Penspen Integrity
Units 7-8
St. Peter's Wharf
Newcastle upon Tyne
NE6 1TZ
United Kingdom

Telephone: +44 (0)191 238 2200
Fax: +44 (0)191 275 9786
Email: integrity.ncl@penspen.com
Website: www.penspenintegrity.com

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SMART PIG 'FINGERPRINT' INSPECTIONS CAN LEAD TO FITNESS FOR PURPOSE ASSESSMENTS AND CONTRACTUAL DISPUTES

Roland Palmer-Jones, Phil Hopkins
Roland.Palmer-Jones@penspen.com
Phil.Hopkins@penspen.com
Penspen Integrity,
4 Riverside Studios,
Amethyst Road,
Newcastle Business Park,
Newcastle upon Tyne, NE4 7YL, UK.
www.penspenintegrity.com

Popi Nafis, Gordon Wintle
Popi.Nafis@vico.co.id,
Gordon.Wintle@vico.co.id
VICO Indonesia
Kalimantan
Indonesia

ABSTRACT

A recent 'fingerprint' smart pigging inspection recorded over 40,000 metal loss (corrosion) features in a 57km 42" diameter, dry gas pipeline supplying a major LNG facility in Indonesia. The pipeline had been in operation for less than 6 months. Assessment of these results by the inspection company identified 10 sections of pipe that required repair according to ASME B31.G, indicating that the pipeline was not 'fit for purpose'. The pipeline operator immediately cut out these 10 sections to ensure the continued safe operation of the new pipeline.

A detailed pipeline corrosion study subsequently identified the features as corrosion that had occurred during transport and storage of the line pipe. In addition, the corrosion was found to be less severe than initially thought and the same work assessed the remaining defects and, calculations using DNV Guideline RP F101, showed that the features were all acceptable.

It was concluded that the high sensitivity of the smart pigging tool, combined with the failure to identify the cause of the features and the simple initial feature assessment overestimated the significance of the corrosion defects.

This demonstrates the need for good care and inspection of line pipe during transport storage and construction. It also highlights the need to conduct engineering assessments to determine the inspection philosophy and to quantify the 'workmanship' level of metal loss features acceptable on a fingerprint run, before the run takes place. Otherwise new pipelines containing 'custom and practice' defects could be the subject of lengthy and costly disputes between operator and constructor.

This paper proposes a method for assessing baseline survey data that provides an acceptance level for pre-existing defects. This methodology will assist operators in assessing smart pigging data from new pipelines.

1. INTRODUCTION

When new transmission pipelines are built it is increasingly common to carry out an inspection using a smart pig. These early inspections, carried out prior to, or within 1 year of commissioning, are often referred to as 'fingerprint' runs. The main benefits include:

- Check construction quality
- Collection of inspection data for future reference

However, smart pig inspection is not a cheap exercise and adds to the overall construction and commissioning costs. Also, modern pipelines receive extensive inspection and testing before any fingerprint smart pig inspection is carried out: the steel quality is checked and tested in the pipe mill, welds are inspected ultrasonically, each pipe spool is pressure tested, visual inspections are carried out when the pipe is coated, and when it is received at the construction site, the girth welds are inspected using radiographic or ultrasonic methods. Finally, the completed pipeline is hydrostatically tested. Consequently, before specifying a fingerprint inspection it is important to decide if it is needed, if it is of benefit, what you want to detect, what the inspection may tell you, and have some idea of what you intend to do with the information gathered.

This paper provides a case study of a fingerprint inspection of a pipeline in Indonesia and addresses the issues listed above.

2. CASE STUDY

VICO Indonesia operate a number of large diameter gas pipelines in Kalimantan FIG 1 HOLD. To cater for an increase in gas production in the onshore and offshore fields around Badak a new 42" pipeline was required to take gas from Badak to the Bontang LNG plant.

The 57km pipeline was designed to the ASME B.31.8 code. The pipeline was built between 1997 and 1999. The basic design and product parameters are given in Table 1. VICO Indonesia carried out final commissioning of the pipeline in May 1999, and are responsible for operating it.

Parameter	
Diameter	42" (1066.8mm)
Material	API 5L Grade X65
Thickness	14.3mm, class 2 areas 17.5mm, class 3 areas
Corrosion Allowance	1.5mm
Manufacturing method	SDSAW-Spiral welded (class 2 pipe) LDSAW – Longitudinal seam (class 3 pipe)
Design Life	25 years
Internal Lining	None
External Coating	4.5mm coal tar enamel
Design Pressure	930 psi (65.4 kg/cm2g, 64.16 barg)
Hydrotest pressure	1457psi to 1958psi (by section)
Design temperature	55°C
Operating Temperature	19°C minimum, 38°C maximum
Expected Operational Flow Rate	1000 mmscfd
Maximum Flow Rate	1600 mmscfd
Methane	83.25 (mol%)
Ethane	5.21 (mol%)
Carbon Dioxide	5.53 (mol%)
Water	0.04 (mol%)
Others	5.97 (mol%)

Table 1 Pipeline Design and Product Details

3. FINGERPRINT INSPECTION

In November 1999, 6 months after the line had been commissioned, a fingerprint smart pig inspection was carried out. The smart pig inspection reported 41,462 metal loss features, 98% of which were internal, and 89% were classified as corrosion. The smart pigging contractor assessed the reported defects using ASME B31G [1]. Ten features were identified that were outside the recommended limits of this code with an 'Estimated Repair Factor (ERF)' of close to, or more than, 1.0. If a defect has an ERF 1, it is not acceptable at the pipeline design pressure using the ASME B31.G criteria. To assure continued safe operation, VICO Indonesia decided to cut out and replace the 10 sections containing these unacceptable features.

4. INVESTIGATION

VICO Indonesia were concerned that a new pipeline, transporting dry gas appeared to have severe internal corrosion (40,000 defects). Metallurgical and chemical investigations were carried out at three laboratories on samples taken from the pieces of line pipe that had been removed to determine the cause of the corrosion. These investigations were inconclusive and gave contradictory causes for the corrosion. Consequently an independent review was commissioned to identify the cause of the corrosion, and to assess the severity of the remaining features.

4.1 Corrosion Assessment

The first stage of the review concentrated on the possible causes of the corrosion. This involved consideration of:

1. Pipeline Configuration
2. Operating Conditions
3. Corrosion Morphology
4. Corrosion Mechanism

4.2 Pipeline Configuration

The pipeline is reasonably flat with several undulations of 30-50m (peak to trough). The hilly terrain around KP 30 -50 has a maximum elevation of approximately 94m with respect to sea level. Under the operating conditions, this configuration is not expected to lead to internal corrosion 'hot' spots. This is supported by the inspection data which reported metal loss features throughout the pipeline with the worst reported in a flat section of the pipeline route.

Therefore, the pipeline configuration gives no reason to expect the corrosion.

4.3 Operating Conditions

Records of the pipeline operation over the period of May - Nov 99 show that it was operated within the design parameters. Under these conditions the gas is dry and not corrosive to carbon steel. The water dew-point of the gas was 10 °C to 20 °C below the minimum environmental and operating temperature of the pipeline. No condensed water would be expected, either during operation, shutdown or depressurisation. Under depressurisation to atmospheric pressure the water dew point of the gas will be approximately -6°C, Ref[2]. This is supported by the corrosion monitoring data reporting an average metal loss of 0.002 mm/yr in the pipeline.

In addition, there are three pipelines running parallel to the pipeline in question, two 36" pipelines and another 42" line.

All are older than the new 42” pipeline, (one dates from 1977). All four pipelines transport gas from a common header manifold. Plant operations personnel for these pipelines reported that they had never observed or experienced internal corrosion problems associated with the gas being transported from Badak to Bontang and that the quantity of water received at Bontang was very low.

Therefore, the pipeline operating conditions give no reason to expect the corrosion.

