



## **METAL LOSS AND CRACK INSPECTION: BENEFITS OF USING ULTRASOUND TECHNOLOGY**

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### Abstract

With pipelines growing older, more and more inspection data of different origin are gathered. Most of the data is acquired by In-Line inspection tools as they can cover the whole length of a pipeline in one inspection job. The comparison of the results of in-line inspections becomes more and more important. Not only should the previous results be verified, but the continuous monitoring of the pipeline's condition allows to derive new conclusions like the assessment of corrosion growth. The paper will discuss how defect growth can be estimated from continuous inspections and what implications the advancement in inspection technology has. Several models of corrosion growth assessment are discussed. Their applicability depends on the condition of the pipeline, i.e. the density of defects and the available data. A stepwise process can be defined in which more detailed information will allow to use more accurate methods of corrosion growth assessment.

In a final stage the data of high-resolution ultrasonic inspection tools can be used to compare defects on a basis of wall thickness C-Scans. This will generate more precise conclusions about corrosion growth on single defects, which was not possible on the traditional statistical approach.

### **Introduction**

In many countries of the world the pipeline regulation not only demands a check of pipeline integrity in case of doubt or after incidents resulting in loss of property or even life. Instead a continuous process of constant monitoring of pipeline integrity is required. Often in-line inspection is the method of choice for these measures. Many regulations demand or recommend the use of intelligent pigs [1,2].

This is one reason why in-line inspection is nowadays a less exceptional event in the operation of pipelines, but for many operators has become a process of every day life. While the inspection results used to be information that was heeded right after delivery and then archived (unless action was required) it is today used in many circumstances even years after the actual inspection has taken place.

It is in the benefit of both parties, the ILI-operator and the pipeline operator, to ensure that the information is delivered such that it can easily be exploited in the future. Naturally the inspection technology is advancing, which results in a desirable improvement in detection levels and reliability. In several cases this has left the impression that the comparability of the results with earlier inspections is compromised. However, the reason for systematic differences in the detection results should not be blamed on the advancement of the technology, but rather on the limitations of the previous inspection technology. The notion "If I missed the defect the last time, I better miss it this time, too, so I am at least consistent" is definitely short-sighted.

The following paper will focus on the issue of repeated ultrasonic inspection. Many aspects, however, are also applicable to MFL-Inspections. Corrosion growth studies are a major issue in repeated in-line inspection. Several methods have been developed to pin-point potential growth sites based on ultrasonic data.

## **Procedures**

### **Matching the lists**

In a first step run comparison is based on the features list, i.e. the result list of findings after an in-line inspection. The POF document describes what the features list should contain at minimum. Whether the old list meets these requirements is not always clear. A minimum requirement is a list of features with the following items

- Defect size in width, length and depth
- Defect location in distance and orientation

If the defect location is given as the position of the deepest point (Ultrasonics) or the maximum magnetic field amplitude (MFL), there is an uncertainty to where exactly the defect starts. This point is not necessarily in the middle of the whole length of the defect. A method describing features by call-boxes is preferable. The location must be given with reference to a pipe tally. Absolute distances cannot be compared in two pig runs. They rather have a sorting function. A pipe tally with distances corresponding to the defect distances has to be supplied as well. Both lists have to be in an electronic version like an Excel-Sheet. This should be especially emphasized to operators. In the past it has become necessary, in some instances, that a print-out was to be read into an Excel-list via a scanner and a word pattern recognition system. Although these tools become better and better, the procedure is still error prone and time consuming. It should be self-evident that record keeping needs to be in electronic format nowadays.

