low	12.0	8.5	4.5	6.5	0.180	0.75%
R08	Long Wedge	Low	14.5	10.5	4.5	6.5	0.230	0.96%
R09	Long Cylindrical	Low	12.0	8.5	4.5	6.5	0.180	0.75%
R10	Long Wedge	Low	14.5	10.5	4.5	6.5	0.230	0.96%

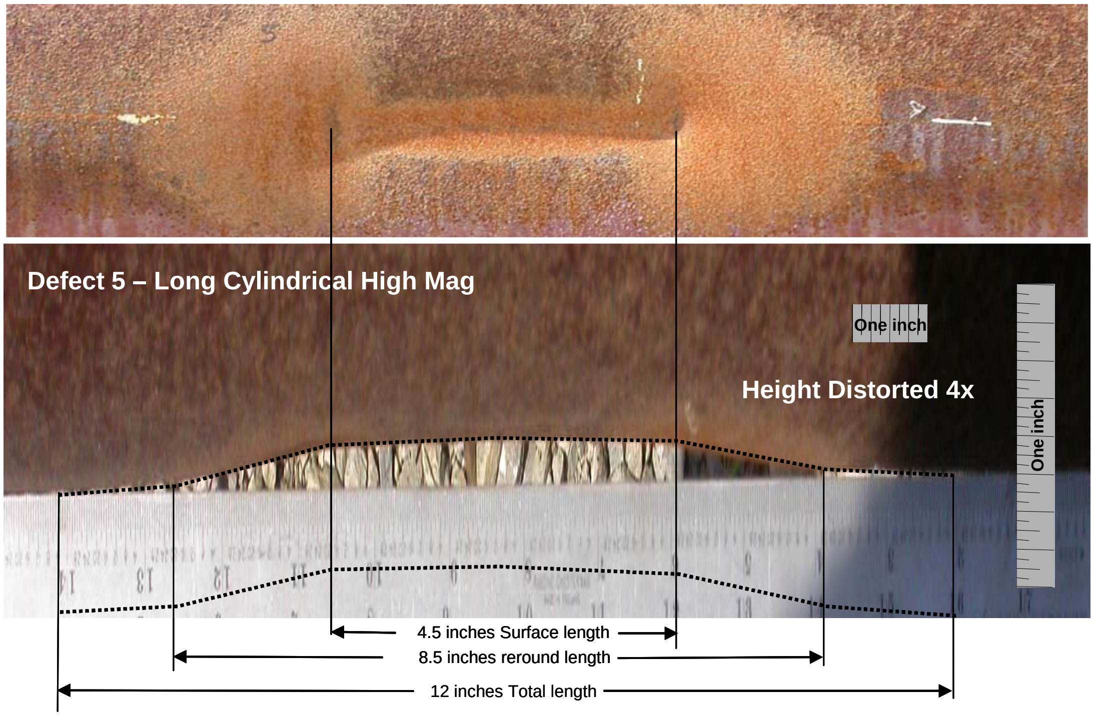
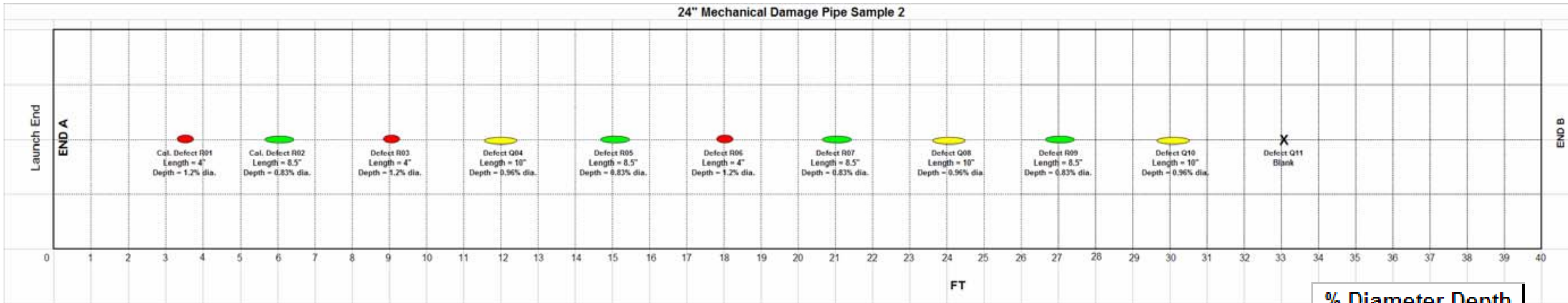


Figure 3-28. Dent length measurements for the long cylindrical indenter.



% Diameter Depth	
(green)	0.83%
(yellow)	0.96%
(red)	1.21%

Pipe Wall Thickness =			**0.28**	
Defect Number	**Approx. Distance from End A (inches) to Center of Region**	**Approx. Distance from End A (feet)**	**Approx. Length of Defect (in)**	**Dent Depth % Dia.**
Cal R01	42	3.5208	4	1.21%
Cal R02	73	6.1042	8.5	0.83%
R03	109	9.1042	4	1.21%
R04	144	12	10	0.96%
R05	183	15.25	8.5	0.83%
R06	217	18.083	4	1.21%
R07	253	21.083	8.5	0.83%
R08	290	24.125	10	0.96%
R09	325	27.083	8.5	0.83%
R10	361	30.042	10	0.96%
R11	397	33.083	-	0.00%

Figure 3-29. 24 inch Mechanical Damage Pipe Sample 2 Defect Map

This page intentionally blank.

