MagneScan™ MFL 3
Inspection Report for
20 inch Crude Oil Pipeline



Enbridge Energy, Limited Partnership

Line 5: 20" East North Straits (ENO) to
East Mackinaw (EMA)
Run Date: 13 March 2019

Work Order Number: W132010430
Contract Number: 31715
Project Number: 451199_20A
Issue 1, 11 June 2019

BAKER HUGHES
a GE company

Executive Summary

A full survey of the Enbridge Energy, Limited Partnership Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA) pipeline was successfully completed by Baker Hughes, a GE company (BHGE), on 13th of March 2019. The tool was pulled from the pipeline on the 13th of March 2019. The pipeline survey was performed using the BHGE Magnetic Flux Leakage (MFL 3) inspection vehicle.

A total of 158 metal loss features have been detected on the inspection survey of which the deepest was 36%. These are distributed throughout the pipeline. Approximately 11% of the total number of spools have metal loss reported within them.

The majority of these are internal and are characteristic of mill/manufacturing faults.

In order to improve the depth prediction of features in the line, BHGE reviewed and manually sized (as needed) all boxed data within Clusters containing:

1. A Box with depth ≥ 45% WT or
2. A Box with a width ≥ 61mm and depth between 20-45% WT.

Note: The girth welds for this inspection have been correlated with the baseline listing provided by Enbridge. The draft pipeline listing was approved by Enbridge on the 10th of June 2019.

Below are the names, roles and certification levels of the analysis team that participated in this project:

Analyst	Role	Certification Level
Aniko Stamp	QA Checker / Report Checker	2
Chih-Hao Sho	Data Analyst / Report Author	1

This report was generated following the Enbridge ILI Minimum Reporting Requirements Guide V.8.2.

We should hereby like to express our appreciation for the assistance and co-operation which we received from Enbridge Energy, Limited Partnership in the course of this project.

Lead Analysis: **Chih-Hao Sho**

Report Approved by: **Aniko Stamp** **Date:** **June 10, 2019**

Integrity Specialist: **Ramzan Mohammed** **Telephone:** **403-298-0233**

Project Manager: **Tanis Lindberg** **Telephone:** **780-465-8277**

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Inspection Summary

This section presents a summary of inspection operation 451199_20A which was conducted for Enbridge Energy, Limited Partnership in the Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA), 20 inch nominal diameter, 4.1 miles, Crude Oil pipeline.

The pipeline was inspected by the BHGE Magnetic Flux Leakage (MFL 3) inspection vehicle on 13th March 2019.

This was a reinspection of the pipeline with a previous inspection having been carried out by BHGE on 20th June 2018.

1.1. Metal Loss

A total of 158 metal loss features have been detected on the inspection survey of which the deepest was 36%. These are distributed throughout the pipeline. Approximately 11% of the total number of spools have metal loss reported within them.

The majority of these are internal and are characteristic of mill/manufacturing faults.

Mill/manufacturing faults will have been present in the pipeline since it was commissioned. It can be difficult to achieve the normal sizing accuracy for mill/manufacturing faults depending on whether these metal loss features are the result of hot working or cold working of the pipe steel. Consequently, it should be noted that the sizing accuracy specified for corrosion in the Inspection System Performance Specification (Appendix G) contained in the contract may not be applicable to mill/manufacturing faults.

Summaries of all the metal loss features are presented in Section 2.1.

Corrosion Severity

Feature Type	Value	GW	MSP Orientation (°)	Radial Position
Worst Depth	25%	31	171	Internal
Worst Eff. Area RPR	1.11	31	171	Internal
Number of Features with Eff. Area RPR ≤ 0.90*	0	N/A	N/A	N/A
Number of Features with Depth ≥ 65%	0	N/A	N/A	N/A

* The Eff. Area RPR is rounded to 2 decimal places when calculating the number of metal loss with Eff. Area RPR ≤ 0.90.

1.2. Pipeline Anomalies

The following is a summary of any pipeline anomalies which have been detected on the inspection survey:

ferrous metal objects:	0
eccentric pipeline casings:	0
dents:	1
girth weld anomalies:	4
shell repairs:	0
patch repaired spools:	0

Girth Weld Anomaly Severity

FeatureType	No. of Features	GW	Orientation (°)	Circumferential Length (in)
GW Anomaly	4	N/A	N/A	N/A
Longest GW Anomaly	N/A	1810	360	2.4

Combination Geometry Features Severity

Feature Type	Top	Bottom	Max Depth (%)
Geometry Feature Depth d ≥ 5%	0	0	N/A
Geometry Feature associated with stress riser, weld, or metal loss	0	0	N/A

Wrinkle/Buckle Severity

Feature Type	Top	Bottom	Max Depth (%)
Wrinkle/Buckles	N/A	N/A	N/A
Wrinkle/Buckles across seam welds or girth welds	N/A	N/A	N/A

Note: MFL tools do not have the capability to detect Wrinkle/Buckle features.

1.3. Inspection Quality

Inspection data was obtained for the full length (4.1 miles) of the pipeline.

The primary sensors for metal loss detection CH 170 was non-responsive from launch and CHs 1, 2, 31, 84, 93 and 9 were under responding throughout the inspection. For the non-adjacent sensors, we can meet full contractual detection and sizing specifications.

For the 2 adjacent under-responding sensors (CHs 1 and 2), we can offer the following revised HR specifications. Please refer to the table below for further details.

Seamwelded Pipe

Faulty Sensor Type	Sensor No.	Start Distance (ft)	End Distance (ft)	Affected Distance	Circumferential Impact	Min diameter for sizing/ detection	Detection (90%POD)		Sizing Specification (80% Confidence Level)		
							General Corrosion / Circum. Groove	Pitting / Axial Groove	Pitting / General Corrosion	Axial Groove	Circumferential Groove
Main T1	2-Jan	0	21753	21753	1.2%	0.55 in	12%	15%	+7/-17%	-22/+7%	-7/+22%

Seamless Pipe

Faulty Channel	No.	Start Distance (ft)	End Distance (ft)	Affected Distance	Circumferential Impact	Min diameter for sizing/ detection	Detection (90%POD)		Sizing Specification (80% Confidence Level)		
							General Corrosion / Circum. Groove	Pitting / Axial Groove	Pitting / General Corrosion	Axial Groove	Circumferential Groove
Main T1	2-Jan	0	21753	21753	1.2%	0.55 in	15%	20%	+7/-17%	-22/+7%	-7/+22%

Apart from this, the quality of the inspection data is satisfactory and this has enabled a comprehensive assessment of the pipeline to be carried out.

1.3.1. Velocity Plot

The velocity plot shows the speed of the inspection vehicle during the inspection run.

The red line on the velocity plot indicates the specified maximum velocity for the inspection vehicle. If the vehicle exceeds the specified maximum velocity then the performance of the inspection vehicle may be degraded.

The velocity of the inspection vehicle exceeded the specified maximum velocity in one section of the pipeline. This speed excursion covered a total distance of 3.4 ft.

Within this excursion area, it is possible that some small area or narrow, axially oriented metal loss features may not have been identified from the inspection data; and that the sizing of detected metal loss features may be impaired. Please note there were no indications previously visible nor reported within this region.

The location and extent of this excursion area is given in the table below:

ABSOLUTE DISTANCE (ft)		GIRTH WELD		DISTANCE OF SPEED EXCURSION (ft)
FROM	TO	FROM	TO	
35.6	39	71	71	3.4

The inspection vehicle's average velocity during the inspection run was 7.4 ft/s.

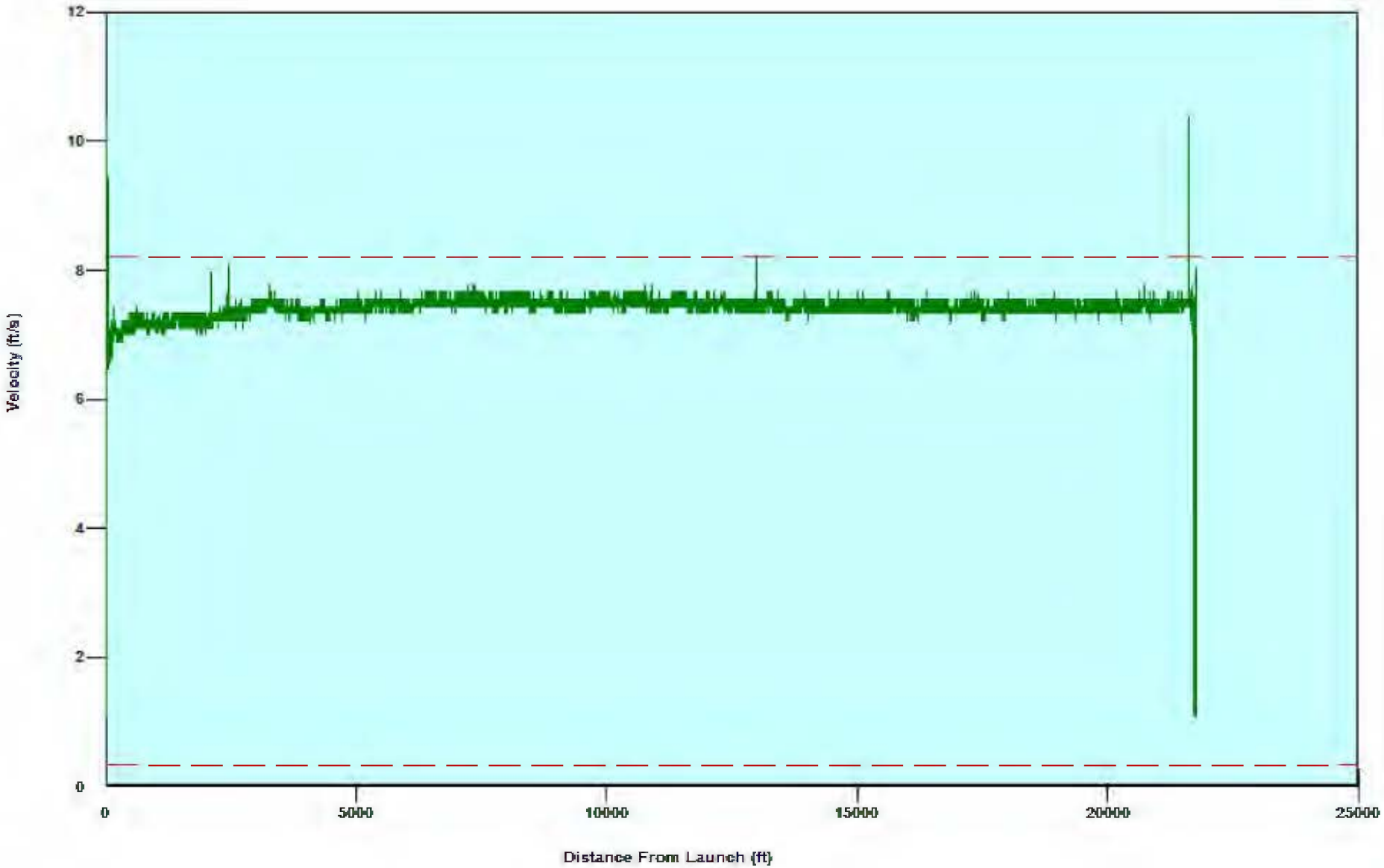
The velocity profile plot is presented overleaf.