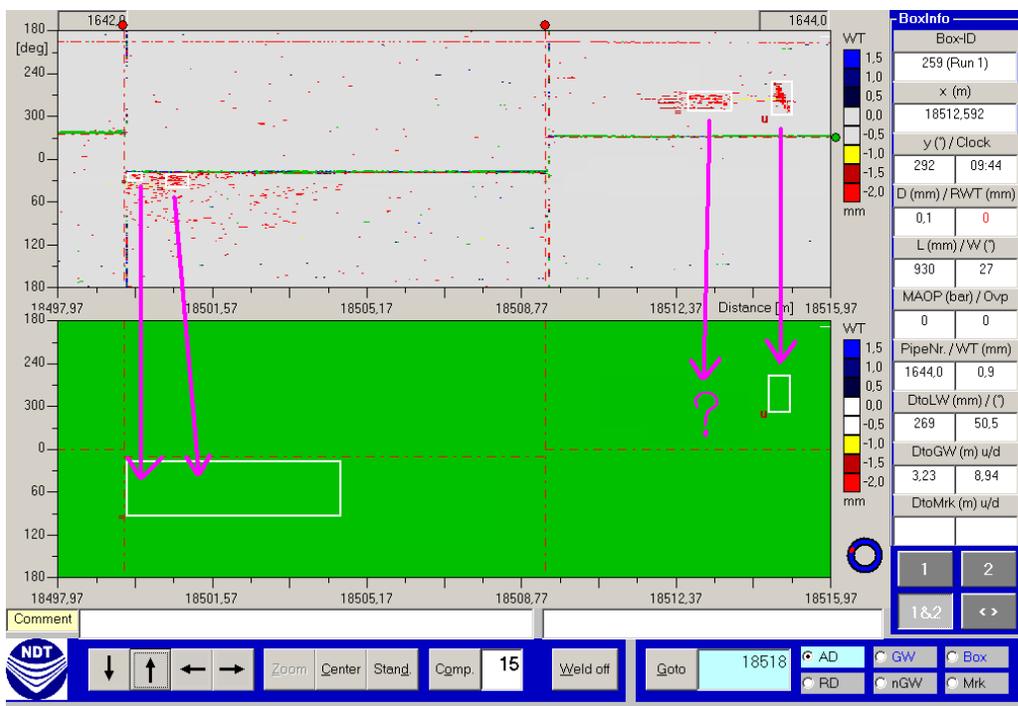
These lists then need to be put into a database table. Either a proprietary format is used or a standard model. At NDT Systems & Services AG a Software has been set up that will first match the two pipe tallies. This is not always trivial and may require some manual work as well. Then features are matched joint by joint locating them with respect to girth welds. Some tolerances can be applied, because deviations of up to 10 cm (4 inch) in axial distance can be found. If the angle parameter is not given the tolerance in orientation can be set to 360°. This will find all features matching by distance alone. If the feature density is high there is a chance that some matches are incorrect. This is a potential problem for older lists, where feature orientation was not always given.

Figure 1 shows a screenshot of the Run Comparison Function of NDT's Analysis Software PIXUS. Note that the girth welds are depicted by dashed red (grey) lines and are located at exactly the same position. Feature locations are depicted by white boxes.

With a comparison based on the features list alone the following information can be derived:

- A list of corresponding metal loss features. This list could be used for a step 1 corrosion growth analysis.

- A list of discrepancies in feature classification. This can be very important information. If a feature was assumed to be an inclusion it was not considered a threat to the integrity of the pipeline. However, if in the second run it is revealed as a pitting corrosion, things are different. Although a thorough data analysis should minimise such discrepancies, the evolution of inspection technology and analysis procedures will inevitably lead to discrepancies.
- A list of features that have been missed in the first inspection. Either they have developed in the meantime or these defects have been missed due to inferior inspection technology.
- A list of features that have been missed in the second inspection. If the second inspection is carried out independent of the results of the first inspection this is still possible although not likely.



