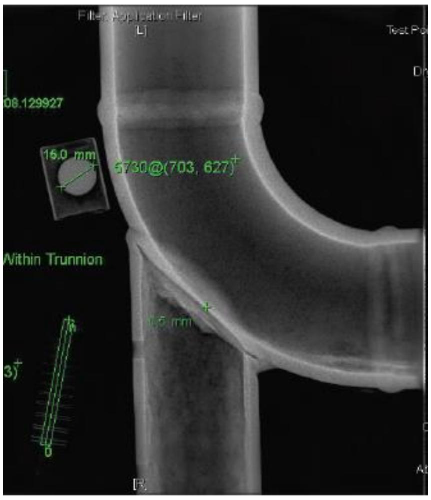

HOIS/OGTC guidance for trunnion pipe support management and inspection

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Executive Summary

Trunnion pipe supports are a common means to support/restrain process pipework both on and offshore – a length of pipe (trunnion) is welded to the process pipework and often has an end closure plate welded on to seal it, resulting in an enclosed volume. The enclosed volume is most often uncoated, there is no corrosion protection on the parent pipe or the internal surface of the trunnion inside the enclosed volume. Consequently, trunnion supports do not permit general visual inspection of areas of the process pipe susceptible to corrosion.

The potential failure of process pipework results from the ingress of water/moisture through small diameter weepholes drilled in the trunnion as part of the welding process. Failure of process pipework supported by trunnions is time dependent, the risk of hydrocarbon release (HCR) increases with the age of assets. HCRs resulting from pipework failure at trunnions have been investigated by the UK HSE and instances have been reported on and offshore and in process plants outside of the UK.

The HOIS project on carbon steel trunnion pipe supports was started in 2017. This followed a proposal put forward by the UK HSE with the aim of increasing awareness of trunnion management and inspection within the industry. Rigorously controlled blind trials were conducted to assess the suitability of available non-destructive testing techniques to identify the presence of corrosion within trunnions and, where possible, to characterise/quantify it. Although the trial report remains confidential to HOIS members [1], the results have been used to inform the development of this guidance.

This document contains an overview of trunnion design, geometry and degradation mechanisms. There are relevant case studies of trunnion failures and inspection, provided by HOIS members, to increase awareness and understanding of the challenges associated with trunnion inspection.

This guidance recommends a campaign-based approach should be used where there is a poor inspection history for trunnions in order to provide a baseline for future inspections. The creation of a trunnion register along with a standardised inspection approach can be developed as part of the campaign, which can then inform the risk based inspection (RBI) process. It may, in some cases, be appropriate to continue with this approach for the lifetime of the asset.

Thereafter, or for new assets, it is recommended that trunnion inspection might be included in the RBI scheme maintained by the asset owner.

An effective risk ranking for trunnions requires a good knowledge of the degradation rates and operating conditions of both the process pipe and the trunnion. Inspection of any given trunnion should be prioritised initially on the assessed criticality of the process pipe to which the trunnion support is welded, and then further prioritised based on the parameters associated with that particular trunnion. The document identifies the critical elements for consideration with respect to external corrosion of process pipework within the trunnion and highlights the parameters which should then be considered to further assess the risk associated with individual trunnions.

The document provides guidance for the selection of appropriate techniques for inspection of trunnion pipe supports, it describes the strengths and limitations of applicable inspection methods with more extensive information given in a detailed Appendix. The aim is that the information provided will assist asset owners and operators with making more informed decisions with respect to selection of inspection techniques and evaluation of the findings, based on an improved understanding of the capabilities and limitations of the techniques. Asset owners and operators will be aware that the onus is on all duty holders to demonstrate the capabilities of inspection methods selected.

The guidance is summarised in simple flowcharts to describe the process of trunnion management, inspection method selection and post-inspection action. This document provides a practicable, good practice approach to the management and inspection of trunnions.

Contents

1 Introduction

Trunnion pipe supports are a common means to support or restrain process pipework both on and offshore. A length of pipe (trunnion) is welded to the process pipework and often has an end closure plate welded on to seal it. The enclosed volume is most often uncoated, there is no corrosion protection on the parent pipe or the internal surface of the trunnion inside the enclosed volume. Consequently, trunnion pipe supports do not generally permit visual inspection of the areas most susceptible to corrosion. HOIS has previously developed guidance on the inspection of pipe supports [2], however trunnions represent a special case which has not been addressed until now.

The potential failure of the carbon steel process pipework within the trunnion results from the ingress of water/moisture through a small diameter ‘weephole’ drilled in the trunnion as part of the welding process. The occluded nature of the trunnion means that moisture is retained and corrosion rates are often unpredictably higher than the external surfaces of the adjacent process pipe, resulting in corrosion of the process pipe wall within the trunnion, as well as the trunnion itself. Drying (particularly where parent pipes are operating at elevated temperatures) and rewetting inside the trunnion may contribute to accelerated corrosion rates. Failure of process pipework supported by trunnions is time dependent, the risk of hydrocarbon release (HCR) increases with the age of assets. HCRs resulting from pipework failure at trunnions have been investigated by the UK HSE and instances have been reported on and offshore [3]. The HSE has actively investigated hydrocarbon releases from pipework failure and previously found that the management and inspection of trunnion supports across industry is inconsistent.

Asset owners and operators will be aware that the onus is on all duty holders to demonstrate the effectiveness of inspection methods used.

Given the increasing industry concerns as mentioned above, the HOIS project on trunnion pipe supports was started in 2017. This followed a proposal put forward by the UK HSE with the aim of increasing the awareness of trunnion management and inspection in the industry.

This HOIS project has conducted rigorously controlled blind trials to establish the effectiveness of existing techniques to initially detect and then quantify and characterise the extent of corrosion within pipe support trunnions. The results of the trial programme, which are confidential to HOIS members [1], have been used to develop this guidance document.

This guidance document contains an overview of trunnion design, geometry and degradation mechanisms Section 5 outlines a good practice approach to the management of trunnions and the factors to consider in a risk ranking process. Section 6 provides guidance on trunnion inspection. Section 7 contains case studies provided by HOIS members with examples of how this guidance might, with hindsight, have applied to those trunnions. Section 8 briefly discusses how trunnion design might mitigate the risk of corrosion. Further detail on individual inspection methods is provided in Appendix 1.