VELOCITY PLOT

Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)

Contractual Maximum and Minimum Velocities

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1.4. Summary of Pipeline Changes

This pipeline was previously inspected by BHGE on 20th June 2018. The previous report reference number is 450634_20A.

The following table summarises the differences in the numbers of the reported features between the current inspection and the previous inspection 450634_20A.

Feature Type	450634_20A - 20 June 2018	451199_20A - 13 March 2019	Comment
External metal loss	0	0	No changes between inspections.
Internal metal loss	12	12	No changes between inspections.
External mill/manufacturing faults	75	74	No significant changes between inspections.
Internal mill/manufacturing faults	74	72	No significant changes between inspections.
Dents	0	1	1 dent not visible in the previous inspection as been reported.
Girth weld anomalies	0	4	4 previously visible GWA anomalies have been reported.
Metal objects	0	0	No changes between inspections.
Eccentric casings	0	0	No changes between inspections.
Shell repairs	0	0	No changes between inspections.
Patch repaired spools	0	0	No changes between inspections.

Pressure Based Pipeline Summary Report

The Pressure Based Pipeline Summary Report provides an overview of the pipeline condition.

2.1. Metal Loss Information

This section provides summaries of all the metal loss features detected along the pipeline in the following formats:

- Pressure Sentenced Plot
- Pressure Based Histograms
- Depth Based Histograms
- Orientation Plot

2.1.1. Pressure Sentenced Plot

The pressure sentenced plot shows the relative significance of each detected metal loss feature.

Metal loss features that have been identified as manufacturing faults are not included on the pressure sentenced plot.

The significance of each metal loss feature has been assessed using the pressure sentencing formulae as supplied by the client and defined in the Appendix to the Specification for the Pipeline Inspection Report (Appendix F).

These formulae depend on the following five variables;

two measured by the BHGE inspection system:

- the predicted peak depth of the metal loss feature, or the area ratio if the metal loss feature consists of two or more metal losses that have been clustered together;

- the predicted axial length of the metal loss feature, or the overall predicted axial length if the metal loss feature consists of two or more metal losses that have been clustered together;

and three specified by the pipeline operator:

- the external pipe radius (r);

- the nominal pipe wall thickness (nwt); and,

- the Specified Minimum Yield Strength (SMYS).

The pressure sentenced plot shows the relative significance of each metal loss feature by plotting the sentenced depth of the metal loss feature against its predicted axial length and by indicating on the graph the appropriate curve that represents an RPR of 1. The curve representing an RPR of 1 will move if any of the values for r, nwt, or SMYS change.

Those metal loss features with RPR values <1 will be plotted above the curve. The lower the value, the higher the significance and the further away from the curve the metal loss feature will be plotted.

The report contains one pressure sentenced plot for each major pipeline segment defined by the pipeline operator. Only those metal loss features within the major segment, and any minor segments within the major segment, are shown on the respective pressure sentenced plot. The RPR unity curve is calculated using the values of r, nwt, and SMYS that have been specified for the major segment by the pipeline operator; these values are also given on each plot.

A pressure sentenced plot will not be provided if the major segment does not contain any metal loss features.

There are two symbols used on the pressure sentenced plot to represent metal loss features. These are:

+	The metal loss feature is within the major segment. That is the spool containing the metal loss feature has pipeline parameters equal to those used to calculate the RPR unity curve.
Δ	The metal loss feature is within a minor segment. That is the spool containing the metal loss feature has pipeline parameters different to those used to calculate the RPR unity curve.

Each pressure sentenced plot is presented overleaf.

SENTENCED PLOT

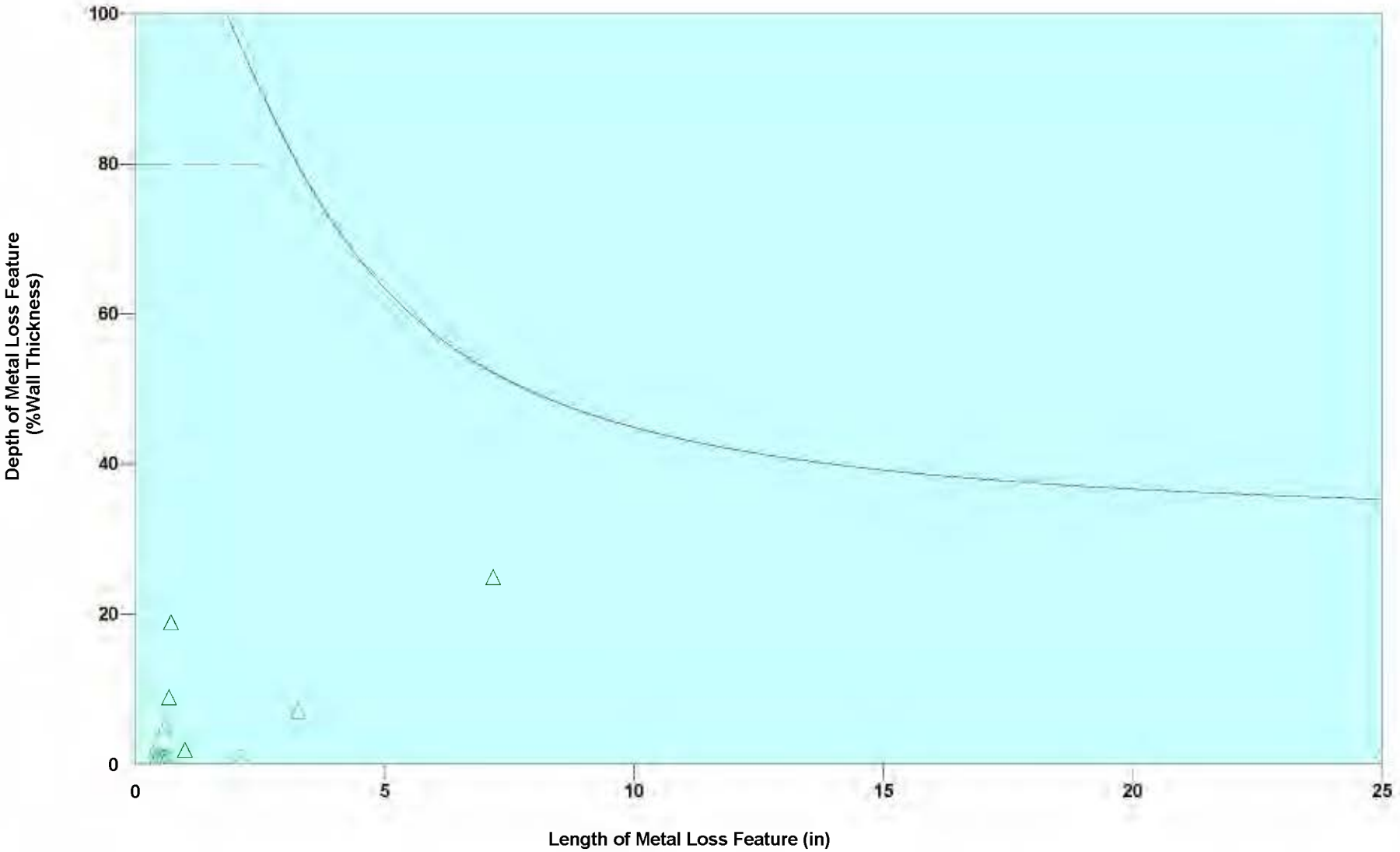
Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)

Major Segment 1

External Diameter 20 in
Wall Thickness 0.812 in
SMYS 30000.0 PSI

R.P.R. = 1.0

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2.1.2. Pressure Based Histograms

The pressure based histograms show the distribution of the most significant metal loss features along the pipeline.

Metal loss features that have been identified as manufacturing faults are not included in the pressure based histograms.

The significance of each metal loss feature has been assessed using the pressure sentencing formulae supplied by the client and defined in the Appendix to the Specification for the Pipeline Inspection Report (Appendix F).

Each pressure based histogram shows the distribution along the pipeline of those metal loss features with RPR values below a chosen pressure sentenced threshold.

Each bar on the histogram represents the number of occurrences within a 50 ft section of the pipeline.

The pressure sentenced thresholds chosen to highlight the most significant metal loss features are as follows:

- all metal loss features with RPR values <1.000
- all metal loss features with RPR values <1.500
- all metal loss features with RPR values <2.000

Summarising from the histograms:

0 metal loss features with RPR values <1.000

12 metal loss features with RPR values <1.500

12 metal loss features with RPR values <2.000

The RPR values are not rounded when calculating this summary.

In addition, a single three-dimensional summary histogram is included which shows the distribution along the pipeline of those metal loss features with RPR values below each of the chosen pressure sentenced thresholds.

The pressure based histograms are presented overleaf.

