PIPELINE INTEGRITY SOFTWARE

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ABSTRACT

It is now commonly accepted that In-Line Inspection is one of the most reliable methods of ensuring pipeline safety. The technologies employed to achieve this aim are being developed all the time and more advanced inspection tools continue to emerge. All efforts are made to detect, by means of in-line inspection, as many defects as possible that pose actual and potential threat to future pipeline integrity. At the same time, a normative framework is being established that includes various standards and recommended practices for assessment of pipeline condition. As a rule, these standards are based on the results of pipeline defect research and large numbers of full-scale tests. Today, the most widespread standards are API 579, BS 7910, DNV RP-F101, API 1156 etc. All of them can be used to forecast the safe operation of pipelines.

The proper use of many of these methods can substantially reduce the costs of repair and maintenance programmes. Weatherford's long experience suggests that most pipeline operators have their own well-grounded preferences for selecting methods to rehabilitate pipelines based on Fitness-For-Purpose assessments. As a rule, analysis of the current condition of pipelines requires that additional factors such as defect growth rate, interaction of adjacent defects, as well as pipeline operators' specific requirements are taken into account almost all the time. The efficiency of defect assessment methods significantly increases when the results of two or more inspections are used. It has become desirable that the pipeline integrity assessment, which is a multi-stage process, would benefit from automation.

This paper describes Weatherford's i-View^{SM} ILI software, which is the result of long experience of dealing with different pipeline operators.

BACKGROUND

Long experience of dealing with pipeline operators has lead us to the idea of developing software for comprehensive and automated assessment of pipeline integrity and making decisions on its rehabilitation based on inspection results and Fitness-For-Purpose assessments (FFP-assessments). Initially, the following principles of i-View^{SM} ILI software development were established:

- To collate all available inspection information, results of all in-line inspections and pipeline operating conditions. In order to do that, and to maintain flexibility, the data base has an option of generating additional fields at user's requests.

- Analysis can be based on results of inspection carried out either by one company or different companies using various inspection techniques. No single technology is capable of detecting the full range of defects which can present a threat to pipeline integrity (see Table 1), therefore it is more important from the pipeline integrity perspective to summarize all the information obtained by means of different ILI technologies. To provide the best information available, the software conducts simultaneous multi-technology data processing.

Table 1. What can be detected and assessed using a Geometry Tool, UTWM, UTCD, MFL and TFI tools.

Feature	Feature detection/identification by different ILI technologies				
	GT	WM	MFL	TFI	CD
Pipe geometry defect:					
• Sharp-edged dent	+	+	+	+	+
• Smooth dent	+	+			+
• Wrinkle	+	+	+	+	+
• Ovality	+				
Mid-wall defects :					
• Lamination		+			
• Slope lamination breaking the pipe surface		+			
External and internal metal loss features:					
• Pitting corrosion			+	+	
• General corrosion		+	+	+	
• Smooth-profiled extensive metal loss		+			
• Metal loss feature on a dent or a wrinkle			+	+	
• Axially oriented notch		+		+	
• Slope notch		+			
Cracks					
• Circumferential crack (opening >= 0.15 mm)			+		
• Longitudinal crack, SCC (opening >= 0.15 mm)				+	+
• Longitudinal crack, SCC (opening < 0.15 mm)					+
Weld anomalies:					
• Girth weld anomaly (crack, lack of penetration, undercut)			+		
• Girth weld anomaly (edges misalignment, protrusion)		+	+		
• Seam weld anomaly				+	

- Multi-purpose application. We have made a decision not to confine the Client to a single strategy for pipeline condition assessment and rehabilitation (pipeline repair program) but give the Client an opportunity to develop its own strategies.

- Flexibility. Any strategy for pipeline condition assessment can be applied for any set of features from the database (based on defect type, their remaining life, location in high risk area etc.) at the Client's discretion.

These requirements, along with numerous requests from our clients, have laid the foundations for i-View^{SM} ILI software development.