4.4 Corrosion Morphology

The pipline constructors suggested that the features were the result of CO_2 corrosion, i.e. the corrosion was caused in service by the product. However, there was no factual evidence to support this view:

i. Analysis of the corrosion products did not identify any iron carbonate ($FeCO_3$), a corrosion product related to CO_2 corrosion. This is sufficient evidence to exclude the possibility of CO_2 corrosion.

ii. None of the corrosion features had the shape or appearance of CO_2 pitting or ‘mesa’ corrosion[3].

iii. All the laboratory reports on the corrosion concluded that the worst corroded areas exhibited the appearance typical of ‘under-deposit’ corrosion. These observations are consistent with the inspection results, which identified long channel type metal loss (see Figure 2) at various orientations (see Figure 3), but with no metal loss near the pipe ends or girth welds (see Figure 4 and Figure 5). CO_2 corrosion would be expected to be consistently in the bottom of the pipe and would be expected to also affect the sections close to the girth welds.

Therefore, the corrosion morphology gives no indication that the corrosion was caused by the operation of the pipeline.

4.5 Corrosion Mechanism

All the laboratories asked to investigate the corrosion reported the presence of Fe_2O_3, Silicon and Chloride. Two of the laboratories reported geothite, α-FeO(OH) and lepidocrocite, FeO(OH). One laboratory reported akaganeite, one reported magnetite (Fe_3O_4) and one reported FeS.

All the iron oxide and iron hydroxide scales are consistent with what would be expected from corrosion of steel exposed to a tropical humid environment. The composition of the rust layer depends on conditions given in the surface electrolyte, due to the action of atmospheric parameters such as temperature, relative humidity (RH), NaCl and SO_2.

During a site visit in February 2001, various observations were made regarding the local environment, the potential for corrosion and the condition of some of the pipes that have remained on site since the construction of the pipeline (Figure 6).

Therefore, the corrosion mechanism shows that the corrosion was caused during transportation and storage.

4.5.1 Storage Conditions

Figure 6 illustrates the local storage environment. The absence of pipe end caps allows sand and other solids to build up in the pipe. These trap water and prevent complete drying out of the pipes after rainfall, or from condensation at night. This leads to a continuously wet bottom layer, or a wet/dry cycle. The wet/dry cycle accounts for the loose iron deposits reported by the laboratories at the sides of the solid deposits.

Debris (solids) is less likely to collect in the pipe ends, and the ends of the pipe will dry out quickly. This explains the corrosion pattern seen on this pipeline, where there is no corrosion within 100mm of the end of any pipe, and very little within 1m of the end of any pipe (see Figure 4 and Figure 5).

The rainfall in 1998 (when the pipes were in storage) was less than average and therefore corrosion might not be expected to be such a problem. However, for the pipe internals to become and remain wet, rainfall is not a requirement in a humid environment. This is illustrated in many isolated villages where metal catch basins are used to collect water from the night air. For example Smith [4] reported that units with a surface area of $100m^2$ collected 50-200 litres of water per clear night. Therefore, it can be seen that if the pipes had internal debris lying in the bottom then this debris would be wetted on a regular basis. This phenomena can also affect above ground pipework and pipelines where condensation forms on the outside pipe and collects at the bottom often causing external corrosion.

4.5.2 Corrosion During Storage

Figure 7 illustrates the wet drying process in operation. The identified corrosion products are explained and typically formed in the following manner[5, 6].

i. The primary reaction products formed in atmospheric corrosion are hydrated ferrous (Fe^{2+}) ions, which are further oxidised to Fe^{3+} and then precipitated as oxyhydroxides (FeOOH), hydroxides and oxides.

ii. The reduction of oxyhydroxides (FeOOH) to magnetite Fe_3O_4 is the cathodic balancing electrochemical reaction. Therefore, anodic dissolution of the metal and reduction of the rust layer (FeOOH) to magnetite, occurs during periods of wetting of the rust.

iii. During the drying cycle re-oxidation of the magnetite to oxyhydroxide by oxygen occurs. This transformation in subsequent stages is oxidised to amorphous FeOOH of two different types, geothite, α-FeO(OH) and lepidocrocite, FeO(OH). These form due to water loss and crystallisation and are therefore the products typically found at the outside of the corroded area.

Corrosion rate reference data indicates that corrosion rates for similar environments are between 0.016 mm/yr and 0.659 mm/yr. This range is dependant on the duration that the steel is wet for; the area covered by soil may be continuously wet for the entire storage duration, but other areas will only be wet during precipitation.

The following corrosion rate equation was proposed by Roy and Ho[6]:

$$\textit{Metal penetration (mm)} = 1.078 + 0.00596\,U$$

Where U = number of hours of wetness.

This indicates that areas continuously wet for a year could have corrosion up to 0.53 mm deep. This would account for the majority of the corrosion reported in the VICO pipeline.

4.5.3 Corrosion Initiation during Transport

The line pipe was transported to Kalimantan by sea. The presence of chloride would accelerate the above corrosion process. The presence of chloride and quartz in all the corrosion products indicates that the corrosion was initiated during transportation of the linepipe by sea.

These observations are consistent with the corrosion product analysis. The reported presence of FeS indicates that anaerobic conditions were present in some locations and that active anaerobic bacterial corrosion took place throu gh the action of sulphate reducing bacteria.

This observation would be expected in the climate provided where the pipes were exposed to seawater, followed by storage close to a brackish river with a temperature of 30 -40 °C and unprotected coverage from the surrounding soil.

4.5.4 Bacterial Considerations

The wet soil coverage promotes a differential aeration cell and the warm low oxygen conditions are ideal conditions for the growth of anaerobic bacterial colonies.

It is considered that some of the deeper pits of around 1 – 1.5mm were formed through microbiological action; this is supported by the identification of iron sulphide in some of the corrosion product and sulphur.

Severe corrosion was reported on receipt of the linepipe from the ships. The depth of th is metal loss was not reported; however, it is assumed from the construction cleaning specification that the remaining wall thickness was not below the manufacturing tolerance.

Some of the pits of 1 – 1.5mm may have had little or no microbial action and could have been a combination of seawater corrosion during transport and the wet dry cyclic process described above. This corrosion process is supported by data from Uhlig[7] and Chandler[8] where short-term (less than a year) corrosion rates of 2.5 mm/yr have been measured for millscale covered steel in wet chloride environments. The effect of the millscale is to produce a small anode, large cathode surface area, thereby accelerating the corrosion process.

5. FEATURE SEVERITY ASSESSMENT

The assessment of the severity of the features focussed on the 41,462 metal loss features reported by the inspection. The severity of the features was assessed using the most up to date guidance available: DNV guide lines DNV RP F101 [9]. Other reported features were also considered, but are not discussed in this paper.

5.1 Objective of Assessment

The objective of the assessment was to determine whether it was safe to operate the 42" H Badak to Bontang pipeline at the design pressure of 64 bar.

5.2 Scope of Assessment

The significance of the reported features has been assessed, taking into account all relevant parameters, including:

- Pipeline design.
- Reported features.
- The feature sizing accuracy (tol erances) of the inspection vehicle.
- Feature interaction.
- Pipeline material properties
- The possible effects of scale in the pipeline.
- Repair works carried out.
- Pipeline operation.

5.2.1 Assessment Tolerances

The contract inspection tolerances for sizing metal los s features are shown in Table 2 and Table 3. The specified minimum wall thickness as defined by API 5L was used throughout this assessment.

Feature Parameters (Note1, Note2)		Tolerance	
Size	Depth	Depth of Feature	Length of Feature
txt	0.4t	±0.2t	±20mm
2tx2t	0.3t	±0.15t	±15mm
3tx3t	0.2t	±0.1t	±10mm

Note 1. Metal loss is characterised by the minimum rectangle of dimensions, circumferential width (W) and axial length (L), which contains the surface area of pipe affected by metal loss.

Note 2. t = Pipe Nominal wall thickness (mm)

Table 2 Inspection Tolerances for Features Classified as Pitting Corrosion

Feature Parameters		Accuracy	
Size	Depth	Depth	Length
>3tx3t	0.2t	±0.1t	±20mm

Note 1. t = Pipe Nominal wall thickness (mm)

Table 3 Inspection Tolerances for Features Classified as General Corrosion

5.2.2 Treatment of Tolerances

Adding the full inspection tolerance to each feature is conservative. Where additional information is available, the inspection tolerance may be adjusted or not used. For this pipeline the following data was available:

i. The corrosion was caused during pipe transportation and storage (See Section 4).

ii. Inspection reports from the storage yards report several cases of corrosion on the inside of the pipes, but do not report deep pitting. In general, pits of 2mm or deeper are clearly visible.

iii. The line has been hydro-tested with no failures.

iv. Linepipe still in storage shows evidence of surface corrosion, but no evidence of deep pitting (See Section 4).

v. Pipe samples cut from the locations reported as 'worst' by the smart pig inspection show no evidence of severe pitting. The measurements made by the laboratories in analysing the removed samples are summarised in Table 4.

vi. Pipe samples cut from the locations reported as 'worst' by the smart pig inspection have some scale on the surface. Scale has been found to slightly distort inspection results in some circumstances [10].

vii. Ultrasonic measurements of 4 locations show the feature depths to be less than the pig reported depths. The results of the ultrasonic inspections are summarised in Table 5.