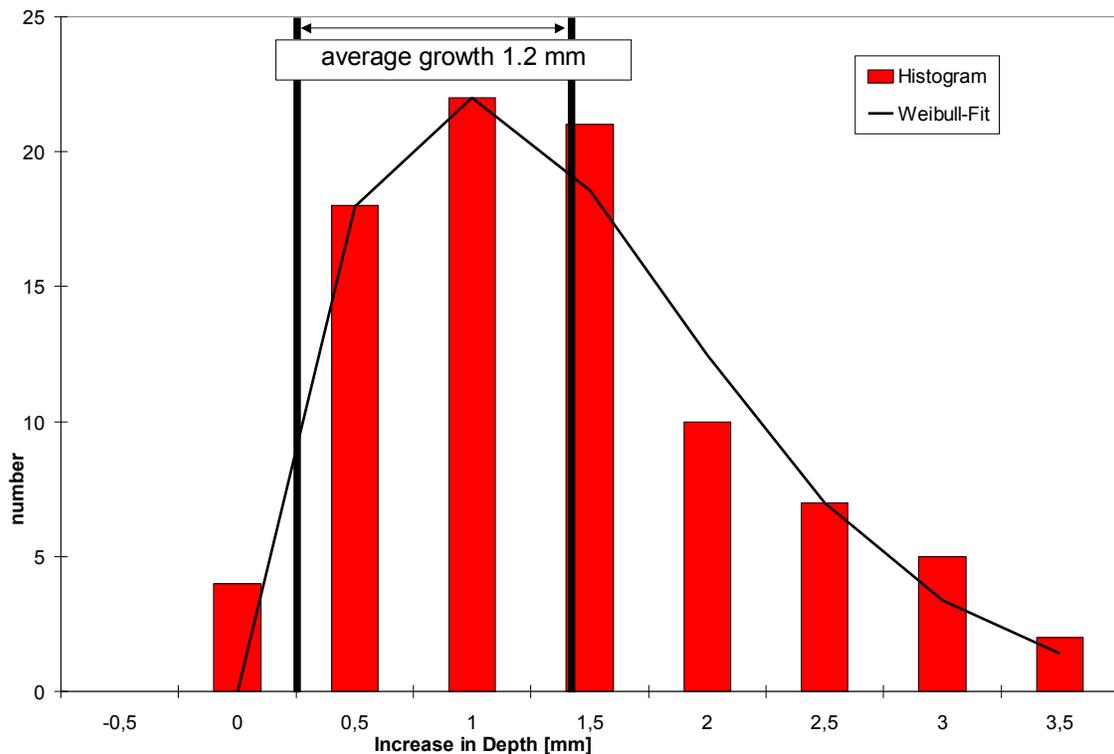
**Figure 1: A sample screenshot of the RunComparison Function of NDT's analysis Software. The purple (dark grey) arrows indicate what correspondences can be found.**

### Statistical Analysis

If a run comparison was carried out for a kind of feature that is associated with a depth (like corrosion) it is time to establish whether it has grown or not. Even for a single defect this has a statistical character, because the measurement itself is associated with a degree of uncertainty. In UT-inspection it is common to take the deepest reading of a box region and report this as the depth of the defect. Thus the depth is an extreme value potentially affected by false readings. It has been proposed to use an average depth value for corrosion growth detection. Although by

definition the corrosion growth rate is the evolution of the deepest point, an average depth value may bring evidence on the existence of active corrosion with a higher certainty.

Albeit, when calculating a corrosion growth rate for every single defect, the measurement error can be dominating. If the measurement is repeated many times the effect of measurement error can be minimized. For In-Line inspection a repetition of the inspection is not an option. If, on the other hand, the assumption is made, that the corrosion rate is the same for most defects, the changes in depth can be used as several measurements of the same corrosion rate. The relevance of the result will thus depend on the number of pairs and the accuracy of the two tools. A sample histogram of changes in depth is shown in Figure 2. It would be an oversimplification to assign a single growth rate to a pipeline altogether. Areas of active corrosion would be hidden if the average is taken over all parts of the line that are potentially no affected.



**Figure 2: The increase in depth for 89 sample pairs of metal loss features as a histogram. There is a deviation of the mean from zero, that cannot be explained by the pig measurement uncertainty alone.**

The ambient conditions are rarely unchanged over the whole length of the line. To account for these problems a certain subset of features should be selected for assessment of corrosion growth. There are several solutions to this problem.

#### **Data Segmentation**

The data has to be segmented into subsets for which the evidence of active corrosion is possibly higher than for the set as a whole. For  $n$  values of change in depth the number of possible subsets would be  $2^n$ . Obviously this number is too large. Important constraints are that the subsets should

not mix internal and external defects and that they should be connected distance-wise. A decision tree method has been proposed in [3] to find these subsets automatically.

### **Running Average**

Another solution for choosing the right subset of metal loss sites for the corrosion growth study has been proposed in [4]. The pipeline is divided into regions that make a natural segmentation of the total distance. Separators could be transitions from above ground to below ground, or other changes. It could be envisaged that soil conditions or other information typical for DA<sup>1</sup> methods be used as a separator as well. No region should be longer than 1 mile. A running average pit depth is calculated of a pipeline and compares it with a previous measurement. In this case it is not necessary to identify every feature with its counterpart in the older report. However, the metal loss features have to be abundant to efficiently use this method. This is another hint that for corrosion growth assessment the pigging vendor should supply the feature information as detailed as possible. Metal loss defects should not be grouped into large clusters and even shallow defects can later on contribute to deliver evidence of corrosion growth.