2 Terms and abbreviations

CR	Computed radiography, uses flexible imaging plate (IP) which is first exposed to radiation which generates a latent image and then scanned using a laser scanner to provide a digital radiograph.
CRA	Corrosion risk assessment
CS	Carbon steel
DDA	Digital detector array. Term used for digital radiography.
DWDI	Double wall double image. A term used in radiography involving use of a radiation source separated from the pipe under inspection such that the radiographic image shows detail in both the pipe walls, including the one on the source side.
EMAT	Electromagnetic acoustic transducer
GWT	Guided wave testing
HCR	Hydrocarbon release
HSE	UK Health and Safety Executive (Government agency and regulatory authority)
ID	Pipe inner diameter (internal surface)
IRR17	The Ionising Radiations Regulations 2017, HSE, UK Statutory Instruments 2017 No. 1075
LPG	Liquefied petroleum gas
MRWT	Minimum remaining wall thickness
NB	Nominal bore
NDT	Non-destructive testing
OD	Pipe outside diameter (external surface)
PA	Phased array
RBA	Risk based assessment
RBI	Risk based inspection
QSR	Quantitative short-range guided wave inspection system developed by Guided Ultrasonics Ltd (GUL)
RMS	Root-mean-square
UT	Ultrasonic
WT	Uncorroded wall thickness, generally measured locally to each area of wall loss. Manufacturing tolerances cause WT to differ slightly from the nominal pipe wall thickness

3 Scope

One of the aims of HOIS is to generate and share knowledge within the industry. The HOIS work in this area and dissemination of this document will lead to an increased awareness of the potential risk of trunnion failure.

This guidance document is intended for asset owners and inspection service providers. It aims to further the understanding of trunnion corrosion, the challenges of inspection and develops a considered approach to the management, inspection and design of trunnion pipe supports.

The component material inspected in this study has been restricted to carbon steel in which the degradation type is wall loss due to corrosion.

There have been examples of failures of stainless-steel and other corrosion resistant alloy trunnion pipe supports due to the corrosion conditions that may arise within trunnions that can provide an effective crevice. Localised pitting corrosion and cracking mechanisms particular to stainless steel types (including duplex stainless steel) have been referred to in the Energy Institute's guidance for corrosion management in oil and gas production and processing [4]. Stress corrosion cracking initiation is largely unpredictable and, once initiated can proceed very quickly to failure. The management of this type of trunnion requires a different approach, beyond the scope of this document.

4 Overview of trunnions

4.1 Trunnion geometry

Pipe support trunnions (sometimes referred to as dummy leg supports) are a common means of supporting process pipework on and offshore – a short length of pipe (trunnion) is welded to the process pipework as shown in Figure 4-1.

Figure 4-1: Horizontal trunnion support on vertical pipework

Trunnions are usually manufactured of the same material as the process pipe and are usually smaller than the pipe they support. Trunnions may also be present on pressure vessels where they are usually used as lifting aids during installation.

The end caps welded to the short length of pipes form an enclosed volume. Weepholes (often in the order of 6mm in diameter) are added to the trunnion prior to the welding process to vent hot gases. The weepholes can be effectively sealed to prevent water ingress however, this is often not the case. Furthermore, filler applied in order to close weepholes may also degrade over time, allowing moisture to enter.

A direct visual inspection and wall thickness measurement of the process pipe inside the trunnion is not usually possible. The end cap is not generally removed because it provides structural strength to the trunnion (and therefore the supported process pipe). If the process pipe is severely corroded, then the act of removing the end cap might cause a leak or rupture because of the additional stress.

Trunnions may be on a bend, a straight pipe or T-piece. They may also have a reinforcement pad or doubler plate. Three different vertical trunnion configurations are shown in Figure 4-2, a horizontal trunnion is shown in Figure 4-1.

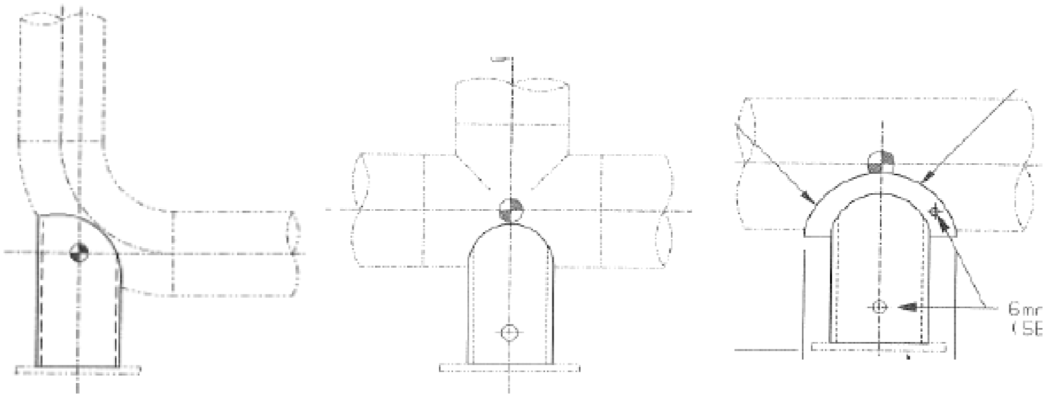

Figure 4-2: Vertical trunnion on an elbow, on straight pipe/T-piece, trunnion on a straight pipe with reinforcement pad.

Reinforcement and doubler plates also have weepholes, as shown in the right hand image in Figure 4-2, but API 510 [5] recommends that these are open to provide visual evidence of leakage as well as to prevent pressure build-up in the cavity. Confusion between the recommendation for open tell-tale holes on reinforcement plates and plugged weepholes on trunnions might be one reason why weepholes on trunnions are found to be left unplugged. However, trunnion weepholes should always be plugged with grease or epoxy which prevent moisture ingress but are not pressure retaining.

Where reinforcement plates are in place, the assumption should not be made that the trunnion is welded to the reinforcement pad and not directly to the parent metal. Drawings should therefore be consulted to understand whether the trunnion is either:

- Welded to the reinforcement pad which is, in turn, welded to the process pipe. In this case the condition of the process pipe beneath the plate should be monitored and the risk to the process pipe associated with the trunnion is lower.

Or:

- The reinforcement is a ring around the trunnion, as in Figure 4-3 and Figure 4-4, and so the condition of the process pipe inside of the trunnion should be monitored. The change in local geometry because of the reinforcement ring will have an effect on inspection method selection to monitor the condition of the process pipe within the trunnion.