Review of i-View^{SM} ILI software

i-View^{SM} ILI software is a multifunctional system that has been initially designed to process data from several inspections of the pipeline which are performed either simultaneously or at different times (fig.1). Synchronization of databases of different inspections is carried out based on girth welds, relative distances and the angular position of defects and features.
The main components of i-View^{SM} ILI software are:

- Software package for 'raw' data processing. Each type of inspection tool which belongs to P&SS Weatherford, utilizes separate software that is designed to display the recorded signals as well as measurements and classification of the detected defects. P&SS Weatherford have the capability to use different technologies to inspect pipelines, namely UT WM, MFL, TFI and CD.

- Service + software which is designed for a consolidated pipeline integrity analysis based on the current and previous inspection results

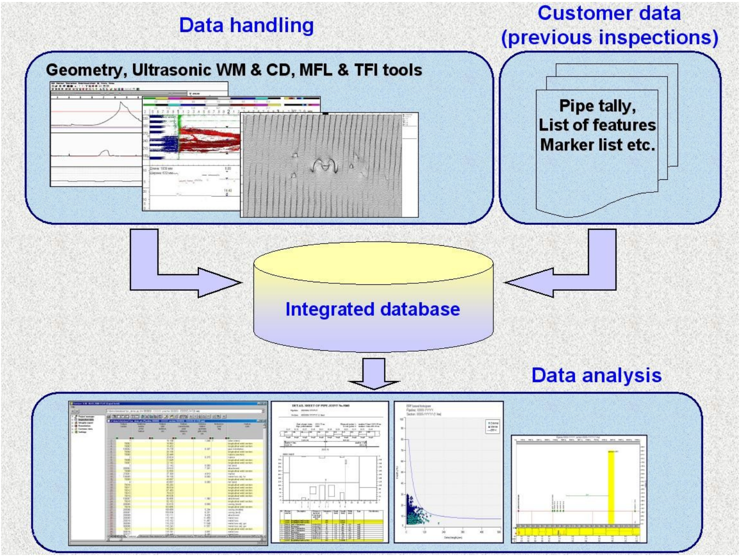

Fig.1. Usage of integrated database.

Any component of the system can operate separately, or closely interact with other components. Thanks to this feature of the system, P&SS Weatherford widely uses a technique for comprehensive processing of data from different inspections. This means that data from several inspection tools can be processed simultaneously, irrespective of the number of inspections (fig. 2).

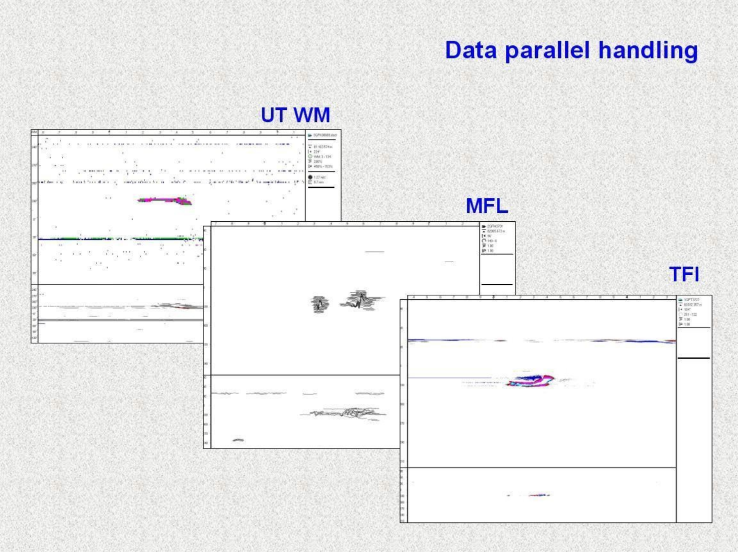

Fig.2. Data parallel handling

Such an approach saves significant data processing time as well as allowing the analyst to classify defect more accurately based on the data from different inspection tools.

The method we are using for matching the results from different inspections is not the same as other ILI vendors usually apply for this purpose. Our method helps minimize odometer system errors that encumber the defect matching. The point is that all the defects are transferred from one tool data to another at the start of the process rather than being matched at the final stage of data processing – the issue of an inspection report (Fig 3.)