Mechanical Damage Pipe Sample 2 Defect Photos

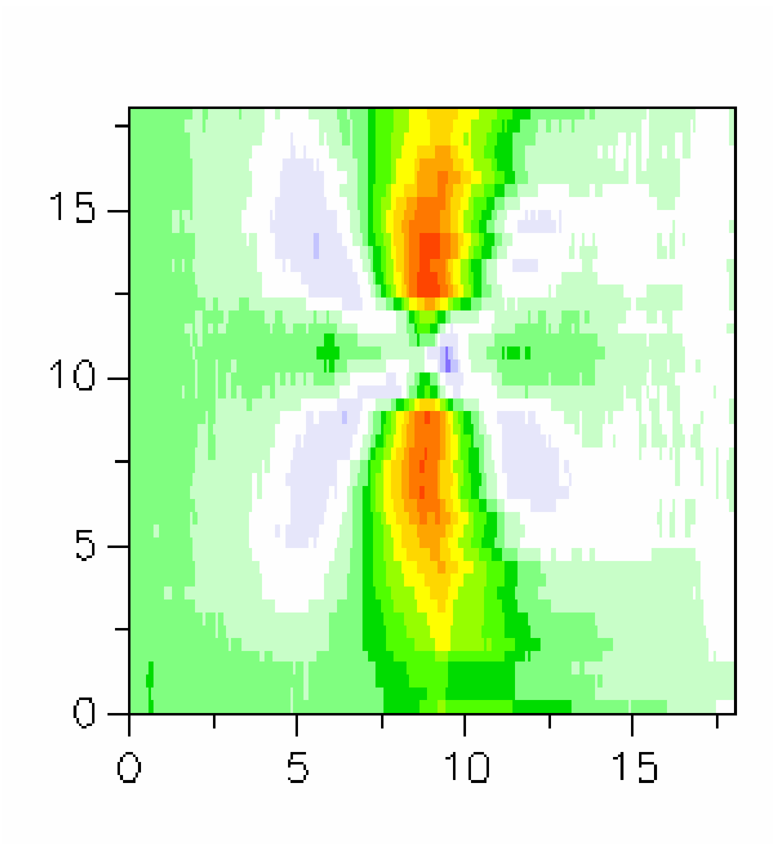


Figure 3-30. Calibration Defect R01

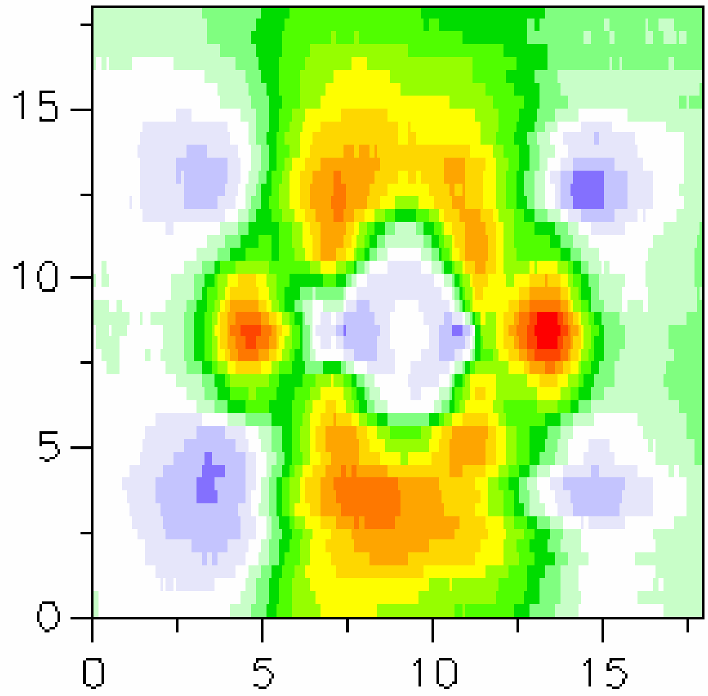


Figure 3-31. Calibration Defect R02

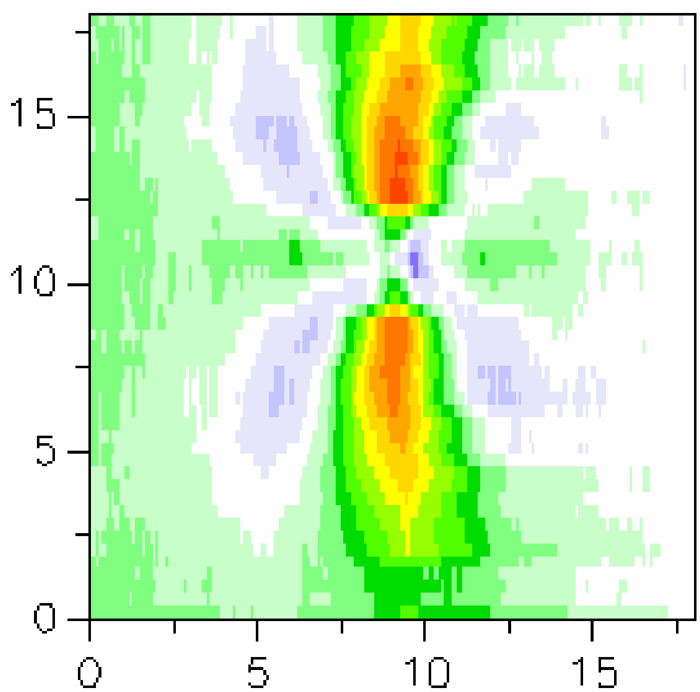


Figure 3-32. Defect R03

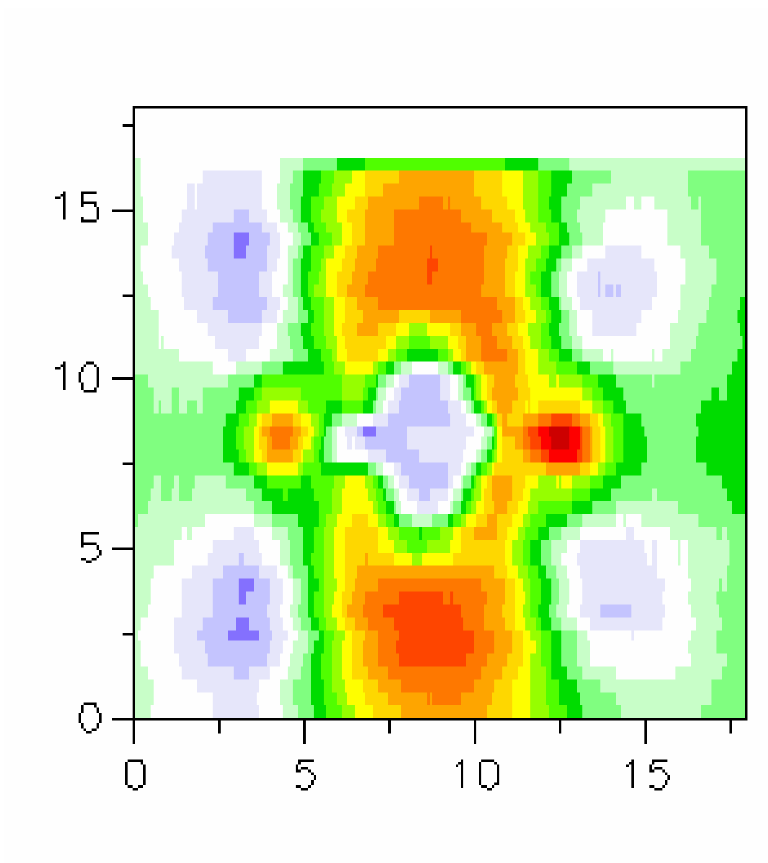


Figure 3-33. Defect R04

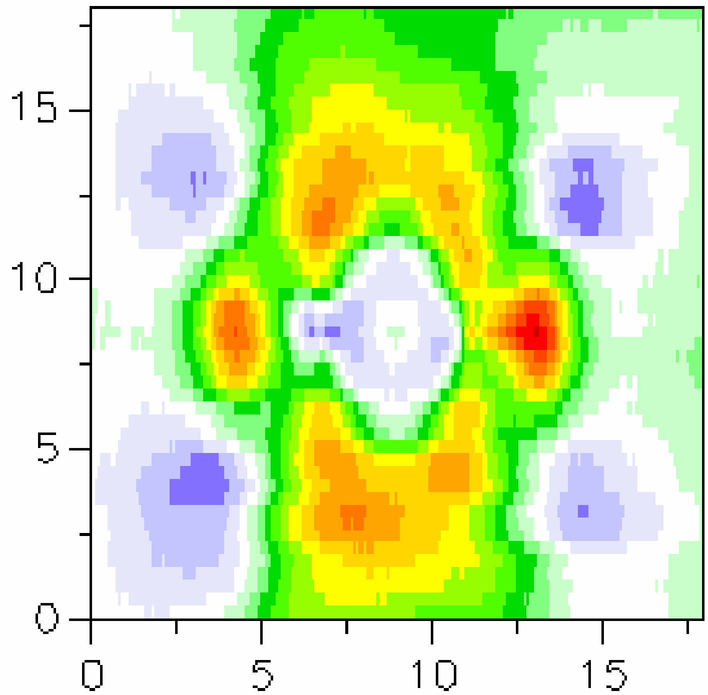


Figure 3-34. Defect R05

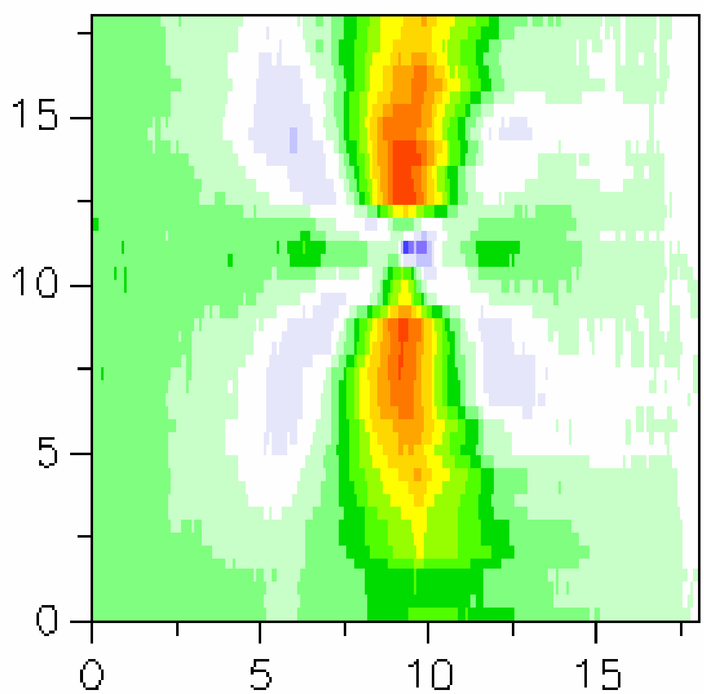


Figure 3-35. Defect R06

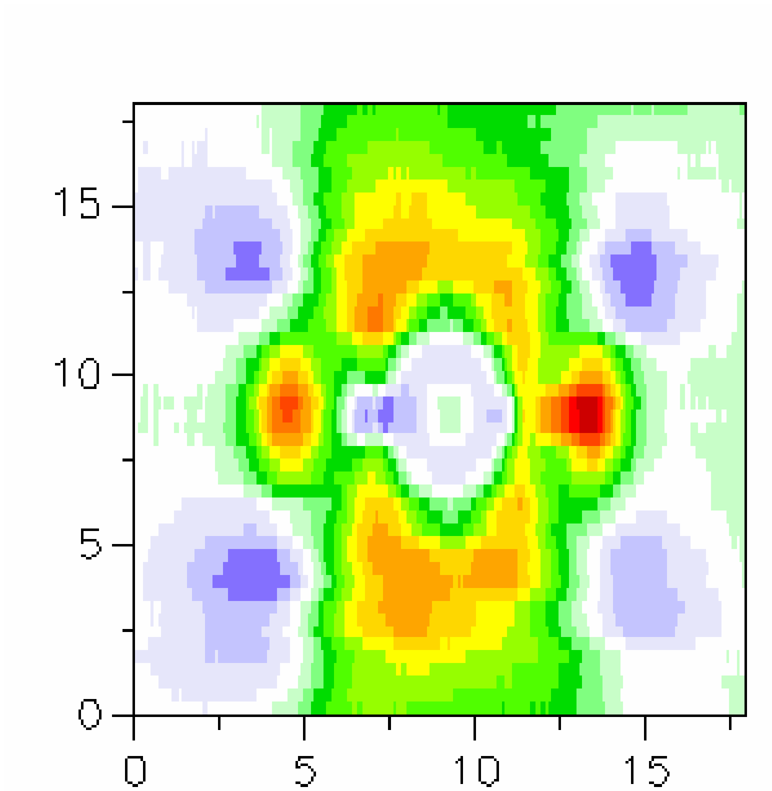


Figure 3-36. Defect R07

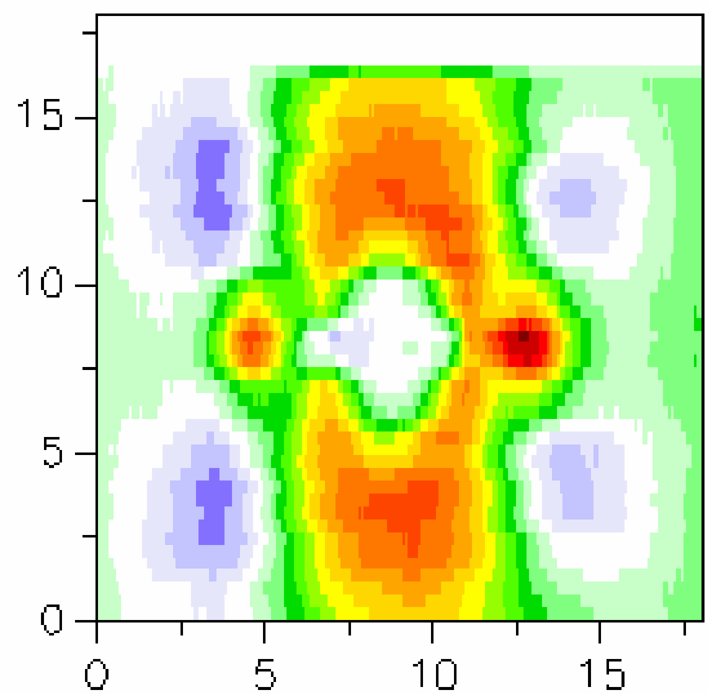


Figure 3-37. Defect R08

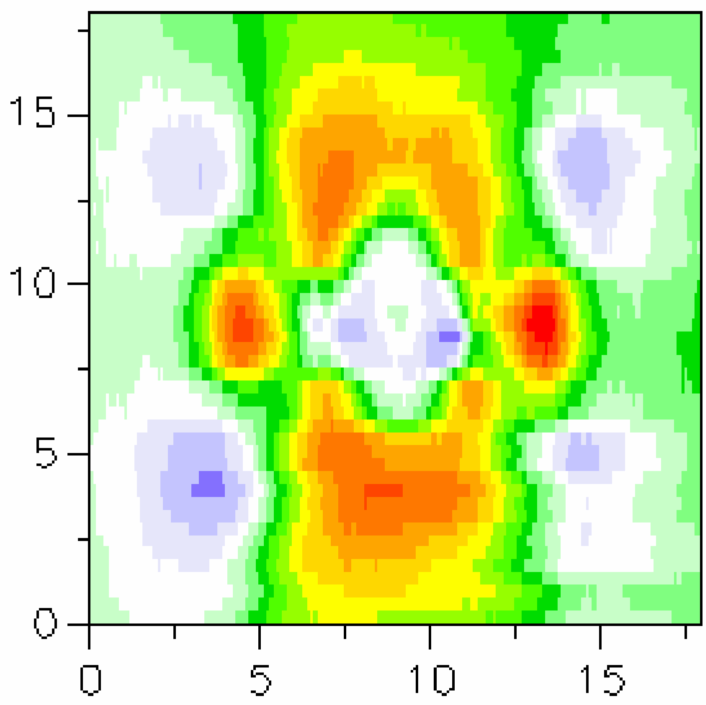


Figure 3-38. Defect R09

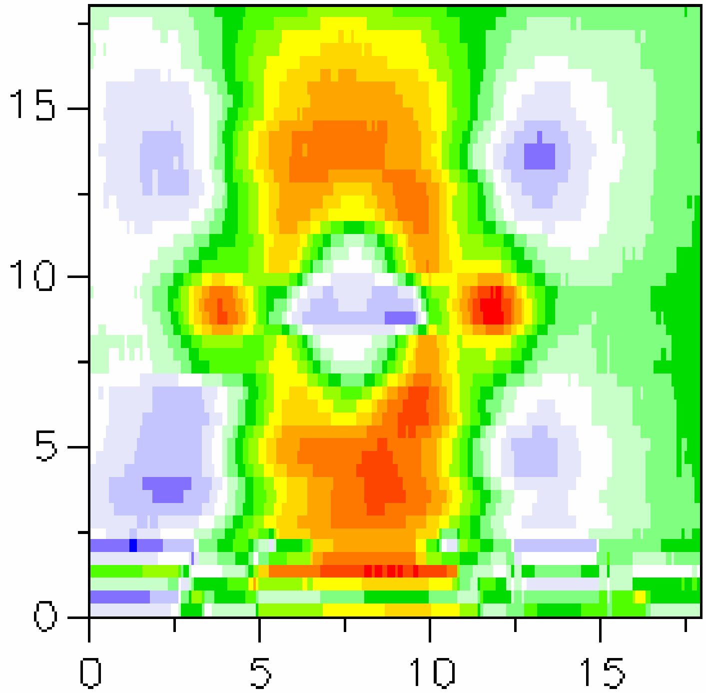


Figure 3-39. Defect R10

Figure 3-40. Blank R11

SECTION 4. SCC INSPECTION TECHNOLOGY ASSESSMENT

INTRODUCTION

The focus of the SCC assessment projects is to develop ultrasonic technologies that can operate in natural gas pipelines. Crack detection technology for liquid pipelines is already commercially available. However, transmitting ultrasonic energy into and out of the pipe without the use of a liquid coupling agent is necessary for the practical inspection of natural gas transmission pipelines.

Stress corrosion cracks are more commonly found in larger diameter pipelines because typical operating pressures produce sufficient stress in the pipe wall to initiate and grow cracks. From an inspection technology viewpoint, the sensors have a relatively large footprint. A typical sensor footprint, without engineering to make them smaller, is on the order of 10 cm (4 inches) per quarter. SCC pipe samples also appear to be more readily available in larger diameter pipes. Therefore, for these practical and implementation reasons, the capability of SCC detection technology is initially focused on pipe diameters greater than 24 inches.

The PSF has available a large number of SCC defects in 26-inch diameter pipe acquired through donations from PRCI member companies. One of the technology developers has already used pipe samples at the PSF and therefore these samples are not included as part of the demonstration. In addition, the external coating on the pipe itself is a significant variable and therefore only pipe without coating was made available for the benchmarking demonstration.

