Inspection Effectiveness and its Effect on the Integrity of Pipework

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ABSTRACT

In order to control the integrity of a pipe section, an NDT technique has to be chosen which gives a maximum of detection rate, reliability, best coverage and minimise false calls. The term inspection effectiveness is used more and more to describe these parameters. This paper describes specific the situation on a pipeline with possible corrosion under insulation. Two NDT inspection techniques are considered and compared for the best effectiveness. Reliability calculations of the pipeline were made for each NDT technique and compared.

INTRODUCTION

The condition of process plant equipment in-service is being inspected on a regular basis to assure its integrity which is essential to the safe and reliable operation. Since the mid-1980s people have become increasingly aware that in many cases the specified effectiveness of non-destructive examinations does not correspond to the facts [1, 2, 3, 4, 5]. The most important cause of the inaccurate expectation with respect to the effectiveness of the inspection is the multitude of factors that influence non-destructive examinations.

In course of time the need to quantify the performance of inspection programmes has been growing. This has been caused by the continuous strive of industry to reduce costs related to inspection and maintenance. Furthermore, inspection performance is an element in Risk Based Inspection approaches and therefore the performance should be quantified in order to account for it. Lastly, there is a trend to apply more non-intrusive inspection techniques rather than visual internal inspection which can only be justified if the performance of the non-intrusive techniques is known. The performance of the non-destructive inspection is of critical importance to the management of the integrity because non-destructive inspection is increasingly the inspector’s only ‘sense’. To devise the correct inspection specification, knowledge is required of the performance of non-destructive inspection and the factors that influence it. An inspection specification must be tailored to the specific application.

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The usual way of quantifying the detection capability of a certain technique is by means of its ‘Probability of Detection’ (POD) and the corresponding POD-curve. This curve represents a value of the POD for a given defect length. However, a number of other factors also affect the POD in addition to defect length, for instance: the other defect sizes, defect shape, defect location and orientation. Obviously, this hampers a simple assessment of the POD. Besides, in order to know the effectiveness of the entire inspection procedure, the inspection scope and the inspection frequency should be taken into account as well. To incorporate all these factors, the appropriate measure of inspection effectiveness is ‘failure rate’. An additional advantage of using this measure is that it also includes the degradation morphology, the degradation rate and the criterion to express the ‘limit state’, which is the equipment’s minimum condition before failure. For this reason the ‘failure rate’ is a more ideal and comprehensive measure rather than POD in order to assess the performance of various inspection procedures and to enable decision-making processes regarding the selection of appropriate techniques, inspection scope or inspection scheduling.

In this paper, the effect from various factors on the inspection performance is demonstrated as well as the added value of the ‘failure rate’ measure to quantify the effectiveness of inspection.

DESCRIPTION OF PIPE SECTION

The lay-out of the pipe section under consideration is shown in Figure 1. The pipe is non buried and insulated. The pipe is made from steel whereas the process fluid contains no-corrosive substances that may possibly result in internal corrosion. The degradation mechanism considered is corrosion under insulation. Since commissioning one inspection has been performed when the pipe section was in service for 15 years. Minor corrosion has been detected. In order to assure the condition future inspection strategies are considered as described in this study. The diameter of the pipe is 350 mm and the wall thickness is 8 mm; the corrosion allowance is 3 mm. The maximum allowable operating pressure (MAOP) is 10 MPa.

The pipe section is not piggable. Two external non-destructive inspection techniques are being considered to screen for defects, i.e. Guided Waves and on-stream Radiography (in screening mode). Upon detection of defects, they will be sized using the Ultrasonic technique.

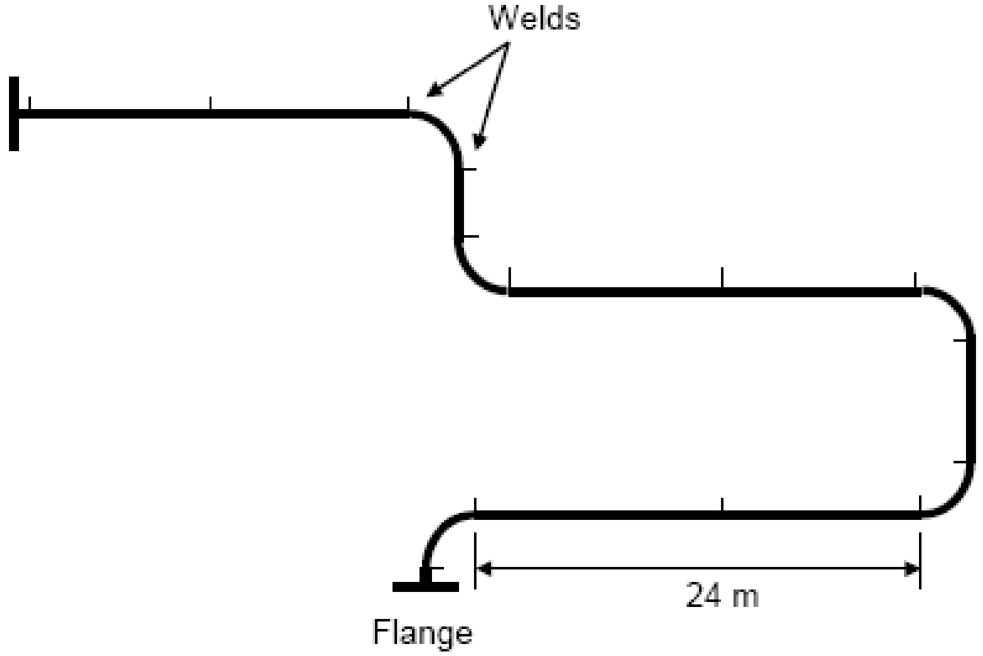


Figure 1; Lay-out of pipe section

INSPECTION OPTIONS

In this study various inspection techniques are considered only aimed at detection of corrosion under insulation without making use of the capability to size wall thinning. So, for the purpose of sound comparison the techniques are considered as purely screening tools whereas sizing is assumed to be performed by ultrasonic examination for all options. A first order indication of the inspection performance of various techniques is given in Figure 2. This data can be used for a first impression of the inspection performance of different techniques. However this data is insufficient for a more quantitative analysis of the influence of inspection performance on the reliability of a construction.