Based on the above points, it was considered that the inspection had in general oversized the deeper defects. Therefore, the addition of the inspection tolerance to the size of every feature was considered to be unduly severe. Consequently, the features were assessed as reported, without the addition of the inspection tolerances.

Items i. and v. in the list above are key in making this judgement that the inspection tolerances do not have to be added to the reported defect depths. If the corrosion mechanism was not understood, and if these sections had not been cut out and measured (providing a direct comparison with the smart pig results), it would have been necessary to include the inspection tolerances in the assessment, and many more sections would have been identified as unacceptable.

5.2.3 Corrosion Assessment Criteria

Features are regarded as acceptable when using DNV RP-F101 if the calculated safe working pressure (SWP) [1] is greater than or equal to the design pressure.

Hydrotesting has long been used as a means of verifying the integrity of a pipeline as constructed [11, 12]. Periodic in-service hydrotesting has been used for many years to demonstrate the fitness for purpose of a pipeline (on the day of the test). Inspection using an intelligent pig is replacing the in-service hydrotest for many pipelines on the grounds of cost and the additional information that is produced regarding the significance of defects in the pipeline [13, 14]. However, the hydrotest has been frequently used in determining the acceptance of defects. If a pipeline survives a hydrotest it does not contain 'significant' defects.

There are numerous examples in the literature (e.g. References 13 to 15) where defect acceptance limits are derived using the pre-commissioning hydrotest pressure. The defect size to cause failure at the hydrotest level is calculated, and any defect in excess of this size is considered unacceptable and requires repair. The rationale is that defects in excess of this size would not have survived the hydrotest, whereas smaller defects would have survived; and are therefore acceptable[14, 15].

This approach is identical to the premise of the acceptance criterion in ASME B31G (and modified B31G), except that the actual pre-commissioning hydrotest pressure was used in this assessment, not a notional test to a hoop stress of 100 percent SMYS.

[1] The safe working pressure (SWP) is a pressure that gives a safety margin on the failure pressure (calculated using fitness for purpose methods), equal to the pipeline design factor.

Sample Orientation hh:mm	Max depth (mm)	Comment
01:00	0.20	Uncorroded reference sample pipe internal surface reported clean and smooth.
08:15	1.03	Dark grey green scaling. Beneath the scale the metal was a rusty colour. No evidence of distinct localised pitting observed.
04:00		Dark grey green scaling. Beneath the scale the metal was a rusty colour. No evidence of distinct localised pitting observed.
03:30	0.56	Dark grey green scaling. Beneath the scale the metal was a rusty colour. No evidence of distinct localised pitting observed.
04:00		Dark grey green scaling. Beneath the scale the metal was a rusty colour. No evidence of distinct localised pitting observed.
03:00	0.47	Dark grey green scaling. Beneath the scale the metal was a rusty colour. No evidence of distinct localised pitting observed.
08:00		Dark grey green scaling. Beneath the sca le the metal was a rusty colour. No evidence of distinct localised pitting observed.
07:45	0.66	Little scale reported. Metal surface rough with distinct rusting.
05:00		Random scale. Surface much smoother than other samples. No evidence of distinct localised pitting.
07:30		Dark grey green scaling. Beneath the scale the metal was a rusty colour. No evidence of distinct localised pitting observed.
08:00	0.59	Scale reported to be thicker than other samples and more uneven. A portion of original met al surface was also said to be more rusty.
Unknown	0.14	Surplus pipe (No. 56). The internal surface was rusty but there was no pitting.
Unknown	-0.03	Slightly thicker than nominal.
unknown	0.10	Uncorroded reference sample
unknown	1.24	
06:00?	1.39	
unknown	-0.08	Sample from storage. Slightly thicker than nominal.
06:00?	1.47	

Table 4 Summary of Measurements made by Two Laboratories

Orientation hh:mm	Max corrosion depth (mm)	Smart Pig max corrosion depth (mm)
05:30	1.8	2.0
05:15	1.6	2.0
07:30	1.4	2.3
08:00	1.3	2.0

Table 5 Summary of Ultrasonic Measurements

5.2.4 Assessment Results

Figure 8 and Figure 9 show the reported metal loss features[2] pl otted for both the 14.3mm nominal wall thickness section and the 17.5mm nominal wall thickness section respectively. The results of this assessment are summarised in Table 6, Table 7, and Table 8.

Figure 10 gives a comparison of the number of spools containing features that fail DNV RP -F101 at each specified pressure, assessed with and without inspection tolerances. It is clear that the inspection tolerances ha ve a significant impact on the number of features and spools that are classified unacceptable. As stated in Section 5.2.1 the key evidence used in justifying carrying out the assessment without the inclusion of the inspection to lerances is the knowledge of the corrosion mechanism, and the comparison of smart pig reported values with directly measured values.

The results of this assessment show that without the inspection tolerances added there are 36 spools that are predicted to fail if the pipeline is pressurised to yield (100% SMYS) and 3 spools that are predicted to fail at the hydrotest pressure of the section of line they are in. The details of these three spools are given in Table 8. Two of these spoo ls were identified by the ASME B.31.G assessment performed as part of the smart pig inspection and had been removed. The remaining spool (Weld number 26380) has a safe working pressure marginally below the MAO P. The features reported in this spool are as sessed in Figure 11. As can be seen, when considered as individual defects, all fall below the acceptance line; however, when interaction effects (see DNV RP -F101 [9]) are considered, a number of 'equiva lent' defects fall above the acceptance line.

Criteria	Number of Interacting Features Predicted to Fail
Pipeline Pressurised to yield	4269
Section Pressurised to reported hydrotest level	353
Pipeline Pressurised to Design	0

Table 6 Summary of Defects that Fail DNV RP -F101 Criteria at Specified Pressure.

[2] Note that these plots show 'interacting' defects. Interacting de fects are neighbouring defects that are close enough to each other to cause interaction and the neighbouring defects act as a single (longer) defect (see DNV RP -F101 [9]).

Criteria	Number of Spools Containing Defects Predicted to Fail
Pipeline Pressurised to yield	36
Section Pressurised to reported hydrotest level	3
Pipeline Pressurised to Design	0

Table 7 Summary of Spools Containing Defects that Fail DNV RP-F101 Criteria at Specified Pressure.

Weld	KP (m)	No. def.	SWP (bar)	Comment
26040	29503.5	146	63.29	Spool Removed. Worst defect size 1759mmx16% (All Internal ML)
26380	29806.4	171	62.19	Worst defect size 1514mmx18% (All Internal ML)
26400	29814.9	36	57.78	Spool Removed. Worst defect size 1315mmx25% (64% Internal ML)

Table 8 Summary of spools containing defects with a predicted failure pressure below the actual hydrotest pressure recorded.

Figure 8 and Figure 9 show that DNV RP-F101 can be conservative, as it predicts failures on hydrotest, but no failures occurred.

This is a significant observation, as it shows that the SWP calculated will also be conservative. The degree of conservatism is evident in Table 6 where 353 failures are predicted, but none were observed. Therefore it was concluded that the 'marginally' unacceptable defects need not be repaired.

5.3 Summary of Investigation

The investigation carried out concluded that:

1. The internal corrosion reported by the smart pig inspection occurred during transport and storage of the line pipe.
2. The features had survived a hydro-test.
3. It was safe to continue to operate the pipeline at the design pressure, without any repair.