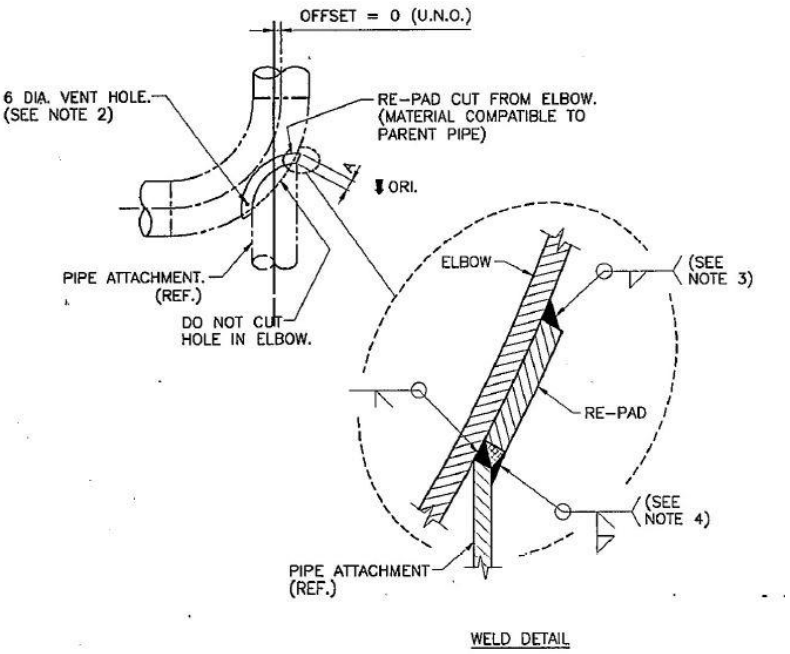

Figure 4-3: Vertical trunnion welded to elbow. With reinforcement plate around the trunnion. External surface of process pipe exposed inside trunnion.

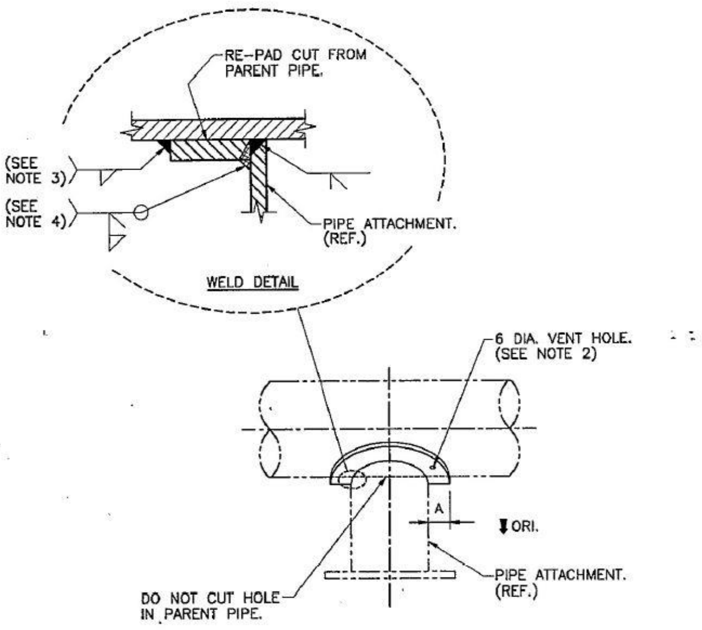

Figure 4-4: Reinforcement plate ring around vertical trunnion on straight pipe. Process pipe external surface exposed inside trunnion.

4.2 Degradation mechanisms for carbon steel trunnions

Carbon steel is widely used in the oil and gas production industry because of its availability, constructability and relatively low costs [6]. However, it has relatively low corrosion resistance and so components are often externally coated.

Trunnion internals are generally not coated and are susceptible to corrosion following moisture ingress through weepholes. Frequently weepholes are either not effectively sealed or the material used to plug them degrades over time which may leave the trunnion open to moisture/water ingress.

Over time, and depending upon a number of variables, corrosion within the trunnion at the interface with the process pipework can occur, which may then result in its failure. There are several types of corrosion relevant to carbon steel trunnions described here. Case studies of in-service corrosion, with illustrative photographs, provided by HOIS members are in Section 7.

4.2.1 General corrosion

In the process of general corrosion, electrochemical reactions proceed uniformly over the entire exposed metal surface. The corrosion of iron in the presence of water and air is the oxidation of iron: The oxidised iron reacts with the hydroxyl ions to form hydrous iron oxide (as an example)

Anodic reaction (oxidation)

$$Fe \rightarrow 2e^- + Fe^{2+}$$

Cathodic reaction (reduction)

$$\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2(OH^-)$$

It often appears to be uniform attack on the metal surface. Closer examination may identify an ‘orange peel’ effect [7], the dimples are individual anodes surrounded by cathodic areas. Corrosion product is deposited over the whole surface, not just where the anodes are located. The overall rate of penetration is generally quite low, but wall thinning can be extensive and a large volume of corrosion product generated. There are typically peaks and valleys over the material surface, but corrosion is considered to be general when there are no small deep corroded areas on the metal.

Trunnions are susceptible to corrosion as moisture/water can enter the enclosed volume through unplugged weepholes but then cannot fully evaporate in the enclosed volume, trapping the water in contact with uncoated carbon steel.

4.2.2 Crevice corrosion

Crevice corrosion is a localised corrosion in narrow clearances or crevices in the metal which allow fluid to become trapped and stagnant which results in concentration differences of corrodents over a metal surface. Electrochemical potential differences result in localised selective crevice or pitting corrosion attack [8]. Crevice corrosion can be very aggressive as differential aeration means that locally acidic conditions occur within the crevice. The process becomes autocatalytic.

The geometry of trunnions creates crevices at the internal weld root, which lead to chemically aggressive environments where corrosion causing ions cannot readily diffuse out of the crevice leading to differential local chemistry. This may be exacerbated by poor welding technique and differences between the pipe and weld metal giving rise to local galvanic effects. Trunnions are therefore particularly susceptible to crevice corrosion, especially where the trunnion to pipe weld is not a fully penetrating continuous weld.

4.2.3 Pitting corrosion

Pitting corrosion is a highly localised attack where corrosion results in distinct, well-defined cavities in the material dissolutes the metal, forming distinct, well defined cavities on the component surface [9]. Corrosion at the bottom of the pit is more aggressive and grows at a faster rate than the pit walls. This type of corrosion is particularly difficult to detect. Both carbon steels and corrosion-resistant alloys can undergo pitting corrosion [10] in an oxidising environment. The susceptibility of metals to pitting corrosion and pitting corrosion rate depend on the metallurgy and the microstructure of the metal and the environment in which it is operating.

There are some factors that initiate and or increase the rate of pitting corrosion, such as

- Mechanical damage e.g. dent or a scratch which occurs during fabrication of the trunnion.
- Water chemistry factors including acidity, and low dissolved oxygen concentrations.
- The presence of seawater (or high chloride concentration media).
- If painted, localised damage or improper application of the coating can lead to pitting.
- Nonuniformities or non-metallic inclusions created during manufacturing.

It is likely that it is the presence of contaminants, such as chloride ions, that leads to localised preferential attack on the inside of trunnions. Potential sources of these contaminants include parent/weld metal contamination and ions dissolved in the water that enters through the weephole - concentrations may build up through hot/cold evaporation cycles.

