Metallurgical Laboratory Failure Examination Protocol Introduction

The objective of a metallurgical analysis of a line pipe failure is to assign one or more probable causes for the failure. The failure analysis may identify issues that must be remediated to ensure the integrity of other sections of the failed line pipe as well as other pipeline segments with similar characteristics (i.e. pipe manufacturer, seam type, grade, other specifications, coating type, and environmental conditions). This protocol specifically addresses the failure analysis of line pipe. Failure analysis of pipeline appurtenances (such as valves, flanges, bolts, etc.) may use the same methodologies as those outlined herein, but a unique test plan should be developed to handle the unique characteristics of the appurtenance.

Besides a metallurgical analysis of the line pipe, the internal and external environment of the line pipe must be considered to arrive at the causal factors that may have caused the line pipe to fail. Therefore, the presence of corrosion products inside and outside the line pipe in the area of the failure must be considered and collected for analysis, as appropriate. For example, soil in the immediate area of the failure, dislodged soil adjacent to the ejected pipe, and soil that had adhered to the line pipe may have to be collected for analysis.

Photographic documentation of the failed section of line pipe prior to its departure from the accident site and upon its arrival at the testing facility must be available to ensure any damage from mishandling is appropriately noted. Before the shipment of the failed section, proper preservation techniques for the fracture surfaces and the section (including coating), if required, should be identified (such as Visqueen®, SaranWrap®, oils, and other protective covers), and a chain of custody should be established for transfer of the failed section to the testing facility.

Before the failed section arrives at the testing facility, it should be determined if destructive testing of the failed section has been approved. Only non-destructive testing is allowed in some instances to preserve the pipe intact for evidentiary purposes. In some instances destructive testing can only occur when all interested parties agree to its necessity and a consensus protocol can be crafted establishing those that can witness the destructive tests.

A typical sequence of analysis is discussed in this document. Engineering decisions must be made during any failure analysis, and the results of each step dictate the next procedure to be performed. The need for other tests to be performed is a determination that should be made during the course of the investigation; and in some instances, additional samples of pipe from adjacent joints may be necessary for testing. In this instance, the proposed test plan should be modified to reflect these changes. It is a waste of resources to routinely perform a test or analysis that has no relevance to the failure. The following steps are suggested as guidance.

- Background information
- Visual and non-destructive examination
- Physical measurements
- Corrosion examination
- Fractography examination

- Metallographic examination
- Mechanical properties

Background Information

Background information should be collected on the pipeline operating history, pipeline attributes, pipe specifications, operating pressure, and failure pressure. Background information provides the investigators data crucial to understanding the technical environment the pipeline was operating in and it assists in identifying potential contributors to the failure. Table 1 provides guidance on data that may be collected during the failure investigation.

Photographic evidence should be collected to document the failure site and other pertinent details regarding the failure. At the least, items of interest for photographic documentation may include the following:

- Overview of failure site including local topography
- Overview of line pipe failure area
- Detail of fracture surface(s), magnified appropriately to show all relevant features at the fracture surfaces and the fracture origin
- Detail of coating in area of failure
- Detail of areas of internal and external corrosion near the fracture surface
- Details of residues or corrosion products near the fracture surface
- Details of areas indicating outside force damage

When removing the failed section, any indication of residual stress in the line should be documented. Spring or movement of the pipe when the first circumferential cut is completed would indicate the presences of residual stress. If a flame cut is used to remove the section containing the failure, do not flame cut within twelve inches of the fracture or failure surfaces as the heat from the torch could change the metallurgical characteristics of the steel. Document the relative location and distance between the cut ends after the first cut is completed.

Guidelines for custody transfer and transportation of physical evidence is provided in Attachment 1. When handling sections containing the failure area and fracture surfaces, care must be taken to preserve specimens in the original condition to provide as much information as possible for determination of the cause of the failure. For any failure the following guidelines preparation of samples for analysis should be followed, as appropriate:

- Do not mechanically clean, sandblast, wire-brush, or acid clean any failed parts prior to proper analysis. Deposits on the failed part might be helpful in determining the cause(s) of the failure.
- If a part is fractured into two or more separate pieces, do not fit the fracture surfaces back together. Certain metallurgical features on the fracture face can help determine the cause of the failure and can be easily damaged.
- Only apply preservatives (e.g. lubricating oil) to fracture surfaces when directed to do so. The lubricating oil can be removed prior to fractographic analysis; however, the integrity of surface deposits and corrosion products could be compromised by apply oil to fracture surfaces.