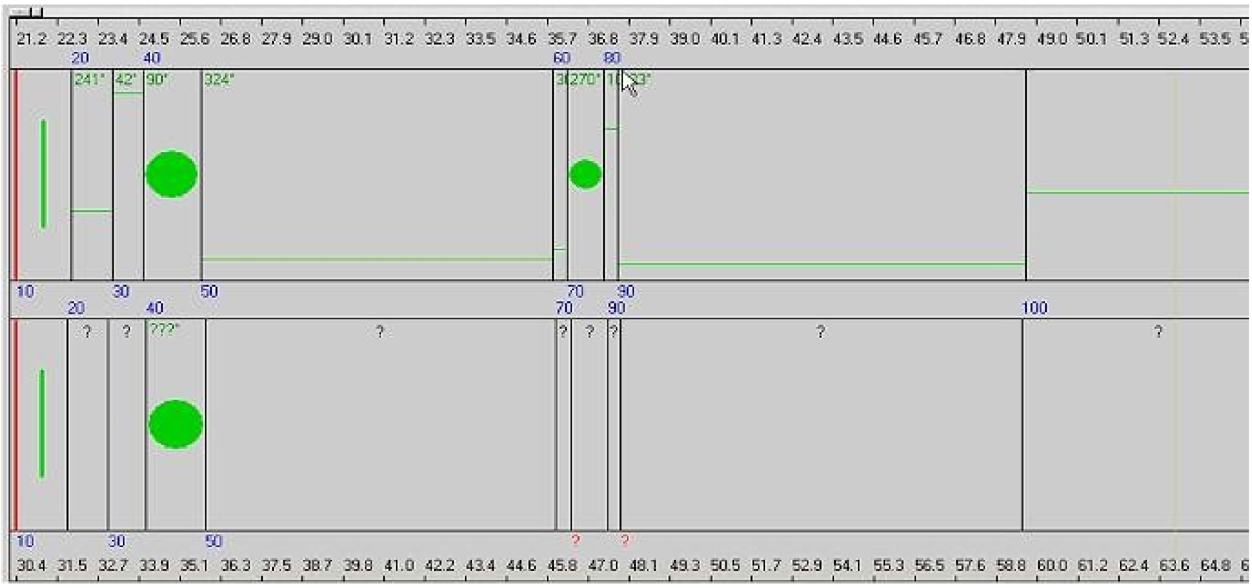

Fig.3. Matching pipeline tallies from different inspection tools (complex inspection) or for re-inspection

In order to do this, we use pre-processed and verified information about girth welds from both data sets. Using this method, the analyst can view one and the same defect location on the first and the second data sets at the same time. The only thing the analyst has to do is to find out more specific defect information and sizes using the second tool data but not to waste time in seeking the defect. In our opinion, this method allows us to save up to 30% in overall data processing time and achieve the maximum possible reliability at the critical processing stage.

Below there are some examples of defects, which have been detected as a result of such simultaneous data processing.

Figure 4 illustrates an example of a surface-breaking lamination. The WM data (Top) showed a lamination L=1940 mm adjacent to a weld seam. This defect was not seen on the MFL data (bottom) as the signal level at the point where the defect comes out on the surface did not exceed the background signal level. No defect identification was possible using only the MFL data. When the WM and MFL data sets were combined, the contact to the surface was confirmed. This defect was severe in terms of strength and that fact was confirmed by the verification digs (Right) that followed the reporting.

<table>
<tr><th>Ultrasonic WM tool</th><th>Verification</th></tr>
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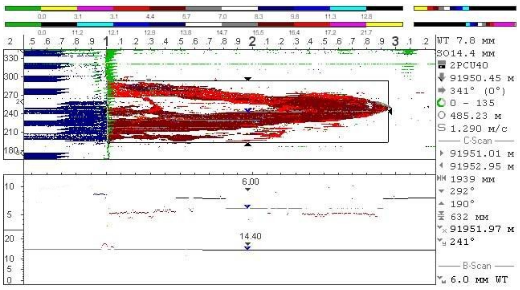