When pitting corrosion is found on a clean uniform metal surface, a slight increase in the corrosiveness of the environment results in general corrosion, meaning a trunnion may exhibit both general and pitting corrosion, as shown in the case studies in Section.

5 Good practice approach to integrity management of trunnions

5.1 Background

While this document focusses on the role of inspection in integrity management of trunnions, it is important to recognise that trunnion integrity is affected by a number of other factors, specifically:

- Design. The orientation of the trunnion and location of weepholes influences the potential for water collection on the process pipe surface (and hence also corrosion).
- Maintenance. Regular maintenance and replacement of weephole plugs can limit the potential for water ingress and associated corrosion. Early intervention to seal unplugged weepholes keeps trunnion inspection simple, resulting in the verification of the absence of corrosion using a screening technique, rather than having to apply advanced NDT methods to attempt to quantify MRWT.
- Provision of reinforcing or doubler plates.

Integrity management of trunnions should follow the principles of good practice applied to all other process, safety and business critical pressure systems assets. For example, a key initial step, following trunnion installation, is that all trunnions should be included in an asset register; baseline assessments of condition should be made for comparison with subsequent inspection results.

If the asset is a mature one, then the same principles apply, although added certainty is required concerning trunnion identification and the assembly of the register – it is likely that engineering changes have been made and that drawings do not accurately reflect the plant. A line walking exercise may be required.

Provided trunnion arrangements are inspected effectively, and at suitable intervals, then the general approach is within the gift of the duty holder, however, there are advantages to the register and campaign approach:

- A single, comprehensive register of trunnions allows for easier and more effective data manipulation, risk ranking, grouping, planning etc.
- Planning for inspection of trunnions as a single or multiple of campaigns may be required where specialist NDT equipment or services have been selected and are not routinely available.

A trunnion register and inspection campaigning approach should be taken, where there is uncertainty over trunnion inspection history and condition, to set an effective baseline.

Thereafter, or for new assets, trunnions may be included in the risk-based inspection (RBI) scheme maintained by the asset owner. The RBI methodology selected, as well as the specifics of the operator's documented RBI process and associated systems (including software) will then influence the framework for management of trunnions. This document does not aim to cover RBI approaches in detail (the reader should refer to well established industry guidelines such as those covered in [11] and [12]. A brief overview of considerations specific to trunnions is provided here.

Management of trunnions requires consideration of multiple factors to assess and mitigate the risk of trunnion failure on assets. For trunnions it is key that an effective risk ranking depends heavily on a good knowledge of the degradation rates and operating conditions of the process pipe *and* the trunnion. Inspection should be prioritised initially based on the assessed criticality of the process pipe on to which the trunnion support is welded and then further prioritised based on a number of parameters related to the trunnion itself, which are described below.

Although the threats and parameters associated with the process pipe have been utilised to establish an initial trunnion risk ranking, when setting trunnion inspection intervals, it should be remembered that corrosion rates within the trunnion may well be greater than that determined for the process pipe as part of the initial RBA, due to effects such as crevice and pitting corrosion.

The recommendations given here are consistent with, but more detailed than, the guidance provided in Annex H of the Energy Institute's Guidelines for the integrity management of corrosion under pipe supports [13].

5.2 Process pipe

This section defines the critical elements for consideration with respect to external corrosion of process pipework within the trunnion using this approach; these are in addition to the consideration of internal corrosion mechanisms that would be part of the piping system corrosion risk assessment (CRA):

Operating temperature – corrosion rate is dependent on temperature. Operating temperature will affect the likelihood and rate of corrosion. Corrosion will be more likely on pipework experiencing hot/cold temperature cycling, particularly in marine environments as chloride content can build up with each evaporation cycle.

Location – Trunnions in marine environments (including offshore locations) will have greater exposure to chloride ions (seawater) which promote crevice corrosion and pitting. The higher the chloride content the more corrosive the water and so the greater the likelihood of corrosion.

More specifically, the exact location on the site also bears relevance. Trunnions high on an open platform weather deck or on an exposed edge in the face of prevailing weather will carry a greater risk. Those situated in an enclosed, dry module may be regarded as at lower risk from incipient corrosion, however, regular deluge or wash down activities may result in the risk being increased. All likely sources of moisture ingress should be considered.

As has been previously highlighted, the lack of an apparent source of direct moisture impingement does not rule out the possibility of internal trunnion corrosion (see 6.3 below)

Process pipe contents – consequence of failure on pipework containing process fluids is higher for hydrocarbons than water.

Internal Corrosion – likely internal corrosion of the process pipework amplifies the need for timely and effective inspection at trunnion support arrangements. Consideration of internal corrosion mechanisms would be part of the piping system CRA.

Operating pressure – the consequence of failure on pipework at high pressure is higher than at low pressure.

Age – the corrosion of carbon steel is a time dependent process and so the age of a component is a relevant parameter. The likelihood of failure will generally increase with age.

Inspection history – Where wall loss has previously been identified, inspection intervals should be determined such that there is a low probability of failure between inspections. Previous inspection results should be compared to baseline measurements, where available. Where inspection history is not available or poor, the campaign and baselining exercise described above, is recommended.

Corrosion allowance – small corrosion allowances will require more frequent inspections to ensure that where corrosion occurs the wall loss does not exceed the corrosion allowance.

Wall Thickness – lower nominal wall thickness pipework potentially narrows the window of opportunity to detect and mitigate trunnion corrosion before a failure occurs.

5.3 Trunnion

Parameters which should be considered to further assess risk associated with individual trunnions are associated with trunnion design, including weepholes. It is important to note that the weephole is present to allow the escape of gases during the installation welding process, preventing blow out of the weld and that it serves no further useful purpose in service, other than a possible access point for internal borescopic inspection. The weephole may have to be enlarged to allow this.

Trunnion orientation. The orientation of the trunnion itself may influence the likelihood of corrosion occurring on the process pipe. For example, a vertical trunnion on the top of a process pipe might be of greater concern than a vertical trunnion on the bottom of the line. This is because any trapped moisture is likely to be in contact with the process pipe in the former case whereas away from the process pipe in the latter. However, caution should be exercised when considering de-prioritising trunnion supports on the basis of trunnion orientation, particularly where the consequences of failure are high. There are two case studies in Section 7 (#3 and #7) which give examples of corrosion of a process pipe for vertical trunnions.