- Wrap the failed section with plastic or other appropriate covering material in the "as is condition" without removal of surface deposits beforehand.
- Do not store failed items outside for long periods of time.

Visual and Nondestructive Examination

1. Photographically document the pipe in the "as-received" condition before initiating the metallurgical analysis. Documentation may include the following:
    - Fracture area and surface
    - Seams
    - Girth welds
    - Coating condition
    - Anomalies
    - Manufacturing flaws or defects
    - Pitting and/or evidence of corrosion on internal and external pipe surfaces
2. Perform visual examination of the internal and external pipe surfaces in the "as-received" condition, and document any anomalies that may be present in the pipe such as the following:
    - Cracks
    - Crevices
    - Dents
    - Bends
    - Buckles
    - Gouges
    - Manufacturing defects
    - Wrinkles, tents or damage to the coating
    - Pitting and/or evidence of corrosion on internal and external pipe surfaces
    - Presence of corrosion products and/or deposits
    - Describe coating, and coating damage (disbonding) if any, in the vicinity of fracture origin and at other locations in the failed pipe sample
    - Describe any internal coating or linings (if used)
    - Examine the pipe sample surface for evidence of stress corrosion cracking
    - Examine for evidence of arc burns, excessive grinding around the surface area near the crack
    - If corrosion is evident, collect corrosion products for analysis
3. Collect solid and liquid samples, if present, from the pipe surface, and conduct elemental analysis and microbial tests on these samples, as appropriate. Examples of samples that may be collected are, but not limited to, the following:
    - Liquid accumulated underneath the coating. If not enough liquid is present for collection, consider using pH paper to characterize pH.
    - Corrosion products and/or deposits from the internal and external surfaces of pipe surface
    - Soil adhering to the pipe
4. If coating is to be removed, it should be removed in a manner that will not be injurious to the pipe. Photographically document and visually inspect the pipe again following coating removal (see 1. and 2. above for guidance). Note any disbondment or possible adhesion problems with coating.
5. It may be necessary to inspect the failed section of pipe for cracking, stress corrosion cracking, or any other condition that could affect the long term integrity of the pipeline using

nondestructive testing techniques. The surfaces of the pipe surrounding the rupture should be cleaned with an appropriate non-abrasive cleaner and subsequently inspected using a wet magnetic particle inspection method (black-on-white or fluorescent). A wet method is preferred over the dry method because internal and external defects can be more readily identified. Other nondestructive examination techniques such as Fluorescent Penetrant, Radiographic, Eddy-Current, Ultrasonic Inspection, and Alternating Current Potential Drop may also be used.

6. The physical location of all samples to be removed from the pipe for examination and metallurgical analysis should be documented such that all relevant features are visible (graphically and/or photographically).

Physical Measurements

1. Measure the diameter and wall thickness on undisturbed areas of the pipe to confirm the information provided in the "Background Information Data Sheet".
2. Measure the diameter and wall thickness at selected locations to determine actual values at these selected locations. Measure and record the diameter and wall thickness of the pipe at each end of each sample. (Wall thickness should be determined based upon four measurements taken 90 degrees apart.)
3. Verify roundness and geometry of pipe at the extremeties and closer to the failed surface.
4. Measure the wall thickness around fracture surfaces and any damaged areas. If corrosion is identified near or around the fracture surfaces, a "corrosion map" should be produced detailing the extent of the corrosion on the pipe surfaces and the pipe wall thicknesses in those areas. This information may be needed to support remaining strength calculations, if required.
5. Align the pipe samples to conform to the pre-fracture bend geometry.
6. Determine and mark the location of the electric-resistance weld at each end of each sample.
7. Determine whether or not any part of each rupture falls within the electric-resistance weld zone.
8. Measure and record the length of each sample.
9. Record any markings detected on the inside or outside surfaces of the pipes.
10. Measure rupture lengths tip-to-tip.
11. Measure the shortest circumferential distance from each fracture origin to the nearest electric-resistance weld.
12. Measure the axial distance from each fracture origin to the nearest girth weld, if any.
13. Map wall thickness of each sample within 12 inches upstream and downstream of each rupture origin. Measurements will be taken on a 2-inch square grid pattern that is centered on the fracture origin and that encompasses 100 percent of the pipe circumference at each origin.
14. Determine depths of cracks using direct exploration (grinding), shear wave ultrasonic testing (UT), Alternating Current Potential Drop (ACPD) or other suitable methods.