The report sections below discuss the demonstration plan for the SCC inspection tool and provides an “answer key” (Table 4-1) for the data sheets filled out by the SCC inspection tool developer during the demonstration. Additional information and photographs are provided in Figures 4-1 through 4-8 which show the magnetic particle maps and the locations and lengths of the natural SCC defects.

26-INCH STRESS CORROSION CRACK DEMONSTRATION PLAN

The test plan for the 26-inch stress corrosion crack test configuration is as follows:

1. The technology(s) to be benchmarked include:
   1.1. ORNL: Strain measurement tool
2. Total length of the pipe sample will be 26 feet
3. The pipe will be 26-inch outside diameter
4. The test sample is comprised of one pipe:

4.1. The length is approximately 26 feet of seam welded pipe
4.2. The nominal wall thickness is 0.281 inches
4.3. The pipe contained 7 stress corrosion crack colonies for examination
4.4. The pipe sample had multiple defect locations requiring three rows for data collection.
4.5. The pipe did not have any external coating
    4.5.1. All defects (except the calibration defects) were covered with a heavy material to prevent the sensor developer from viewing the defects. A separate SCC pipe sample measuring 38-feet in length was available for system check-out and calibration.

This page intentionally blank.

26 INCH SCC DEFECT ASSESSMENT INFORMATION

Benchmarking of Inspection Technologies Detection of SCC - Page 1						
Name:						
Date:						
Company:						
Sensor Design:						
CALIBRATION DATA						
Pipe Sample: 993	Calibration Crack Location	Length	Depth	Measured Length	Measured Depth	Comments
	inches from end B	inches	% wall thickness			
1	186.4	2.5				multiple cracks; max = ~3/4"
2	58.7	5				multiple cracks; max = ~1/4"
3	86.4	5				multiple cracks; max = ~3 1/4"
4	82.4	2.5				multiple cracks; max = ~1/2"