	Visual	Radiography		UT, manual puls echo	UT mechanised		Magnetic Particle	Liquid penetrant	Eddy current		Magnetic Flux leakage	Guided waves
		film	RTR		puls echo	TOFD			conventional	pulsed		
Material	all	all	all	most	most	finegrain	magnetisable	non-porous	elec.cond.	elec.cond.	magnetisable	all
Wall Thickness Range (steel, mm)	arbitrary	0 - 100	0 - 30	2 - >500	2 - >500	6 - >500	arbitrary	arbitrary	0 - >2	Mar-45	2 - >20	0 – 35
Volume Inspection	no	especially	yes	yes	yes	yes	no	no	limited	no	yes	Yes
Weld Inspection	geometry	yes	yes	yes	yes	yes	yes, surface	yes, surface	yes	no	no	No
Surface Inspection	yes, only	yes	yes	yes	yes	limited	yes	yes	yes	no	yes	Yes
Degradation mechanism	**Definition of parameters: Definition of values:**			**D = Detection capability 3 = Excellent / Good**				**S = Sizing capability 2 = Fairly / Reasonable**			**1 = Moderate / Poor**	
Uniform corrosion / wall thinning	D: 1	D: 2	D: 2	D: 2	D: 3	D: 3	D: n.a.	D: n.a.	D: n.a.	D: 2	D: 1	D: 2
	S: 1	S: 1	S: 1	S: 3	S: 3	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: 2	S: 1	S: n.a.
Pitting corrosion	D: 2[1]	D: 3	D: 3	D: 1	D: 1	D: n.a.	D: n.a.	D: n.a.	D: 1	D: n.a.	D: 3[2]	D: n.a.
	S: 1[1]	S: 1	S: 1	S: 3	S: 1	S: n.a.	S: n.a.	S: n.a.	S: 1	S: n.a.	S: n.a.	S: n.a.
Branched type of cracking, e.g. due to corrosion	D: n.a.	D: 1	D: 1	D: 2	D: 2	D: 2	D: 3[3]	D:3[3]	D:2[4]	D: n.a.	D: n.a.	D: n.a.
	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: 1	S: 2	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.
Non-branched type of cracking, e.g. due to fatigue	D: n.a.	D: 1[5]	D: 1[5]	D: 2	D: 3	D: 3	D: 3[3]	D: n.a.	D: 3[4]	D: n.a.	D: 1	D: n.a.
	S: n.a.	S: n.a.	S: n.a.	S: 1	S: 1[6]	S: 3	S: n.a.	S: n.a.	S: 1	S: n.a.	S: n.a.	S: n.a.
Delamination	D: n.a.	D: n.a.	D: n.a.	D: 3	D: 3	D: 3	D: n.a.	D: n.a.	D: n.a.	D: n.a.	D: n.a.	D: n.a.
	S: n.a.	S: n.a.	S: n.a.	S: 3	S: 3	S: 3	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.
Corrosion Under Insulation	D: 3[7]	D: 2	D: 1	D: n.a.	D: n.a.	D: n.a.	D: n.a.	D: n.a.	D: n.a.	D: 2	D: n.a.	D: 3
	S: 1[7]	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: n.a.	S: 1	S: n.a.	S: n.a.

(1): Provided that it is accessible and not coated (2): Dependent on the depth (3): Provided there is surface-breaking
(4): Only at greater wall thickness and provided there is surface breaking (5): Provided that wall thickness > 10 mm; if wall thickness < 10 mm then D = 2
(6): S = 2 provided that there is a sufficient number of transducers (7): After removal of insulation

Figure 2; Inspection performance

The Guided Wave technique is capable of screening a pipeline for corrosion under insulation. Screening means with an economically low cost approach detect the position of possible corrosion for less or more 100% of the pipeline. Only locations with corrosion under insulation above a certain detection threshold will be given. Depending on the extent of the corrosion (remaining wall thickness and area size of the corrosion) and the extent of exceeding the detection threshold gives the POD. Also the measured position accuracy of the detected indication is important. If it is not accurate enough, the evaluation will be taken at the wrong position.

The digital radiography technique is capable for detection and sizing (depending on the diameter and wall thickness and whether the pipe is filled with product or not. Detection can be obtained by either measuring the wall thickness on two points in circumferential or analysing the grey-level changing of the image. Depending on the extent of the corrosion (remaining wall thickness and area size of the corrosion) and the extent of crossing the detection threshold gives the POD. The POD's are calculated as function of the defect size. Also the measured position accuracy of the detected indication is important. If it is not accurate enough, the evaluation will be taken at the wrong position.

Further evaluation is necessary to determine whether it is a false call or a real indication.
All indications that cannot be traced with the evaluation technique will be noted as false call or missed defect. If it is a real indication the remaining wall thickness has to be determined. Depending on the technique we will have again to consider the effectiveness of the evaluation technique. (e.g. onstream radiography or manually puls-echo or automated puls-echo ultrasound)

Guided Waves (abbreviated as GW)
The Guided Wave technology screens pipe work for metal loss features such as corrosion and erosion. Originally developed for the inspection of corrosion under insulation; the technology is suited for application to pipelines and process pipe work, including road crossings, bridge, piers and poorly accessed pipe work generally.
Guided Wave uses low frequency guided ultrasound travelling along the pipe, providing 100% coverage of the pipe wall. In normal application, tens of meters of pipe work may be inspected from a single location. Potentially effective areas are precisely located in terms of distance from the transducer ring and highlighted for local examination by visual or conventional NDT methods. The guided waves used are capable of propagating long distances, even beneath a layer of

insulation. The ultrasound is transmitted and received from a single location (see Figure 3). The response from the metal loss feature is a function of the depth and circumferential extent of the metal loss.

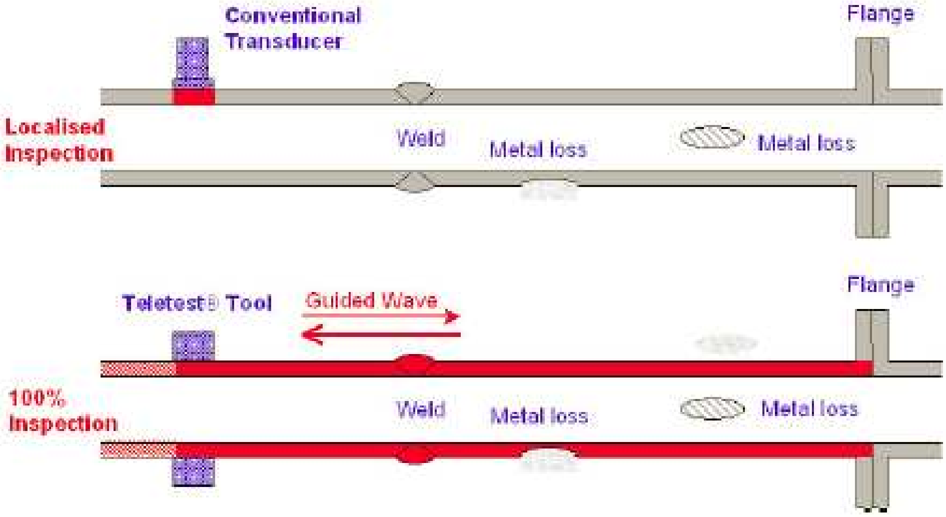


Figure 3: Principle of long range testing compared with conventional ultrasonic

There are three types of wave modes (see Figure 4), which can exist in a pipe: Longitudinal, Torsional and Flexural. The Guided Wave system transmits two Longitudinal waves, the L(0,1) and the L(0,2) and receives two waves the L(0,2) and the F(1,3) wave (see Figure 5).