Attachment 2 provides a worksheet for documenting physical measurements.

Corrosion Examination

Surface deposits and residues associated with the fracture area and adjacent areas should be collected and analyzed to characterize and determine the origin of the deposits. Attachment 2 provides a worksheet for documenting chemical analysis results of corrosion products.

Based on the results of the visual, non-destructive, and metallographic examinations, the presence of corrosion should be documented, and the type and characteristics of any corrosion present should be evaluated. Remaining strength calculations (RSTRENG/ASME B31G) may be performed on corroded areas to support the failure investigation.

If an in-line inspection (ILI) tool has inspected the failure site in the past, investigation of the ILI log and report can provide information relevant to corrosion growth rate. The operator may not have this information immediately available, but it may be desirable to do this research. In the case of finding the anomaly present in the past ILI report, it is important to understand the operator's excavation criteria in effect at the time of the ILI and the application of RSTRENG calculations and anomaly interaction criteria.

Fractographic Examination

1. Visually examine the fracture surfaces in detail to identify the characteristics of the fracture, the nature of the original defect, and the failure initiation point(s). It may become necessary to open the fracture surface in order to conduct part of the examination, and a suitable technique that is dependent upon the particular circumstances of the failure should be used to open the fracture surface.

2. Clean samples in an appropriate manner (e.g., inhibited acid, Endox, Citronox solution) to remove loose rust, scale, etc. as necessary.

3. Utilize a suitable method to thoroughly document the fracture surface including dimensional documentation. Suitable methods to document the fracture surface include, but are not limited to, the following:
   - Foil method
   - Photographs of macroscopic examination

4. Remove selected fractographic samples as necessary for detailed microscopic examination using optical or scanning electron microscope. Examine and document the fracture surface morphology. When chevron marks are present on the fracture surface, they typically point back towards the fracture origin in steels with an ultimate tensile strength of 60,000 psi and less. It is important to be able to characterize the fracture surface morphology, and fractures can be classified into four groups on a macroscopic scale, as follows:
   - Ductile fractures
   - Brittle fractures
   - Fatigue fractures
   - Fractures resulting from combined effects of stress and environment
   - Under low magnification under TLM, observe if there is evidence of fatigue, and ridges to indicate application of high pressure, such as due to hydrostatic testing.

Metallographic Examination

1. Identify metallographic sample origin (sample identification, location, orientation, etc.), perform metallographic evaluation, and take representative photomicrographs. Areas of particular concern are:
   - At or near the fracture origin
   - Fracture surfaces
   - Weld seams
   - Anomalies
   - Areas with indications of defects or cracks identified through visual and/or non-destructive testing
   - Areas exhibiting “typical” microstructures of the base metal, weld metal, and heat-affected-zone

2. Perform micro-hardness profiles at appropriate locations such as the following:
   - At or near the fracture origin
   - Weld seams

3. Metallographic samples should be examined to characterize and validate any appropriate issues specific to the failure such as:
   - Pipe specification, grade, and heat treatment
   - Weld seam in area of fracture
   - Weld seam in un-affected area
   - Corrosion
   - Indications of outside force damage

Attachment 2 provides a worksheet for documenting metallographic specimens and photographs.

Mechanical Properties

Testing should be performed to determine the mechanical properties of the pipe and any appurtenances. Mechanical properties of test specimens should not be taken from areas of the pipe that have been plastically deformed as a result of the failure. These mechanical tests should at least include the following:

- Tensile testing
- Charpy V-notch testing
- Chemical analysis

Attachment 2 provides a worksheet for documenting mechanical tests performed and a worksheet for documenting the chemical analysis tests performed on the pipe steel.

Tensile Testing

Tensile test specimens should be prepared and tested in accordance with ASTM A370 (Mechanical Testing of Steel Products) for the pipe base metal and weld seams to measure yield strength, ultimate tensile strength, and elongation. The pipe base metal should, at a minimum be tested in the transverse direction, and weld seam specimens should be taken across the weld seam.