6. PIPE QUALITY ASSESSMENT

The pipe used in the construction of the Badak to Bontang 42"H pipeline contained internal corrosion. In addition to the corrosion study reported a short review of the relevant sections of API 5L and ASME B31.8 was carried out in order to identify the criteria against which the condition of the pipe may be judged. Factors that were considered include:

1. Wall Thickness Tolerance
2. Imperfection Allowance
3. Design Corrosion Allowance

6.1 *API* 5L

API 5L is a specification for line pipe. It is a specification for the manufacturer giving the attributes of pipe to be supplied. Two sections are relevant:

1. Section 7.3 Wall Thickness - this states:

   "Each length of pipe shall be measured for conformance to the specified wall thickness requirements. The wall thickness at any location shall be within the tolerances specified in Table 9, except that the weld area shall not be limited by the plus tolerance."

   Table 9 of API 5L gives a tolerance of –8% of specified wall thickness for pipe of grade X42 or higher with a diameter of 20 inches or more (The specified wall thickness is the thickness specified by the purchaser to the manufacturer, API 5L section 4.1). For the Badak to Bontang 42" H gas pipeline 2 wall thickness' were specified to the manufacturers: 14.3mm and 17.5mm.

2. Section 7.8 Workmanship and Defects – This States:

   "Imperfections of the types described in 7.8.1 – 7.8.12 that exceed the specified criteria shall be considered defects. The manufacturer shall take all reasonable precautions to minimize recurring imperfections, damage and defects."

   Sections 7.8.1 – 7.8.11 cover a variety of features such as laminations and dents.

   Section 7.8.12 Other Defects – States:

   "Any imperfection having a depth of greater than 12½ percent of the specified wall thickness, measured from the surface of the pipe, shall be considered a defect."

Therefore for the Badak to Bontang 42" H line (and other pipelines) we can draw the following conclusions:

1. Wall thinning of 8% below the specified thickness (14.3 or 17.5 mm) would be acceptable, from the manufacturer (corrosion cannot be considered to be manufacturing related wall thinning).
2. Some imperfections of up to 12½% of the specified wall thickness would be also be acceptable, from the manufacturer.
3. Recurring imperfections are not acceptable, from the pipe manufacturer.

4. Consequently, any spool with recurring defects greater than 8% of the specified wall thickness, or any defect more than 12% of the specified wall thickness would not meet the API 5L specification.

6.2 *ASME* B31.8

ASME B31.8 is a code used in the design of gas transmission pipelines. The following sections are relevant to this case:

1. Chapter 1 Materials and Equipment, Paragraph 811.21 states:

   "Items which conform to standards or specifications referenced in this code [para. 811.1(a)] may be used for appropriate applications, as prescribed and limited by this code without further qualification (see para. 814)."

2. Chapter 1 Materials and Equipment, Paragraph 811.22 states:

   "Important items of a type for which standards or specifications are referenced in this Code, such as pipe, valves, and flanges, but which do not conform to standards or specifications referenced in this Code [para. 811.1(b)] shall be qualified as described in para. 811.221 or 811.222"

3. Chapter 1 Materials and Equipment, Paragraph 811.221 states:

   "A material conforming to a written specification which does not vary substantially from a referenced standard or specification and which meets the minimum requirements of this Code with respect to quality of materials and workmanship may be used. This paragraph shall not be construed to permit deviations which would tend to affect the weldability or ductility adversely. If deviations tend to reduce strength, full allowance for the reduction shall be provided for in the design."

Therefore, the Badak to Bontang line pipe spools that do not conform to API 5L due to the presence of metal loss features may be used provided they conform to a written specification and provided allowance has been made in the design for the reduction in strength.

An allowance has been made in the design for the development of corrosion features during transportation, storage and operation. This allowance is 1.5mm. Consequently, any pipe spools containing metal loss features deeper than 1.5mm do not comply with the requirements of the design.

7. ISSUES RAISED BY CASE STUDY

A number of interesting issues are raised by this case study that are of general interest to the pipeline industry:

1. What is the appropriate level of defect reporting from a smart pig inspection.
2. What Fitness for purpose criteria should be used in assessing features found during a 'fingerprint' inspection.
3. How should the inspection tolerances be treated.
4. What is an acceptable level of metal loss damage during line pipe transport, storage and construction.

7.1 Choice of Assessment Method

Smart pigs are becoming ever smarter, they can now detect and report very small features. In the case study described, many thousands of defects less than 1mm deep were reported. Surely all of this data is useful in assessing the condition of the pipeline?

Well it is, but only if it is used carefully. For example problems can arise when defects are grouped together or 'clustered'. Clustering is a method some smart pig inspection contractors use for simplifying the inspection data. Individual defects are recoded as 'boxes', with the box length, width and depth equal to the maximum length width and depth of the defect. For defects that are close together, the boxes that define that defect are 'clustered' together according to defect interaction rules. Consequently, they are treated as a single defect with the length equal to the distance from the start of the first 'box' to the end of the last 'box', and the depth is equal to the depth of the deepest 'box' within the cluster (Figure 12). This method is well proven; however in the past only defects that were deeper then 10% or 20% of the wall thickness would have been reported and then clustered. Now very shallow defects are also being included. This can lead to extremely conservative defect sizing. A theoretical example is shown in Figure 13.

Using simple grouping and assessment tools on detailed defect data may result in a very conservative assessment, and lead to unnecessary repairs or reductions in operating pressure. To avoid this, and obtain the best value from an inspection, an appropriate level of assessment should be carried out. If detailed data is collected (usually at great expense) then it makes sense to look closely at it and analyse it carefully. This is demonstrated in Figure 14 where the equivalent defect size based on the DNV RP-F101 is overlaid on the cluster profile and the defect shape used for calculating the ERF value. The DNV equivalent defect size includes the quoted inspection tolerances, but is still significantly smaller than the clustered defect shape used for calculating the ERF value.

7.2 Defect Assessment Criteria for Fingerprint Runs

There are numerous criteria against which defects found in a pipe may be assessed. The most common criteria include:

1. The pipeline design code or regulation
2. The line pipe specification
3. The design corrosion allowance.
4. Fitness-for-purpose codes such as ASME B31.G or DNV RP-F101.

A pipeline operator should clearly specify the criteria he/she wants to use for defects detected in a fingerprint run, and ensure that defects which are considered 'custom and practice' are reported accordingly. Additionally, he/she should consider how many defects that are within the criteria will be acceptable. For example, 400 defects of >5% but <10% wall thickness may be acceptable, but 40,000 would indicate poor storage.

7.3 Treatment of Tolerances

The inherent variability or error in defect sizing associated with a smart pig inspection can cause problems. Obviously, a perfect measurement is impossible; defects will invariably be oversized or undersized. Smart pig companies acknowledge this, and a typical contract defect sizing tolerance is the actual depth is within +/- 10% of the pipe wall thickness of the reported depth, 80% of the time. In the absence of specific sizing tolerances (e.g. from excavated defects), or factual evidence to show conservatism, the contract tolerances should be included in any assessment.

7.4 Transport, Storage and Construction Damage

API 5L the industry standard line pipe specification does not make a specific allowance for corrosion damage. However, it would be reasonable to accept corrosion defects, related to transport, storage and construction, that are within the limits in API 5L for manufacturing defects.

Line pipe containing defects that exceed the limits in API 5L may be accepted (in accordance with the pipeline design code ASME B31.8) if they are within a specific allowance made at the design stage. Since it is virtually impossible to prevent some corrosion damage, under normal pipeline construction site conditions, good pipeline design should include a specific allowance for transport, storage and construction metal loss damage.

8. SUMMARY AND CONCLUSIONS

Pipeline inspection using modern smart pigs can identify very small features, and a combination of feature sizing and defect analysis methods can lead to the repair or removal of line pipe containing 'custom and practice' construction defects, which present no threat to the future integrity of the pipeline.

In specifying a 'fingerprint' inspection the pipeline operator should consider why the inspection being is done, as this will affect the defect reporting levels, assessment method and acceptance criteria that should be used:

1. Construction Quality - If the inspection is to check the quality of construction,. then defect reporting levels should be based on the line pipe specification, and any assessment or acceptance should be against industry 'custom and practice' or a specified corrosion and damage allowance for transport, storage and construction. The operator should also consider what would be an acceptable number of reported features, within the acceptance criteria.
2. Integrity - If the inspection is also to assess the integrity of the pipeline then the defect reporting levels should be set to give the maximum possible detail: the assessment should be based on fitness for purpose methods, and the acceptance criteria should be agreed e.g. based on the pre-commissioning hydrotest pressure.