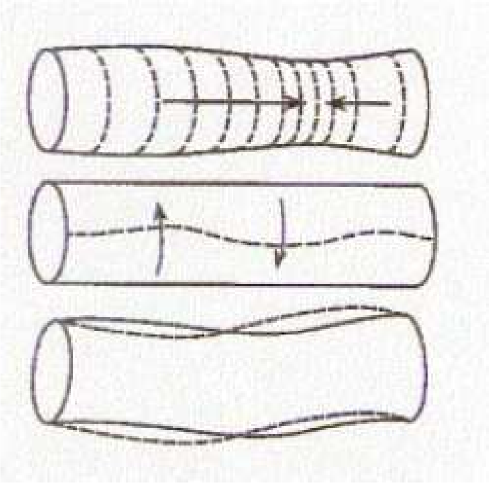


Figure 4: Wave modes in pipe

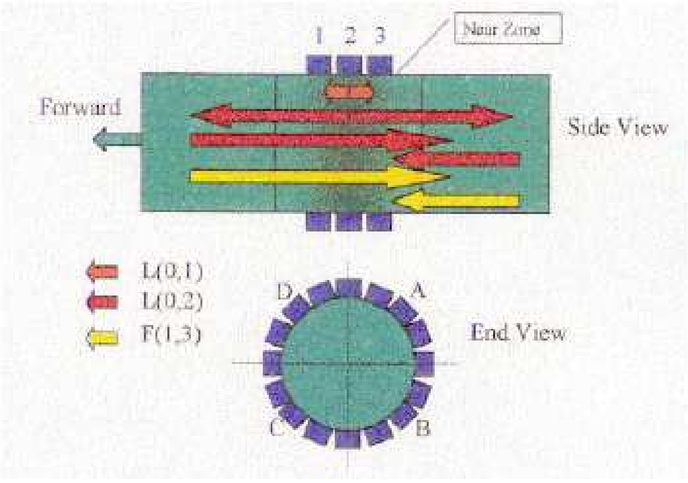


Figure 5: Transmitting and receiving waves

By using the ideal frequency, the L(0,1) is cancelled out (see Figure 3). The ideal frequency can be determined, when knowing the parameters diameter and thickness, with the dispersion curves. When another frequency than the ideal frequency is used the L(0,1) can cause so called “Ghost echoes”. The reason why other frequencies are used is because not all indication reflects the best with the ideal frequency. When a certain volume change at a section of the circumference occurs a reflection can be received. The reflected signals can be distinguished in symmetrical, horizontal and vertical modes, see Figure 6.

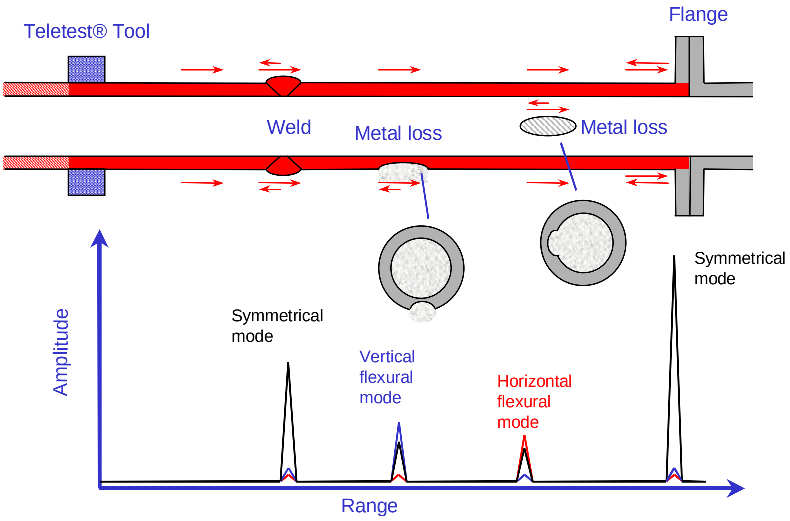


Figure 6: Types of reflected signals

Distance Amplitude Correction {DAC} curves (see Figure 7) are superimposed on the display to provide lines of equal sensitivity with distance from the transducers. Four curves are normally displayed:

- The uppermost represents the amplitude from a pipe end, which is designated as 0dB (this being a 100% area reflector).
- The second line represents the amplitude of responses likely to be obtained from welds. This is 14dB below the 0dB line.
- The third line is the reporting level. This is equivalent to a reflection from a 9% area flaw and is set at 26dB below the pipe end (0dB) level.
- The fourth, dashed, line is a target level for backscattered noise ('grass' signals). Where these consistently exceed this level the limit of test range has been reached.

Three traces are plotted, superimposed on each other. The main trace is the directly reflected longitudinal (L(0,2) mode) response from features and flaws. The other two are vertical and horizontal components of mode converted signals, which are generated when the out-going longitudinal mode is reflected from rough and/or asymmetric reflectors. The presence of high levels of mode-converted signals is indicative of flaws and is an essential factor in the interpretation process.