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<tr><th colspan="2">MFL tool</th></tr>
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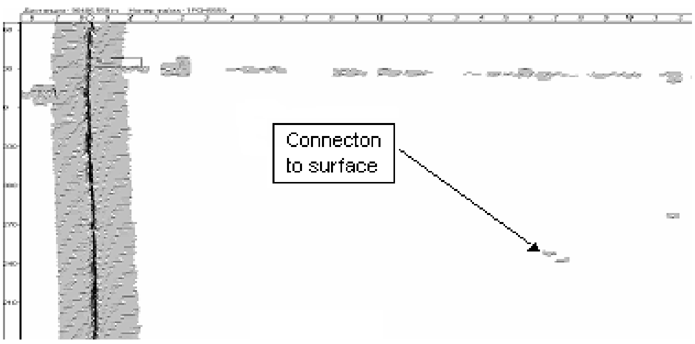

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Fig.4. Example of surface-breaking lamination.

The next example (Fig. 5.) is a seam weld anomaly, 48% deep, ,212 mm long and 19mm wide. The MFL tool detected only pitting corrosion on a longitudinal weld, the TFI tool detected a severe defect at the same location. If we hadn't used the TFI data, the severity of this longitudinal weld would have been underestimated from the pipeline integrity perspective.

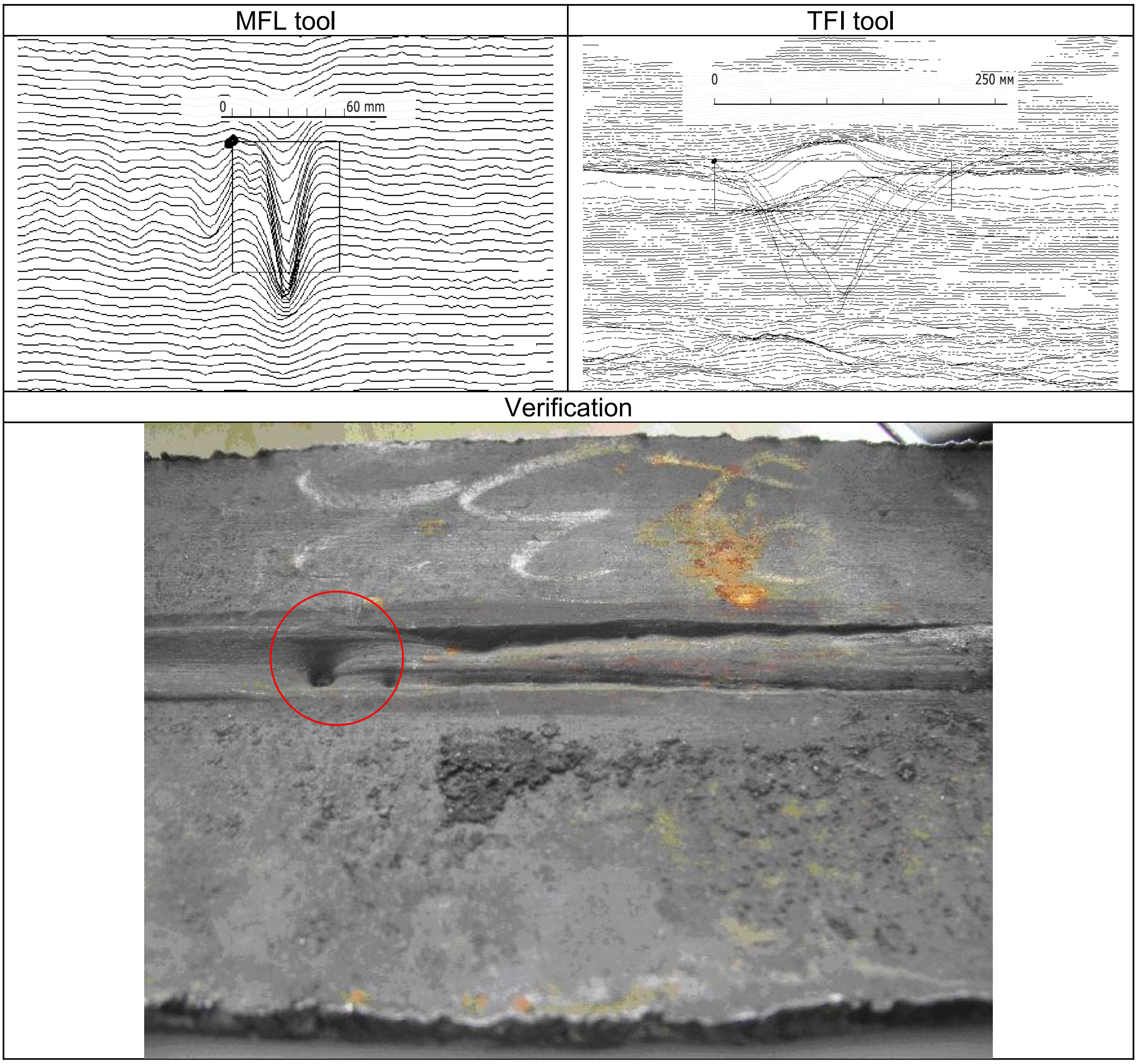


Fig.5. Example of seam weld anomaly

The above examples clearly illustrate how efficient the simultaneous multi-technology data processing can be in getting the best and reliable inspection results.

Utilization of different types of inspection tools (UT, MFL, TFI, CD etc.) for detecting defects makes it possible to create an integrated database that is the source material for further analysis. The integrated database can be created based on the results of one or several inspections (fig. 1), regardless of which company has inspected the pipeline.

Assessment of the technical condition of pipelines

In order to assess the condition of pipelines, the Service+ program has been included into i-View[SM] ILI software. The service software has 3 operational levels: basic, advanced and expert. Each level can be used for analysis of inspection results. The advanced and expert levels would require pipeline integrity assessment training.

Basic level, as a general rule, is commonly used for routine operations with data and allows:

- Filtering and searching information in the integrated database.
- Generating reports and inspection sheets for any number of pipeline features in order to locate them.
- Presenting inspection results using graphs.
- Obtaining an image of any defective pipeline area.