### **Run Comparison with UT-data**

Because ultrasonic data has no intrinsic ambiguity, it is also much more valuable long-term. Archived MFL data that is older than 10 years is often not used for Run Comparisons. While for UT data advancements in technology have also improved the overall value of the measurement data, even very old data is still directly comparable to data of very recent UT pigs. Figure 3 shows a metal loss defect as recorded by two inspections. The lower part shows the result of an earlier inspection that is about 12 years old. The upper part shows the recent results as they were obtained by NDT. The upper diagram in each box is the C-Scan the lower one a B-Scan with the deepest point.

The data of the earlier inspection was governed by echo loss. It is shown in green (dark grey in black and white reprints). Except for some spots in the weld echo loss is missing in the recent data. The effect is also seen in the B-Scans. In the earlier measurement the profile is basically flat at 0 mm (which is the conventional way of indicating echo loss in the data). Only a few points with a wall thickness deviating from the nominal wall thickness can be observed. In the recent measurement the full profile is revealed.

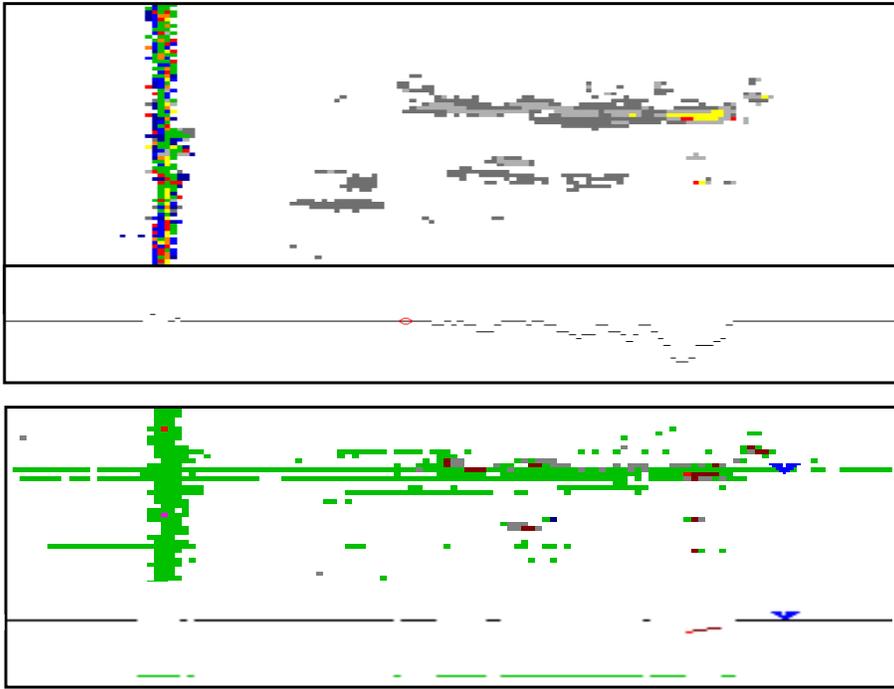
The presence of echo loss has an effect on the reported depth. In the first inspection the defect was reported with a depth of 2 mm. The deepest point is now measured as 3 mm. Based on a simple feature to feature comparison one may be tempted to conclude that active corrosion has been present (or still is). The analysis of the actual data, however, reveals that it is much more likely that the deepest point was masked by echo loss, thus leading to a shallower depth.

The conclusion that the old tool should be run again, in order to have the same masking of the defect and hence the same depth is not permissible. The distribution of echo loss is a matter of probability. To account for this uncertainty the accuracy of the tools should be altered. While the recent measurement is likely to fulfil its stated accuracy level of  $\pm 0.4$  mm (0.016 Inch), the old measurement falls short of the accuracy of  $\pm 0.5$  mm (0.02 Inch). Instead a lower level of

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<sup>1</sup> Direct Assessment, A method to assess the integrity of a pipeline based on various sources of information. See for instance NACE RP 0502.

accuracy, like for instance  $\pm 1$  mm (0.04 Inch) should be assumed. This way also a feature by feature comparison can be carried out, which would then reveal, whether the data quality is sufficient or not. Here the result would not be the presence (or absence) of active corrosion, but the lack of evidence.