5	44.4	3				multiple cracks; max = ~1/2"
Blank Area:						

TEST DATA					
Pipe Sample:		**893**			
Defect Set:		26" Diameter Pipe with Stress Corrosion Cracks; Length = 26 feet			
		TEST LINE 1			
Defect Number	Search Region (Distance from End B)	Start of Crack Region from Side B	End of Crack Region from Side B	Type of SCC	Comments
	inches	inches	inches		
SCC5 **(Blank 1)**	140" to 152"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank 1**
SCC4 **(Blank 2)**	175" to 187"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank 2**
SCC3 **(8)**	210" to 222"	**209.25**	**212.25**	☐ Isolated Crack ☑ **Colony of Cracks** ☐ None	**Multiple 1/4" cracks; cracked area 2 3/4" by 2 1/2"**
SCC2 **(5 & 4)**	226" to 242"	**225.25**	**238.25**	☑ **Isolated Cracks** ☐ Colony of Cracks ☐ None	**Two isolated cracks; cracked area 4" by 1 1/2" with ~2" long crack; cracked area 5 1/4" by 1 1/4" with ~3" long crack**
SCC1 **(Blank 3)**	242" to 254"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank 3**

Table 4-1. 26 inch SCC Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies Detection of SCC - Page 2					
Name:					
Date:					
Company:					
Sensor Design:					
TEST DATA					
Pipe Sample:	**893**				
Defect Set:	26" Diameter Pipe with Stress Corrosion Cracks; Length = 26 feet				
	TEST LINE 2				
Defect Number	Search Region (Distance from End B)	Start of Crack Region from Side B	End of Crack Region from Side B	Type of SCC	Comments
	inches	inches	inches		
SCC10 **(9)**	140" to 152"	**141.5**	**145.5**	☐ Isolated Crack ☑ **Colony of Cracks** ☐ None	**Multiple cracks; max ~1/4" long; cracked area 3 1/2" by 3 1/2"**
SCC9 **(7)**	188" to 200"	**189.25**	**193.5**	☐ Isolated Crack ☑ **Colony of Cracks** ☐ None	**Multiple cracks; max ~1/4" long; cracked area 4 1/4" by 3 3/4"**
SCC8 **(6)**	210" to 222"	**210.75**	**213.5**	☐ Isolated Crack ☑ **Colony of Cracks** ☐ None	**Multiple cracks; max ~1/2" long; cracked area 3" by 2 1/2"**
SCC7 **(Blank 4)**	234" to 246"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank**
SCC6 **(Blank 5)**	246" to 258"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank**

