GETTING MORE FROM YOUR INTELLIGENT PIG REPORT
ASSESSING CLUSTERS

By, Roland Palmer-Jones, Andre Goncalves, Prof. Phil Hopkins,
Penspen Integrity, Newcastle upon Tyne, UK.

INTRODUCTION

Intelligent pigs are used extensively for inspecting pipelines, due to their proven benefits, expanding capabilities, and legislative requirements.

Previous papers[,] have discussed how to manage an inspection project, and have given guidance on understanding the inspection report. In this paper we will look in more detail at the assessment of corrosion defects reported in a pipeline by an intelligent pig inspection, and, in particular, large defects or groups of defects.

At this point it is important to draw a distinction between:

- i) the analysis of inspection data to identify defects, and
- ii) the assessment of the defects and their implications for the integrity of the pipeline.

These are two separate tasks: the first is carried out by someone who is familiar with the inspection technology and understands what the recorded data (voltage levels for coil sensor MFL tools, or time delays for ultrasonic tools) indicates in terms of pipe wall metal loss or other possible features; the second requires an understanding of how pipeline defects are caused, and how they behave when subject to internal pressure or other loads.

INSPECTION TECHNOLOGIES AND DATA ANALYSIS

The most commonly used technologies for the detection and sizing of corrosion defects in pipelines are magnetic flux leakage (MFL), and ultrasonic testing (UT).

Magnetic Flux Leakage

Technology

MFL inspection identifies changes in the pipe wall thickness by measuring changes in a magnetic field close to the pipe wall. There is a magnetic attraction force between the north and south poles of a magnet. This force is generally represented by drawing 'flux' lines between the poles. These flux lines show the strength and direction of the magnetic field. When a magnet is placed close to, or in contact with, a steel pipe wall the magnetic field is concentrated into the steel. There is a small residual magnetic field near the surface of the pipe wall. Where there is a change in the pipe wall thickness, there will also be a change in the magnetic field in the pipe wall, and near the pipe wall. If the pipe wall gets thinner then the magnetic field in the pipe will reduce and the field near the wall will get stronger, less of the magnetic field will be concentrated into steel. This can be visualised by imagining that some of the flux lines have 'leaked' out, see Figure 1. More information on magnetic flux leakage can be found in Reference .

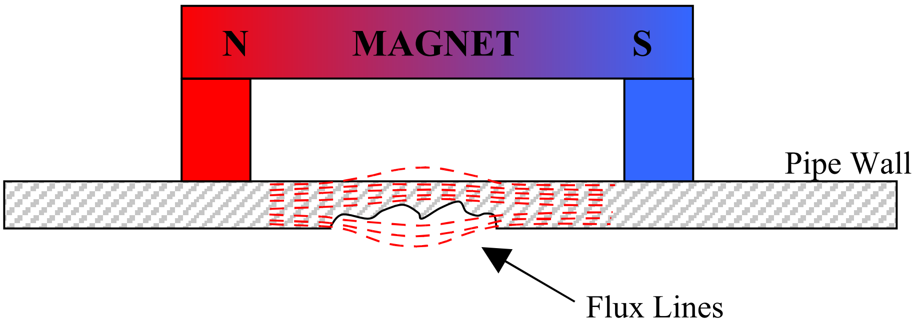

Figure 1 Magnetic Flux Leakage.

Sensors are used to measure these changes in the magnetic field close to the pipe wall. These sensors are either coil sensors or Hall effect sensors. The signals output from these sensors are recorded, and used to estimate the depth (relative to the pipe wall thickness), length and width of the corrosion defect. It is based primarily on the proportion of the magnetic field that leaks out of the pipe wall. Typical MFL inspection pigs have a large number of sensors arranged around the circumference of the pipe, see Figure 2, but it is important to remember that only a relative measurement of defect depth can be made,

Figure 2 MFL Pig Sensors

The signals recorded by all sensors are interpreted either automatically using specially developed software or by an analyst who views the data on screen, Figure 3. Individual defects are identified (often the area of the defect is defined by a ‘box’), and the dimensions estimated. The accuracy of these estimates will vary with the particular inspection tool, the type of pipe being inspected (e.g. seam welded or seamless), the dimensions of the defects, the experience of the analyst, etc. These dimensions are reported in the defect listing.