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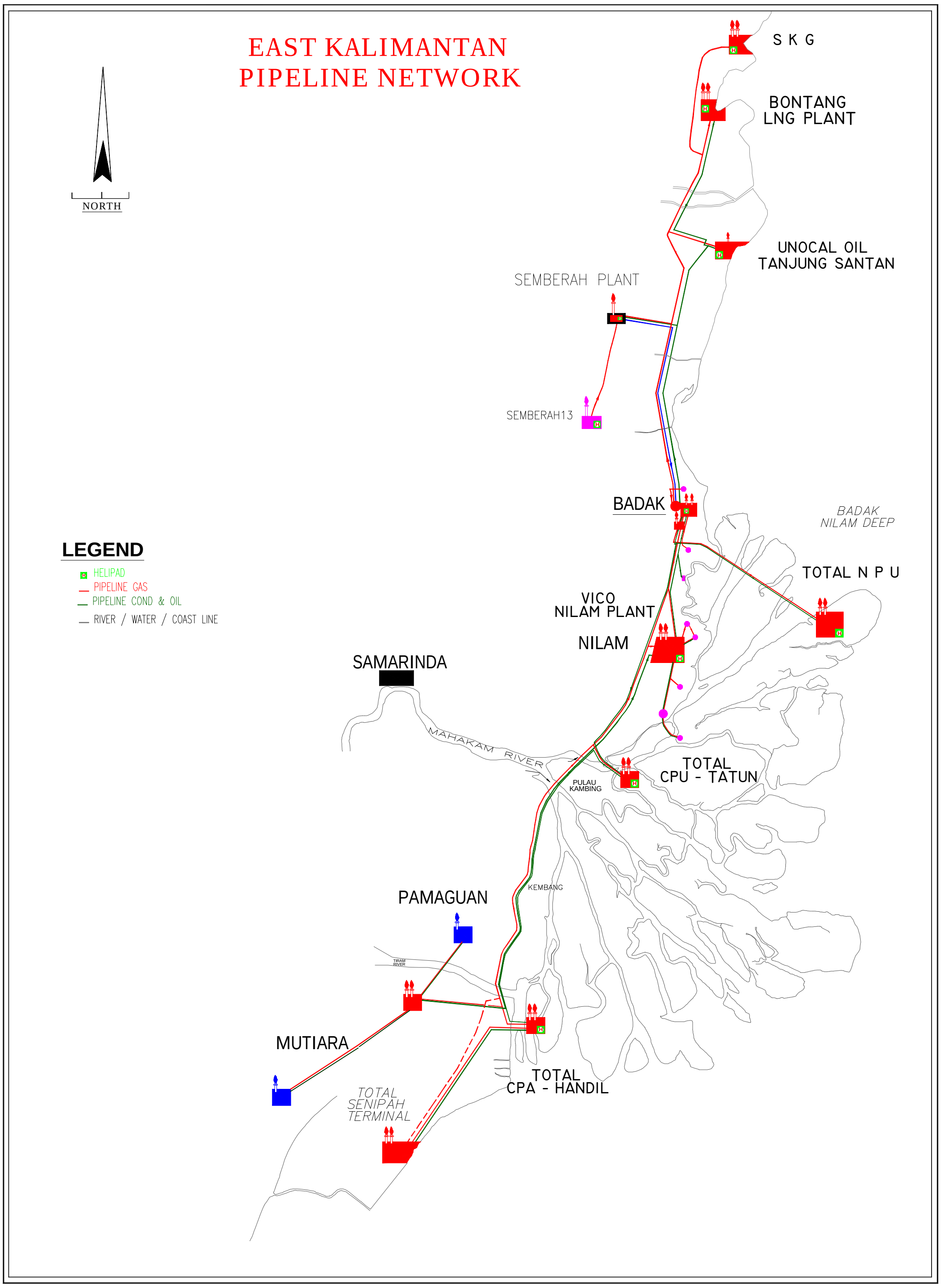