  This level can be used for field work in order to obtain full information about the defective section of the pipeline.

Advanced level performs all functions of the basic level as well as developing a pipeline repair program for the next few years using recommendations on defect repair methods and defect repair period received from an inspection company. The advantage of this method is that a user can develop several options of repair program and choose one of them. Moreover, any types and quantity of defects can be taken into account. A repair program can be compiled either to show the defects to be repaired (one can see how many defects need to be addressed to), or to identify the locations where repair should be performed by using repair shells/sleeves or section replacement to remove several defects at once. In the second case, the information is more useful for repair planning if it is a short pipeline section containing a lot of defect clusters. These lists also contain information on recommended repair period and a list of all defects that will be covered with these repairs.

Expert level performs all functions of the basic and advanced levels as well as developing and using the operator's own strategy for pipeline condition assessment and pipeline rehabilitation (pipeline repairing program), considering possible changes in operating conditions. As a general rule, this level is used by experts with experience in pipeline integrity assessment. In order to assess the severity of defects, B31G, RSTRENG methods and Shell92, Shell92 Cluster, DNV RP-F101, API RP 579 modifications and some others can be used.

Some examples of i-View[SM] ILI software operation at expert level are given below.

i-View[SM] ILI software includes several sections that can be used for development of one's own strategy pipeline condition assessment and pipeline rehabilitation (fig. 6).

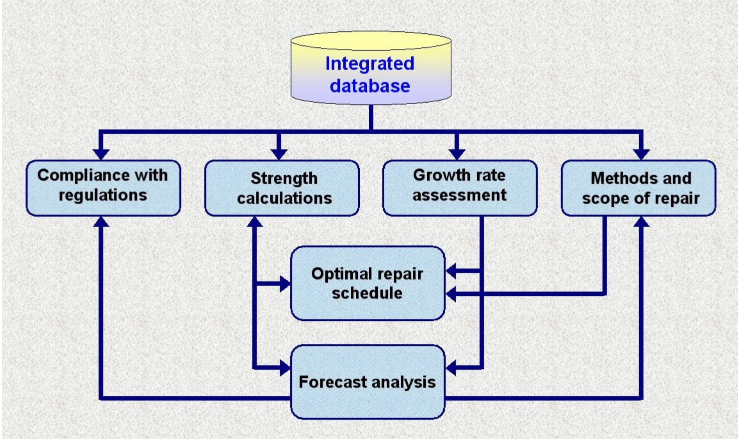


Fig.6. Main functions of the service software.