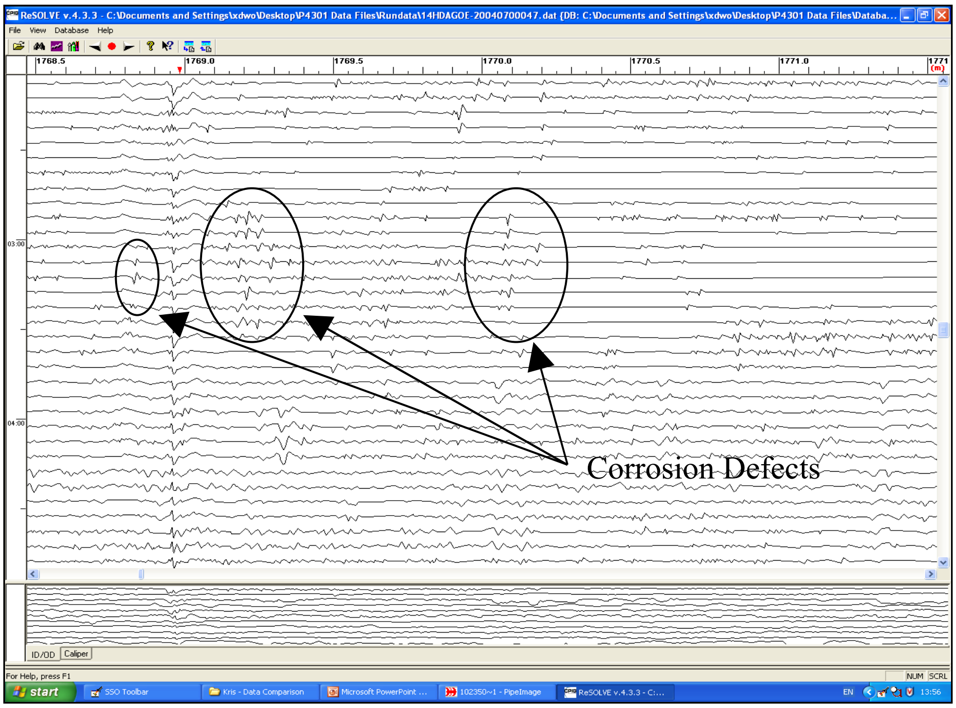

Figure 3 MFL Data on Screen

MFL and Reporting Defects

Where there are a large number of defects close together these may be grouped or 'clustered', and for conservatism and simplicity reported as a single defect, with a length equal to the overall length of the cluster, a width equal to the overall width of the cluster, and a depth equal to the maximum defect depth. An example of how two defects may be combined is given in Figure 4. This defect grouping or 'clustering' will follow set rules generally based on the axial or circumferential separation of the defects. A typical clustering rule is to combine two defects if the axial separation is less than three times the pipe wall thickness.

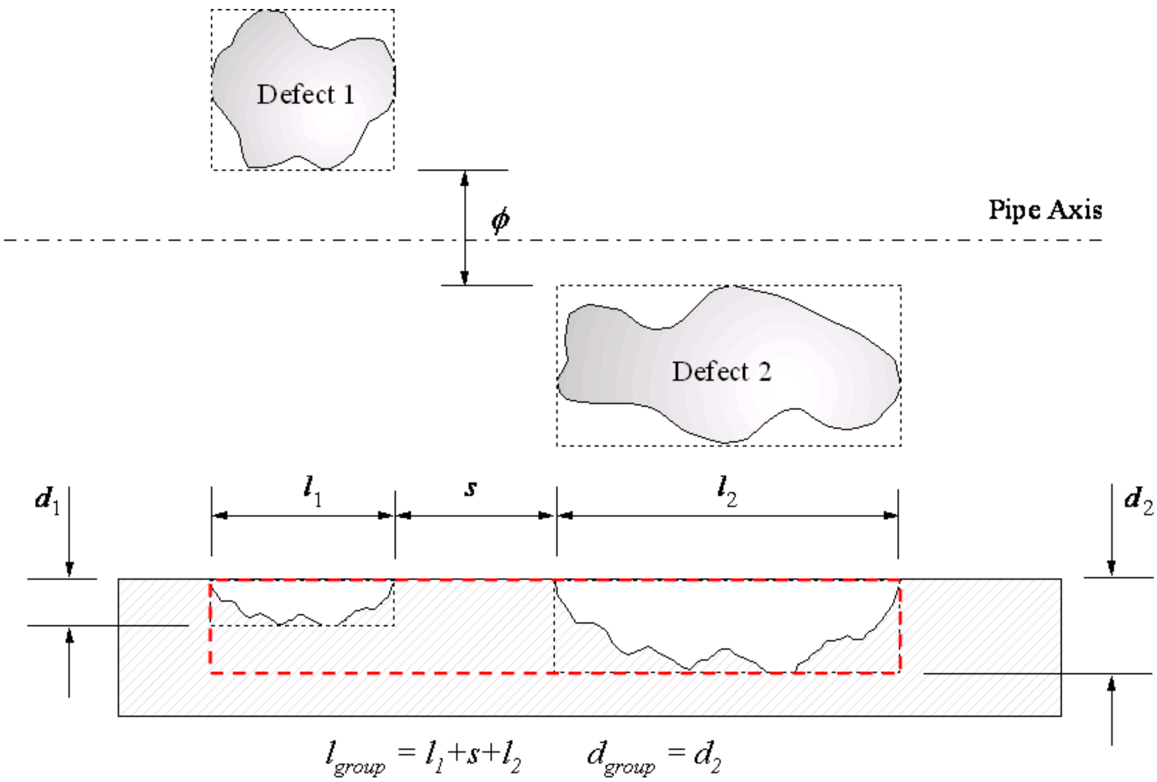

Figure 4 Defect Grouping (Clustering) Example

Figure 5 shows a typical defect cluster. Individual defects are identified by blue ovals, there are many defects close together, these have been grouped, and the group is identified by the orange rectangle, which defines the defect reported in the final defect listing. Therefore, a defect that is listed in an inspection report could be a single defect, or could be cluster of numerous real defects, as shown in Figure 5.