Weephole orientation – weepholes should ideally be positioned away from the weld and oriented to limit moisture ingress. For horizontal trunnions this is usually at the lowest point, or side, of the trunnion. There may be exceptions to this, as outlined in case study 5 (Section 7.6) from an HSE safety alert [3] where, although the weephole was at 6 o'clock, it was sited directly on support steelwork and, as a result, the void within the trunnion gradually drew in moisture by capillary action which then condensed on the process pipe wall. This in turn led to accelerated localised corrosion of the process pipe. For vertical trunnions weephole orientation is less critical but should be located away from the weld.

Caution should be exercised when considering de-prioritising trunnion supports on the basis of weephole orientation, in particular, where the consequences of failure are high.

Weephole plugging – weepholes which have not been adequately plugged or where the plug has degraded over time will increase the likelihood of water or moisture ingress which causes corrosion which may lead to failure. As plugs may degrade over time, the age of the trunnion (or at least that of the plug material) is also relevant.

Absence of Weephole – should general or close visual inspection of a trunnion indicate that no weephole is present, then the case should be investigated further. The provision of a weephole is normal practice.

If a weephole is not evident, it may mean that:

- The hole has been plugged and painted over.
- The hole is covered with corrosion product (if external corrosion has taken place)
- In the case of a horizontal trunnion (or a vertical trunnion provided for the means of restricting pipe movement), the hole may be sitting on top of the supporting structural member.

Instances have occurred whereby weepholes in corroded trunnions have only become apparent once blasting had taken place for one or more of the three reasons above.

Furthermore, extreme care should be exercised when dealing with trunnion supports with no apparent weephole on high pressure/high consequence equipment; the case should be considered that there is, indeed, no weephole and that the process pipework within has been corroded and breached. The possibility exists that the trunnion itself may be retaining process pressure.

Trunnion design – there have been examples where particular trunnion geometries, as in case study 5 (Section 7.6) from an HSE safety alert [3], have led to corrosion of the process pipe within the trunnion. Where this has been identified, all similar trunnions on the asset should then be inspected.

6 Trunnion inspection

6.1 Background

This section covers background and guidance for the inspection of trunnion pipe supports. The aim is that the information provided will assist asset owners and operators with making more informed decisions with respect to selection of inspection techniques and evaluation of the findings, based on an improved understanding of the capabilities and limitations of the techniques.

Note that it is predominantly the condition of the pipe supported by the trunnion that is of interest; the condition of the trunnion does not necessarily correlate with the condition of the process pipe. Hence estimates of wall loss on the trunnion itself cannot be used to predict wall loss on the process pipe. Case Study 4 in Section 7 is an example of a trunnion with external corrosion, and evidence of water ingress, but no wall loss on the process pipe.

6.2 HOIS NDT trials

The HOIS trials were conducted with the aim of assessing the capabilities and limitations of existing and developmental techniques to detect and, if possible, to characterise the extent of corrosion within trunnion pipe supports. The trial programme was expanded as a result of joint funding of the project by The Oil & Gas Technology Centre.

Trials were performed on three different sets of samples (although not all methods were applied to all samples):

- Manufactured components (open and blind trials) comprising elbows and straight pipes with machined round bottomed holes of various diameters to simulate pitting corrosion and some areas of material ground away to simulate more generalised corrosion.
- Ex-service trunnions (blind trials), comprising seven ex-service components with eight trunnions welded to them, a mixture of elbows and straights. The majority were found to be heavily corroded (wall loss >50%).
- Shell samples (blind trial), comprising ex-service pipes, some with in-service degradation as a result of corrosion under insulation or corrosion under a pipe support. Additional drilled holes were added to some of the samples to more accurately simulate the localised pitting observed inside trunnions.

Across all the HOIS trials, detection of corroded trunnions was generally good. However, there were significant differences in the sizing performance of the trials between the manufactured and ex-service test pieces with wall loss consistently underestimated. The report on trial results [1] remains confidential to HOIS members but has been used to develop the recommendations given here.

6.3 Relevant inspection methods

Relevant inspection methods for trunnion inspection, included in the HOIS trial programme (note that not all techniques were applied to all samples) are:

- Borescope video probes

- Medium range guided bulk wave techniques
- Medium range phased array
- M-skip
- Radiography
- Verkade method

Other techniques, not assessed in HOIS blind trials, but which may be applicable include:

- Long range guided wave testing
- QSR – quantitative short range guided wave method.

A summary table of the strengths and limitations of several different inspection methods is given in Table 6-1. Further detail on each method including a discussion of trial experience and overall summaries of each method is given in Appendix 1.

Table 6-1: Applicable inspection methods with strengths and limitations

Method	Strengths	Limitations
Borescope video probes	Useful screening method – can confirm the absence of corrosion on external surface of process pipe inside the trunnion or possibly rank severity of any corrosion present. Allows direct visualisation of the corrosion product. Rapid and simple to do.	No quantitative measure of wall loss or remaining wall thickness. Where large amounts of corrosion product are present, can be difficult to differentiate between trunnion and process pipe walls in the images. Requires weephole to be unplugged – must be refilled to prevent water ingress. Will not detect internal wall loss of process pipe – limited to external pipe surface assessment.
Long range guided wave testing	Can cover long lengths of straight pipe runs in one rapid measurement. Likely application of screening several trunnions with the aim of identifying the most corroded ones for follow up. Applicable to a wide range of pipe diameters and thicknesses. Sensitivity to loss of cross-sectional area can be assessed from data. Can be used for monitoring using a permanently installed sensor ring for greater sensitivity.	Reflected signals are obtained from the trunnion to pipe weld and other supports, so it can be challenging to reliably distinguish between corroded and uncorroded trunnions, although multi-frequency examination and focussing/c-scan displays provide additional information. Sensitive to loss of cross-sectional area and not local %wall loss. Hence can miss circumferentially localised but deep corrosion pits. Application limited to straight pipe runs. Not applicable to complex geometries. Propagation of guided waves can be reduced by some forms of coating.

Method	Strengths	Limitations
Medium range guided bulk wave techniques	Applicable to wide range of pipe diameters, wall thicknesses and geometries. Simple to perform – single probe in pulse echo. For repeat inspection, where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion.	Reflected signals are obtained from the trunnion to pipe weld and it can be difficult to reliably distinguish between corroded and uncorroded trunnions. Will be affected by surface condition where transducers are placed adjacent to the trunnion, must be relatively free from loose scale. Difficult to apply to elbows. Not clear how ultrasound beam propagates in the axial direction for circumferential locations away from the extrados which may affect interpretation (and therefore reliability) of results. Not clear how transfer losses between the process pipe and any calibration pipe sections are allowed for. The accuracy and reliability of the results is strongly dependent on the training and expertise of the inspector and the testing procedures used (including post inspection analysis). Limited detection of generalised corrosion which will often produce very weak pulse-echo responses.