A brief description of each section is listed below.

- **Compliance with regulations.** This section is applied before use of the next sections. It is used to select the defects which require further review. As a rule, these defects are subject to further analysis such as strength calculations, determining of recommended repair period etc.

- **Strength calculations.** This section allows the operator to detect defects that fall into the category of severe defects in accordance with static strength criteria, and which can require reduction of operating pressure. There are two possible approaches to assessing defect severity. One is the classical one that employs ERF based histogram for preset maximum operating (design) pressure, and the second uses actual data on pumping stations operating modes and pipeline profile (Operating pressure based histogram). The latter approach can be used to define defect severity with respect to the prescribed pumping regime. As can be seen from figure 7, the former approach shows 2 severe defects, whereas the latter approach shows nothing for this prescribed pumping mode.

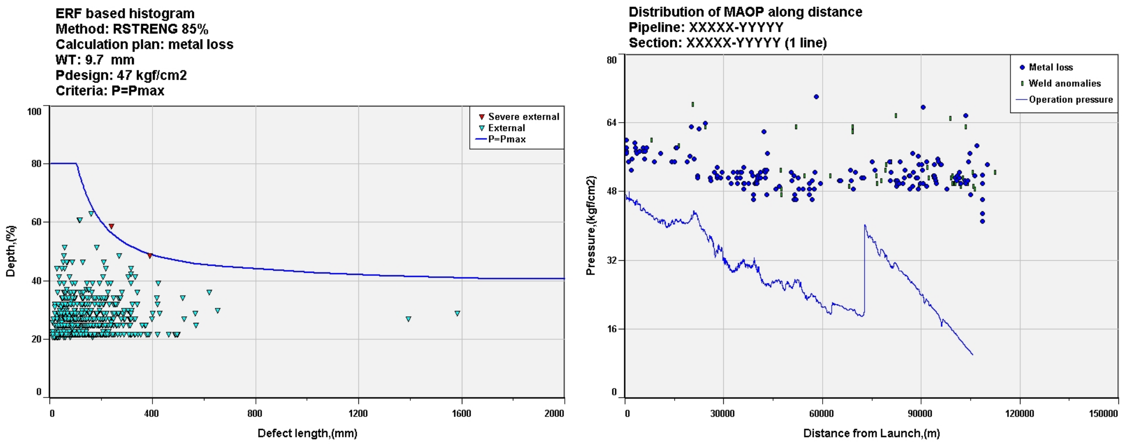


Fig.7. Example of approaches to assessing defect severity.

The latter approach results into a substantial reduction in the number of required repairs in case there are a lot of defects. In order to make calculations, such methods as Shell92, Shell92 Cluster, DNV RP-F101, API RP 579 as well as some Russian methods can be used.

- **Assessment of corrosion growth rate.** To make this assessment, probabilistic (statistical) methods are employed that allow defining defect growth rate along the section of specified length. It may be a separate pipe spool, a section of fixed length or the entire pipeline (fig.8). The confidence level is to be chosen by the user prior to assessment. The results of the assessment can be used for a predictive estimate of pipeline condition as well as a repair program.