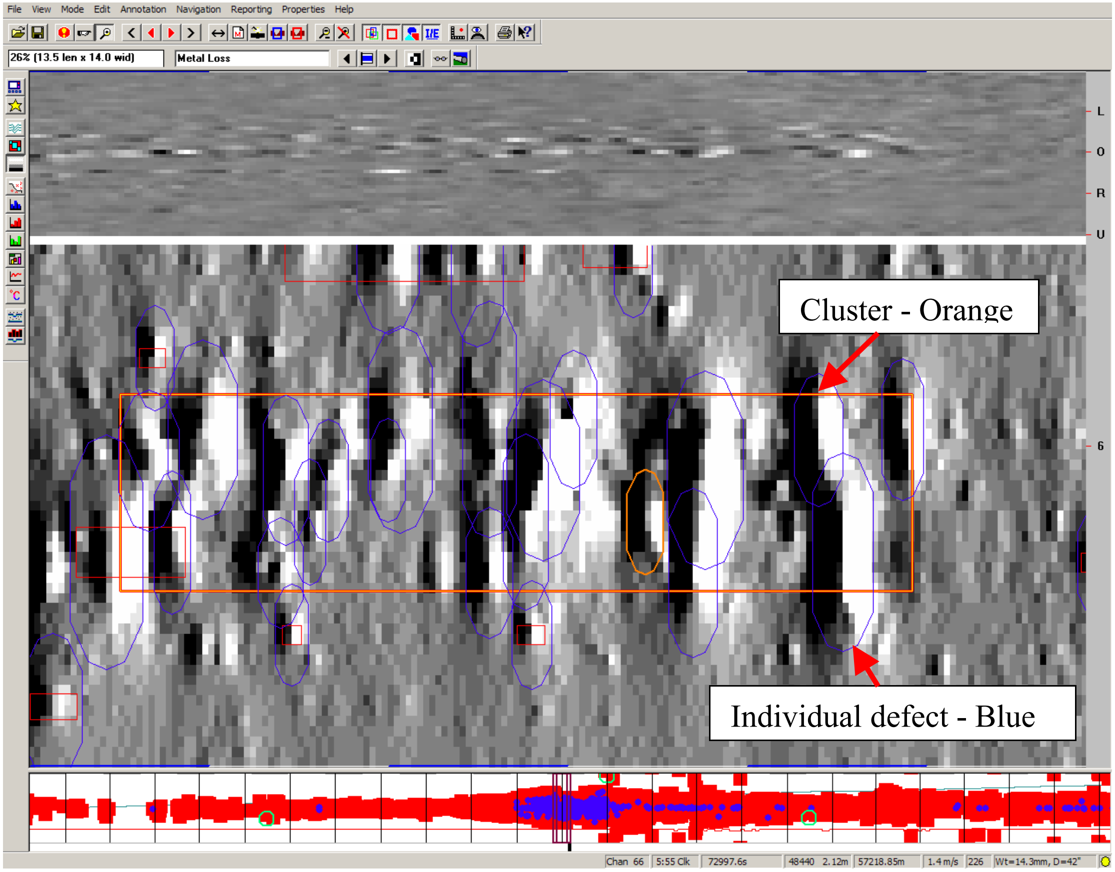

Figure 5 Defect Grouping

A typical defect listing is shown in Figure 6. In this case there is no differentiation between individual defects and groups of defects that have been clustered.

Upstream Girth Weld	Relative Distance (metres)	Absolute Distance (metres)	Comment	Peak Depth (%wt)	Length (mm)	ERF	Orientatio (hrs:mins)
30	10.6	19.6					
40	9.7	29.4					
50	0.7	30.1	NWT 7.80/9.53MM				
60	3.0	33.1	NWT 9.53/7.80MM				
	0.2	33.3	*EXT ML	21%	79	0.260	02:15
63	0.2	33.3					
68	5.3	38.7					
	0.0	38.7	*EXT ML	40%	694	0.406	05:45
70	0.7	39.4	NWT 7.80/9.53MM				
	0.1	39.6	EXT ML	26%	19	0.245	05:00
80	3.0	42.5	NWT 9.53/7.80MM				
	0.8	43.3	*EXT ML	23%	52	0.255	05:30
	0.9	43.4	EXT ML	16%	32	0.246	05:30
90	1.4	43.8					
100	10.2	54.0					
	8.3	62.3	EXT ML	15%	25	0.245	04:15
	8.4	62.4	*EXT ML	20%	46	0.251	05:45
110	10.9	64.9					
115	3.8	68.7	NWT 7.80/10.97MM				
130	3.1	71.8	NWT 10.97/7.80MM				
	1.4	73.2	*EXT ML	24%	36	0.250	05:30
	10.0	81.8	EXT ML	13%	34	0.246	04:15
140	11.2	82.9					
	0.1	83.1	*EXT ML	40%	94	0.288	05:00
	0.5	83.4	*EXT ML	32%	35	0.253	06:45
	0.6	83.5	*EXT ML	64%	93	0.335	07:15
	0.9	83.9	EXT ML	15%	75	0.253	11:45
	1.5	84.4	EXT ML	25%	59	0.259	07:00
	4.5	87.4	EXT ML	18%	63	0.254	05:45
	6.6	89.5	EXT ML	31%	38	0.254	04:45
	7.0	90.0	EXT ML	21%	48	0.253	05:30

Figure 6 Typical MFL Inspection Defect Listing

Ultrasonic Inspection

Ultrasonic inspection is a method for measuring the pipe wall thickness based on firing a pulse of ultrasound into the pipe wall and recording the time taken for reflections to come back to the transducer. This is illustrated in Figure 7. With knowledge of the speed of sound in the coupling medium, and the pipe steel, the stand off distance and the pipe wall thickness can be estimated. Where there is an internal defect the stand-off distance will increase, where there is an external defect the back wall echo will return sooner. For more information on ultrasonic inspection technology see Reference .

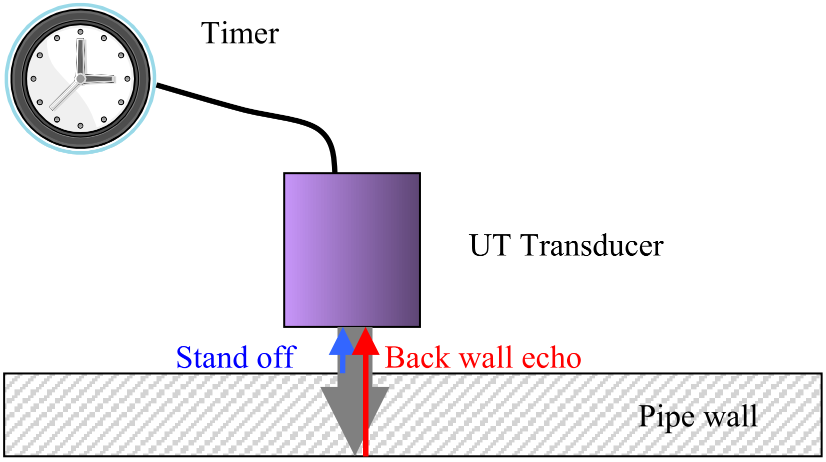

Figure 7 UT Measurement

UT inspection tools usually have numerous sensors, generally mounted in a sensor module that is towed behind the main pig. An example of a UT tool sensor carrier is shown in Figure 8.