Number of Metal Loss Features

PRESSURE BASED HISTOGRAM

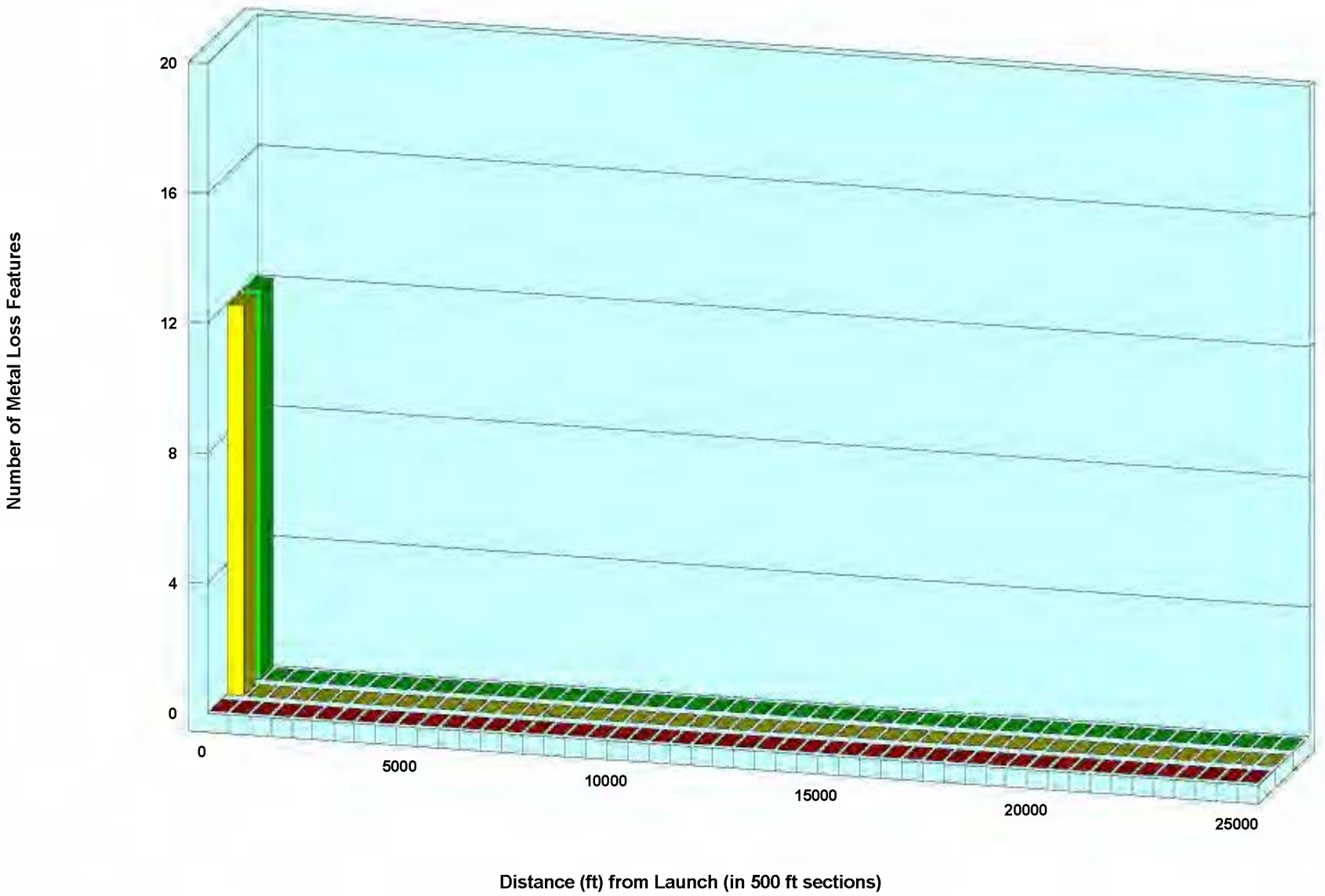
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PRESSURE BASED HISTOGRAM

Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)

R.P.R. < 2.000
R.P.R. < 1.500
R.P.R. < 1.000



2.1.3. Depth Based Histograms

The depth based histograms show the distribution of all detected metal loss features along the pipeline.

Twelve histograms are presented in this section:

- three ungraded metal loss histograms
- eight graded metal loss histograms
- one three-dimensional summary histogram

Ungraded Metal Loss Histograms

The total metal loss histogram shows the distribution of all metal loss features along the pipeline. Each bar on the histogram represents the number of occurrences within a 50 ft section of the pipeline.

The area metal loss histogram shows how much of the pipe surface has been affected by metal loss. Each bar on the histogram represents the total surface area of the metal loss within a 50 ft section of the pipeline. This is expressed as a percentage of the surface area of an undamaged pipe section.

The volume metal loss histogram shows how the volume of metal in the pipeline has been affected by metal loss. Each bar on the histogram represents the total volume of the metal loss features within a 50 ft section of the pipeline. This is expressed as a percentage of the volume of metal in an undamaged pipe section.

Graded Metal Loss Histograms

The metal loss features are graded into eight categories, which are derived from combinations of two length and four predicted peak depth categories.

There is one graded metal loss histogram for each category. Each bar on the histogram represents the number of occurrences within a 50 ft section of the pipeline.

Summarising from the histograms, a total of **158** metal loss features have been identified within the pipeline. These have been graded as follows:

103 metal loss features with predicted axial lengths ≤ 3t.
Of these:

53	have a predicted peak depth of ≤ 10%t.
6	have a predicted peak depth of > 10%t and ≤ 15%t.
17	have a predicted peak depth of > 15%t and ≤ 20%t.
27	have a predicted peak depth of > 20%t.

55 metal loss features with a predicted length > 3t.
Of these:

14	have a predicted peak depth of ≤ 10%t.
7	have a predicted peak depth of > 10%t and ≤ 15%t.
4	have a predicted peak depth of > 15%t and ≤ 20%t.
30	have a predicted peak depth of > 20%t.

Three-Dimensional Summary Histogram

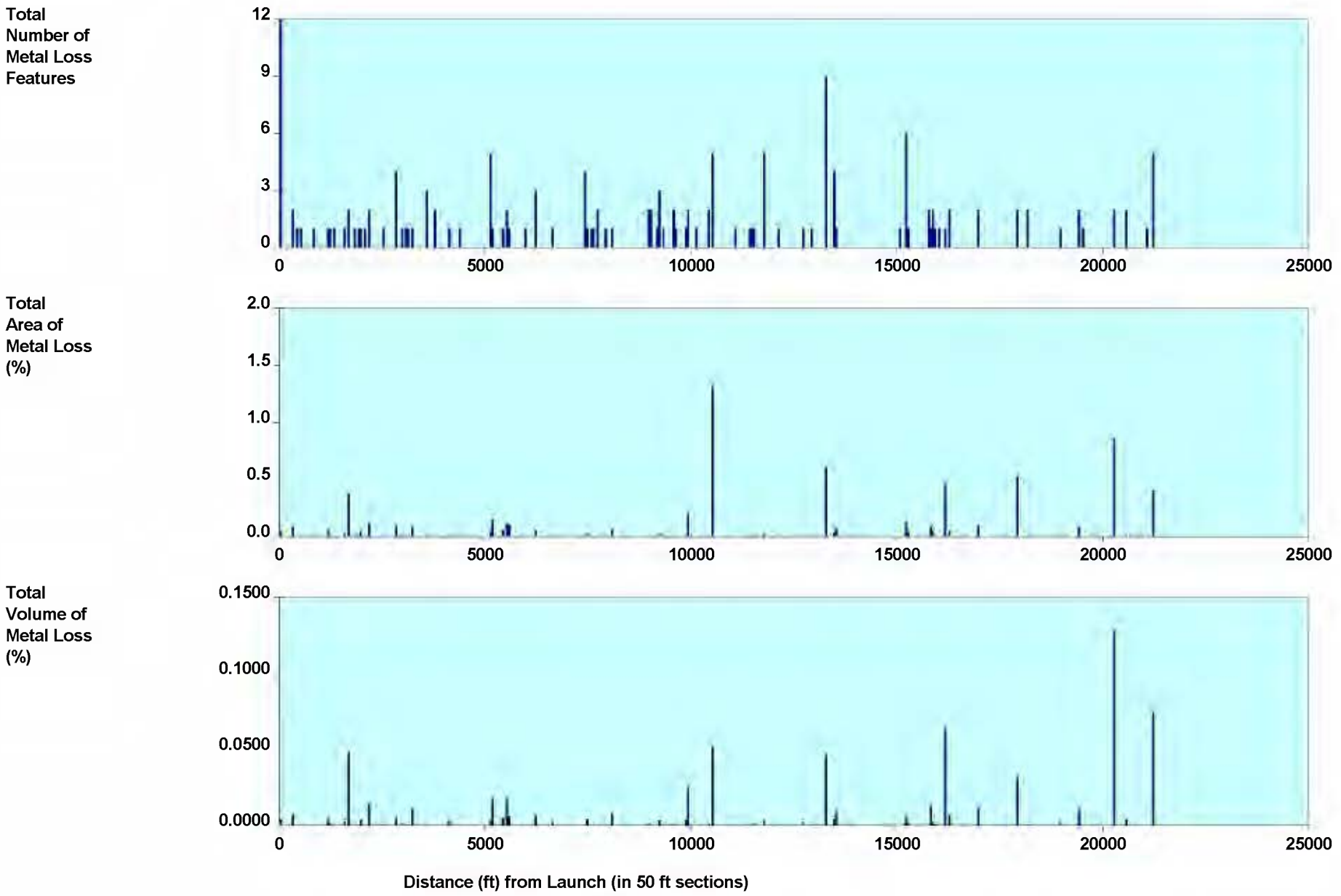
The metal loss features are graded into nine depth categories and displayed on a single three-dimensional histogram. Each bar on the summary histogram represents the number of metal loss occurrences within the appropriate depth category for a specific section of the pipeline.

The histograms are presented on four pages overleaf.