Figure 1 Map showing VICO Pipeline System in East Kalimantan

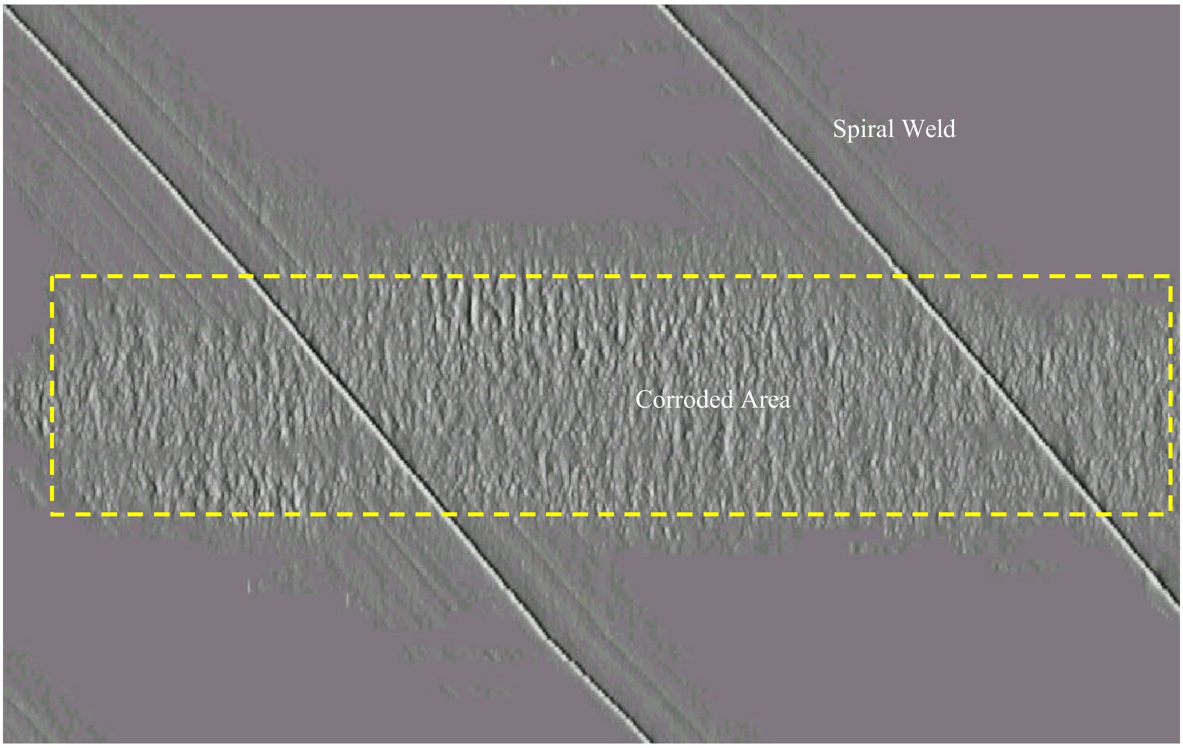

Figure 2 Typical pattern of corrosion in pipeline

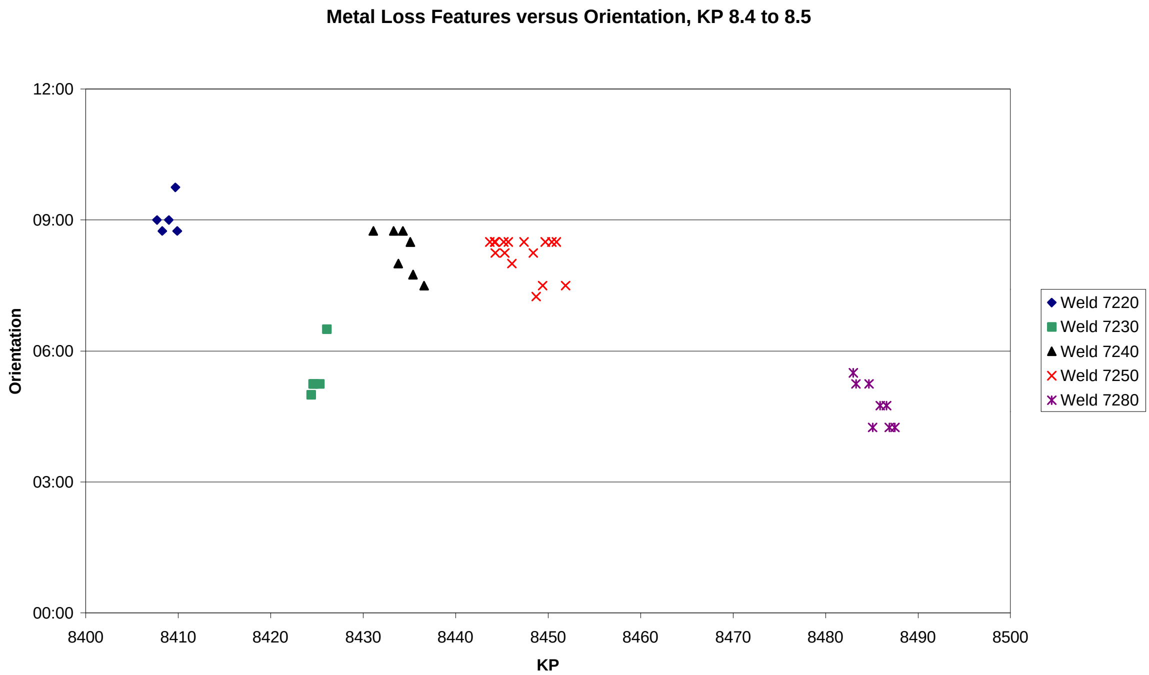

Figure 3 KP 8.4 to 8.5 - Metal Loss Features against position in the pipeline, and orientation around pipe (06:00 position is the bottom of the pipe)

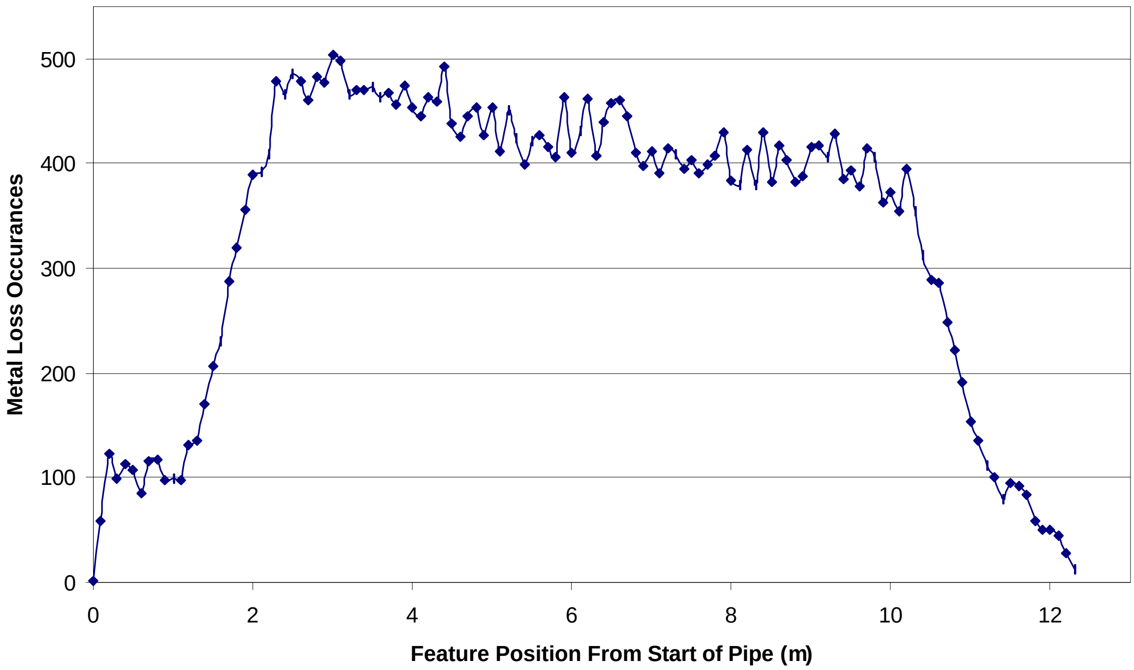

Figure 4 Position of reported features along all pipe spools

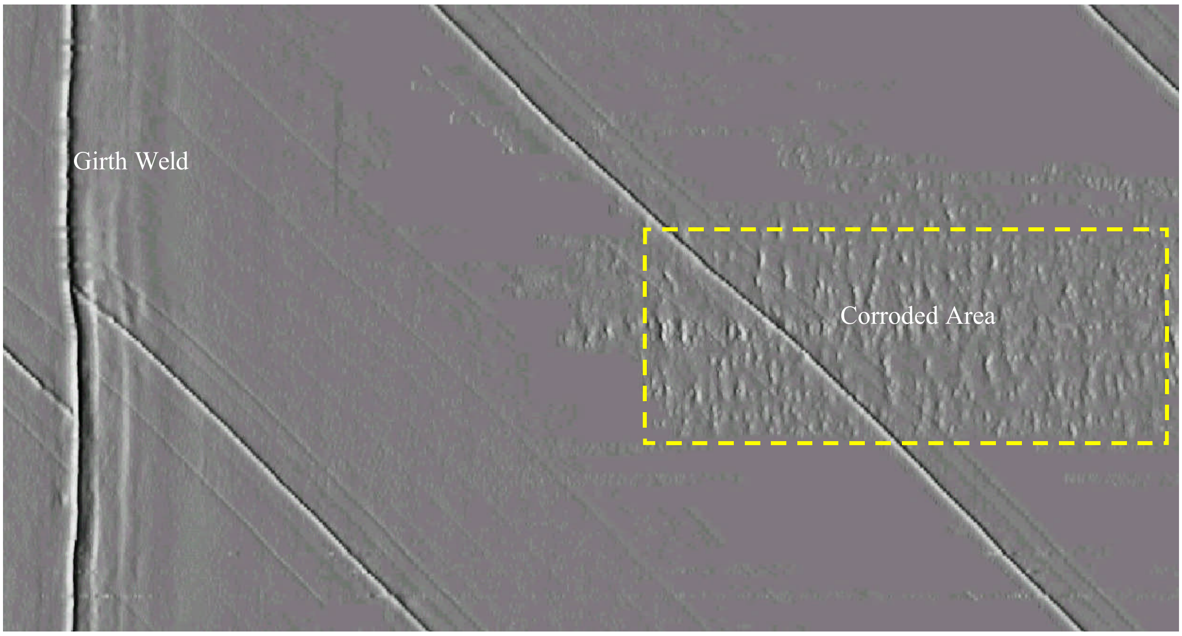

Figure 5 Typical pattern of corrosion away from girth weld (note absence of corrosion at the girth weld)

Figure 6 Spare Storage Pipes at KP 41

Figure 7 Illustration of Wet / Dry Corrosion Cell in a Spare Pipe

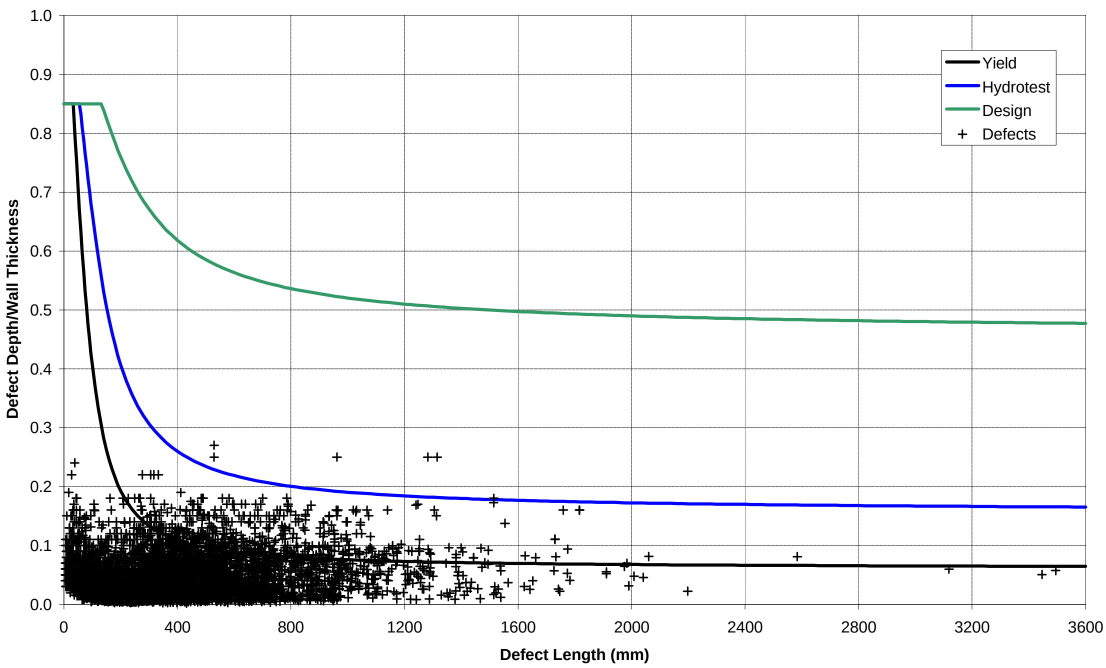

Figure 8 Assessment of Features in 14.3mm Nominal Wall Thickness Linepipe, Using DNV RP-F101 Criteria.