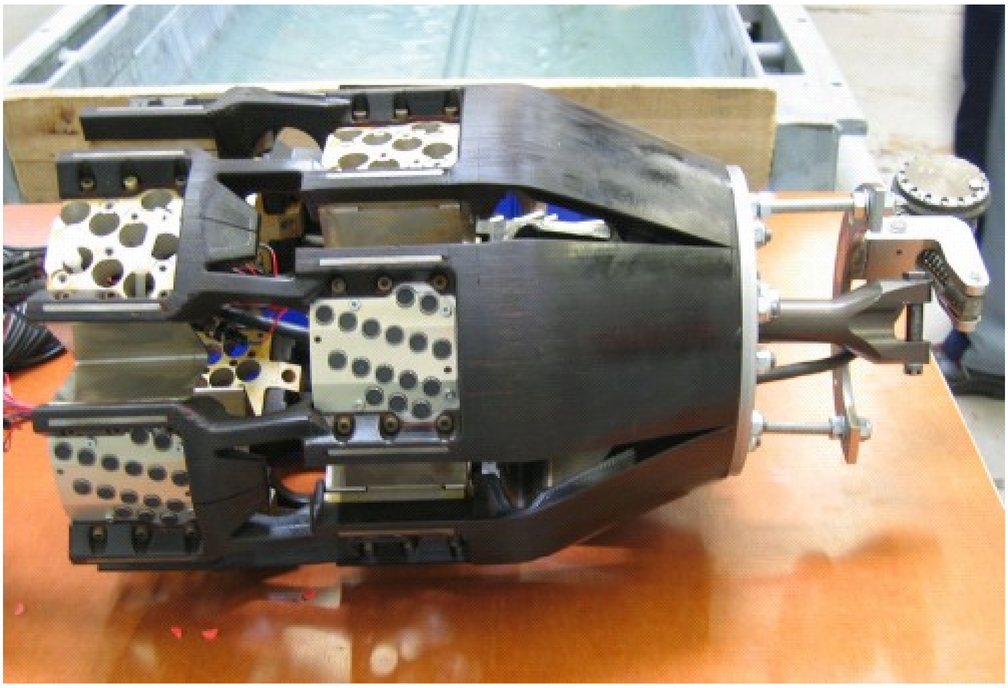

Figure 8 UT Sensor Carrier (courtesy of NDT)

The data collected by an ultrasonic inspection pig is often presented as a colour plot with different colours denoting different remaining wall thickness. A typical example is shown in Figure 9.

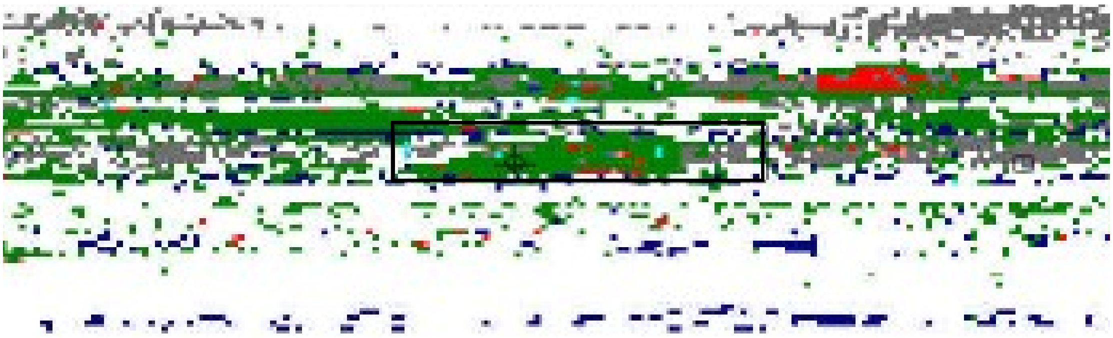

Figure 9 UT Inspection Data

An analyst will view the plots and identify defects to be included in the defect listing (shown as black rectangles in Figure 9). The accuracy of the measurement is dependent on a variety of factors including the cleanliness of the pipeline, the calibration of the tool, and the experience of the analyst. As with MFL inspections, where defects overlap or are close together, they will be grouped and described as a single defect in the defect report.

A typical UT inspection defect listing is shown in Figure 10. Again there is no differentiation between individual defects and clustered defects.

Pipe No.	Master Distance [m]	Master Rel. Distance [m]	Tool Distance [m]	Feat. Type	Comment	Rad. Pos.	Length [mm]	Width [mm]	Feat. Orient. [°]	Depth [mm]	Depth [%] Wt	Ref. Wt [mm]	ERF
17710	20009.08	11.59	20009.08	Pipe	X42		11585					8	
	20009.35	0.28	20009.35	Metal Loss		ext	130	70	207	1.40	17	8	0.970
	20010.08	1.01	20010.08	Metal Loss		ext	30	46	141	1.20	15	8	0.917
	20011.06	1.98	20011.06	Metal Loss		ext	45	70	203	0.80	10	8	0.919
	20011.16	2.08	20011.16	Metal Loss		ext	80	157	198	1.60	20	8	0.954
	20011.56	2.48	20011.56	Metal Loss		ext	105	52	213	0.80	10	8	0.937
	20011.60	2.53	20011.60	Metal Loss		ext	60	201	185	1.40	17	8	0.936
	20011.65	2.58	20011.65	Metal Loss		ext	90	122	153	2.00	25	8	0.976
	20011.69	2.61	20011.69	Metal Loss		ext	73	157	188	1.20	15	8	0.939
	20011.78	2.70	20011.78	Metal Loss		ext	65	122	203	1.20	15	8	0.935
	20011.87	2.79	20011.87	Metal Loss		ext	188	113	217	1.00	12	8	0.962
	20012.52	3.44	20012.52	Metal Loss		ext	105	87	175	0.80	10	8	0.937
	20012.65	3.58	20012.65	Metal Loss		ext	30	35	173	1.80	22	8	0.921
	20012.81	3.74	20012.81	Metal Loss		ext	70	52	158	1.00	12	8	0.932
	20012.92	3.84	20012.92	Metal Loss		ext	62	122	149	1.00	12	8	0.929
	20013.00	3.93	20013.00	Metal Loss		ext	83	148	153	1.20	15	8	0.943
	20013.06	3.99	20013.06	Metal Loss		ext	27	61	187	0.80	10	8	0.913
	20013.11	4.04	20013.11	Metal Loss		ext	35	113	173	0.80	10	8	0.915
	20014.50	5.42	20014.50	Metal Loss		ext	72	87	181	1.20	15	8	0.938
	20014.70	5.63	20014.70	Metal Loss		ext	30	52	203	0.60	7	8	0.913