DEPTH BASED HISTOGRAM - ALL METAL LOSS

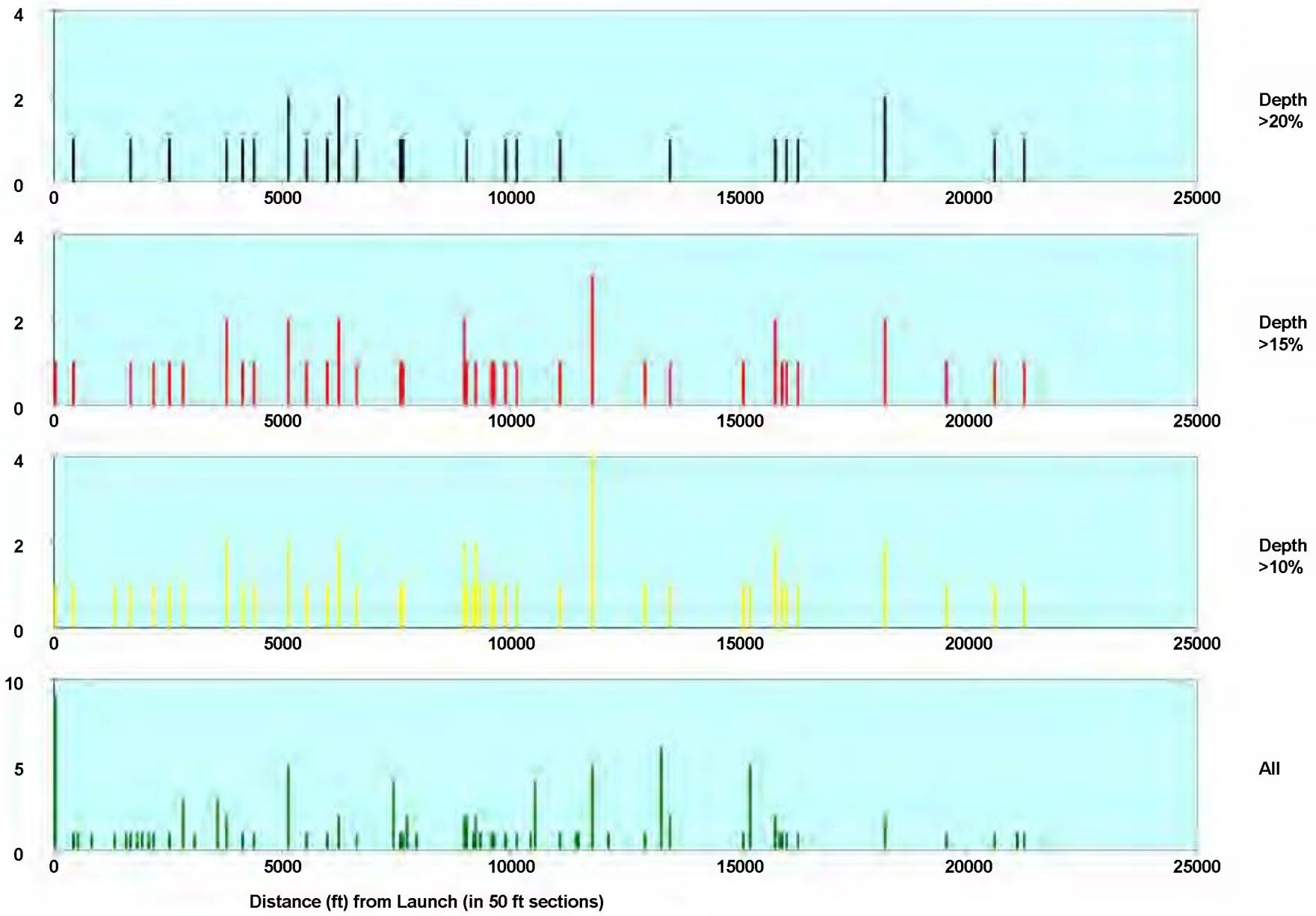
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Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)



Number of
Metal Loss
Features

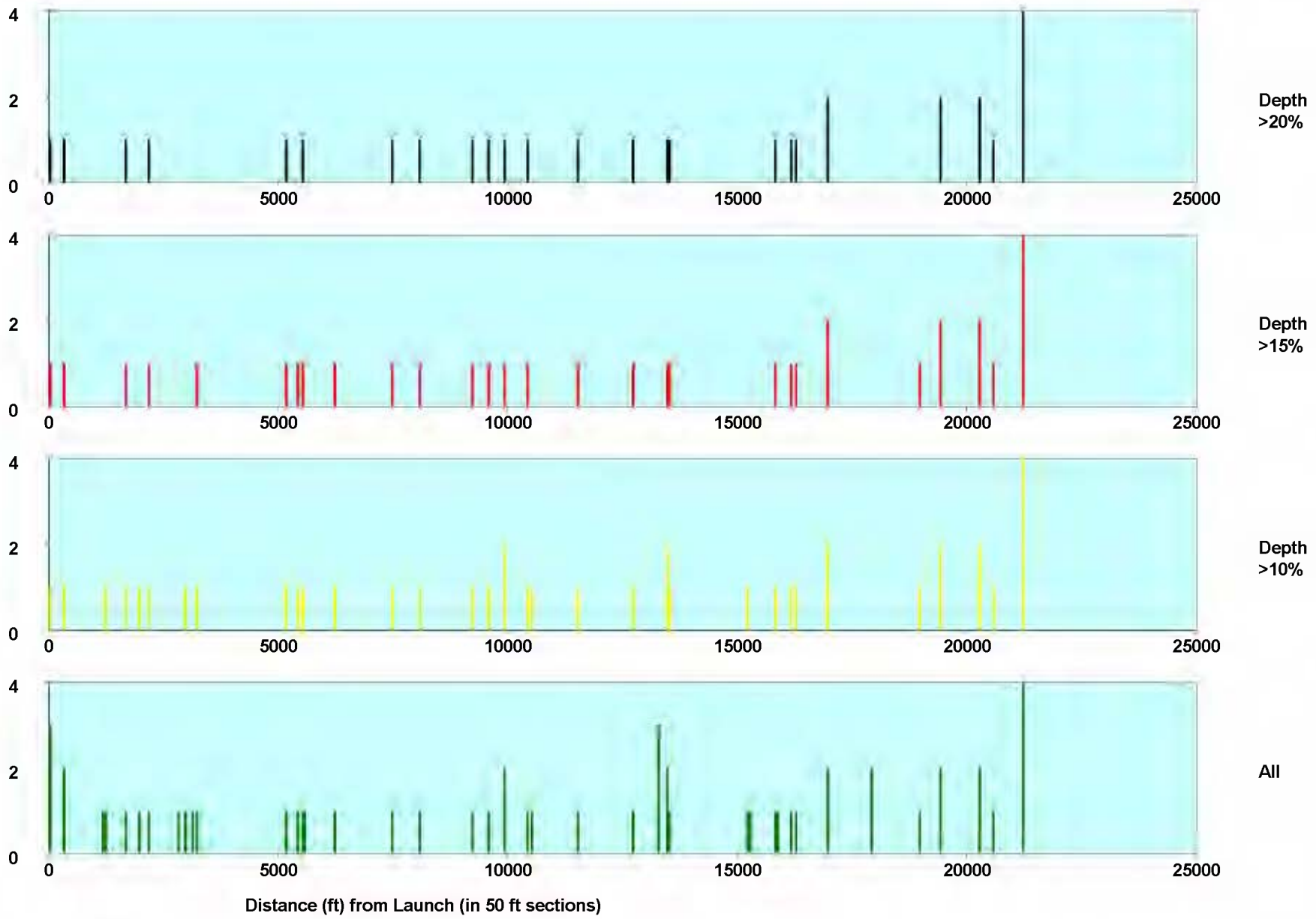
DEPTH BASED HISTOGRAM
Axial Length ≤ 3t
Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)



Number of
Metal Loss
Features

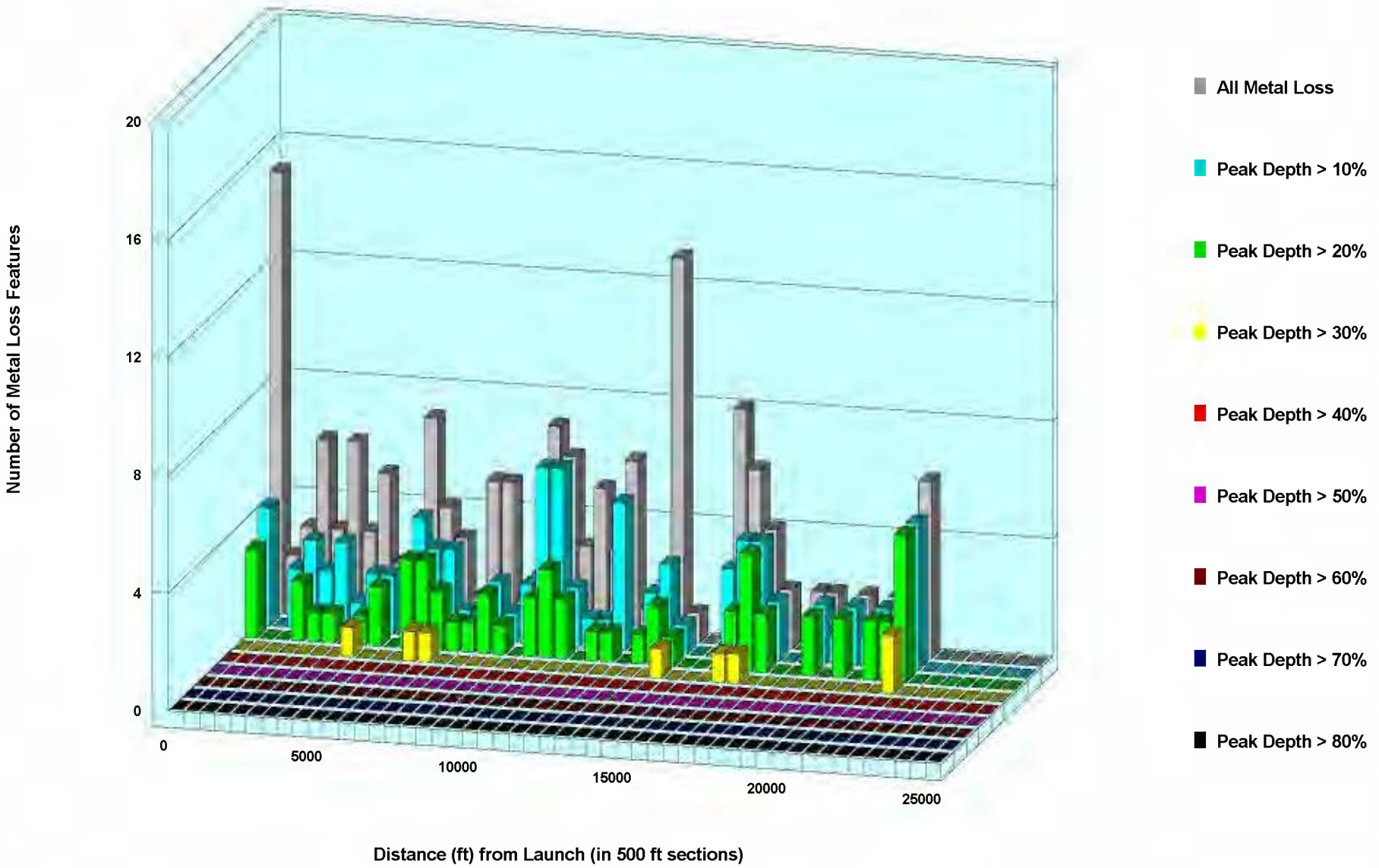
DEPTH BASED HISTOGRAM
Axial Length > 3t
Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)

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DEPTH BASED HISTOGRAM

Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)



2.1.4. Orientation Plot

The orientation plot shows the location and extent of each metal loss feature around the pipe's circumference.

The absolute distance from the launch is plotted against the orientation of the metal loss. The orientation is based on a 12 hour clock as viewed in the direction of product flow; for example, twelve indicates the top of the pipe and six indicates the bottom.

For each metal loss feature a box is drawn on the plot showing the predicted circumferential and axial extent of the metal loss feature. Due to the scale along the distance axis, each metal loss feature appears as a solid vertical line on the plot.