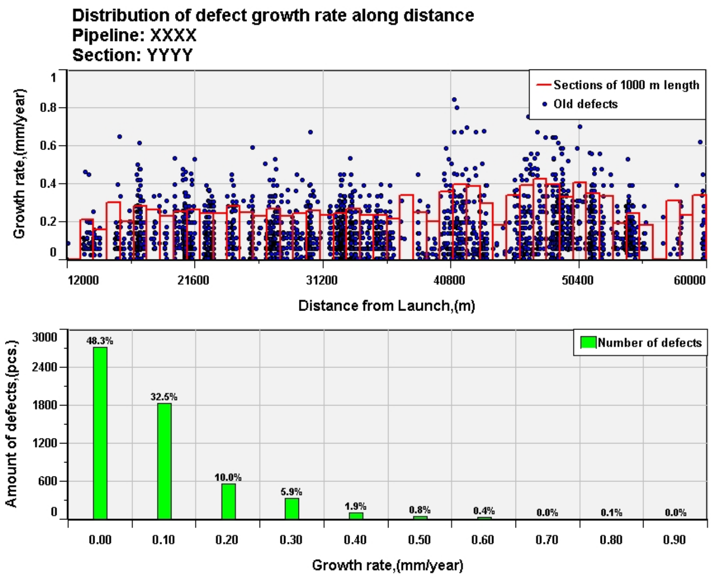
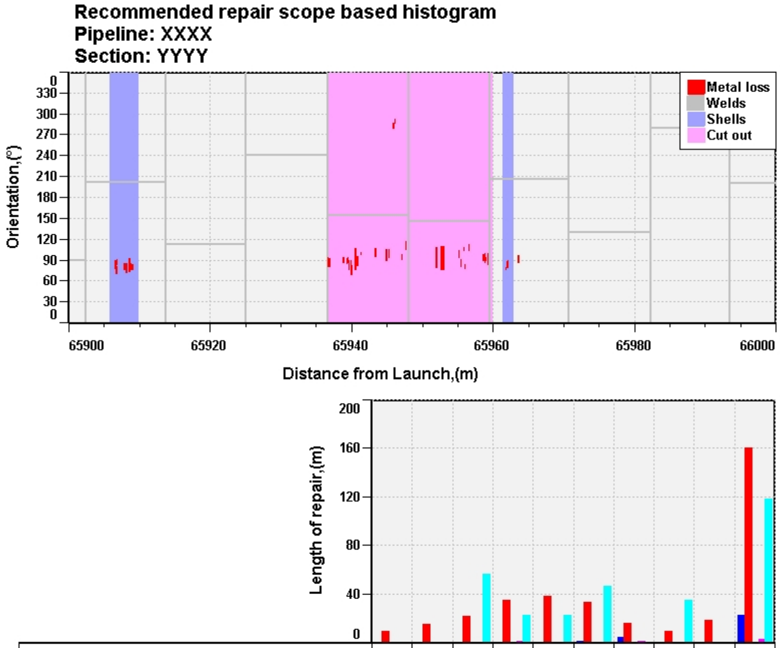


Fig.8. Example of growth rate assessment.

- **Determination of recommended repair periods, methods and scope of repair.** This section, along with results of strength calculations and assessment of defect growth rate, allows a user to develop program for repairing pipeline defects specifying recommended repair periods and methods. In order to determine repair period and growth rate of crack-like defects, a fatigue analysis is to be done using a history of pipeline cycling loading. i-View^{SM} ILI software allows the user to develop any number of alternative repair programs to give a choice of selecting an optimal program. Fig. 9 shows one of the alternative repair programs. This program has taken into account all defects detected by the in-line inspection.



	up to 1 year	1-2 years	2-3 years	3-4 years	4-5 years	5-6 years	6-7 years	7-8 years	8-9 years	>9 years
Welding (weld-on)				0.03		0.98	4.17			22.41
(P1)CST	9	15	22	35	38	33	16	9	18	160
(P2)Compression weld-in sleeve										
(P4)Fluting plane sleeve for joints with a short cavity				1.07	0.18		0.96			2.21
Replacement of a section			56	23	23	46		35		118

Recommended repair period (years)

Fig.9. Example of repair scope assessment.

A similar program can be developed for any number of defects. For example, a repair program can be developed for specifics type of defects and/or severity levels. Additional criteria for including a defect into a repair plan can be set by the operators themselves.

- **Pipeline failure probability analysis.** This analysis employs reliability-based limit state methods and allows assessment of the probability of pipeline leakage or burst under specified operating conditions. Assessment of the probability of failure (leakage or burst) can be based on the last inspection results or it can be done for giving a short-term forecast. The probability of failure can be determined for the entire pipeline, ranked by segment between joints or for a given defect. Then, it can be compared with target probabilities which are established either from historic failure rates or from risk criteria. This comparison allows the operator to formulate cost effective strategies for the future safe operation of the pipeline. Fig. 10 shows an example of assessment of the probability of failure (POF) along the distance of the pipeline. We can see that the current pipeline condition (in the figure starting from 2007) does not secure the specified reliability level (POF_{target}) , and without taking required measures the probability of failure will increase as time goes by. In order to secure the reliability of $POF_{target,}$ the defects are to be repaired. Fig. 11 shows the dependence of pipeline POF on the required number of repairs. This analysis can be used as an alternative or addition to the existing repair program of a pipeline.