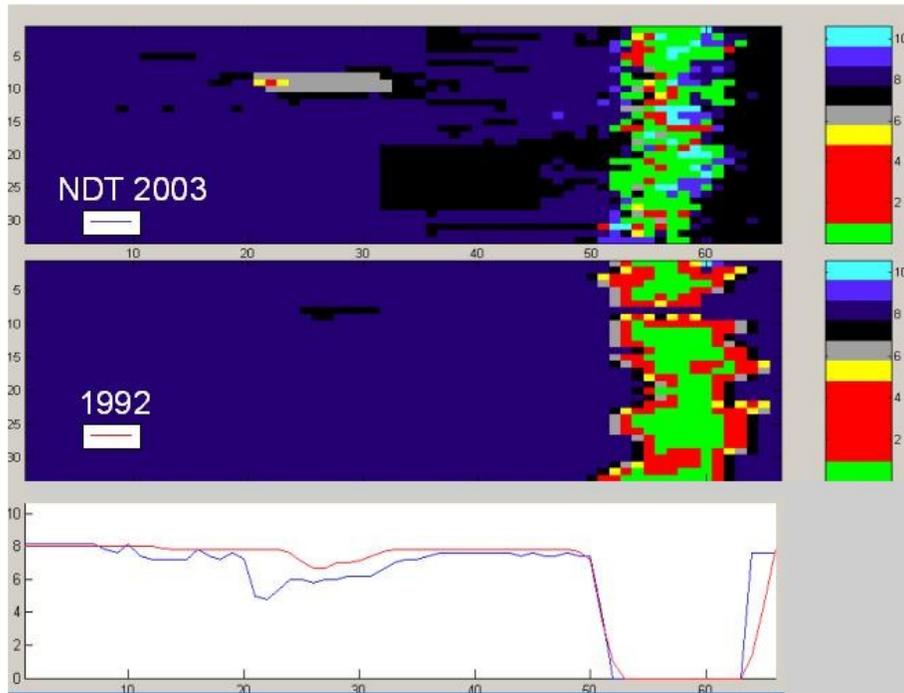


**Figure 3 A defect seen by two inspections with different UT-tools. The lower inspection is over 12 years old. The upper picture show the defect as it was seen recently by an NDT pig.**

If the investigation is then extended to a pixel-by-pixel comparison, some treatment of the matrix of wall thickness data is needed to account for the following discrepancies:

- The sensor spacing may be different. Thus the number of lines in the matrix corresponding to the same circumferential range is different. The matrix with the lower number of lines can be interpolated.
- The same applies for the axial sampling density. In traditional tools the sampling was controlled by frequency. Speed variation would thus change the spacing in between data points.
- The cut-out of the feature box from the C-Scan will always vary. So a means to move the boxes with respect to each other is required.
- The wall thickness of the nominal wall next to the defect should be compared. If it doesn't give the same value, a correction should be done.
- Echo loss is the most problematic adaptation. Echo loss can also be interpolated, but this generates defect profiles that have not really been measured. It would be better to neglect areas with echo loss altogether. In the example in Figure 3 only the shape can be compared.

Figure 4 shows a sample comparison of two matrices of wall thickness values. Both data values are displayed with the same colour code. The sizes have been adapted to show the same area of the pipe surface. In the lower part the river bottom profile is shown for the two measurements. There is a relevant deviation between the two indications – a growth of the metal loss.



**Figure 4: Pixel-by-pixel comparison of a metal loss defect. No change is found.**

### Run Comparison with Crack Inspection Data

Crack inspection using ILI-tools has also become a widely used inspection task in the pipeline industry in the recent years. Although not applied on a routine basis, many pipelines are not only inspected in the case of actual threat but also as in a precautionary manner. However, the experience in run comparison of subsequent crack inspections is very limited. This has different reasons.