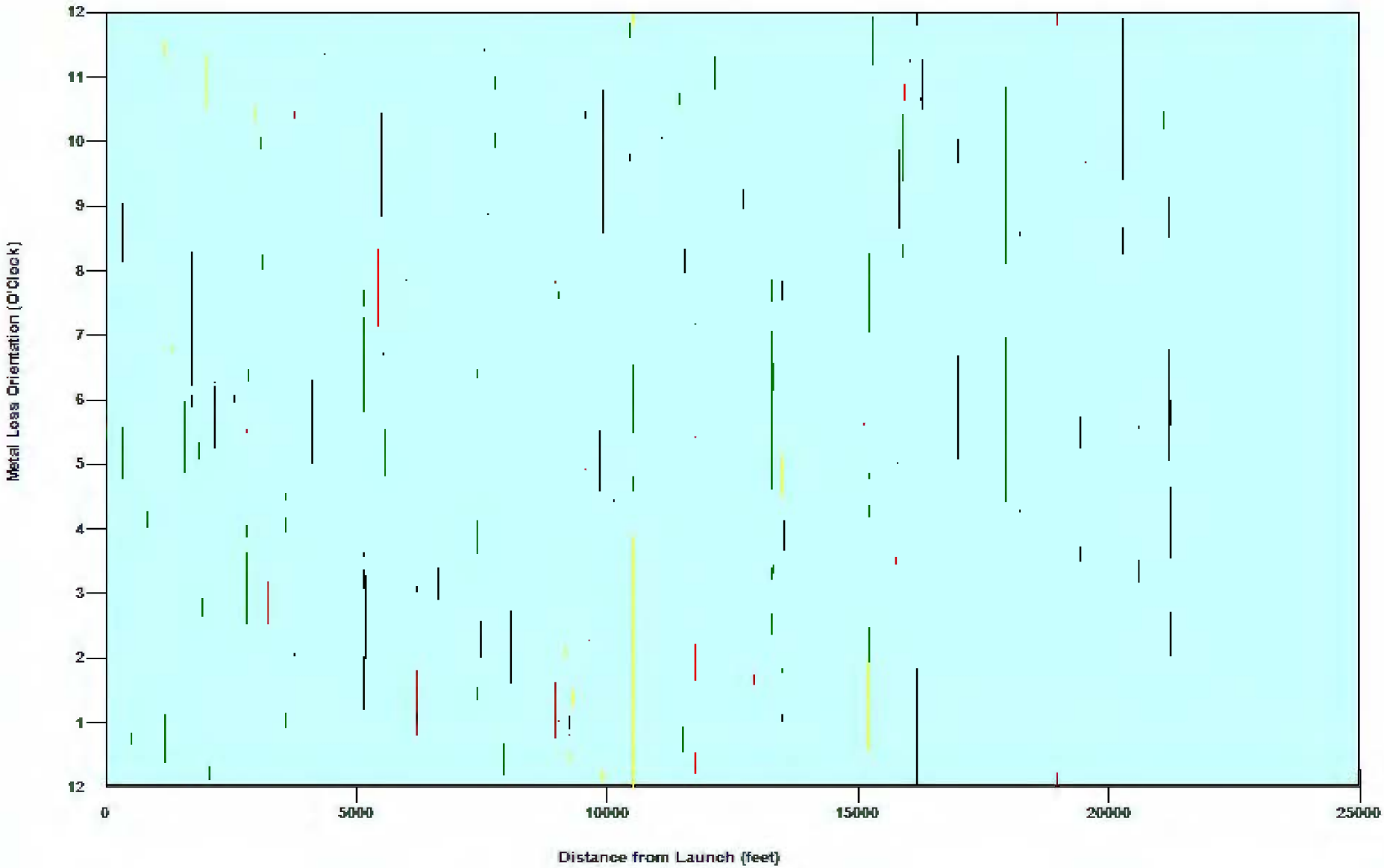
The orientation plot is presented overleaf.

ORIENTATION PLOT

Line 5: 20" East North Straits (ENO) to East Mackinaw (EMA)

Peak Depth ≤ 10%
10% < Peak Depth ≤ 15%
15% < Peak Depth ≤ 20%
Peak Depth > 20%

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2.2. Pipeline Listing

The pipeline listing is presented electronically in an excel spreadsheet, in the format specified by Enbridge and it follows the ILI Minimum Reporting Requirements Guide V.8.2.

Appendix A. Locating Metal Loss Features And Pipeline Anomalies

Locating metal loss features or pipeline anomalies is a difficult task, which can cost the pipeline operator valuable time and resources. Therefore, it is important that appropriate techniques are used at each stage in locating these features.

This appendix gives guidelines for locating pipeline features efficiently and effectively.

A1. Reference Points

Wherever possible, the position of metal loss features and pipeline anomalies is related to reference points that can be easily identified and located from the surface.

Reference points are either pipeline fittings, such as mainline valves, offtakes, anodes or side bends, or artificial reference points, such as magnets or line markers; these will have been placed on or near the pipeline at the time of the inspection.

At least one reference point is provided for each metal loss feature reported on the inspection sheets. If the reference point is more than 1600 feet from the metal loss feature then a second reference point will usually be provided.

Two reference points are provided for each pipeline anomaly. These reference points are extracted automatically from the pipeline listing and are limited to mainline valves and line markers.

A2. Location of Features

The location of the feature can be carried out in two stages; locating the spool that contains the metal loss feature or pipeline anomaly; then locating the feature within that spool.

To locate the spool containing the feature, the distance from the reference point to the girth weld at the upstream end of the spool is provided.

To locate the feature within the spool, the distance from the upstream girth weld to the feature and the location of the feature around the circumference of the pipe, as viewed in the direction of flow, are provided. Girth weld anomalies will be located within the upstream girth weld.

These distances are given to an accuracy of ±1%. It is recommended that electronic distance measuring equipment (EDM) is used to measure out these distances accurately.

A3. Identification of Features

Metal objects should be easily identified. Metal loss, dents and girth weld anomalies will require an area of the protective wrap to be removed.

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A minimum area of approximately 2 ft along the pipe axis by 45° of the circumference, centred on the reported feature position, should be cleaned back to bare metal.

Once this has been done, any external metal loss, dents or the girth weld that contains an anomaly should be easily identified. The position of internal metal loss should be marked on the outside of the pipe in preparation for further examination.

Shallow dents can usually be identified by running one's hand along the pipe surface, or by placing a straight edge along the pipe.

NOTE: Features that are wholly contained within the pipe wall, such as voids, slag inclusions, or non-magnetic alloys, may have been classified as external metal loss, however these anomalies are quite rare.

A4. Contacting BHGE

BHGE aims to provide its clients with a quality service. If you cannot locate a metal loss feature from the information provided on the inspection sheet or if the metal loss is very different from the description given on the inspection sheet, then please do not hesitate to contact the project manager at BHGE.

BHGE Telephone Numbers:

Project Manager:	Tanis Lindberg
Telephone:	403-262-7447 (CANADA)
Address:	BHGE Canada Ltd. (Calgary) 4908 - 52nd Street S.E. Calgary, Alberta T2B 3R2 CANADA

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Appendix B. Guidance Notes for Recording Excavation of Metal Loss Features

Contents

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B2. Preparing pipe surface for inspection and recording

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B4. External metal loss depth recording

B5. Wall thickness and remaining ligament thickness recording

B6. Locating and quantifying internal metal loss in gas pipelines using x-radiography

B6.1 Introduction
B6.2 Technique for Quantifying Internal Metal Loss

Illustrations

Figure 1 Example of rubbing

Figure 2 Typical micrometer and bridging bar arrangement

Figure 3 Typical arrangement for X-ray technique

Figure 4 Procedure for inspecting and recording reported metal loss features - simplified flow diagram

Figure 5 Example of completed Pipeline Damage Record form

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B1. Introduction

To help maintain and improve the defect sizing accuracy from these high resolution inspection systems it is extremely valuable to have feedback from defect excavations.

Reliable and accurate information from site investigations can be used to monitor actual defect dimensions against the dimensions reported from the inspection survey. This site data can then be used to improve defect sizing methods which brings benefit to all users of the inspection service.

We would ask pipeline operators wherever possible to feed any available comparison data from excavations back to us to help improve our service even more. For guidance, the most useful format for this data is as shown in the sample Damage Record Form in figure 5. This shows feature dimensions and location information.

We would like to express our appreciation to those who have provided this data in the past.

B2. Preparing Pipe Surface For Inspection And Recording

B2.1 Surface Preparation

To achieve satisfactory recording and measurement of the feature it is essential that the specified area of pipe surface is cleaned back to bare bright metal.

There are a number of methods for removing pipe wrap primer including:

(a) Solvent cleaning.

(b) Chemical cleaning.

(c) Wire brushing.

(d) Grit blasting.

For certain types of corrosion product it is possible to produce a finish resembling bright metal when cleaned using a wire brush. In this instance grit blasting is the preferred method in order to remove all the corrosion product.

B3. External Metal Loss Area Mapping

B3.1 Rubbing and Photographic Methods

The preferred method of mapping is by taking a simple rubbing. This is achieved by placing a sheet of paper over the feature, holding the paper firmly in place with, for example, small magnets and rubbing the long edge of a wax crayon over the surface of the paper. The edges of the feature will be delineated and if required, can be highlighted by careful manipulation of the crayon.

The following parameters should be annotated on the paper:

(a) Feature identity (e.g. BHGE Report Number and Feature Number).

(b) Direction of flow.

(c) Orientation of the feature.

(d) Distance of the feature from the nearest girth weld.

Refer to Figure 1 for an example of a mapped area using the rubbing technique.

The rubbing technique has a definite advantage over photographic recording methods in that it is possible to record all subsequent measurements directly on the rubbing in the appropriate location e.g. each individual pit depth in multiple pitting. Refer to Figure 1 for the example.

Photographic recording can be used but unless a 'polaroid' type film is used it can be a lengthy process before a result is obtained.

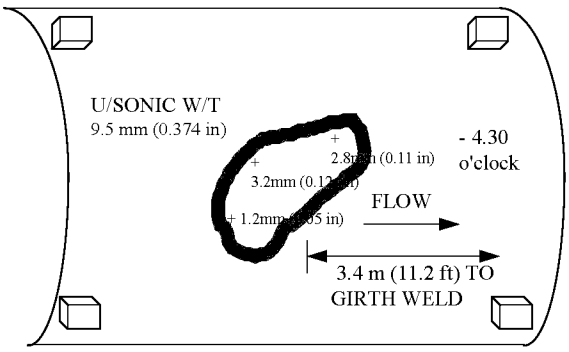


Figure 1: Example of Rubbing

B4. External Metal Loss Depth Recording

The most effective method for recording external metal loss depth is by using a depth micrometer in conjunction with a large bridging bar. Refer to Figure 2 for a typical arrangement.