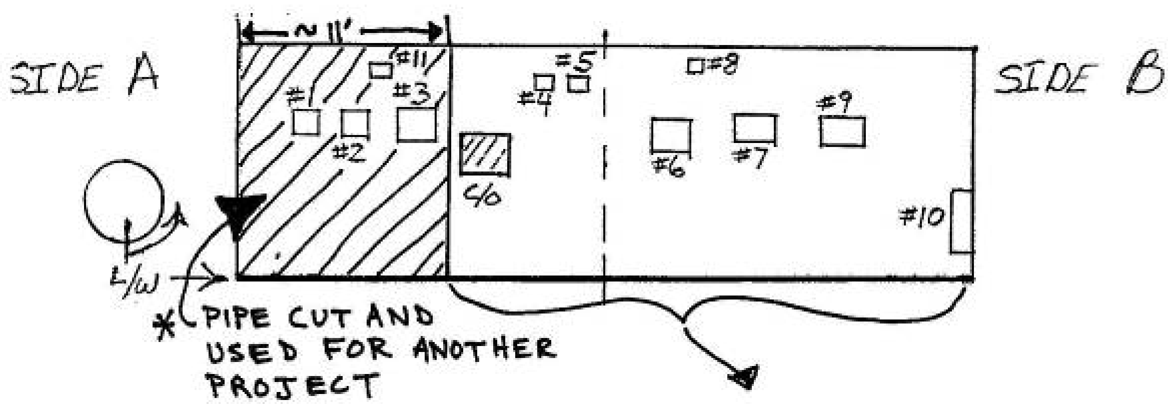
Table 4-1 (cont). 26 inch SCC Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies Detection of SCC - Page 3					
Name:					
Date:					
Company:					
Sensor Design:					
TEST DATA					
Pipe Sample:	893				
Defect Set:	26" Diameter Pipe with Stress Corrosion Cracks; Length = 26 feet				
	TEST LINE 3				
Defect Number	Search Region (Distance from End B)	Start of Crack Region from Side B	End of Crack Region from Side B	Type of SCC	Comments
	inches	inches	inches		
SCC14 **(Blank 6)**	140" to 152"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank**
SCC13 **(Blank 7)**	188" to 200"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank**
SCC12 **(Blank 8)**	210" to 222"	**---**	**---**	☐ Isolated Crack ☐ Colony of Cracks ☑ **None**	**Blank**
SCC11 **(16)**	225" to 245"	**224.25**	**241.25**	☐ Isolated Crack ☑ **Colony of Cracks** ☐ None	**Multiple cracks; max ~3/4" long; cracked area 17" by 1 3/4"**

Table 4-1 (cont). 26 inch SCC Inspection Technology Data Sheet "Answer Key"

26 INCH SCC PIPE SAMPLE 893 DOCUMENTATION

Pipe Sample No. 893
Drawing #1 of 2

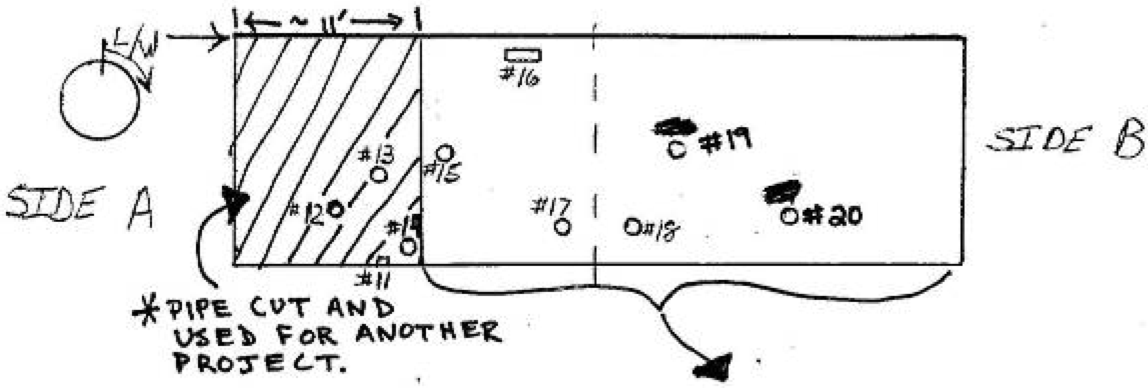


Ind.#	Cracks Max Size	Cracked Area	Old Distances EOP	Distance L.W.	New Distances EOP to start of box
	inches	inches	inches	inches	Inches
✶ ~~1~~	~~multi ¼~~	~~2 x 1 ¾~~	~~A 90~~	~~18 ¼~~	A – Not Available
✶ ~~2~~	~~multi ¼~~	~~2 x 2~~	~~A 97~~	~~19~~	A – Not Available
✶ ~~3~~	~~multi 1 ½~~	~~11 x 7~~	~~A 104~~	~~14~~	A – Not Available
4	multi ¼	5 ¼ x 1 ¼	~~A 208 ¾~~	33	B 233 ¼
5	multi ¼	4 x 1 ½	~~A 216 ¾~~	32	B 225 ¼
6	multi ½	3 x 2 ½	B 215	18	B 210 ¾
7	multi ¼`	4 ¼ x 3 ¾	B 193 ½	16 ½	B 189 ¼
8	multi ¼	2 ¾ x 2 ½	B 214	37	B 209 ¼
9	multi ¼	3 ½ x 3 ½	B 145 ¾	19 ¼	B 141 ½
10	multi ¼	3 ½ x 11	--	15	B --
✶ ~~11~~	~~multi ¾~~	~~2 x 2~~	~~A 101~~	~~33~~	A -- Not Available

✶ A portion of pipe specimen 893 was cut and used for another project. The cut portion is no longer available for use. The new distances from the edge of the pipe are presented in the table.