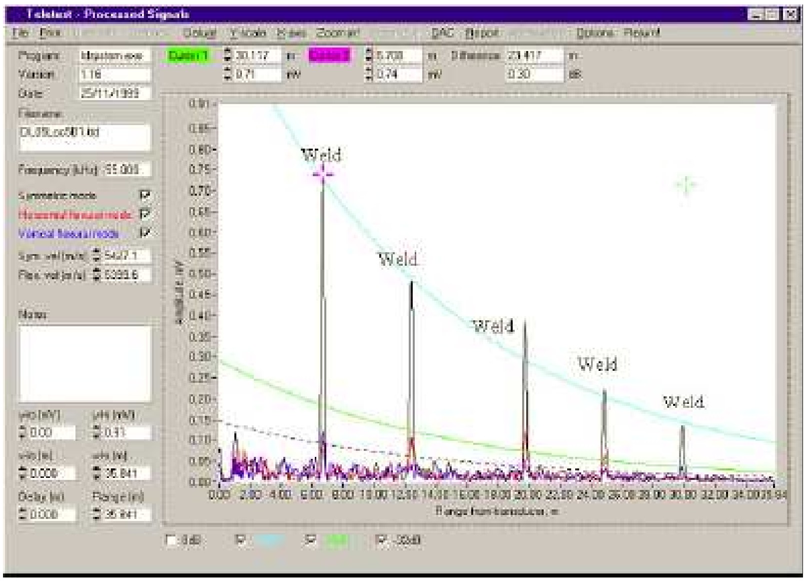


Figure 7: DAC-curves

Earlier work showed that the smallest area of metal loss, which long range UT can detect, is approximately 3% of the pipe wall cross-section. The reporting level, which is normally used, is a signal amplitude equivalent to 9% area. This is to ensure that false call rates are kept to an acceptable level. However, if clear and unambiguous indications are detected below the reporting level, they are identified as minor defects. An opportunity arose to determine whether these thresholds were capable of being met through involvement in the joint European RACH project, which was managed by University College London. A major part of this was the gathering of NDT data from controlled corroded pipe specimens using eight different methods in order to there determine detection and evaluation performance. The trials were conducted 'blind' without knowledge of the defects present and the results were evaluated by an independent team from Bureau Veritas, Paris. Figure 8 shows the results from the Guided Wave technique on 36 individual defects. The plot is in terms of depth and circumferential extent of the defects and indications whether each was detected or not. The lines representing 3% and 9% defect area for the 6" diameter pipes tested are also included.

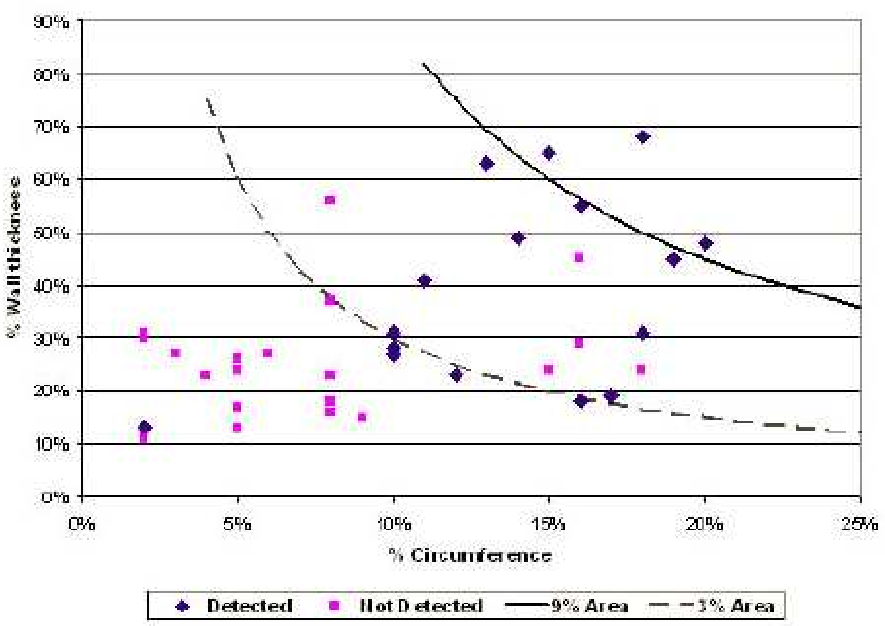
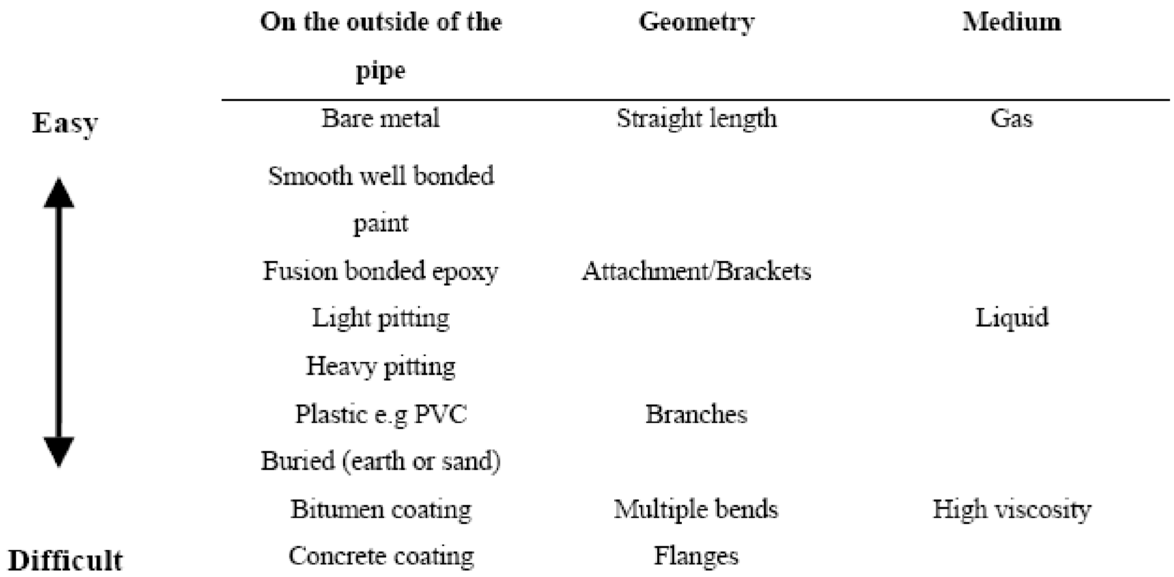


Figure 8: Detection results for Guided wave on 6" diameter pipes from the RACH project

The factors the possible inspection length and sensitivity are depicted in Figure 9.



	On the outside of the pipe	Geometry	Medium
Easy	Bare metal	Straight length	Gas
	Smooth well bonded paint		
	Fusion bonded epoxy	Attachment/Brackets	
	Light pitting		Liquid
	Heavy pitting		
	Plastic e.g PVC	Branches	
	Buried (earth or sand)		
	Bitumen coating	Multiple bends	High viscosity
Difficult	Concrete coating	Flanges	

Figure 9: Factors influencing Guided Wave inspection performance

On-stream Radiography (abbreviated as RT)

The source to generate radiation may be either an X-ray generator or a radioactive isotope. For the given pipe section X-ray is the appropriate technique because of the wall thickness. The density of the radiation that passes through the component varies dependent on the amount of material or the presence of defects. The variations produce a shadow on a radiographic film and are a direct measure of the remaining wall thickness or the depth of the corroded spot. In the group of Radiography, the on-stream Radiography technique produces images that are electronically stored and processed. The technique can be applied in a screening mode and in sizing mode (named ‘tangential mode’). In the screening mode a smaller exposure time is selected. In this study the ultrasonic technique is used to perform the sizing of defects although Radiography could be used as well to size with a good sizing accuracy.