It is recommended that the micrometer anvil be ground to a taper with a tip diameter of approximately 0.04 inches. This will enable entry into the small diameter pitting and concave surfaces found at the bottom of most metal loss features.

A pit gauge is not recommended because of its potential inaccuracy of up to 0.08 inches. A depth micrometer has a resolution of better than 0.002 inches.

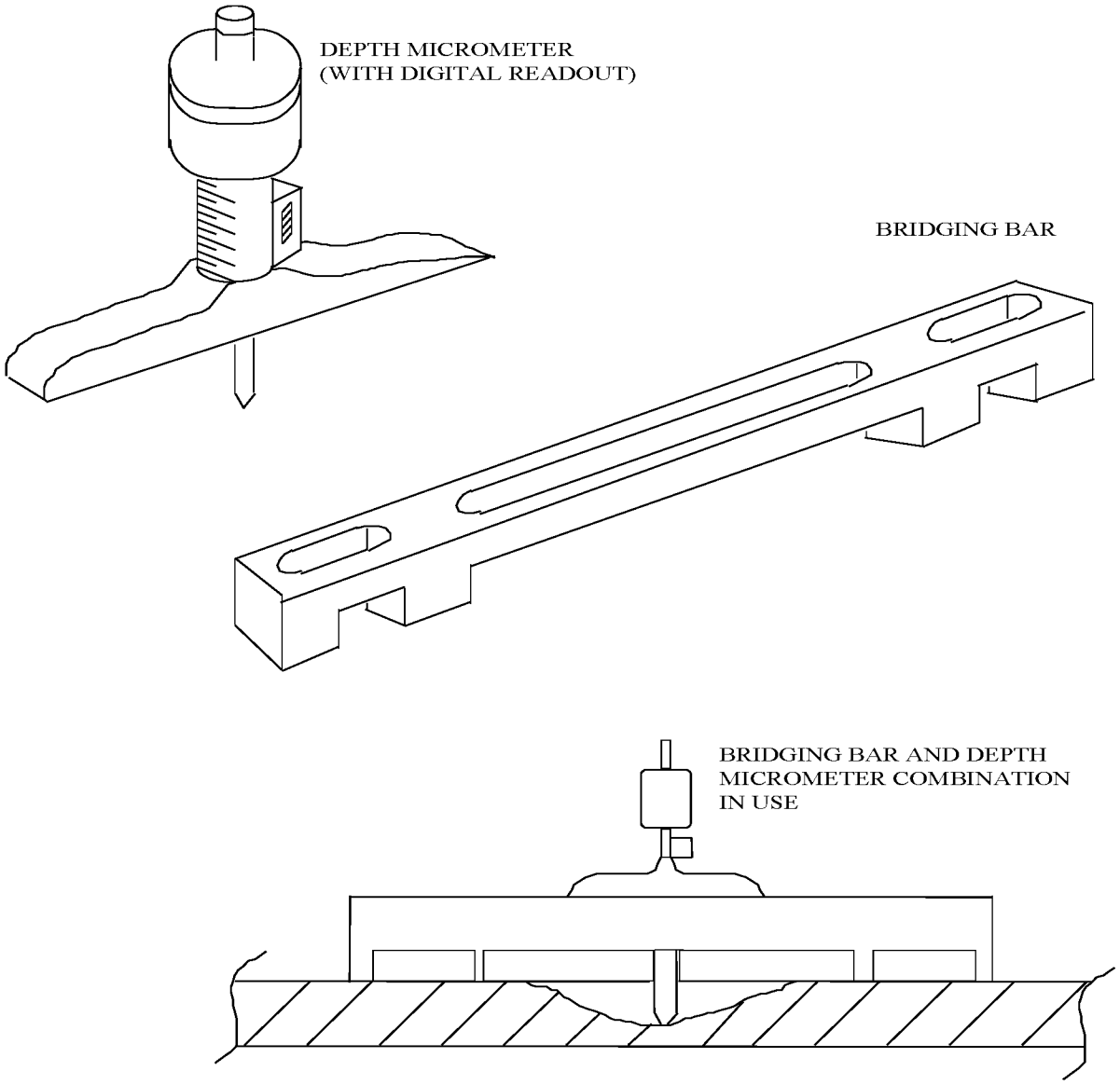


Figure 2: Typical Micrometer and Bridging Bar Arrangement

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B5. Wall Thickness And Remaining Ligament Thickness Recording

Pipe wall thicknesses and remaining ligament thicknesses of internal damage can be measured to an accuracy of ±0.002 inches using standard ultrasonic wall thicknesses meters and suitable couplant.

Extreme care should be exercised when attempting to measure remaining ligament thicknesses directly within an area of external damage because there is extra couplant under the transducer when mounted on concave surfaces which results in an overestimated reading.

Decisions on assessing the significance of the damage are primarily based on the remaining ligament thickness. It is therefore important to obtain a reliable reading. This is best accomplished by obtaining the minimum ultrasonic thickness reading immediately surrounding the damage and subtracting the mechanical depth measurement.

B6. Locating And Quantifying Internal Metal Loss In Gas Pipelines Using X-Radiography

B6.1 Introduction

Locating a small area of internal metal loss is occasionally difficult using manual ultrasonic techniques. In these instances it is usually preferable to obtain an X-ray of the suspect area to locate the feature. Although time consuming the X-ray technique does have the advantage of providing a permanent record of the feature, and obtaining full inspection coverage.

Gamma radiography is not recommended since this technique is relatively insensitive to metal loss. Depending on wall thickness and the diameter of the pipe a sensitivity of approximately 10% of wall thickness can be achieved using gamma-ray techniques whereas X-ray techniques can achieve a sensitivity of better than 2% of wall thickness.

B6.2 Technique for Quantifying Internal Metal Loss

The following procedure for quantifying metal loss using X-radiograph has been devised and proved successful by BHGE. Refer to Figure 3.

(1) Locate area of metal loss using ultrasonic or Double Wall Single Image (DWSI) X-ray techniques.

(2) Place plate of known thickness over the metal loss area or deepest part of the metal loss. The plate thickness must be equal to or greater than the damage through-wall thickness.

(3) Place an ultrasonic step wedge on the pipe surface the adjacent to the metal loss but on sound pipe.

(4) Carry out DWSI X-radiography aiming for a density of approximately 3 on the parent plate.

(5) Using a densitometer on the radiograph compare the density of the darkest part in the metal loss plus plate with that on the step wedge and note the step thickness.

(6) Subtract the step thickness from the plate thickness to give the through-wall depth of the metal loss.

NOTE: It has been shown that slag or air are equally transparent to X-ray when using the energies applied to steel pipelines where the density is equal to that of the metal loss.