Figure 10 UT Defect Listing

Standard Defect Assessment

Standard assessments of in-line inspection results generally involve calculating the failure pressure of the metal loss defects reported, applying a safety factor, and comparing the resulting ‘safe’ pressure with the maximum allowable operating or design pressure of the pipeline.

Failure Pressure = P_f
Safety Factor - = s
Safe Pressure = P_{safe}
P_{safe} = P_f / s

If P_{safe} > MAOP then the defect is acceptable

If $P_{safe} \leq$ MAOP then the defect is not acceptable

Methods that are commonly used include ASME B31.G▯, modified ASME B31.G▯, and DNV RP-F101▯. The Engineering Repair Factor ‘ERF’ included in many in-line inspection reports is based on a calculation using the ASME B31.G method (see Figure 6, and Figure 10). In general these methods will give a conservative estimate of the failure pressure of a metal loss defect, particularly if the appropriate tolerances (accuracy) of the inspection tool are taken into account. In some cases they can result in a very conservative assessment, particularly when a number of defects have been grouped together, most of which are shallow and just one of which is deep. An example of this is shown in Figure 11, which shows an idealised defect profile based on the maximum depth reported for 'boxes' within a 'cluster', moving along the pipeline.

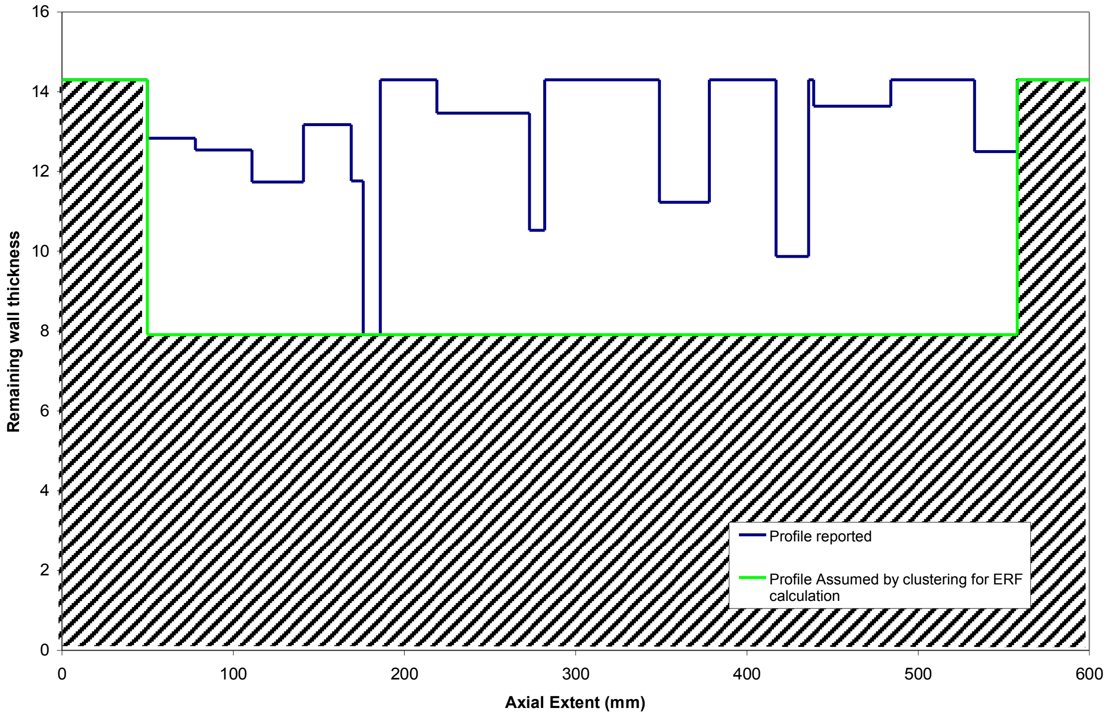

Figure 11 Cluster Dimensions

Where the initial assessment results in a prediction that the defect is not acceptable, there may be the option of carrying out a more detailed assessment, if the data is available. The more detailed level of assessment is covered in the next section.

Expert Level Assessment of Metal Loss

The assessment of corrosion defects based on detailed measurements of the shape is sometimes referred to as 'river bottom' assessment. Where detailed measurements of external corrosion are available (e.g. from a laser scanning device), then a very detailed defect profile can be developed. An example 'river-bottom' profile of corrosion is shown in Figure 12. These assessment techniques take account of the strength offered by all the remaining wall thickness, rather than assuming a simplified defect profile.