Figure 4-1. SCC Pipe 893 Data

Pipe Sample No. 893
Drawing #2 of 2



	Ind.#	Cracks Max Size	Cracked Area	Old Distances EOP	Distance L.W.	New Distances EOP to start of box
		inches	inches	inches	inches	Inches
✶	11	multi ¾	2 x 2	A 101 see dwg #1	33	A – Not Available
✶	12	¾	¾	A 49 ½	38	A – Not Available
✶	13	¼	¼	A 105 ½	30	A – Not Available
✶	14	1	1	A 120	45	A – Not Available
	15	½	½	A 139	28	B 307 ½
	16	multi ¾	17 x 1 ¾	A 206	8	B 224 ¼
	17	1	1	A 226	41	B 218 ¼
	18	½	½	B 219	41	B 213 ¾
	19	1	1	B 213 ½	27 ½	B 207 ½
	20	1	1	B 94	40	B 88

Figure 4-1 (cont). SCC Pipe 893 Data

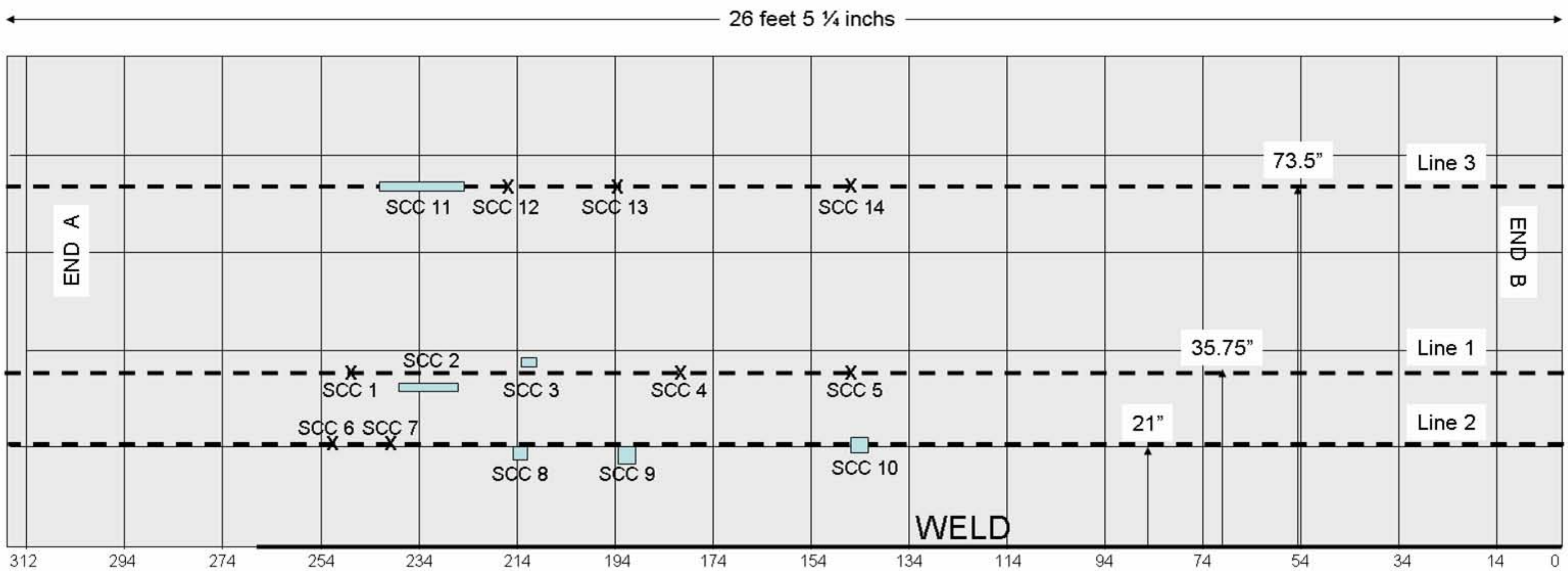


Figure 4-2. Diagram of SCC Pipe 893

Data Sheet Code #	Indication #	Max Size Cracks	Area Cracked	Distance to Start of Crack Area (from End of Pipe – Side B)	Distance L/W (from weld to start of crack area)	Line #
SCC1	Blank 3	***	***	***	***	Line 1
SCC2	4 & 5	¼”	5 ¼” x 1 ¼” and 4” x 1 ½”	225.25”	33” and 32”	Line 1
SCC3	8	¼”	2 ¾” x 2 ½”	209.25”	37”	Line 1
SCC4	Blank 2	***	***	***	***	Line 1
SCC5	Blank 1	***	***	***	***	Line 1
SCC6	Blank 5	***	***	***	***	Line 2
SCC7	Blank 4	***	***	***	***	Line 2
SCC8	6	½”	3” x 2 ½”	210.75”	18”	Line 2
SCC9	7	¼”	4 ¼” x 3 ¾”	189.25”	16.5”	Line 2
SCC10	9	¼”	3 ½” x 3 ½”	141.5”	19.25”	Line 2
SCC11	16	¾”	17” x 1¾”	224.25”	72.5”	Line 3
SCC12	Blank 8	***	***	***	***	Line 3
SCC13	Blank 7	***	***	***	***	Line 3
SCC14	Blank 6	***	***	***	***	Line 3

Table 4-2. SCC Pipe 893 Data

Pipe 1093 SCC Defect Photos

Figure 4-3. Defect SCC 2 (4 & 5)

Figure 4-4. SCC 3 (8)

Figure 4-5. Defect SCC 8 (6)

Figure 4-6. Defect SCC 9 (7)

Figure 4-7. Defect SCC 10 (9)

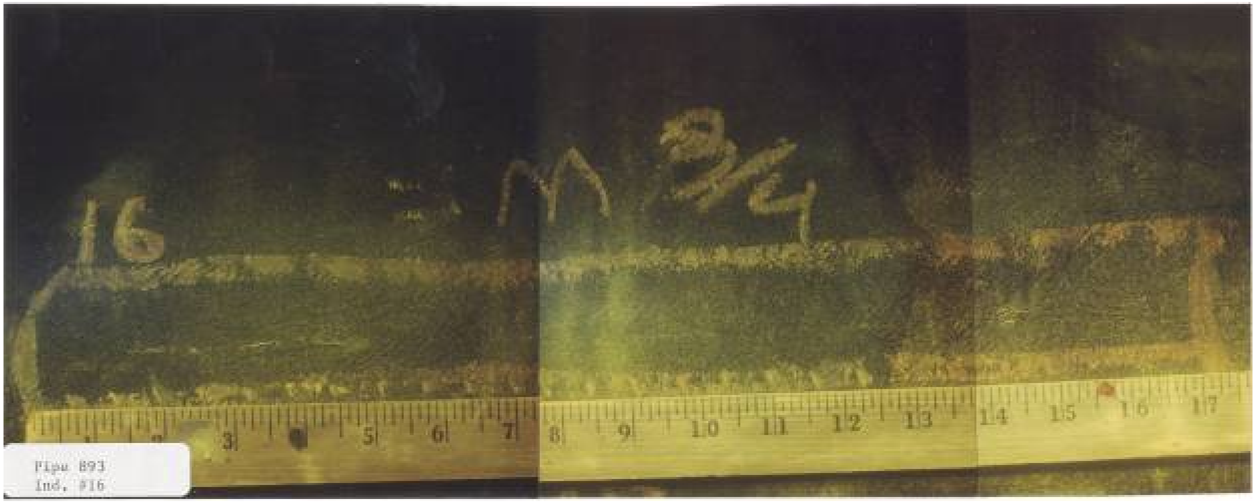


Figure 4-8. Defect SCC 11 (16)

SECTION 5. PLASTIC PIPE INSPECTION TECHNOLOGY ASSESSMENT

INTRODUCTION

One new sensor technology was added in this Phase II Benchmarking Demonstration. This technology inspects plastic pipe for small volumetric anomalies with a detection threshold of approximately 0.015 cubic inches. The measurement technology is localized and therefore anomalies in close proximity and pipe end effects do not influence its detection capabilities.