Charpy V-notch Impact Testing

When Charpy V-notch (CVN) Impact Testing is determined to be necessary, the CVN specimens should be prepared and tested in accordance with ASTM E23 (Notched Bar Impact Testing of Metallic Materials) to determine the toughness characteristics of the pipe in the L-T (transverse) direction. In some cases (depending on pipe size and wall thickness) it may be necessary to use sub-size CVN specimens, and these results should be corrected back to full sized specimen values using the formula provided in Table 2. Results from CVN testing may be reported in some or all of the following forms depending on the testing results:

- Upper-Shelf Energy (in ft-lbs)
- Lower-Shelf Energy (in ft-lbs)
- Ductile-to-Brittle Transition Temperature (in °F) determined from graphical representation of testing results at the midpoint of the best-fit curve
- Test Temperature corresponding to 15 ft-lbs of absorbed impact energy
- Fracture Appearance Transition Temperature (in °F) corresponding to 50% and 80% shear
- Lateral expansion (to measure notch toughness)

In some steels it may be difficult to measure percent shear because of “woody” fracture surfaces. In these cases it would be more appropriate to use lateral expansion and absorbed energy measurements to obtain a more accurate transition temperature. A sample testing methodology for generating Charpy V-notch Curves for line pipe steels is provided in Table 2.

Chemical Analysis

The chemical composition of the pipe material should be determined using an appropriate method to validate the pipe specification and grade, as well as, to determine its carbon equivalent (for weldability issues). Spectrochemical methods (i.e. optical emission) are usually employed to determine steel chemical compositions. Wet chemical methods may also be used.

Energy dispersive spectroscopy (EDS) and either x-ray diffraction (XRD) or x-ray photoelectron spectroscopy (XPS) analyses may be used to determine elements and compounds present in surface deposits that were collected during the visual examination.

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Table 1 – Background Information Data Sheet (fill in all applicable fields)

No.	Line Pipe Attribute	Data
1	Operating Company	
2	Product Transported	
3	Line Name and Number and/or System Name	
4	Survey Station and Mile Post	
5	Date of Failure / Incident / Anomaly	
6	How Failure / Incident / Anomaly was found	
7	Closest City or town, County, and State	
8	Pipe Nominal Outside Diameter	
9	Pipe Nominal Wall Thickness	
10	Pipe Grade	
11	Pipe Seam Type and approx. Joint Length	
12	Pipe Manufacturer	
13	Year of Installation	
14	Depth of Cover in area of failure	
15	Coating Type	
16	Cathodic Protection Type and Year installed (if applicable)	
17	Distance to nearest rectifier or anode bed (if applicable) (Note any Pipe-to-Soil Readings or Surveys done before accident)	
18	Terrain and Soil Conditions, including Soil Ph (if applicable)	
19	Distance to Upstream and Downstream Compressor or Pumping Station	
20	Distance to Upstream and Downstream Girth Welds	
21	Position of Failure / Incident / Anomaly on Pipe (from top or bottom and/or O'clock position)	
22	Pressure at time and location of Failure / Incident / Anomaly	
23	Normal Operating Pressure at Location of Failure / Incident / Anomaly	
24	MOP, MAOP, Design Factor, and/or Location Class	

No.	Line Pipe Attribute	Data
25	Date, Test Pressure, and Duration of most recent Hydrostatic Test (if applicable). Note any test failures and probable cause	
26	Hydrostatic Test Pressure at Location of Failure / Incident / Anomaly (if applicable)	
27	Note the date of the last in-line inspection (ILI) and any anomalies or repairs near failure site	
28	Note any previous NDT test performed in or around the failure site (X-rays, UT scans, etc)	
29	Note any historical pictures of failure site	
30	Other Comments or Observations	
31	Name, Telephone, and Fax Numbers of contact for Operator for further Questions	
32	Name, Telephone, and Fax Numbers of contact for OPS for further Questions	
33	NRC Report Number (if applicable)	

Sketch a schematic of the failure area showing direction of flow and other prominent features:

Table 2 – A testing methodology for generating Charpy V-notch Curves for line pipe steels

Note: The following is an example test protocol to generate a Charpy V-notch (CVN) Curve and to determine the Ductile-to-Brittle Transition Temperature (DBTT) for API-X52 and lower grade line pipe. Prepare a minimum of 12 Charpy V-notch specimens (preferably 16 specimens) in the L-T (transverse) direction and perform CVN testing according to ASTM E23.