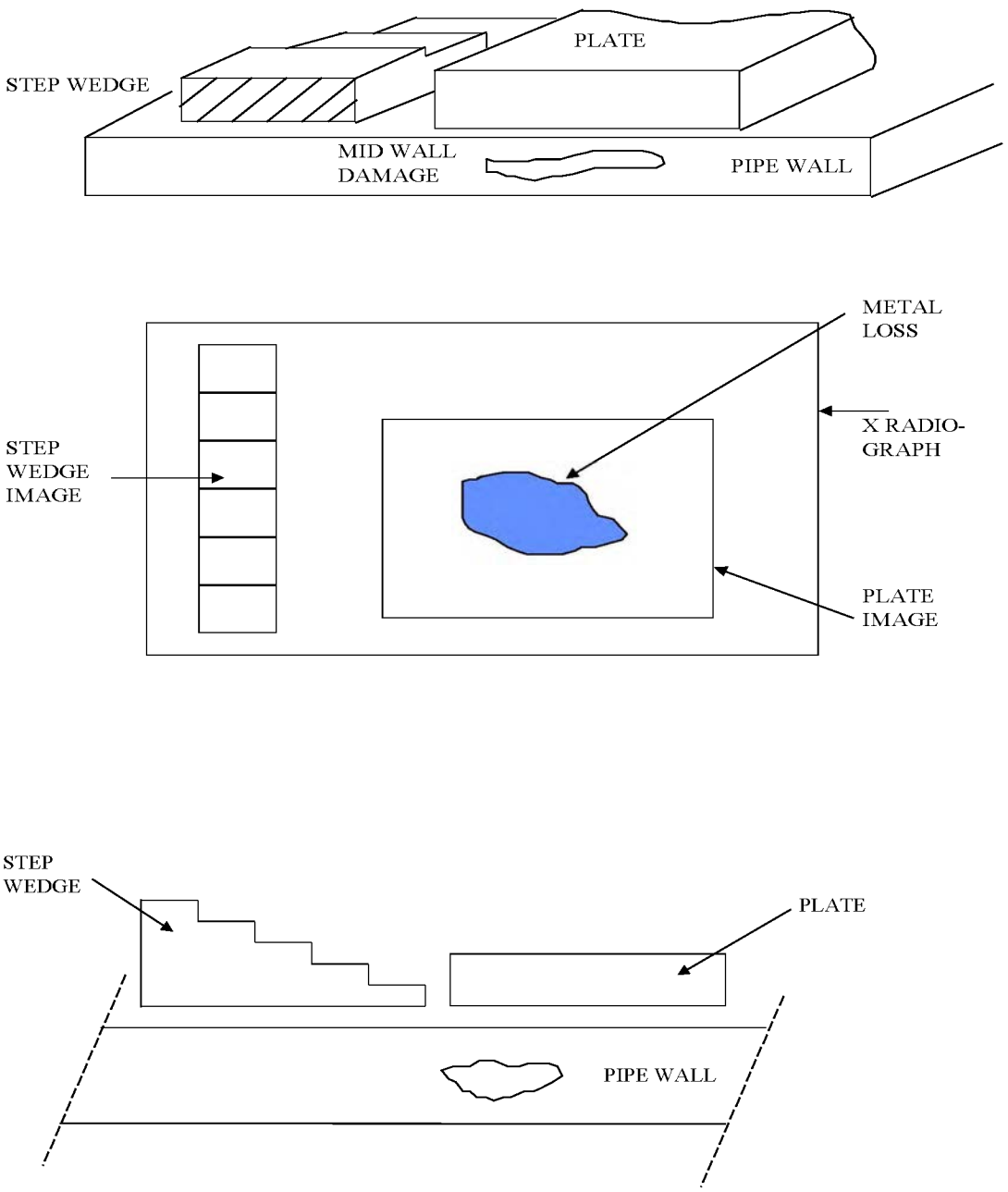


Figure 3: Typical Arrangement for X-ray Technique

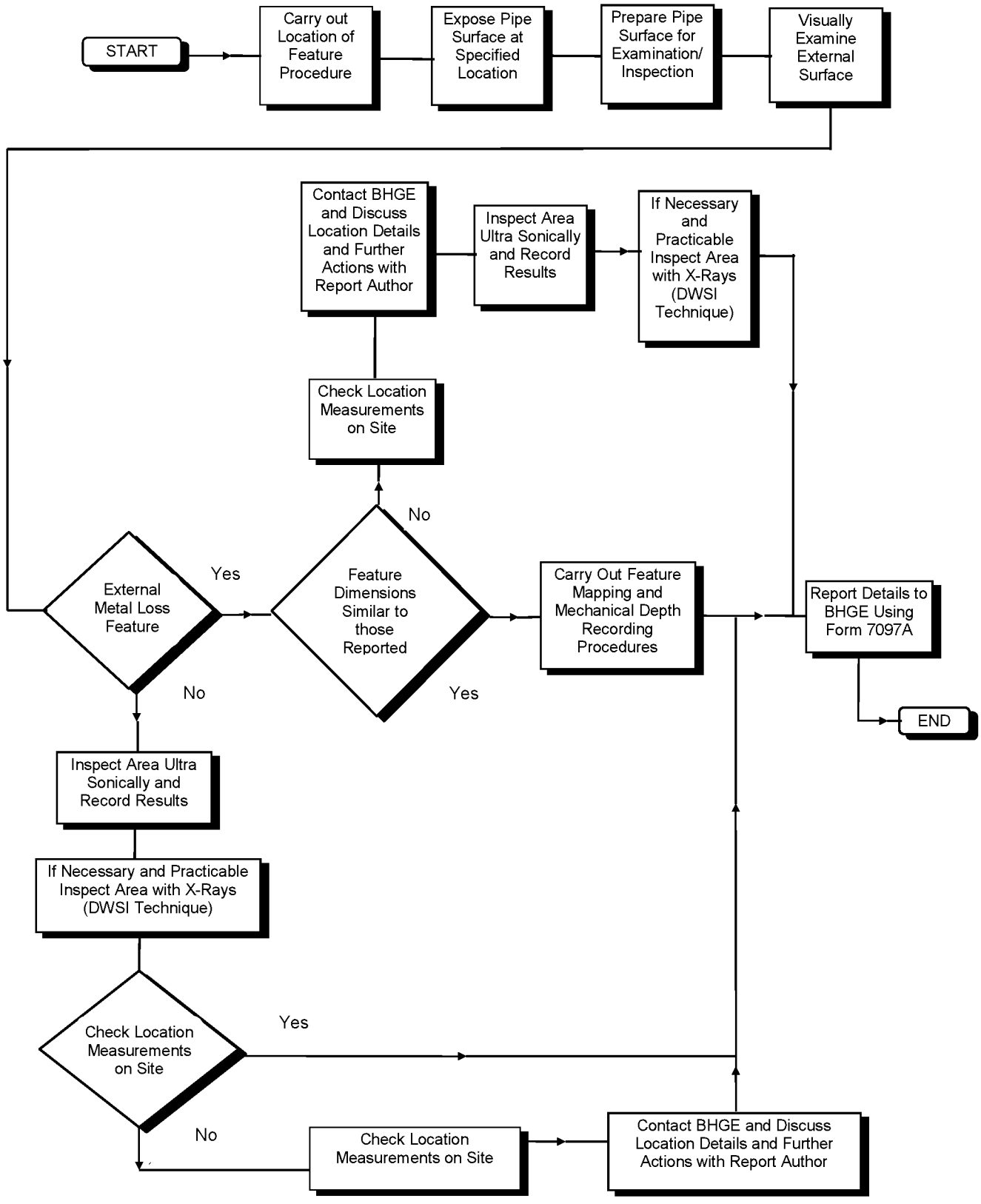


Figure 4: Procedure for Inspecting and Recording Reported Metal Loss Features - Simplified Flow Diagram

PIPELINE DAMAGE RECORD

7097A
Oct 18/93

1. LOCATION OF DAMAGE

PIPELINE START: .....Somewhere Launch..... END: .....Somewhere Receive.....

FEATURE IDENTITY (BHGE) - REPORT NUMBER: ..SR 192..... INSP SHEET NO: ....3.....

FEATURE TYPE: General Corrosion ☒ Isolated Pit ☐ Gouge ☐ Manufacturing (Mill) ☐

Other: .....

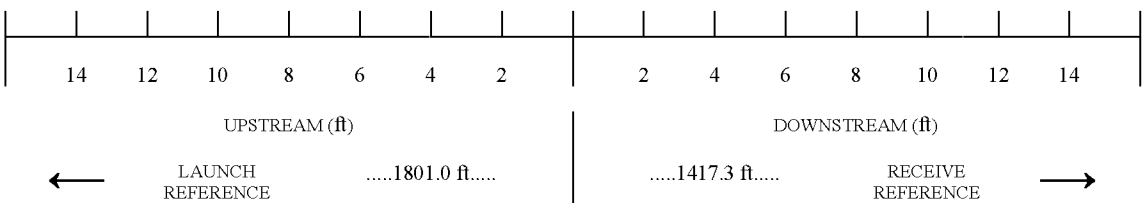
MEASURED WALL THICKNESS: .....0.361in.....

2. FEATURE DIMENSIONS

BHGE FEATURE NO.	EXACT POSITION UPSTREAM OR DOWNSTREAM OF REF. GIRTH WELD (ft)	ORIENTATION (o'clock)	AXIAL LENGTH (in)	CIRC'L WIDTH (in)	DEPTH	
					AVERAGE in% WT	PEAK in% WT
3/1	4.25 ft down	4.45	2.6	3.2		0.13
3/2	5.10 ft down	4.45	4.1	5.0		0.15
3/3	7.5 ft down	2.45	0.8	0.9		0.28

3. PLAN DIAGRAM OF SPOOL

CLOCK POSITION		REF GIRTH WELD
6	BOTTOM	.....
7	.....	.....
8	.....	.....
9	.....	.....
10	.....	.....
11	.....	.....
12	TOP	.....
1	.....	.....
2	.....	.....3/3.....
3	.....	.....+.....
4	.....	.....3/1.....3/2.....
5	.....	.....+.....+.....
6	BOTTOM	.....



NOTE: FOR COMPLEX FEATURES PLEASE ATTACH A 'RUBBING' OR SKETCH WITH DIMENSIONS AND DEPTHS IDENTIFIED.

RUBBING ATTACHED ☐ SKETCH ATTACHED ☐

DATA OF SITE INSPECTION: ..... SIGNATURE: .....

Figure 5: Example of completed Pipeline Damage Record Form (7097A)

ENBDNR0005781

PIPELINE DAMAGE RECORD

7097A
Oct 18/93

1. LOCATION OF DAMAGE

PIPELINE START: ..... END: .....

FEATURE IDENTITY (BHGE) - REPORT NUMBER: ..... INSP SHEET NO: .....

FEATURE TYPE: General Corrosion ☐ Isolated Pit ☐ Gauge ☐ Manufacturing (Mill) ☐

Other: .....

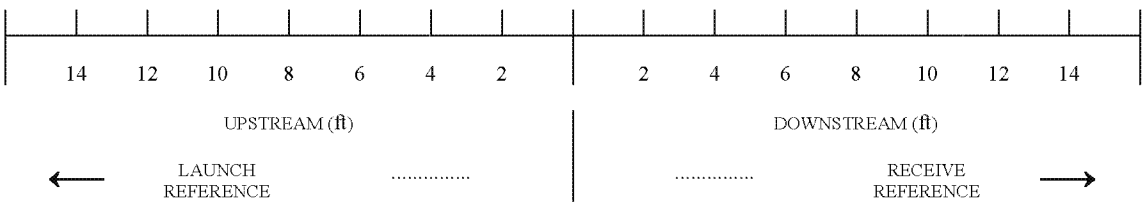
MEASURED WALL THICKNESS: .....

2. FEATURE DIMENSIONS

BHGE FEATURE NO.	EXACT POSITION UPSTREAM OR DOWNSTREAM OF REF. GIRTH WELD (ft)	ORIENTATION (o'clock)	AXIAL LENGTH (in)	CIRC'L WIDTH (in)	DEPTH	
					AVERAGE in% WT	PEAK in% WT

3. PLAN DIAGRAM OF SPOOL

CLOCK POSITION		REF GIRTH WELD
6	BOTTOM	.....
7	.....	.....
8	.....	.....
9	.....	.....
10	.....	.....
11	.....	.....
12	TOP	.....
1	.....	.....
2	.....	.....
3	.....	.....
4	.....	.....
5	.....	.....
6	BOTTOM	.....



NOTE: FOR COMPLEX FEATURES PLEASE ATTACH A 'RUBBING' OR SKETCH WITH DIMENSIONS AND DEPTHS IDENTIFIED.

RUBBING ATTACHED ☐ SKETCH ATTACHED ☐

DATA OF SITE INSPECTION: ..... SIGNATURE: .....

Appendix C. Operational Details

Contract Number	451199_20A
Operator	Enbridge Energy, Limited Partnership
Launch Site	East North Straits (ENO)
Receive Site	East Mackinaw (EMA)
Inspection Run	
Date of Operation	13 March 2019
Duration of Run	0 hours 48 minutes
Data Recorded	0.0 miles to 4.1 miles
Inspection Modules	MV : 620 IMU : 430336
Processor Pack	MF3DPP018

Appendix D. Pipeline Details

Contract Number	451199_20A
Date of Pipeline Commission	1953
Pipeline Outside Diameter	20 inches nominal
Product	Crude Oil
Pipeline Length (Client Data)	4.1 miles
Pipeline Length (BHGE Data)	4.1 miles
API Grade	A
Predominant Pipe Type	Seamless
Previous BHGE Inspection	2018 MFL - 450634_20A.

Appendix E. Additional Services

As a complement to the inspection service BHGE can offer the following:

- Assessment

  This involves an Integrity Assessment which relates the severity of any defects reported by the inspection to the required future operating conditions of the pipeline. At BHGE we have a dedicated team of engineers who have:

  - successfully conducted over 60 commercial consultancies for major oil and gas companies world-wide;
  - pioneered new integrity assessment methods now accepted by Regulatory Authorities (which have been included in pipeline codes); and
  - initiated and conducted extensive pipeline research.

- Repair

  Specialist repair services can be provided based on proven technologies established to support British Gas' 11000 miles pipeline transmission system. The repair team have extensive experience of operating a pipeline repair service, including work for many clients in Europe and the Middle East.

Appendix F. Pipeline Inspection Report Specification

The contents of the pipeline inspection report and the selection rules for selecting individual metal loss features for detailed analysis and reporting are specified in the Specification for the Pipeline Inspection Report, a copy of which is provided overleaf.