Battelle procured a medium density polyethylene pipe sample (yellow in color) for the benchmarking demonstration. The pipe sample has an inside diameter of approximately 5.5-inches and wall thickness of 0.5 inch. Cylindrical hole and saw cut defects were manufactured along one row of the pipe sample to assess the capabilities of the sensor technology.

The report sections below discuss the demonstration plan for the plastic pipe inspection tool and provides an “answer key” (Table 5-1) for the data sheets filled out by the inspection tool developer during the demonstration. Additional information and photographs are provided in Figures 5-1 through 5-13 which show the locations and size of the plastic pipe defects. This information was used as the guide to assess the performance of the sensor technology developer.

6 INCH PLASTIC PIPE DEMONSTRATION PLAN

The demonstration plan for the 6-inch plastic pipe test configuration is as follows:

1. The technologies benchmarked included:
    a. DOE NETL plastic pipe sensor

2. The pipe is 6.5-inch outside diameter

3. The pipe wall thickness is 0.5 inch making the inside diameter approximately 5.5 inches. The pipe had some ovality and a slight twist.

4. The demonstration sample was comprised of one medium density (yellow) polyethylene pipe:
    3.1. A 13 foot long 6" Polyethylene Pipe positioned horizontally was used as the test sample. The sample was supported from the bottom and only at the ends.
    3.2. A single row of defects was located directly above the center line (plus or minus 1/4 inch). Defects were placed 6 to 7 inches apart and one foot from the end, allowing 20 defect locations.

3.3. Eight locations did not have a defect. Defects were covered with a heavy material to prevent sensor developers from viewing the defects. One defect near End A remained uncovered for system check-out and calibration.

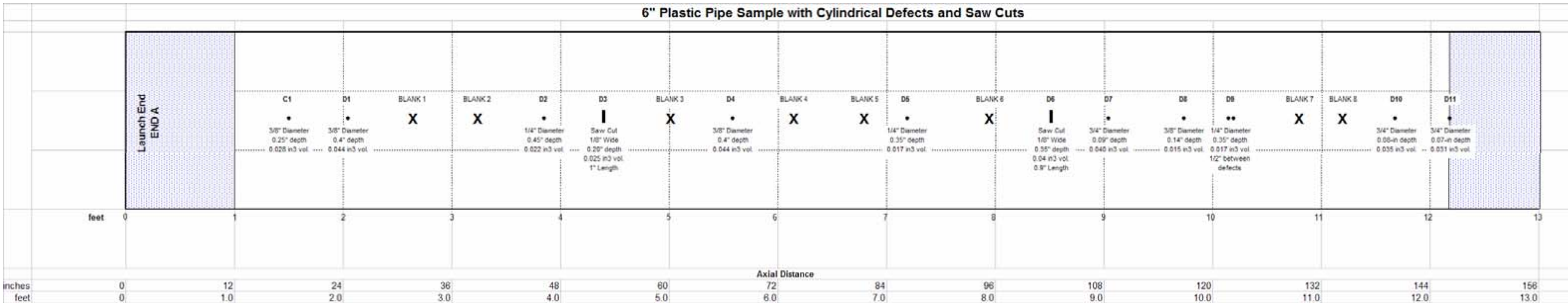
3.4. Typical defects included small cylindrical holes and saw cuts. The volume of these defects ranged from 0.015 to 0.05 cubic inches. All defects were on the outside surface of the pipe sample.

6 INCH PLASTIC PIPE ASSESSMENT INFORMATION

Table 5-1. 6 inch Plastic Pipe Inspection Technology Data Sheet "Answer Key"

Benchmarking of Inspection Technologies Detection of Plastic Pipe Defects - Page 1							
Name:							
Date:							
Company:							
Sensor Design:							
CALIBRATION DATA							
Defect		Calibration Defect Location	Volume of Defect	Depth of Defect	Diameter of Defect	Comments	
		inches from end A	cubic inches	inches	inches		
C1:		18	0.028	0.25	0.375		
TEST DATA							
Pipe Sample:		PLASTIC PIPE SAMPLE					
Pipe Parameters:		6" Diameter, 0.5" Wall Thickness Pipe Sample, ~13' in length					
		LINE 1					
Defect Number	Search Region (Distance from End A)	Location of Defect Region from Side A	Significance of Defect (based on volume ratio from calibration defect)	Volume of Defect (in³) (provided to participant after defect signif reported)	Depth of Defect (in) (provided to participant after defect signif reported)	Diameter of Defect (in) (provided to participant after defect signif reported)	Comments
	inches	inches	Calibration Defect = 1 Less Severe <1 More Severe >1	cubic inches	inches	inches	
D1	21" to 27"	25"	1.57	0.044	0.4	0.375	
D2	28" to 34"	BLANK	0	----	----	----	
D3	35" to 41"	BLANK	0	----	----	----	
D4	42" to 48"	46"	0.79	0.022	0.45	0.25	
D5	49" to 55"	53"	0.89	0.025	0.2	0.125	Saw Cut ~1" long and 1/8" wide
D6	56" to 62"	BLANK	0	----	----	----	
D7	63" to 69"	67"	1.57	0.044	0.4	0.375	Same as D1
D8	70" to 76"	BLANK	0	----	----	----	
D9	77" to 83"	BLANK	0	----	----	----	
D10	84" to 90"	88"	0.61	0.017	0.35	0.25	
D11	91" to 97"	BLANK	0	----	----	----	
D12	98" to 104"	102"	1.43	0.04	0.35	0.125	Saw Cut ~0.9" long and 1/8" wide
D13	105" to 111"	109"	1.43	0.04	0.09	0.75	
D14	112" to 118"	116"	0.54	0.015	0.14	0.375	
D15	119" to 125"	123" and 123.5"	0.61 (each)	0.017 (each)	0.35 (each)	0.25 (each)	Defect consists of two identical holes 1/2" apart
D16	126" to 132"	BLANK	0	----	----	----	
D17	132" to 138"	BLANK	0	----	----	----	
D18	138" to 144"	140"	1.25	0.035	0.08	0.75	
D19	144" to 150"	148"	1.11	0.031	0.07	0.75	

6 INCH PLASTIC PIPE SAMPLE DOCUMENTATION



Defect Number	Distance from End A to Defect Center (inches)	Distance from End A to Defect Center (feet)	Defect Diameter (in)	Defect Depth (in)	Defect Length (in)	Volume of Defect (in3)
C1	18.0	1.5	0.375	0.25	-	0.028
D1	25.0	2.1	0.375	0.4	-	0.044
Blank 1	32.0	2.7	-	-	-	
Blank 2	39.0	3.3	-	-	-	
D2	46.0	3.8	0.25	0.45	-	0.022
D3	53.0	4.4	-	0.2	1.00	0.025
Blank 3	60.0	5.0	-	-	-	
D4	67.0	5.6	0.375	0.4	-	0.044
Blank 4	74.0	6.2	-	-	-	
Blank 5	81.0	6.8	-	-	-	
D5	88.0	7.3	0.25	0.35	-	0.017
Blank 6	95.0	7.9	-	-	-	
D6	102.0	8.5	-	0.35	0.91	0.04
D7	109.0	9.1	0.75	0.09	-	0.040
D8	116.0	9.7	0.375	0.14	-	0.015
D9	123.0	10.3	0.25	0.35	2 holes spaced 1/2" apart	0.017
Blank 7	130.0	10.8	-	-	-	
Blank 8	135.0	11.3	-	-	-	
D10	140.0	11.7	0.75	0.08	-	0.035
D11	148.0	12.3	0.75	0.07	-	0.031