Radiography is often applied in those cases where the inspection coverage can be strongly limited compared to the total surface of the component because of the relatively large time effort needed for this technique. Based on historical knowledge of the most susceptible areas, the selection of the inspected area should be made. For the given piece of pipe, assuming that only one working day is available, 2.5 m2 can be inspected implying a coverage of about 2% (40 shots per day with film size of 30X40 cm taking account of 50% effective film size). Although in practice the inspection coverage of the Radiography examination cannot be increased much above 2%, in this study values for the inspection coverage are considered up to 100% just to enable sound comparison with the Guided Wave technique.

APPROACH TO MODELLING

In order to compute the likelihood that failure of the pipe section takes place, a number of models are required including the modelling of the degradation mechanism, the inspection technique and the structural integrity.

The simulation is based on a ‘Monte Carlo approach’ to allow a high number of draws from a population of defects to arrive at a result representing a statistical averaged situation.

In the simulation a number of events are assumed to take place in the following sequence:

- A certain defect distribution (corrosion spots with a certain depth) is postulated being present at a moment that is set as ‘time = zero’ representing the condition of the pipe section after 11 years of service;
- This group of pits grow during a time period of 30 years with a certain postulated growth rate;
- A first and second inspection is performed after 10 years and 20 years using a certain technique with corresponding POD and coverage;
- Because of the limited capability of detection, expressed by the parameter ‘Probability of Detection’ (POD) and the inspection coverage, some corrosion defects may be missed;
- If defects are detected, they will be sized with a sizing technique representing a certain sizing accuracy;

- The defect size is evaluated based on a ‘repair criterion’ resulting into repair if the criterion is exceeded whereas non repaired defects will grow further in the subsequent inspection interval;
- If defects are not detected and/or not repaired, they will grow in the subsequent inspection interval;
- Growing defects may exceed a maximum allowable size, named ‘failure criterion’, resulting into failure.

The computed ‘likelihood of failure’ represents the number of failure events relative to the total number of draws for a given defect. The likelihood can either be cumulated over the elapsed time resulting into a cumulative probability of failure or calculated per time unit, resulting into a ‘failure rate’. The models on degradation, inspection and integrity are elaborated in the following sections.

Degradation Mechanism

The degradation mechanism under consideration is wall thinning due to corrosion under insulation. In order to simulate the failure rate, the degradation should be characterised regarding its morphology, initiation rate and propagation rate. In this study the defect morphology that is present after 15 years of service, the so-called ‘initial defect morphology’, is postulated and accounts for both the defect morphology and the initiation rate.

Initial defect morphology

The defect morphology that is assumed to be present after the operating time of 15 years is characterised by a certain distribution of defect depth and defect length. This initial defect morphology represents the defects that are still present after having inspected and missed these defects so that they are present at the beginning of the next service period. The probability distribution of the initial defect depth is presented in Figure 10.

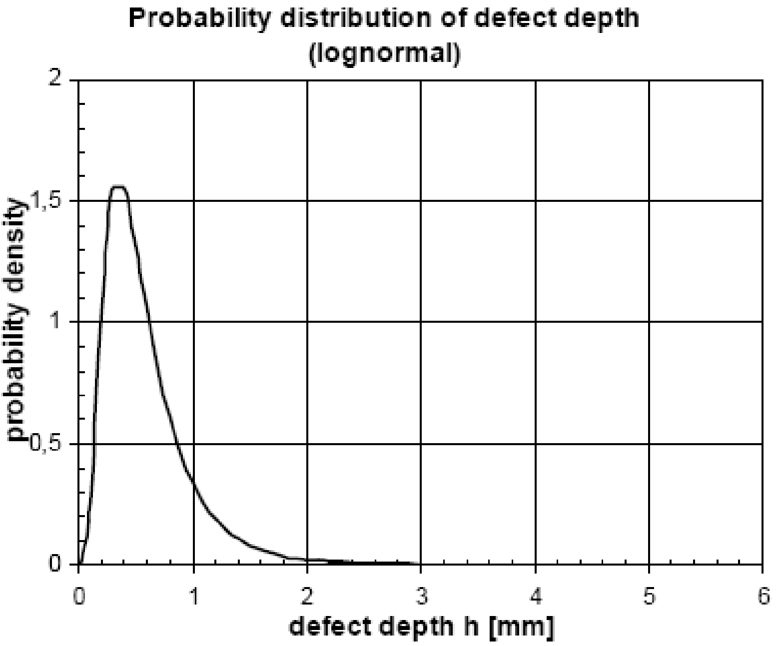


Figure 10: Initial defect depth distribution

The defect length is considered equal in both longitudinal direction and along the circumference. The ratio between defect depth and defect length, has influence on the capability of detection for certain inspection techniques and affects the pipe resistance when defects are present. Therefore, the ratio should be defined as well. Based on historical knowledge of the corrosion process, the length to depth ratio of the defects is 10.

Propagation rate

The corrosion defects will grow over time. The corrosion rate is modelled according to the probability distribution which is presented in Figure 11 and Figure 12. This distribution is based on expert judgement taking account of the specific process fluid and historical data.
The figures show that the propagation has a rate of about 0.1 mm/year in depth direction and about 0.3 mm/year in lateral direction. Due to the difference in corrosion rate the corrosion spots will widen in course of time.