All the sections and listings for this report are in accordance with the Enbridge ILI Minimum Reporting Requirements Guide V.8.2 mentioned in the executive summary.

All the sections and listings for this report are in accordance with the **Enbridge Reporting Profile Standard V.8.2**

The following are the mathematical formulae used as a basis for the sentencing calculations performed in PipeImage:

1 Sentencing Formulae

The variables used in the formulae in this section are defined below:

d = Actual depth (m)
$d_{\%}$ = Peak depth as a percentage of wall thickness
t = Wall thickness (m) at the peak of the cluster
D = External diameter of pipe (m)
L = Length of defect (m)
P_{des} = Design pressure (Pa)
F_{stress} = Flow stress (should be SMYS + 10000psi) (Pa)
SF = Safety factor (> 1)
DF = Design Factor $\left(= \frac{1}{SF} \right)$
$MAOP$ = Maximum Allowable Operating Pressure (Pa)
$SMYS$ = Specified Minimum Yield Strength (Pa)
$SUTS$ = Specified Ultimate Tensile Strength (Pa)

P_{des} and DF are linked by the equation $P_{des} = \frac{2tDF \times SMYS}{D}$

N.B. In the case of a cluster straddling a segment boundary, the segment characteristics used in the following formulae are taken from the segment corresponding to the peak of the cluster.

1.1 RPR 085

The Modified ASME B31.G 0.85dL sentencing method is used to calculate the Burst Pressure.

$S =$ Hoop stress level at failure

$$A = \frac{L^2}{Dt}$$

If the value of A is greater than 50

$$M_{085} = 3.3 + 0.032A$$

If the value of A is less than or equal to 50

$$M_{085} = \sqrt{1 + 0.6275A - 0.003375A^2}$$

$$T = \frac{1 - \frac{0.85d_{\%}}{100}}{1 - \frac{0.85d_{\%}}{100M_{085}}}$$

$$S = F_{stress}T$$

Burst Pressure = $\frac{2tS}{D}$

Safe Operating Pressure = DF x Burst Pressure

RPR 085 DL = $\frac{S}{SMYS}$

1.2 LAPA RPR (Effective Area RPR)

$S =$ Hoop stress level at failure

$$A = \frac{L_{Eff}{}^2}{Dt}$$

Where L_{Eff} = LAPA Length of cluster (m) = Effective Length of cluster

If the value of A is greater than 50

$$M = 3.3 + 0.032A$$

If the value of A is less than or equal to 50

$$M = \sqrt{1 + 0.6275A - 0.003375A^2}$$

$$T = \frac{100 - d_{Eff\%}}{100 - \frac{d_{Eff\%}}{M}}$$

Where $d_{Eff\%}$ = LAPA Depth (%t) = Effective Depth (%t)

$$S = F_{stress}T$$

Burst Pressure = $\frac{2tS}{D}$

Safe Operating Pressure = DF x Burst Pressure

LAPA RPR = Effective Area RPR = $\frac{S}{SMYS}$

2 Interaction Rules

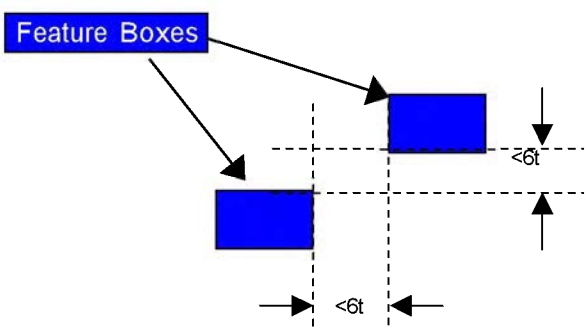
The Interaction Rules are intended to represent the physical interaction between areas of metal loss (boxes). The Interaction Rules to be used in the compilation of the Pipeline Inspection Report are as follows:

(i) Feature boxes will “interact” if their axial separation and their circumferential separation are both no more than 6 wall-thicknesses (6t).

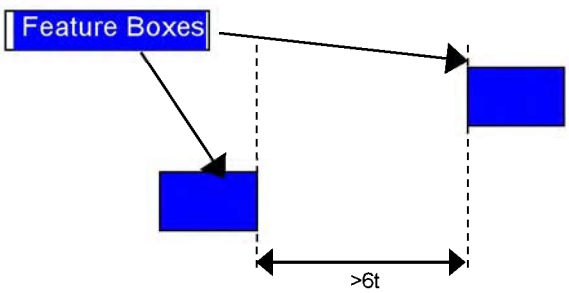
(ii) A set of interacting boxes will form a “cluster”

An example is as follows:

Example of Feature Boxes that Interact



Example of Feature Boxes that Do Not Interact



Feature Boxes must be within 6 Wall Thicknesses (6t) in both directions.

A cluster of pits situated across a girth weld shall be considered to be continuous (i.e. girth welds do not prevent interaction).

Appendix G. Inspection System Performance Specification

The pipeline inspection system employed by BHGE has been designed to carry out a genuine high resolution pipeline inspection.

The performance capabilities of the inspection system are defined in the Inspection System Performance Specification, a copy of which is provided overleaf:

THE INSPECTION PERFORMANCE SPECIFICATION

1. Introduction

The Contractor's Inspection Vehicles have been specifically designed to ensure high resolution inspection of the full circumferential extent of the Pipeline and the detection of metal loss occurrences therein.

Inspection data obtained during the Inspection Vehicle run(s) in the Pipeline is subjected to a two stage processing and analysis procedure.

During Stage 1, preliminary processing and analysis is performed using the Contractor's automatic data analysis facilities. All Metal Loss Features detected by the Inspection System irrespective of depth or surface dimension are automatically sized and are reported together with Pipeline Anomalies and Pipeline Fittings, in the Pipeline Summary Report detailed in the Client Profile. The analysis systems employed during this stage are specifically designed such that all Metal Loss Features which may be of concern to the integrity of the Pipeline are highlighted and are selected for more detailed processing and analysis, subject to the maximum number of Features specified in the Client profile.

During Stage 2, the most significant Metal Loss Features identified in Stage 1 are selected using the priority rules detailed in the Client Profile, for more detailed processing and analysis and reported. Those Metal Loss Features
that have undergone such detailed processing and analysis shall be sized to the accuracy detailed in section 4 below.

The Contractor's Inspection Vehicles together with the aforementioned data processing and analysis comprise the Contractor's Inspection System.

2. Detection Capability

The capability of the Contractor's Inspection System, which applies irrespective of the type of pipeline construction (i.e. seamless, seamwelded, spiral etc.), is such that the following types of feature present in the pipeline can be detected:

(a) Metal Loss

(i) associated with corrosion, including
- such metal loss in the vicinity of girth welds
- such metal loss associated with dents
- such metal loss situated beneath casings

(ii) associated with gouging

All such metal loss of depth and surface dimension greater than the minimum required for accurate sizing as detailed in Table 1 shall be detected. Metal loss below such depth and surface dimension can be detected. However, the probability of detection is reduced as the depth and surface dimension of the feature is reduced.

(b) Metal loss situated beneath repair clamps

(c) Metal loss associated with manufacturing faults

(d) Welds - girth, seam and spiral

(e) Girth weld anomalies including circumferential cracks within girth welds

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(f) Dents

(g) Manufacturing/mill type defects

(h) Construction damage

(i) Changes in nominal pipe wall thickness

(j) Pipeline fixtures and fittings including: (i) Tees
(ii) Offtakes
(iii) Valves (iv) Bends (v) Anodes
(vi) Buckle Arrestors
(vii) External Supports
(viii) Ground Anchors
(ix) Repair Shells
(x) CP Connections - ferro-magnetic type

(k) Ferrous metal objects in close proximity to the pipeline considered likely to affect the carrier protective coating or cathodic protection system.

(l) Casings, including eccentric casings where the degree of eccentricity is considered likely to affect the carrier protective coating or cathodic protection system.

(m) Reference marker magnets

3. Location Accuracy

3.1 All those features detailed in section 2 detected by the Inspection System shall be located to the accuracy detailed in Table 1.

4. Sizing Accuracy

4.1 Those Metal Loss Features as detailed in section 2.(a) detected by the Inspection System and which during the process of selection have undergone detailed processing and analysis subject to section 4.2, be sized to the accuracy detailed in Table 1 attached hereto.

4.2 It should be noted that the sizing accuracy is dependent upon several factors such as pipeline cleanliness, pipe construction methods, product flow conditions etc. These factors have been taken into account by the Contractor when designing the Inspection System. However it has been found impractical to compensate fully for the extremes which have been noticed in practice and as a result the accuracy with which Metal Loss Features can be detected and sized can vary from point to point along a pipeline. The Contractor's experience of operating on-line Inspection Systems show that the sizing accuracy detailed in Table 1 is attained for greater than 80% of Metal Loss Features reported.

ENBDNR0005793

TABLE 1 DETECTION, SIZING AND LOCATION ACCURACY (10/20)

POF 12" to 56" MagneScan

Inspection of Seamwelded Pipes – Manual Sizing

Property	Full detection and sizing accuracy or metal loss in body of pipe					Full detection and sizing accuracy for metal loss in the vicinity of a weld*			
	Certainty (Probability)	General Metal loss	Pitting	Axial Grooving	Circumferential Grooving	General Metal Loss	Pitting	Axial Grooving	Circumferential Grooving
Min. Depth At 90% POD		5%	8%	8%	5%	9%	13%	13%	9%
Depth Sizing Accuracy	80% 90%	±10% ±15%	±10% ±15%	-15%/+10% -20%/+15%	-10%/+15% -15%/+20%	±15% -	±15% -	-20%/+15% -	-15%/+20% -
Width Sizing Accuracy	80% 90%	±20 mm ±25 mm	±20 mm ±25 mm	±20 mm ±25 mm	±20 mm ±25 mm	±25 mm -	±25 mm -	±25 mm -	±25 mm -
Length Sizing Accuracy	80% 90%	±15 mm ±20 mm	±10 mm ±15 mm	±20 mm ±25 mm	±20 mm ±25 mm	±20 mm -	±15 mm -	±25 mm -	±25 mm -

* The vicinity of the weld refers to the heat affected zone – not in the weld material.
POD = Probability of Detection (reference diameters of the defect areas: 4t for General Metal Loss and 2t for Pitting)
POI =Probability of identification.

Pipeline Anomalies (i.e. Dents, Weld Anomalies, Eccentric Casings, and Metal Objects) and Pipeline Fittings (i.e. Valves, Offtakes, etc.) shall also be located to the accuracy stated above.