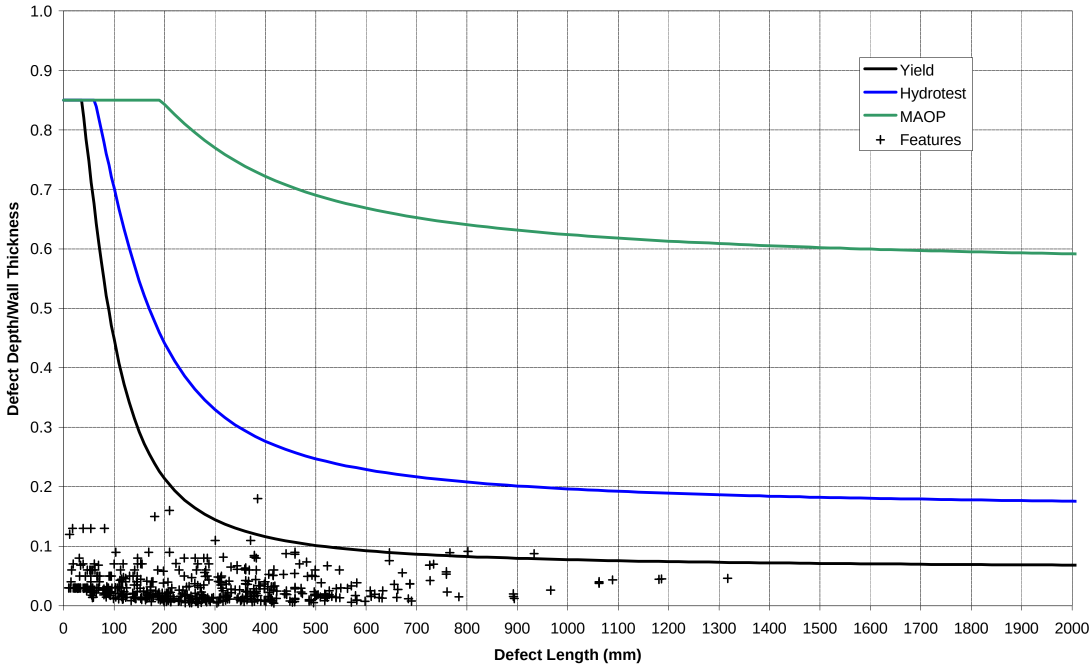

Figure 9 Assessment of Features in, 17.5mm Nominal Wall Thickness, using DNV RP-F101 Criteria.

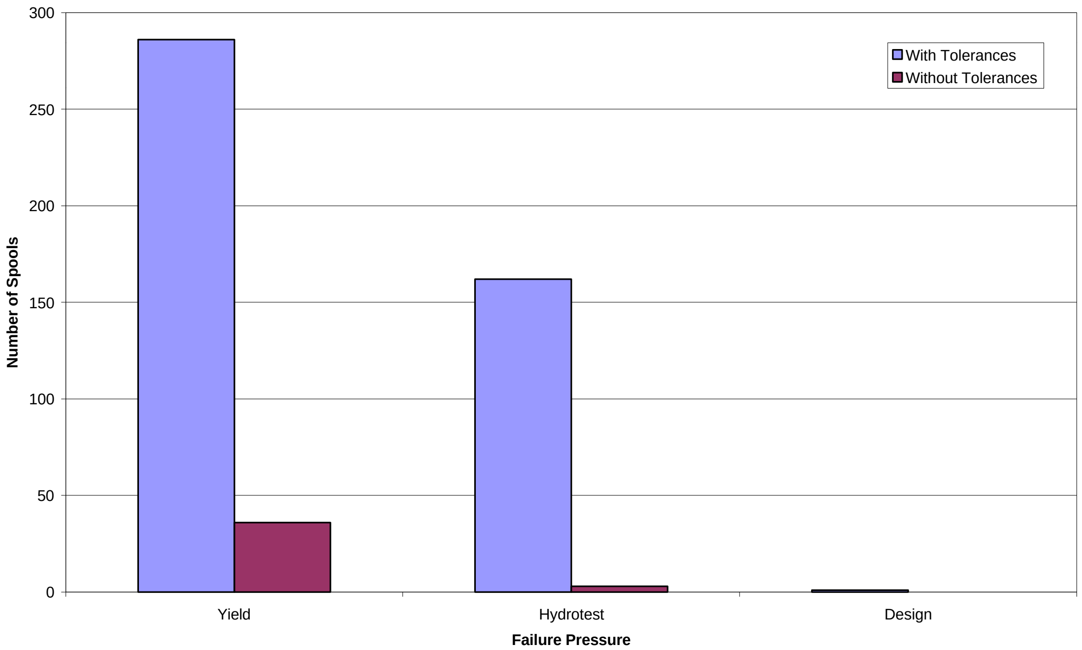

Figure 10 A comparison of the number of spools containing defects that fail DNV RP -F101 with and without inspection tolerances added.

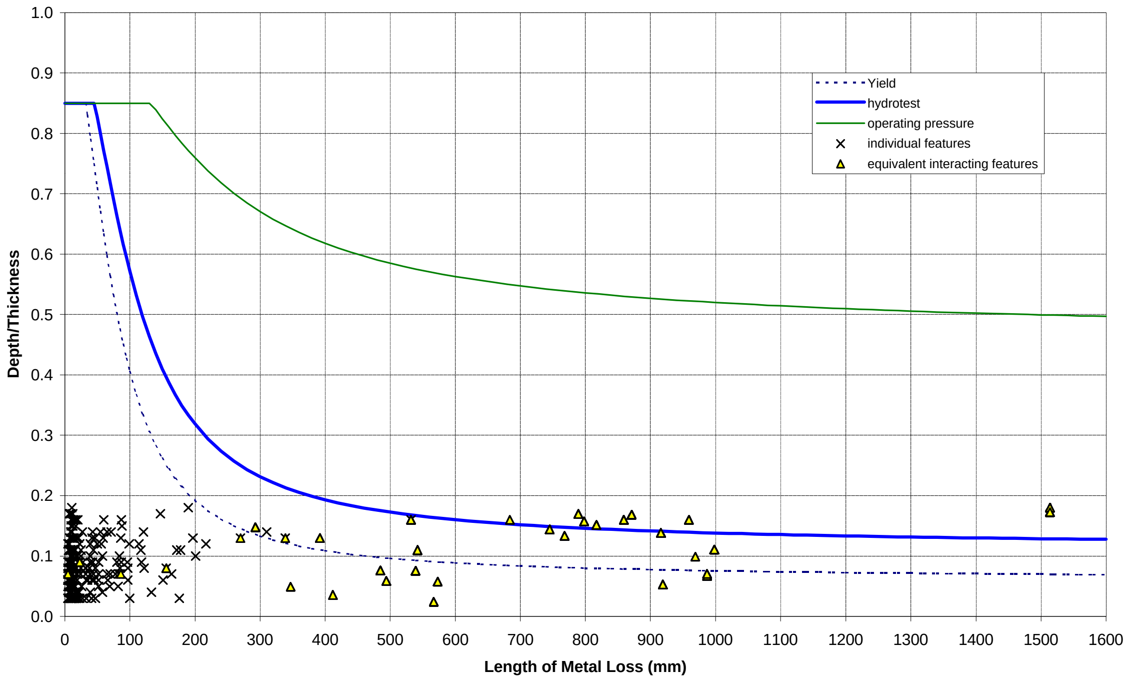

Figure 11 Sentencing plot of defects on spool 26380, Safe Working Pressure 62 bar