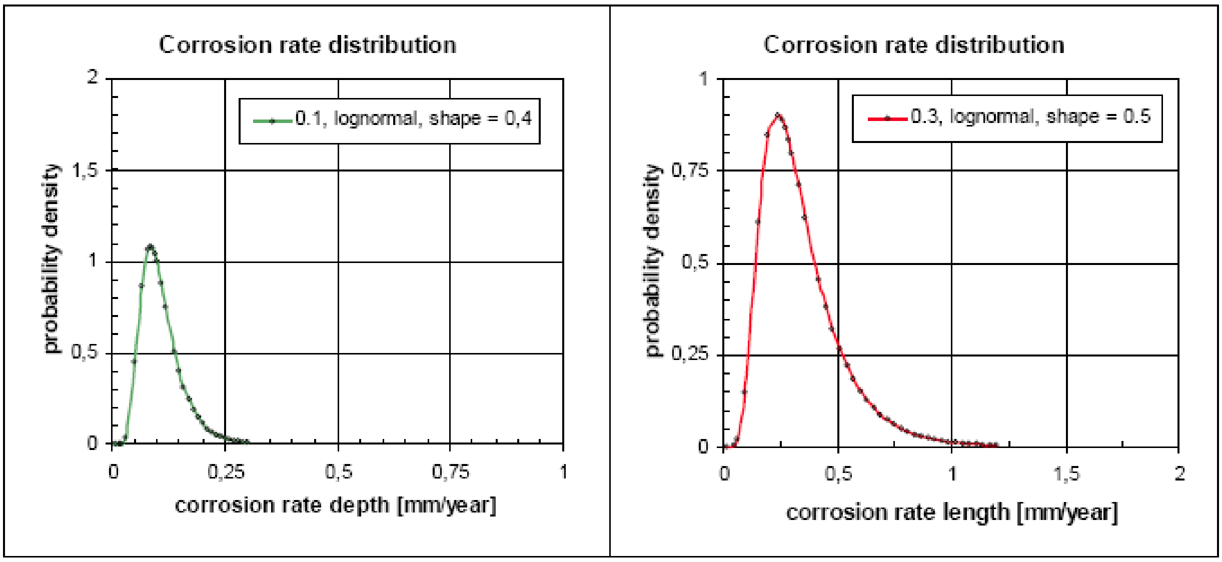


Figure 11: Corrosion rate distribution in depth and length direction

The accuracy of the degradation model can be increased during the component's service time by periodic updating making use of new inspection data that represents the ongoing degradation process.

Inspection technique

Both the 'probability of detection' and the 'sizing accuracy' are modelled, as described in the sections below.

Probability of Detection

The POD-curves for the techniques of Guided Waves (GW) and X-ray (RT) are presented in Figure 12. The curves have been constructed based on expert experience. For GW the POD-curve is derived from the assumption that the POD is 92% for a reduction of 9% in cross section and the POD is 58% for a reduction of 3% in cross section, knowing that the POD of 58% is too optimistic and 25% would be a more realistic value.

As explained in section 'inspection options' the techniques differ in their physical response, viz. RT responds directly on the defect depth and GW responds on the area of the corroded cross section. Therefore, a translation has been performed to express the POD as function of defect depth for the last techniques. The outcome of this translation is highly dependent on the defect morphology, i.e. the length to depth ratio. To construct the POD-curves in figure 4, the initial defect morphology has been used that is described in section 'degradation mechanism'.

The curves show that the detection capability is higher for X-ray than for Guided Waves technique.

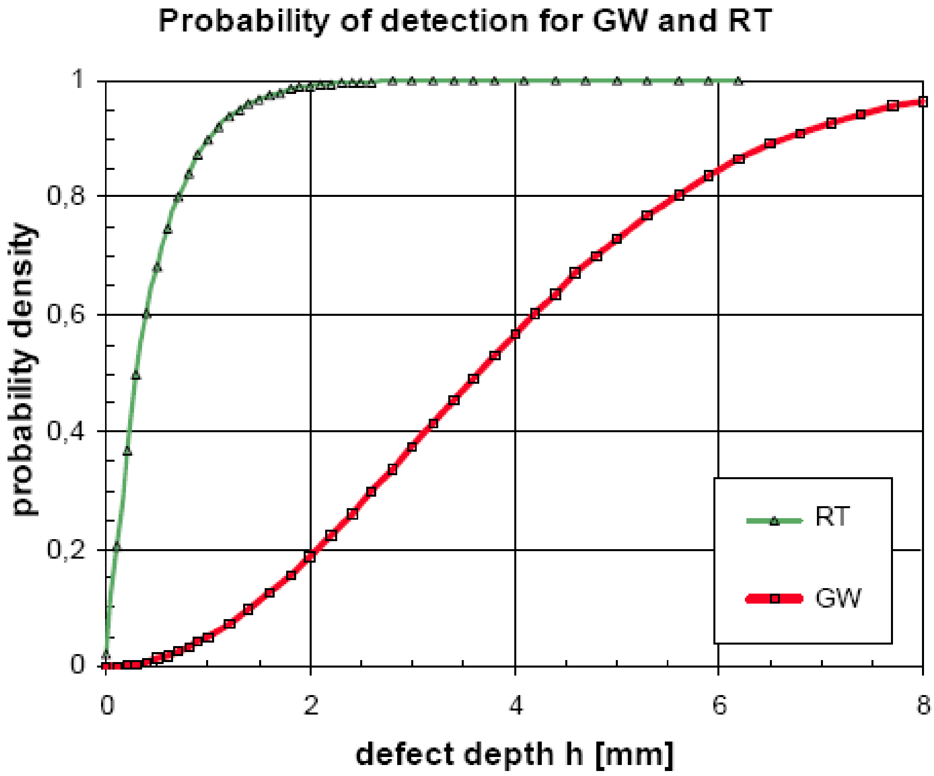


Figure 12: POD curve

Sizing accuracy

When a defect is detected in the simulation, its true depth and length are sized with the depth and length measurement error. For the purpose of comparison, the sizing accuracy has been assumed equal for both techniques; this represents the situation that sizing is undertaken by means of a separate technique, e.g. ultrasonic inspection. The sizing accuracy in the examples is postulated 0.5 mm for the depth measurement and 2.0 mm for the length measurement unless other values are stated.

Structural Integrity

The modelling of the structural integrity is essentially undertaken according to the principles of a Structural Reliability Analysis, which is composed of the following elements:

- The generation of a limit state function (the failure criterion), which is a mathematical equation describing the onset of pipe failure in terms of pipe attributes, stresses and damage geometry, e.g. yield strength, fracture toughness, modulus, diameter, wall thickness, pressure, crack/corrosion geometry;

- Generation of probability density functions based on pipe work integrity data, which describe the statistical distributions of parameters such as: wall thickness, yield strength, corrosion defect length, time-dependent defect depth;
- Integration of the limit state functions and probability density functions to give the probability of failure.

These steps are elaborated in the sections below.

Repair criterion

In the integrity model local thinning due to corrosion rather than uniform thinning is considered to take place. Due to the shape of a local corrosion spot, failure will occur on a higher pressure level compared to uniform thinning. Various models for the effect of local thinning on the failure pressure have been developed, e.g. Shell-92, DNV-99 and Pandey. The DNV-99 and Shell-92 model are based on the tensile strength [9], as Pandey is based on the yield strength [10]. The DNV-99 model is less conservative and the Shell-92 is more on the conservative side. The model of Pandey, which is close to Shell-92, is used in this study.