Test 1 specimen at -20°F
Test 1 specimen at 0°F
If CVN values are less than 4 ft-lbs. (full scale), then consider this a part of the lower shelf temperatures
Test 1 specimen at 70°F
Test 1 specimen at 100°F
If CVN values are greater than 20 ft-lbs. and are close together, then consider this part of the upper shelf temperatures. If the difference in CVN values is more than 5 ft-lbs., then:
Test 1 specimen at 70°F
Test 1 specimen at 50°F
If CVN values are close together, then the DBTT is likely to be around 50°F, then:
Test 1 specimen at 50°F
Test 1 specimen at 40°F
Test 1 specimen at 20°F
If the difference in CVN values at 50°F and 70°F is greater than 5ft-lbs., then
Test 1 specimen at 50°F
Test 1 specimen at 60°F
Test the remaining specimens at other temperatures, as appropriate, to ensure that data has been collected at temperatures that the testing has shown to be of importance.
Draw the CVN Curve to a best-fit curve plotting Impact Energy (ft-lbs.) versus Temperature (°F).
Determine the Ductile-to-Brittle Transition Temperature (DBTT) from the CVN Curve (in °F) based on the best-fit curve midpoint.
Determine the Temperature (in °F) corresponding to 15 ft-lbs. absorbed impact energy.
Determine the Fracture Appearance Transition Temperature (FATT) corresponding to 50% and/or 80% shear (ductile failure).
Determine the Upper-Shelf Energy (in ft-lbs.).
Determine the Lower-Shelf Energy (in ft-lbs).
If a sub-scale CVN specimen is used (less than 10 mm), determine the “normalized to full-size value” for a full sized CVN specimen using the following formula from API 5L, Section SR5B.3 which states that when sub-sized specimens are used, the individual readings are divided by the ratio of the specimen thickness tested to the full-size specimen thickness (typically 10mm (0.394 inches)) and compared with the full-size acceptance criteria. Note that for line pipe manufactured when there was not an acceptance criteria, the CVN data generated is for information analysis purposes.

Attachment 1 – Evidence Custody Transfer Control Procedures

PURPOSE:
To provide guidance for gathering, preserving and controlling evidence.

SECTIONS:
1. Gathering Physical Evidence
2. Gathering Documentation
3. Controlling Evidence

SECTION 1 - Gathering Physical Evidence

1. Before disturbance, photograph the incident scene using still and video cameras to document the site at initial entry.
2. Before collection, label and photograph evidence to be removed. Prepare and prioritize a list of the physical evidence to be gathered and/or analyzed. Collect any perishable evidence as soon as it can be accessed after arrival at the site.
3. Prior to removing evidence, notify all other agencies and company officials of the schedule for its removal. Determine whether this evidence has been or is scheduled to be removed or analyzed by other PHMSA investigators, other agency investigators, or company officials. Coordinate with these individuals to ensure that PHMSA's issues will be resolved.
4. Coordinate with other PHMSA investigators, other agency investigators, and company officials to determine whether they have other issues that an analysis of the physical evidence can resolve, or if they have concerns about the analysis or removal of the item. Develop an analysis plan that meets PHMSA needs and others' to the extent appropriate.
5. Fully photograph all physical evidence before it is moved. Ensure that the position of the evidence within the context of the incident scene is recorded.
6. Document the scene from a wide angle to a narrow angle to ensure the context of the scene is understood later. Perform a running narration when using the video camera.
7. Photograph physical evidence from multiple angles.
8. Place a ruler, scale, or other recognizable item near physical evidence to indicate size and distance. During photography, macro measurement of the failed parts and other pertinent components should be made.
9. Complete a log entry for each photographic activity. Label all photographic media with the PHMSA incident ID, time, date, and location of the photography, photographer, and a short description of the contents of the photographic record.
10. Determine whether an analysis of an item is required. Including NDE, examining in a laboratory of; parts, components, corrosion product, coating samples, liquids w/syringe and other related evidence.
11. If analysis is required, determine whether the analysis can be conducted at the scene or will have to be conducted externally.