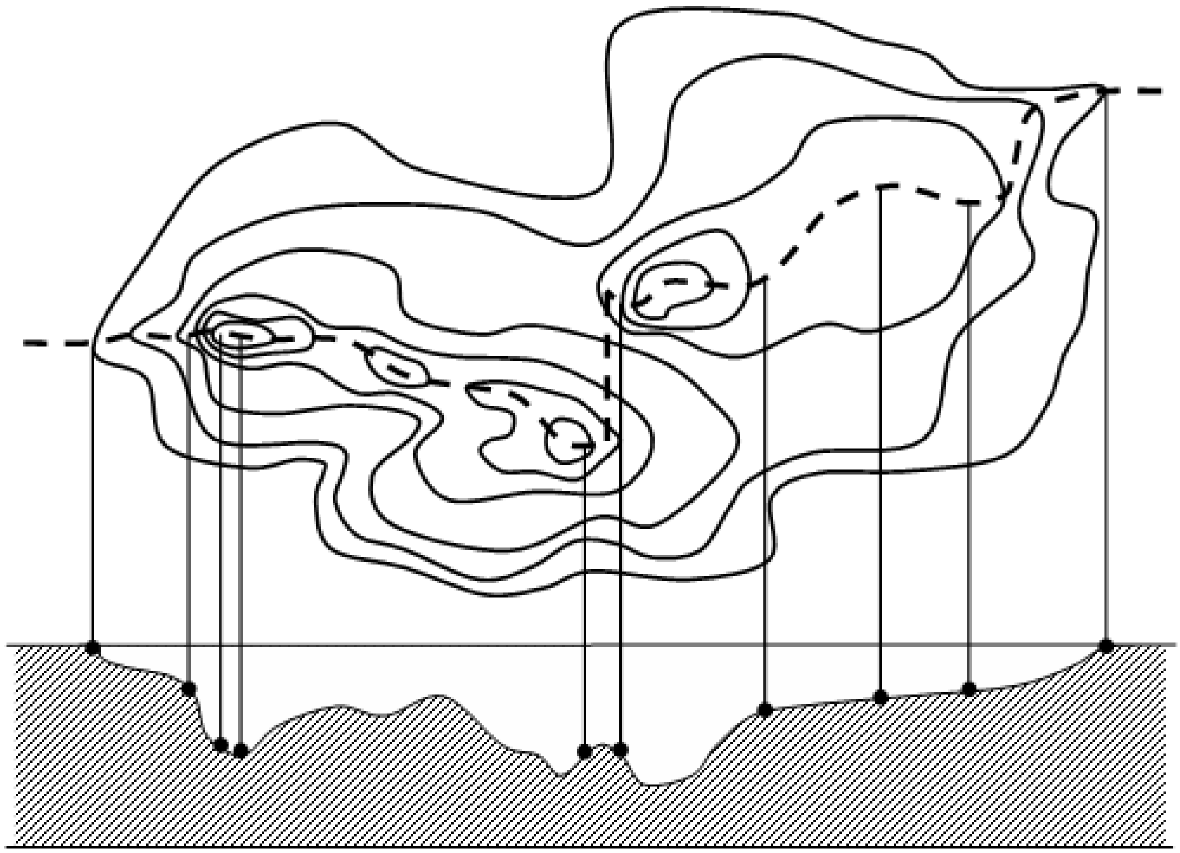

Figure 12 – Typical River- Bottom Profile of a Defect

Examples of such methods include the RSTRENG™ method▯ or the complex defect method in DNV-RP-F101▯.

The DNV method treats the corrosion defect as a combination of a general area of corrosion ‘patch’, within which there are deeper ‘pits’, as shown in Figure 13. The assessment method then determines whether the defect behaves as a single irregular ‘patch’, or whether local ‘pits’ within the patch dominate the failure. Potential interaction between the pits is also assessed. A progressive depth analyses is then performed which divides the defect into a number of increments based on depth, and modelled by an idealised ‘patch’ containing a number of idealised ‘pits’. The combination giving the lowest predicted failure pressure is selected as representative for the particular defect.

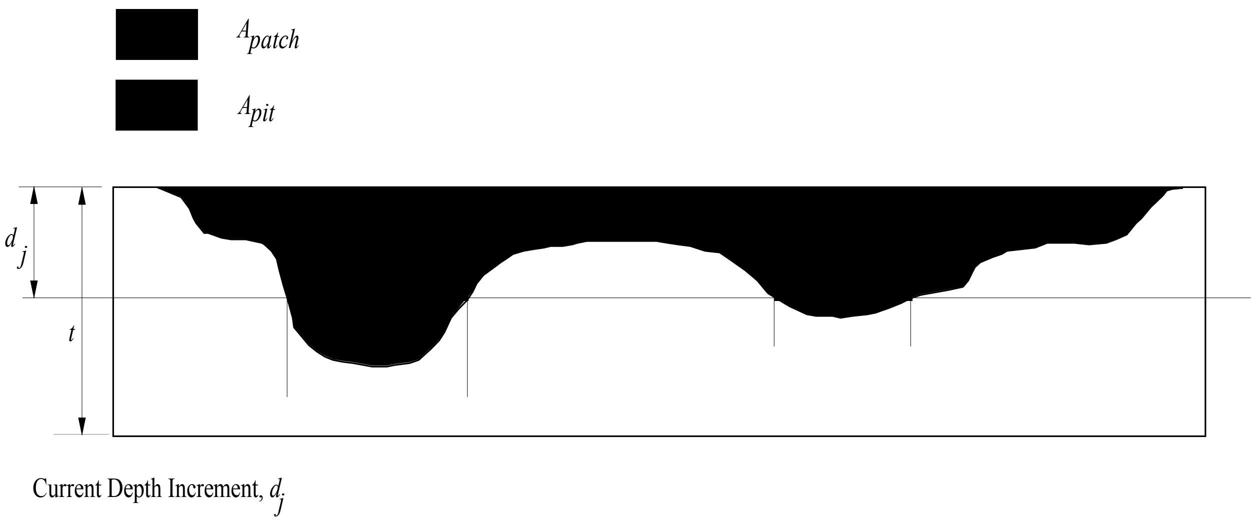

Figure 13 – “Patch” and “Pit” in a Corrosion Defect as assessed by DNV-RP-F101

This type of assessment can be carried out using intelligent pig data, if the box data, or in the case of a UT inspection, the detailed profile data, can be extracted.