Method	Strengths	Limitations
Medium range phased array	Applicable to a wide range of pipe diameters and wall thicknesses. Simple to apply, rapid scanning using readily available tools. For repeat inspection, where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion.	Affected by surface condition where transducers are placed adjacent to the trunnion, must be relatively free from loose scale. May be affected by coatings on the pipe. Difficult to apply to elbows. Not clear how ultrasound beam propagates in the axial direction for circumferential locations away from the extrados which may affect interpretation (and therefore reliability) of results. Limited detection of generalised corrosion which will often produce very weak pulse-echo responses. The accuracy and reliability of the results is strongly dependent on the training and expertise of the inspector and the testing procedures used (including post inspection analysis).

Method	Strengths	Limitations
M-Skip	Effective confirmation of lack of corrosion for thin and thick-walled pipes. Combination of axial and circumferential beam scanning on straight components provides more confidence in results. Rapid scanning. Quantitative sizing is possible is some cases.	Can be affected by surface roughness and poor surface condition, resulting in loss of signal responses. Coatings can have very variable effects which need to be assessed on a case by case basis. Sizing generally only possible on thicker walled pipes (>15mm). Sizing information subject to uncertainty depending on the corrosion extent along beam direction and profile. Complete loss of signal (no sizing information) may occur for thin-walled, heavily corroded components. (<10mm) with only moderate levels of corrosion. The effect of the weld on M-skip signals is not well understood. Very challenging to apply on bends, restricted to straight lengths of pipe as not clear how ultrasound beam propagates in the axial direction for circumferential locations away from the extrados. Limited application experience.

Method	Strengths	Limitations
QSR	EMAT probes are much less affected by surface condition/coatings than conventional ultrasonic probes. Rapid inspection. Quantitative indication of defect severity for wall losses <50%. For repeat inspection, where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion.	Requires access to the pipe on the opposite side of the trunnion. Probe beamwidth is stated to be 40mm, but the instrument is said to be capable of reliably sizing localised areas of wall loss down to ~25mm in axial extent. Corroded areas smaller than this are likely to be undersized. Suitable for straight pipes wall thickness >6mm, pipe diameter >8inches. Not applicable to elbows. New developmental method – limited field experience.
Radiography	Direct visualisation of the corrosion. Quantitative (with some caveats) remaining wall thickness measurements for a range of corrosion shapes/profiles but only at the tangent position. Widely used for this application for small bore pipes and sometimes larger diameters. When it is not possible to penetrate the pipe wall fully to determine remaining wall thickness, quantitative information on wall loss can sometimes still be obtained. For larger pipe diameters and schedules for which full penetration of the pipe wall is not possible (ID not visible on the radiographs), the method of measurement of wall loss, relative to the adjacent uncorroded pipe OD, allows extension of the method to a greater range of pipes than specified in ISO 20769:1.	Radiation safety issues. Slow. Generally restricted to small bore pipes (total penetrated thickness of the tangent to the ID, including the trunnion, <80mm for Ir 192), although measurements of wall loss can be obtained for larger diameter pipes and heavier schedules. Circumferential coverage of a single shot is very limited, and corrosion away from the tangential position may be missed or unreliably sized – see ISO 20769:1. Requires access around the trunnion and may be difficult to image the precise area of interest.

Method	Strengths	Limitations
Verkade Method	Allows confirmation of lack of corrosion for thin and thick-walled pipes and vessels. Combination of axial and circumferential beam scanning for straight pipes may provide more confidence in results. Quantitative sizing of minimum remaining wall thickness.	Can be affected by surface roughness and poor surface condition (coating etc.), resulting in loss of signal responses. Coatings can have very variable effects and may need to be removed. Limited to axial scanning only on elbows/complex geometries which will affect reliability of results.

6.4 Inspection method recommendations

Although this report focusses on the capability of inspection techniques able to determine internal condition, it is most likely that the 'first pass' inspection of all trunnions will be by visual inspection. Although external only, the general condition and context provided by visual inspection may well provide a valuable indicator of the likely internal condition, particularly if the external surface and surroundings are poor, this may well point to internal degradation. The opposite may not be true, however, and a good external condition is not necessarily an indication of a lack of internal degradation.

It is likely, though, and dependent on weephole orientation, that significant internal degradation (carbon steels) is indicated by corrosion product or staining emanating from the weephole.

Borescope inspection has been shown in the HOIS trials to be a useful method as a screening inspection method. The videoscope probes used in the trials were effective at identifying corrosion where present on the OD of the process pipe (and the ID of the trunnion). The videoscopes were successful as a screening tool but cannot provide a quantitative assessment of remaining wall thickness, although may offer a ranking of corrosion severity.

One limitation of the use of borescopes (highlighted in the HOIS trials) is that if an internal degradation mechanism of the process pipe (such as internal pitting) is present, it cannot be detected. Internal degradation would not necessarily be associated with the trunnion but be more widespread, wall thickness measurements away from the trunnion would be able to detect the issue. Hence, if the corrosion risk assessment considers that an internal degradation mechanism is likely, borescopic examination of a trunnion should be combined with further wall thickness measurements away from the trunnion.

Where this screening process has identified corrosion inside the trunnion, the selection of an appropriate non-destructive testing method or methods, dependent on pipe geometry and access conditions, may allow assessment of the severity of the corrosion and estimation of the MRWT.

For small bore pipework, the most appropriate, and widely used, technique is tangential radiography where multiple shots at different angles determine MRWT. There are limitations to its applicability and caveats on sizing of external corrosion. For some external corrosion morphologies (mainly those with localised circumferential extents) there are significant uncertainties in remaining wall thickness. All in-service radiography should be in accordance with ISO20769:2018 Part 1. Further detail is given in Appendix 10A1.7. The combination of pipe diameter and wall thickness determines the maximum penetrated thickness for tangential radiography. Using Ir 192 sources there is a limit of c. 80mm on the chord length (dependent on the wall thickness and diameter) which generally limits the applicability of tangential radiography (for wall thickness measurements) to small bore pipes.

For larger pipe diameters and schedules for which full penetration of the pipe wall is not possible (ID not visible on radiographs), measuring wall loss, relative to the adjacent uncorroded pipe OD potentially allows extension of the method to a greater range of pipes than specified in ISO 20769:1.

Where wall thickness measurements are not possible, radiographs identifying corrosion product within a trunnion, indicative of active corrosion, are still of value.

Several radiographs in the HOIS trials also showed evidence of pitting, see structure in the double wall portion of the radiograph highlighting wall loss in the process pipe, for example radiographs in Figure 6-1, Figure 6-2 and Figure 6-3

Figure 6-1: CR image (courtesy CAN), evidence of through wall external corrosion of process pipe, large volume of corrosion product inside trunnion.