12. Label the evidence at the scene with the PHMSA incident ID, date, time, location of the evidence, name of the investigator, and evidence tracking number. Photograph labeled evidence for pattern analysis before removing.
13. Protect the evidence from further damage and/or contamination, as described in the analysis plan for this evidence. Preservation of evidence includes bubble wrap and only use a benign protective oily spray or grease on items when directed to do so. Packaging should only be removed, analyzed, or examined in a laboratory. Wrapping the evidence with “Saran” wrap or other plastic wrap in preparation for transport is appropriate as long as moisture is not locked in the package such that corrosion could take place.
14. If the evidence will be removed, identify a suitably secure location to store the evidence for later analysis in accordance with the plan requirements. If evidence consists of sections of pipe, valves and other large components, they should be placed in a secure place such as warehouses, hangers and areas with locked fences covered with plastic awning.
15. Remove the evidence, if appropriate/necessary (if the evidence removal requires a third-party specialist, coordinate with HQ and the Regional Office to obtain this assistance). Only certain people are qualified for this (e.g. the lead investigator or qualified third party).
16. Ensure that the removal has been recorded and document its custody.
17. Perform the required analysis in accordance with the analysis plan.

SECTION 2 - Gathering Documentation

1. Note: When the investigator obtains documents from companies or private entities, he or she should request that the company or private entity mark all information that it believes contains trade secrets or confidential business information (CBI).
2. Obtain documentation requests from the investigators.
3. Transmit the request.
4. Assign an easily comprehensible tracking number to the documentation request.
5. Record documentation requested in the Evidence Collection List.
6. If the documentation is not received by the time indicated on the request form, consult with the requesting investigator to determine whether he or she still needs the document.
7. If the investigator still needs the documentation, consult with PHMSA PHC to determine what will be needed to obtain it (e.g. a subpoena).
8. Once the documentation is received and logged, give it to the requesting investigator.
9. A procedure should be included to obtain names and contact information of all witnesses directly related to the incident.

SECTION 3 - Controlling Evidence

1. Assign an information type code to the evidence or document and apply it to the evidence. Coordinate with tracking number
2. Obtain the evidence and any additional information or notes regarding the evidence from the investigator.

3. Date stamp the evidence (this may require using an evidence tag).
4. Generate an Evidence Control Form and complete an Evidence Control Form entry for the information or evidence.
5. Attach the Evidence Control Form to the physical evidence/notes, if available.
6. Complete a Master Evidence Log entry for the new evidence.
7. File the Evidence Control Form according to the information type code and securely store it.
8. Lock the room and/or file cabinet in which controlled information or evidence is stored when you are not physically present.
9. Ensure that computer-based information or evidence is password-protected.
10. Sign-out evidence into/from the locked storage area.
11. Maintain the evidence in your immediate possession at all times when it is removed from the locked storage area.

Evidence Tag Example:

<table>
<tr><td colspan="2">Evidence and Custody Transfer Tag (Example)</td></tr>
<tr><td>Incident Type:</td><td></td></tr>
<tr><td>Tracking No.:</td><td></td></tr>
<tr><td>Date Collected:</td><td></td></tr>
<tr><td>Collected By:</td><td></td></tr>
<tr><td>Location:</td><td></td></tr>
<tr><td>Operator:</td><td></td></tr>
<tr><td>System:</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="8">Disposition:
Where the evidence is to be taken and by whom (e.g.; origin; destination; shipper).
As evidence custody is transferred, each receiver shall sign form and identify their agency.</td><td>Received From:</td></tr>
<tr><td>Received By:</td></tr>
<tr><td>Date: Time:</td></tr>
<tr><td></td></tr>
<tr><td>Received From:</td></tr>
<tr><td>Received By:</td></tr>
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<tr><td></td><td></td></tr>
<tr><td rowspan="9">Item Description and Notes</td><td></td></tr>
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</table>

Evidence Collection List

Priority	Description	Information Type Code	Owner	Requested?
Notes and Comments				

Evidence Control Form

Evidence Identification				
Tracking Number	Date Received	Item	Description	Storage Location

Action Log				
Date	Action (e.g. checked out, returned, shipped)	Person/Organization	Current Location	Notes

Master Evidence Log

PHMSA Tracking #	Supplying Organization's Tracking #	Date Received	Item	Description	Received by:	Received From:	Notes:

Attachment 2 – Metallurgical Testing Worksheets

PURPOSE:
To provide sample worksheets for documenting testing that is performed in support of the metallurgical analysis.