An example of a set of UT data and the 'rectangular' defect, and 'river bottom' profile from the same data is given in Figure 14, Figure 15, and Figure 16.

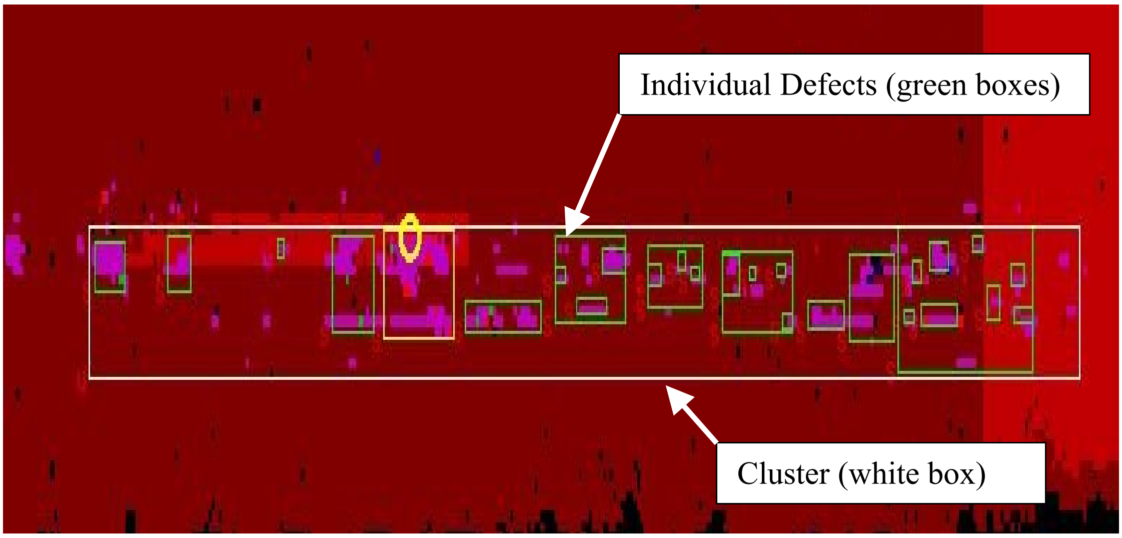

Figure 14 UT Inspection Data

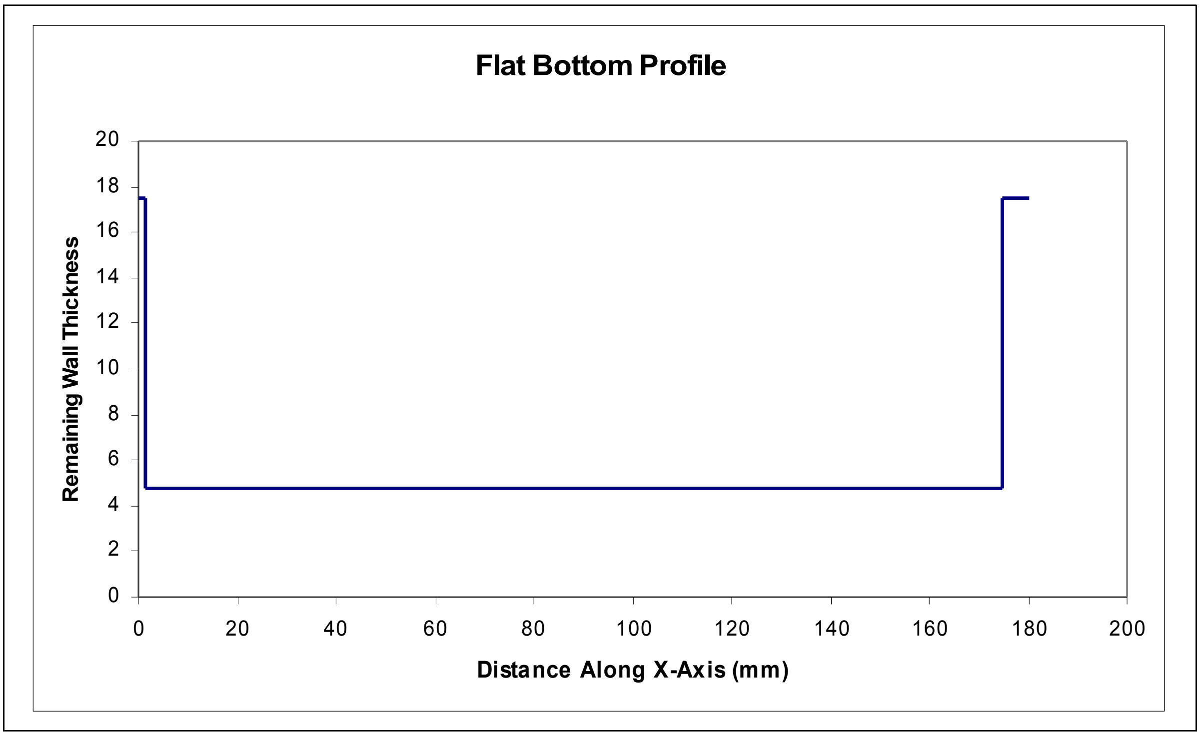

Figure 15 Cluster Profile from UT Data

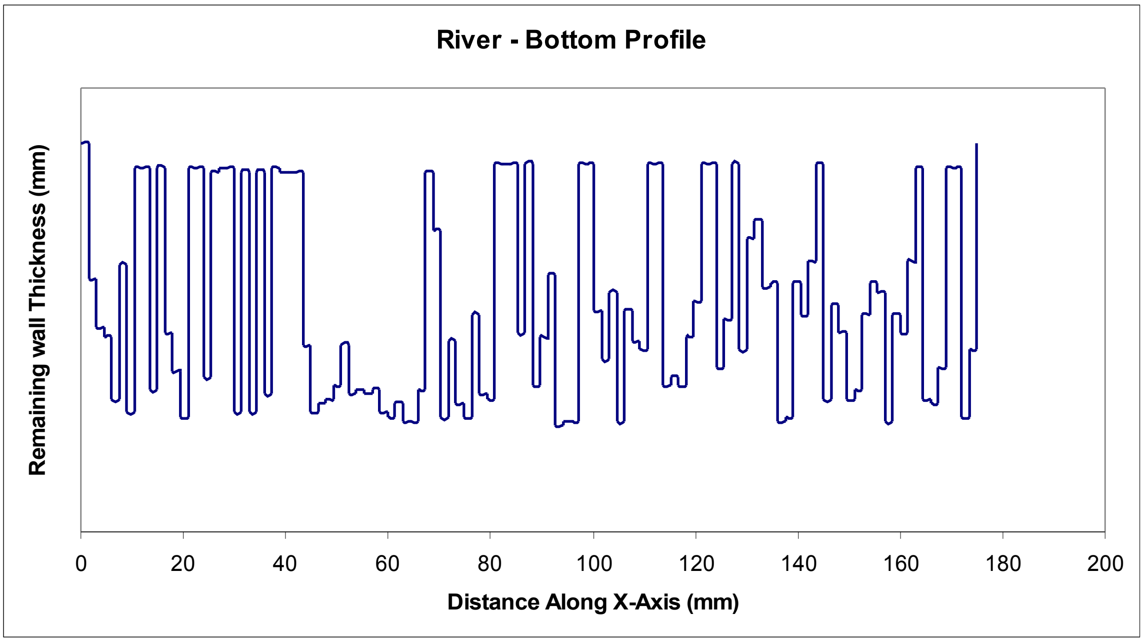

Figure 16 ‘River-bottom’ Profile from UT Data

Care is required to ensure that the profile generated is conservative: it is not a simple matter of drawing a straight line along the axis and measuring the deepest points. Defects that are separated circumferentially may interact, and the transition from one deepest point to the next must be modelled correctly.

Example

An internal corrosion defect reported by MFL inspection in a crude oil pipeline was recently assessed.

The defect had a reported depth of 63% of the pipe wall thickness, and a length of 330 mm. The failure pressure was calculated using the DNV-RP F101 methodology, and the guidance in PDAM.

- Using reported ‘cluster’ dimensions – rectangular defect assumed.
- Using ‘idealised’ profile, based on ‘box’ dimensions.
- Using ‘idealised’ profile generated from external UT scan of the damage area.

The results of the different assessments are given in Table 1.

Assessment	**Data**	**Maximum Reported Depth (%t)**	**Length (mm)**	**Defect Profile**	**Failure Pressure (Bar)**
Standard	MFL pig ‘Cluster’	63	330	Rectangular	53
Expert	MFL pig ‘ Boxes’	63	330	‘River-Bottom’	113
Expert	External UT	50.5	1760	‘River-Bottom’	85

Table 1 Calculated Failure Pressures

As can be seen the standard assessment (similar to the ERF) gives a lower failure pressure than the more detailed assessments. This could lead to unnecessary pressure reductions or repairs. Utilising the ‘box’ data can offer significant benefits, but caution is required as it may result in un-conservative answers. Using other data sources, such as external UT can provide benefits, but detailed data is required.