- Most of the crack inspection is done with the angled beam ultrasonic technique [5]. Other technologies have also been applied like Elastic Wave [6] and Transverse MFL [7]. Apart from the angled beam UT, none of the technologies ever gained widespread support. Because of the difficulties in technology, a direct comparison between different technologies does not seem reasonable.
- The accuracy of the depth measurement is not as reliable as for ultrasonic wall thickness inspection. Cracks can grow in length and in depth. From a defect assessment point of view the depth is a crucial measure. Comparing the depth based on the features list is not very revealing.
- Usually the crack inspection technology is applied if the pipeline is susceptible to stress corrosion cracking. These types of cracks are typically found in colonies. Crack colonies

are easily detected with the angled beam tools. However, the resolution of single cracks is often not possible. This would be necessary if the change in size of the cracks was to be evaluated. SCC is a crack type that potentially grows quite rapidly. If cracks of this type are found, the affected pipe sections would most often be replaced and thus are no longer found in a second inspection later on.

- For corrosion the corrosion rate will immediately allow to calculate the remaining life of a pipeline and give information on reasonable reinspection intervals. The corrosion rate is easily found with two inspection runs, assuming the time interval to be sufficiently large. For cracks the growth rate is governed by fracture mechanical laws. Both, for SCC and for fatigue cracks the growth rate is given by crack size, stress levels and time or number of cycles. The remaining life can thus be calculated even without reinspection.

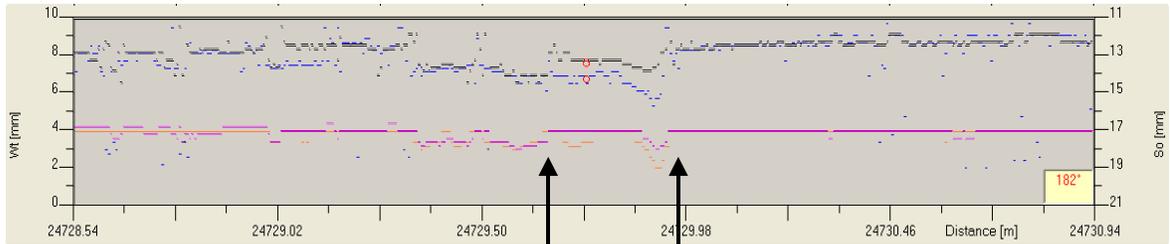
Nevertheless the question of comparing results between crack inspections will arise some day and even here some conclusive results are anticipated. Other advancements in the field of crack detection will support this development. One of the upcoming news in the field of crack inspection is the introduction of pigs that will detect cracks in circumferential orientation.

### **Run Comparison with Channeling Corrosion**

Channeling or 6 o'clock corrosion is a special challenge for in-line inspection. This is not so much the case for the detection of this type of corrosion, but moreover for the proper reporting. Usually most of the pipeline is affected by corrosion. The description of this corrosion by a simple box, which states length, width and depth is not appropriate. Instead many small adjacent boxes should be inserted into the list which describe the depth at that very position. However, for pipeline length of often 20-30 km this will increase reporting times and does not make the lists very handy with thousands of reported features. Corrosion growth studies based on these list can be a nightmare. It is almost impossible to assure that the proper boxes are compared.

Channeling corrosion may appear in different forms. Sometimes the groove is very smooth and the depth is constant over many meters. In other instances the channel is intermittent and the profile shows many variations in depth. It has become common practice to describe the profile with about three deepest spots per pipe joint and the channel as a whole with a typical depth. For comparison these spots are then compared in depth. Again this is not necessarily the best practice as corrosion may proceed in rather shallow areas.

Figure 5 shows data of a depth profile obtained in a section of channelling corrosion. The upper two lines show the wall thickness of two measurements that are two years apart. The black line is older than the blue line. The lower lines show the stand-off readings. The purple line is older than the orange line. While the profile is very well reproduced in the right part of the picture, especially between the arrows a section with definite increase in depth is found. The right arrow is at a girth weld position, which is not seen in this depiction. It is found that changes can occur very abruptly.



**Figure 5: Sample data of a depth profile obtained in a section of channeling corrosion. The upper two lines show the wall thickness of two measurements that are two years apart. The lower line show the stand-off readings. The growth is found only at a specific spot.**

### Conclusion

The data originating from an in-line inspection is nowadays not only used at the time the report is issued, but will be put in context with other inspection data. This can be especially valuable in the case of ultrasonic inspection. As pigging vendors and inspection technologies change, the pipeline operators should ensure that inspection data and results are made available at the time of delivery and are still available to third parties many years later. The advancement of inspection technology does not diminish the continuity in inspection but allows to draw conclusions even with pigging results that have been archived for a long time.

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