SECTIONS:
1. Mechanical Testing worksheets
2. Fracture Sketch and Physical Measurements worksheet
3. Chemical Analysis worksheet
4. Metallographic Specimens and Photograph worksheet

SECTION 1 – Mechanical Testing worksheet

Test Locations: (e.g.; specific segment of pipe; location; comments)	

Table 1 Transverse Pipe Body Tensile Test Results			
Test Location	Yield Strength (PSI)	Tensile Strength (PSI)	% Elongation in 2”

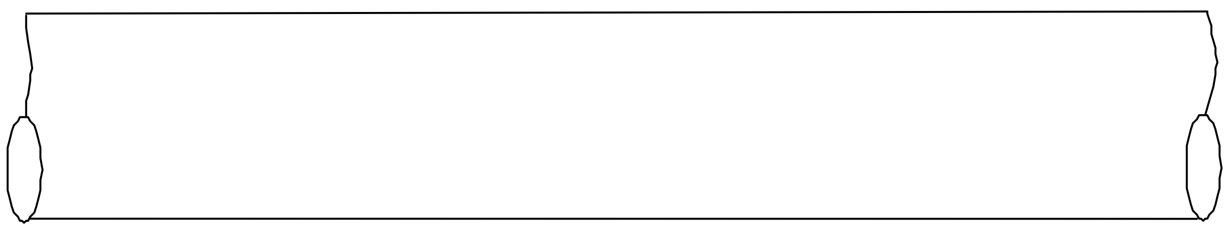
Table 2 Transverse Weld Tensile Test Results			
Test Location	Tensile Strength (PSI)	% Elongation in 2”	Fracture Location

Table 3 Transverse Pipe Body Charpy Tests Specimen Size - ____ mm x 10 mm				
Test Temperature (° F)	Absorbed Energy (ft-lbs)	Absorbed Energy adjusted to normal size Specimen (ft-lbs)	Lateral Expansion (mils)	% Shear

Table 4 Transverse Weld & HAZ Charpy Tests Specimen Size - ____ mm x 10 mm				
Test Temperature (° F)	Absorbed Energy (ft-lbs)	Absorbed Energy adjusted to normal size Specimen (ft-lbs)	Lateral Expansion (mils)	% Shear

SECTION 2 – Fracture Sketch and Measurements worksheet

Flow →



Notes: ____

____

____

Longitudinal Length (in):		
Max. Opening Width (in):		
Long Seam Position (O'clock):		
OD at Pipe End (0º-180º):		
OD at Pipe End (90º-270º):		

Wall Thickness Survey at Pipe Ends		
Circumferential Position	Upstream End	Downstream End
12:00		
1:00		
2:00		
3:00		
4:00		
5:00		
6:00		
7:00		
8:00		
9:00		
10:00		
11:00		

SECTION 3 – Chemical Analysis worksheet

Test Locations: (e.g.; specific segment of pipe; location; comments)	

Table 1
Chemical Analysis

Element	Weight Percent	Element	Weight Percent
Carbon (C)		Molybdenum (Mo)	
Manganese (Mn)		Columbium (Cb)	
Phosphorus (P)		Vanadium (V)	
Sulfur (S)		Titanium (Ti)	
Silicon (Si)		Cobalt (Co)	
Aluminum (Al)		Tin (Sn)	
Copper (Cu)		Arsenic (As)	
Nickel (Ni)		Boron (B)	
Chromium (Cr)		Calcium (Ca)	

Table 2
Chemical Analysis of Corrosion Products present at Failure Site

Location	Significant Constituents	Comments and Findings

Table 3
Chemical Analysis of Liquids or other Materials of interest present at Failure Site

Location	Significant Constituents	Comments and Findings

Remarks:

SECTION 4 – Metallographic Specimens and Photograph worksheet

Metallographic Specimen worksheet		
Sample #	**Location**	**Description**

Metallographic Sections and Photograph worksheet				
Photo#	**Sample #**	**Mag**	**Etchant**	**Description**