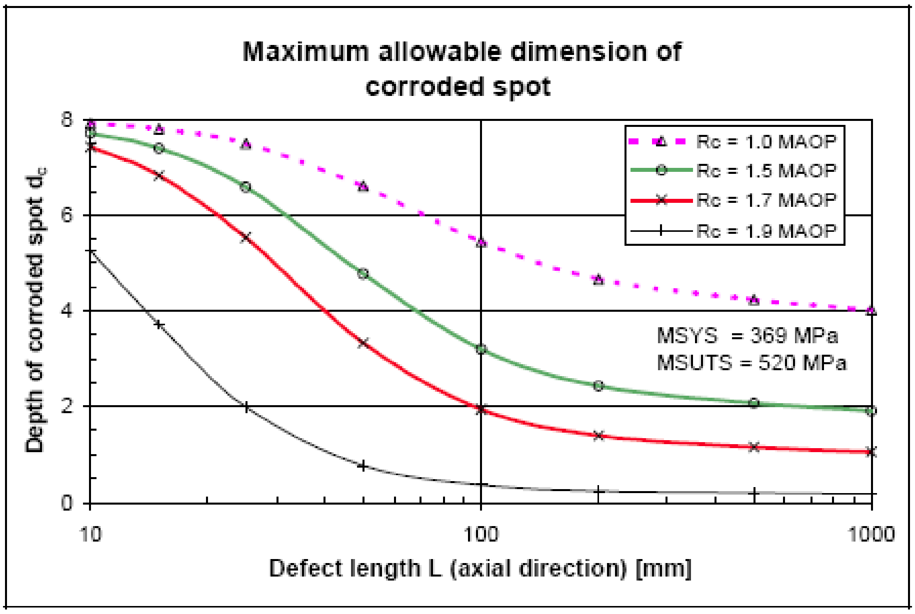


Figure 13: Maximum allowable defect

Figure 13 shows the maximum allowable defect dimensions assuming various values for the internal pressure. These pressures are defined as a factor times the maximum allowable operating pressure, abbreviated as ‘MAOP’ and they represent the so-called ‘repair criterion’. The repair criterion implies that repair is considered necessary (decision for repair) when certain defect dimensions exceed the presented allowable dimensions in Figure 13. In addition the dimensions are shown that lead to failure represented by the line, assigned to as ‘1.0 MAOP’. In this study the repair criterion 1.7 times MAOP is used.

Failure criterion

A potential corrosion pit is assumed to grow according to a random draw from the corrosion growth rate distribution shown in Figure 11. After each year it is calculated whether the growing defect will lead to failure during its lifetime. If failure occurs, this will contribute to the probability of failure.

The strength of a corroded pipe section is a time dependent non linear function of random variables. Failure due to a specific defect takes place when the pipe resistance, the so-called failure pressure of the given defect, falls below the pipeline operating pressure. Thus, the probability of failure can be estimated as:

$$P_{f|d}(t) = P[Q(t) - p_0 \leq 0] \tag{1}$$

where: $P_{f|d}$ (t) = the probability of failure at a given defect d in a time interval 0 to t

Q(t) = the ‘failure pressure’ of the given defect, representing the pipe resistance

p0 = the operating pressure

The calculated ‘probability of failure’ represents the probability of failure for a given defect (specific depth) in a time interval 0 to t, so it represents the cumulative value over the elapsed period. As alternative to the ‘probability of failure’, the ‘failure rate’ can be calculated that is defined as the ‘probability of failure’ per time unit, in other words the slope of the time dependent function of the ‘probability of failure’.

It is usual to define the failure probability per km length of pipeline. Assuming that corrosion defects occur randomly along the pipe length, and the failure of any defect is independent of other defects on the pipeline, the probability of failure per km of pipe length can be obtained as:

$$P_f(t) = 1 - \left[1 - P_{f|d}(t)\right]^{n} \tag{2}$$

where: P_f (t) = the probability of failure per km of pipe length

$P_{f|d}$ (t) = the probability of failure at a given defect d in a time interval 0 to t, see eq. (1)

n = the average number of defects per km length of the pipeline

In essence, a 1 km long pipe section is modelled as a series system with ‘n’ critical elements such that failure of any element (i.e. defect) amounts to the failure of the whole system. This implies that the probability for a 1 km section is approximately ‘n’ times larger than for a single defect. However, in section ‘Results’ the probability of failure values are presented for a single defect.

Input data

Outer diameter D_u	350	mm	
Wall thickness t	8.0	mm	including a probability distribution
Corrosion allowance (40 y x 0.05 mm/year)	3.0	mm	
Steel grade	Fe52		
Minimum specified Yield strength MSYS	369	MPa	
Yield strength YS	410	MPa	including a probability distribution
Minimum specified Tensile strength MSUTS	520	MPa	
Tensile strength UTS	550	MPa	
Maximum allowable operating pressure	10	MPa	

RESULTS

In the simulation, a first and second inspection is performed after 10 years and 20 years using a certain inspection technique with given POD and inspection coverage. The figures show the failure rate over the period of 30 years. The ‘failure rate’ is defined as the ‘probability of failure’ per time unit, actually ‘per year’ in this study. In the figures shown, the effect of inspection is best demonstrated by the reduction in ‘failure rate’ immediately after inspection compared to the ‘failure rate’ just before inspection. All figures contain results of the repair criterion 1.7MAOP. Please note when reading the figures below that time is given the value zero after 15 years of service and that a certain degree of corrosion is postulated being present at that moment.

The effect of POD

Figure 14 represents the evolution of the ‘failure rate’ in time for the case of inspection using Guided Waves and X-ray with 100% coverage.

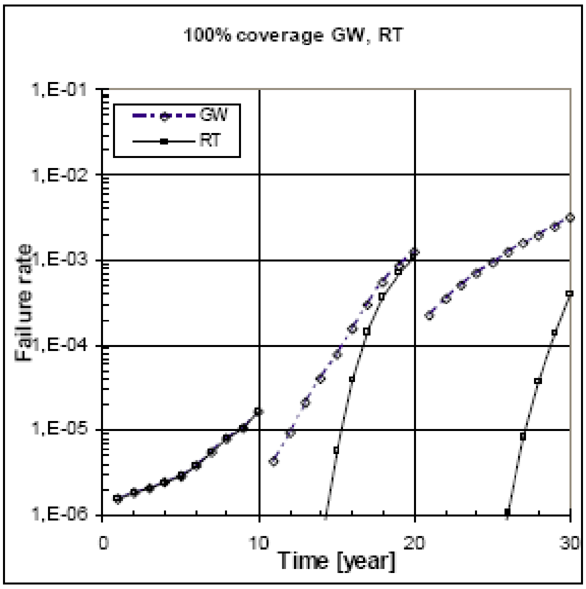


Figure 14: Effect of POD on failure

The figures show that the failure rate is reduced after inspection and repair. The reduction is very large for 100% RT. However at 20 years the failure rate has become equal for both techniques. The real difference becomes apparent at 30 years. The failure rate of the pipe inspected with 100% RT is about a decade smaller. However, in practice 100% coverage will not be feasible for pipe work with RT due to the needed time to perform inspections with this technique.