CONCLUSIONS

Extracting detailed defect profile data from intelligent pig reports can offer significant benefits in defect assessment.

Detailed data is collected as a part of the inspection process, whether the inspection is by MFL pig, UT pig, or external UT. Consequently, this data should be provided in readily transferable electronic format (e.g. Microsoft Excel spreadsheet) free of charge with any inspection report.

REFERENCES

1. Palmer-Jones, R, Hopkins, P., "*Managing ILI Projects To Get The Results You Need*", Pigging Products and Services Technical Seminar, Aberdeen 2005. www.penspenintegrity.com
2. Palmer-Jones, R, Hopkins, P., Eyre, D., "*Understanding the Results of an Intelligent Pig Inspection*", Pigging Products and Services Technical Seminar, Aberdeen 2006. www.penspenintegrity.com
3. Nestleroth, J.B., Bubenik, T.A., "*Magnetic Flux Leakage Technology for Natural Gas Pipeline Inspection*", Battelle, for the Gas Research Institute, February 1999. http://www.battelle.org/pipetechnology/MFL/MFL98Main.html.
4. Anon, '*Standard Recommended Practice In-Line Inspection*', NACE Standard RP0102-2002, 2002.
5. Beller, M., "*Applying Ultrasound for In-Line Inspection: Facts and Issues*", PPSA, 2006. http://www.ppsa-online.com/papers/2006-Aberdeen-2-Beller.pdf.
6. Anon., Manual for Determining the Remaining Strength of Corroded Pipelines, A Supplement to ASME B31 Code for Pressure Piping, ASME B31G-1991 (Revision of ANSI/ASME B31G-1984), The American Society of Mechanical Engineers, New York, USA, 1991.
7. KIEFNER,J.F., VIETH,P.H.; "*A Modified Criterion for Evaluating the Strength of Corroded Pipe*", Final Report for Project PR 3-805 to the Pipeline Supervisory Committee of the American Gas Association, Battelle, Ohio, 1989.
8. ANON; "*Corroded Pipelines*", Recommended Practice DNV-RP-F101, Det Norske Veritas, 2004.
9. Hopkins, P., Cosham, A., '*The Pipeline Defect Assessment Manual*', Joint Industry Project, Penspen Ltd., 1999 – 2007.