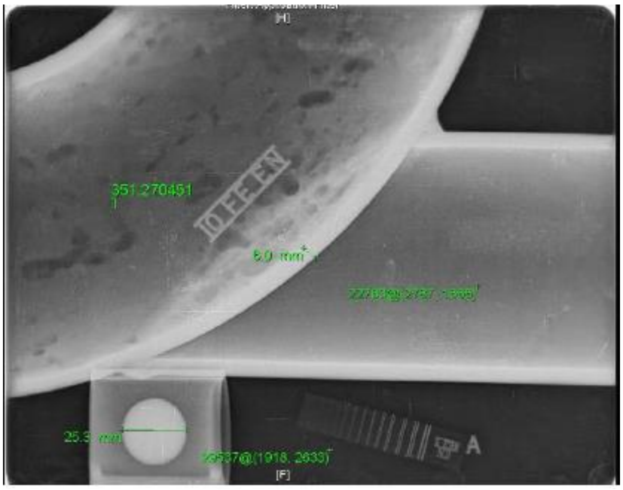

Figure 6-2 CR image (courtesy CAN), evidence of pitting type wall loss of the process pipe. Internal corrosion not limited to the section of process pipe covered by the trunnion.

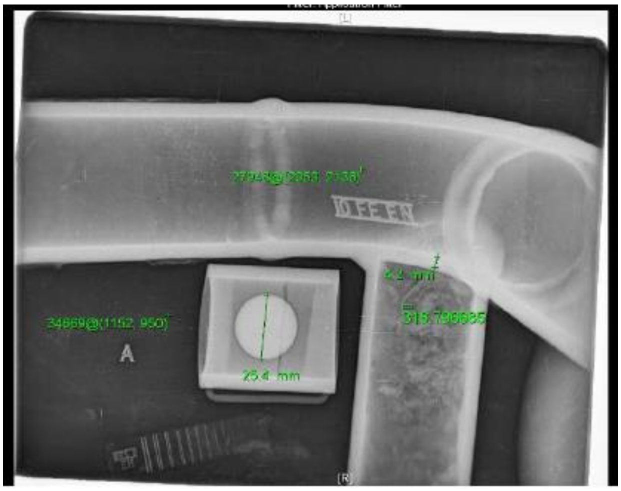

Figure 6-3: CR image (courtesy CAN) external corrosion noted within trunnion, MRWT measured. Some evidence of pitting in the process pipe wall within the trunnion would put further caveats on MRWT measurement. Significant volume of corrosion product visible inside trunnion.

Where radiography is not applicable (either because of geometry, access or difficulties of managing safety requirements) other ultrasonic based techniques should be deployed.

<u>The UK regulator, the HSE, emphasises that the onus is on the duty holder to be able to demonstrate that a selected inspection technique is effective</u>.

The HOIS trial results of various NDT techniques showed that detection was generally good, but that wall loss was consistently underestimated. There were significant differences in sizing performance of different techniques. The best performing techniques in the HOIS trials reported wall loss to within 10% of the benchmarked value but there were other techniques which had mean differences (and maximum undersizing, RMS values) much larger than this on the trial components. It is recommended that an appropriate tolerance should be applied to reported remaining wall thickness values.

For thin walled components, even small tolerances on wall loss measurements may lead to a component requiring isolation and removal. This is illustrated in

Table 6-2 which considers a reported wall loss of 2.1mm ± 1.0mm for two different pipe schedules. For the thin wall pipe (Sch 20) the maximum estimated wall loss is likely to be unacceptable (49%WT) but of less concern (17% WT) for the thicker walled pipe (Sch 120).

If there is not sufficient confidence in the NDT, then alternative action should be considered. This might include removing the end cap, close visual inspection, blasting and local wall thickness or wall loss (pit depth) measurements, or removal of the trunnion altogether. Any blasting of live lines will require appropriate safety considerations.

The guidance given here and in Section 5 is summarised in Figure 6-4 and Figure 6-5

Table 6-2: Effect of tolerances on wall thickness measurements for two different pipe wall thicknesses

	Sch 20	Sch 120
Pipe nominal bore (inches)	8.0	8.0
Nominal wall thickness (mm)	6.4	18.3
Measured wall loss (mm)	2.1	2.1
Tolerance (mm)	1.0	1.0
Max estimated wall loss (mm)	3.1	3.1
Max estimated wall loss (%WT)	49%	17%

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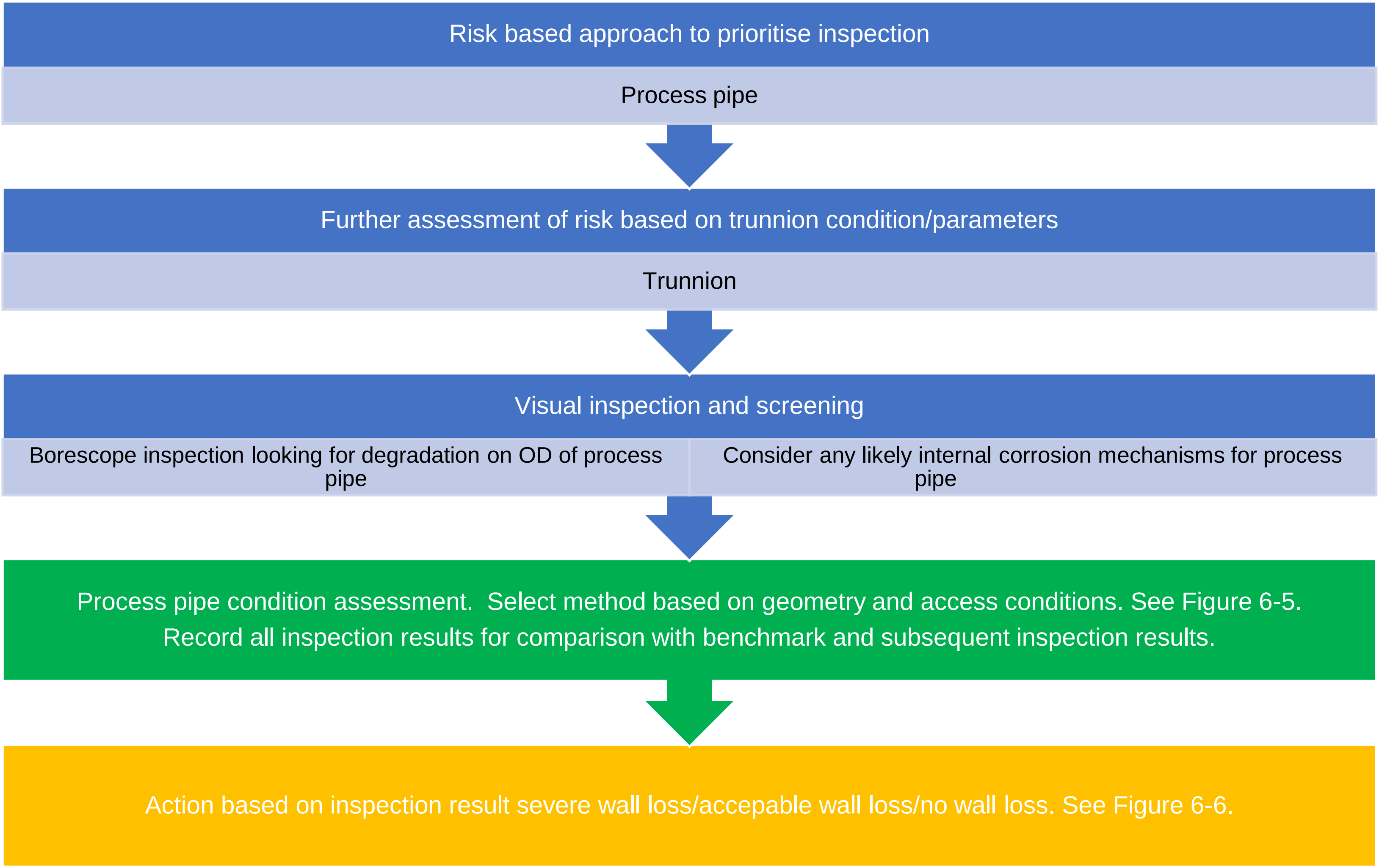