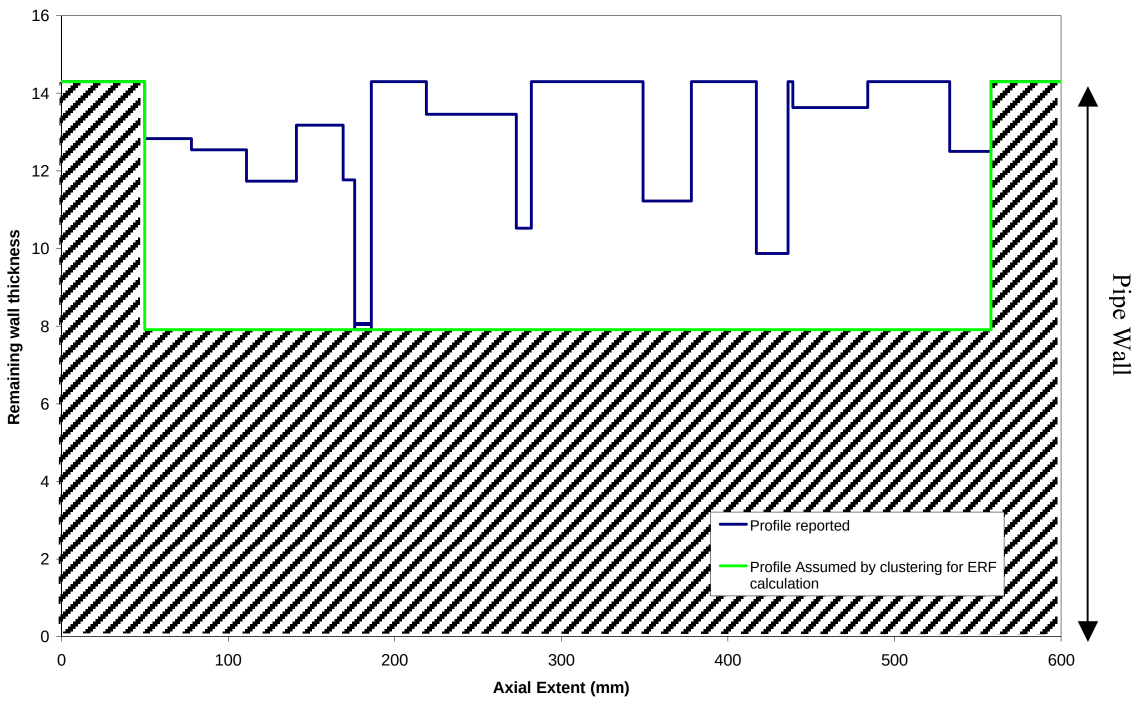

Figure 12 Reported profile of a defect cluster, with profile used in assessing ERF value.

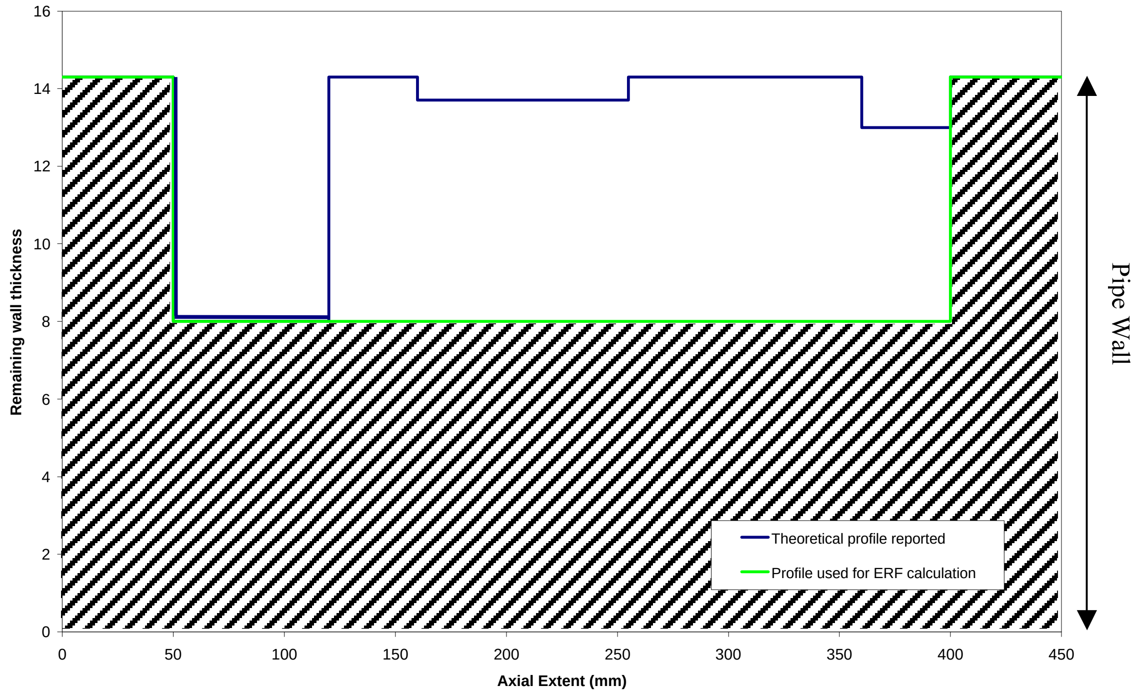

Figure 13 Theoretical profile of a defect cluster, with profile used in assessing ERF value.

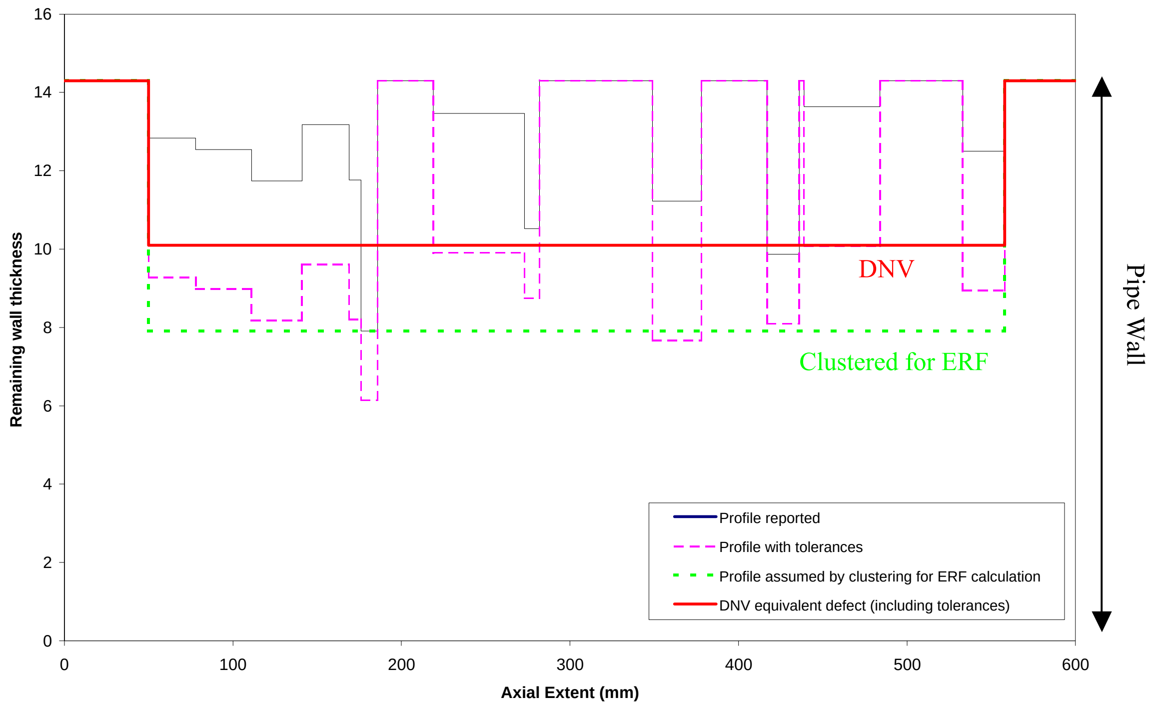

Figure 14 Comparison of DNV equivalent defect and defect used for ERF calculation.