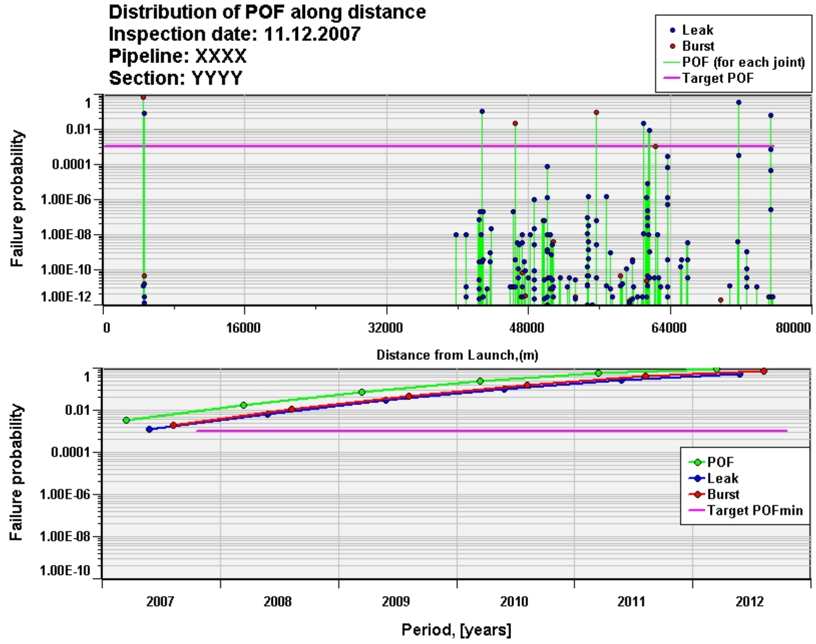


Fig.10. Example of POF assessment.

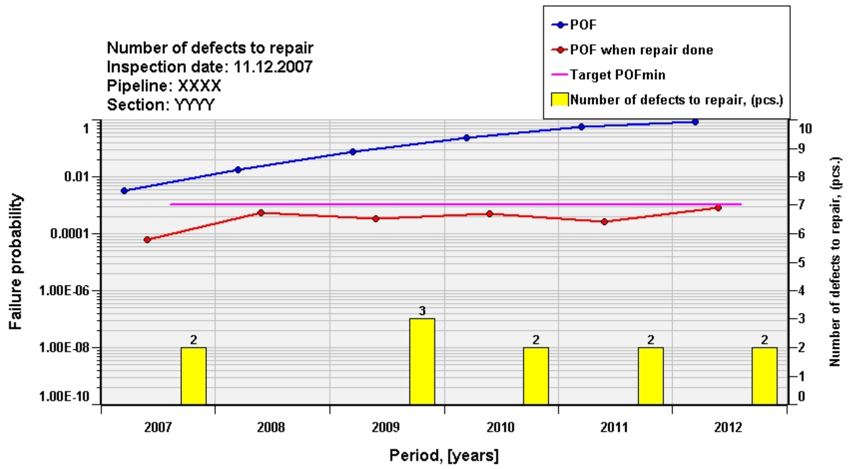


Fig.11. Repair program to decrease POF.

CONCLUSION

The aim of the paper has been to present the i-View^{SM} ILI software package, which is actively utilized by both pipeline operators and P&SS Weatherford for inspection data processing and analysis to meet growing clients' need. i-View^{SM} ILI software allows the operator to conduct various types of FFP-assessments and analysis of inspection data to secure pipeline integrity. Close cooperation with pipeline operators makes it possible to keep improving this software package utilizing the latest assessment methods.

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5. ISO 13623, Petroleum and natural gas industries — Pipeline transportation systems, 2000