The effect of inspection coverage

Figure 15 represents the results for X-ray when the inspection coverage is reduced to 2% of the suspected area. The figure shows a very strong effect of reduction of the inspection coverage. A reduction to 2% coverage does not reduce the failure rate after inspection. Because executing inspection using the X-ray technique takes more time than other techniques, there will be a tendency to reduce the inspection coverage. The above results show that this reduces the effectiveness of inspection unless the reduction of coverage is justified by knowledge that corrosion may occur only in the restricted area.

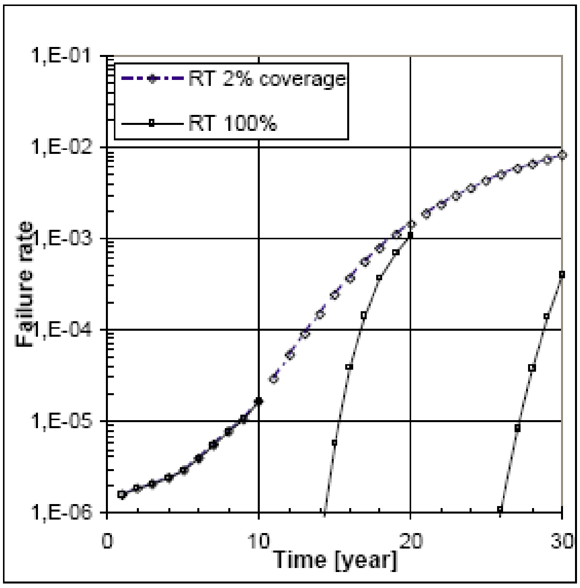


Figure 15: Effect of coverage on the failure rate

Comparison of 100% Guided Waves and 2% RT

Figure 16 compares the result from a 100% Guided wave inspection with a 2% RT inspection. These are coverage's are normally associated with the techniques. Although the POD curve of RT lies above the POD curve of Guided Wave, this does not compensate for the lack of coverage. The difference becomes more pronounced after 30 years.

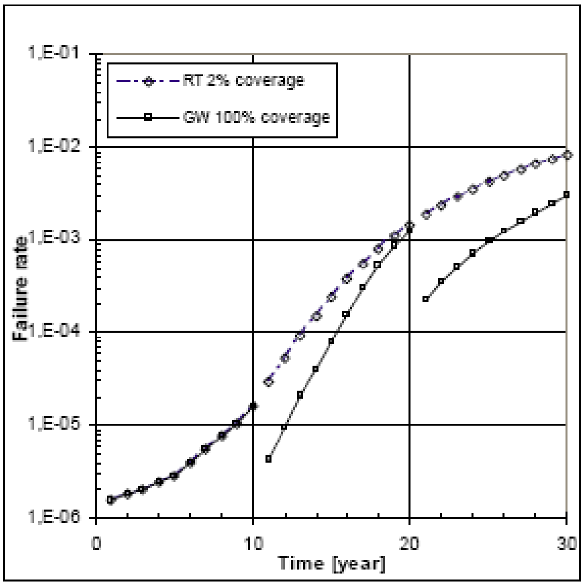


Figure 16: Comparison of 100% GW and 2%

DISCUSSION

Inspection effectiveness is strongly determined by the percentage of coverage relative to the suspected area. Consequently, RT is not considered cost effective as screening tool for corrosion under insulation in pipe work due to fact that the suspected area cannot be reduced significantly compared to the total pipe surface. The higher detection capability of RT relative to the Guided Wave techniques cannot compensate for the restriction of the inspected area needed from a cost effectiveness point of view.
Generally speaking, the results show that reduction of inspection coverage is only acceptable when the suspected area, known from historical experience, is smaller than the total surface.

The effect of inspection on the equipment's integrity is dependent on quite a number of factors, viz.: POD, sizing accuracy, inspection coverage, inspection frequency, defect morphology, defect initiation and propagation, repair criterion and failure criterion. It is common practice to take account of the influencing factors individually. This study has shown the potential of using models describing inspection, degradation and integrity to get insight in the relative significance of influencing factors. In this study only a few of the influencing factors have been modelled. The major advantage of the presented approach is the ability to combine the expertise from various fields, i.e. inspection, materials and mechanical engineering. The knowledge and experience in each field can be improved in course of time and systematically implemented to improve the reliability of the simulation and corresponding decision-making process. Modelling would be of great benefit for both inspection firms to specify their non-destructive inspection and end-users (the industry inspectors) to devise inspection programmes. Currently, communication is hindered between the end-users (read: in-house inspectors) who require a certain effectiveness and the providers of non-destructive inspection (read: inspection contractor or NDT specialists). The relationship between the required effectiveness and the performance of inspection procedures is simply too unclear within the field of in-service inspection.

Development of an integrated model and corresponding software-tool is currently undertaken by TNO in collaboration with a number of inspection firms as well as end-users. With the foreseen software-tool it should be possible to establish the resulting effectiveness for a specific situation (degradation type, extent of defect, geometry, etc.) depending on the selected inspection procedure. Conversely, it can be used to determine which inspection procedure is necessary to achieve a required inspection effectiveness based on a certain objective regarding the integrity.

CONCLUSIONS

This study has demonstrated that partial inspection is not effective if it is not sure that all possible degraded or corroded areas are being covered. Inspections executed with a lower detection capability but 100% coverage are mostly more effective than a partial inspection with a higher detection capability. An inspection technique with higher performance cannot easily compensate a certain reduction of inspection coverage. In this study it has been shown that a 100% inspection with Guided Wave is preferable to a 2% inspection using RT.

It has been shown that the ‘failure rate’ is an appropriate measure to incorporate all influencing factors.

The need to quantify the effectiveness of inspection procedures for in-service asset management is greater than ever due to the introduction of Risk Based Inspection methodologies or similar prioritising strategies. This study confirms the existing awareness that assessing inspection effectiveness is a complicated job due to the high number of influencing factors. An integrated model taking account of all factors controlling inspection, degradation and integrity is currently being developed. This new model will enable the combination of expertise from the fields of inspection, materials and mechanical engineering and allows a continuous process of updating experienced based know-how.

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