Figure 5-1. 6-inch Plastic Pipe Sample Defect Map

Plastic Pipe Sample Defect Photos

Figure 5-2. Calibration Defect C1

Figure 5-3. Defect D1 (D1)

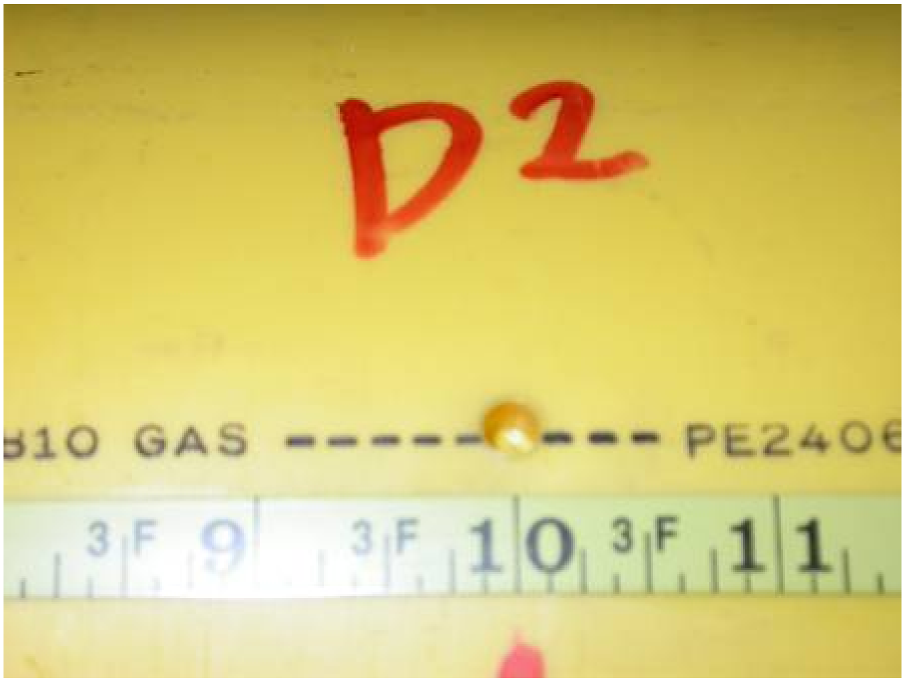


Figure 5-4. Defect D4 (D2)

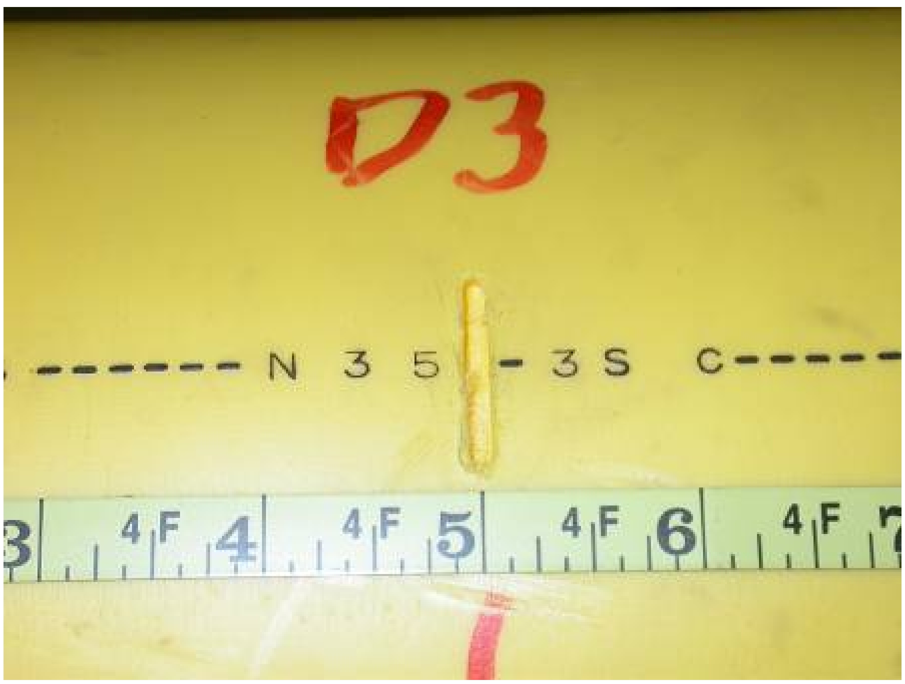


Figure 5-5. Defect D5 (D3)

Figure 5-6. Defect D7 (D4)

Figure 5-7. Defect D10 (D5)

Figure 5-8. Defect D12 (D6)

Figure 5-9. Defect D13 (D7)

Figure 5-10. Defect D14 (D8)

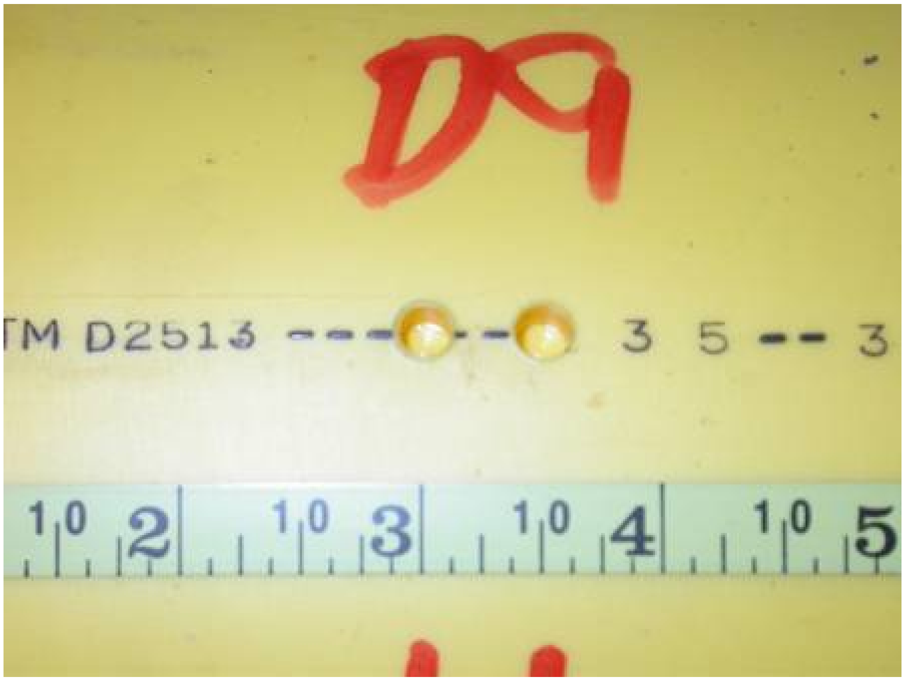


Figure 5-11. Defect D15 (D9)

Figure 5-12. Defect D18 (D10)

Figure 5-13. Defect D19 (D11)