Figure 6-4: Trunnion management flowchart

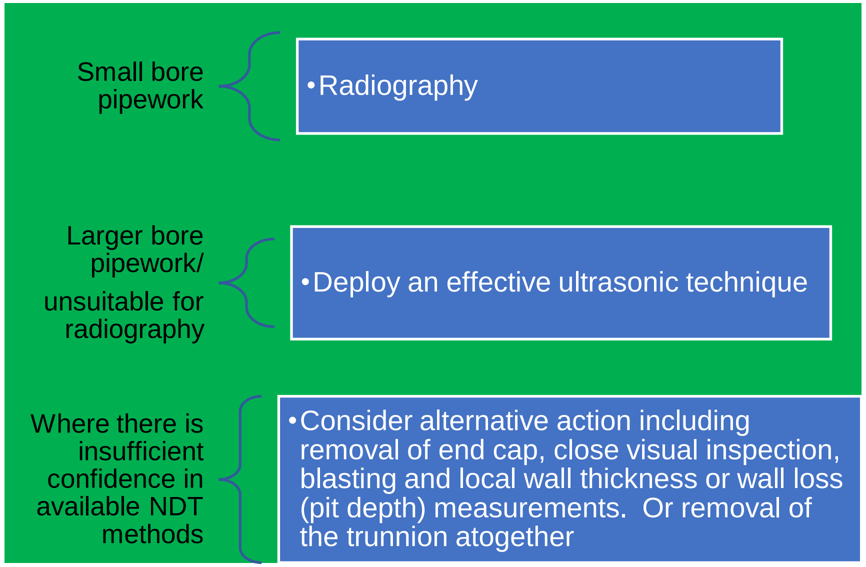

Figure 6-5: Inspection method selection

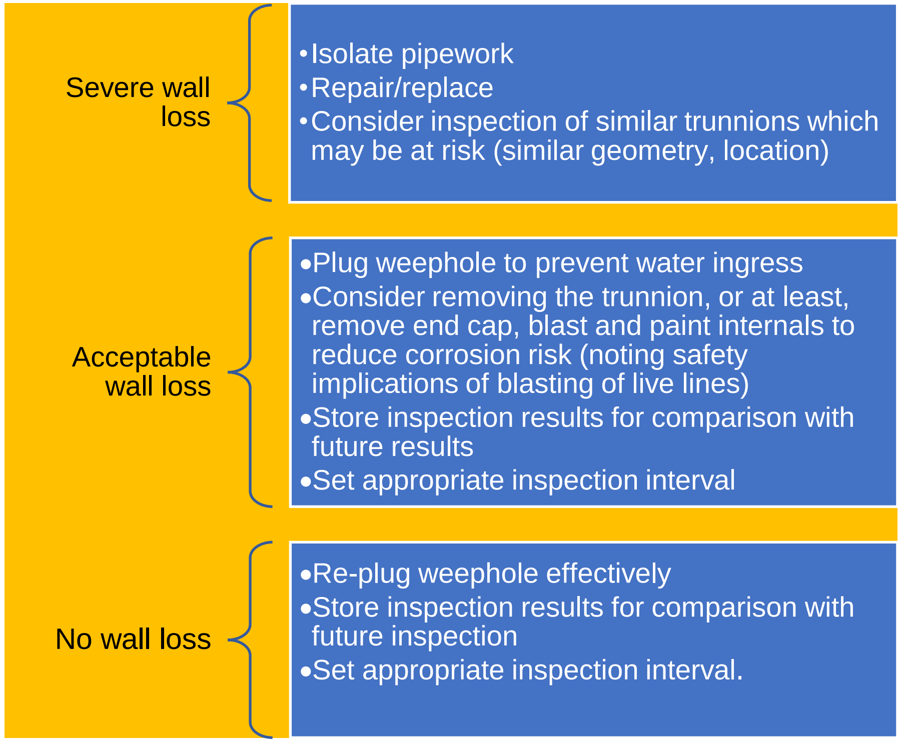

Figure 6-6: Post inspection action

6.5 Post inspection action

All inspection results should be compared against baseline measurements or previous inspection results to look for changes in condition.

The action required following an inspection depends on the inspection results, as shown in Figure 6-6, and summarised here:

Where severe wall loss is suspected:
- Isolate the pipework
- Replace/repair.

Where the remaining wall thickness is assessed to be acceptable:
Either:
- Fill the trunnion weephole with grease/effectively plug it to prevent water ingress[1] (see Section 8)
- Store inspection results for comparison with future results
- Set appropriate future inspection interval.

Or:
- Consider removing the trunnion, or at least, remove end cap (considering the possible role of the end cap in load bearing)
- Blast (note safety implications of blasting of live lines – consider isolation of components) and paint internals to reduce corrosion risk
- Set appropriate future inspection interval.

Where there is no significant wall loss:
- Re-plug the weephole.
- Store inspection results for comparison with future inspections.
- Set appropriate future inspection interval.

7 Trunnion corrosion case studies

7.1 Background

This section describes seven case studies of trunnion corrosion/inspection provided by HOIS members to illustrate some of the key issues.

Each case study begins with a description of the trunnion in as much detail as possible using the available information provided by the HOIS member. Key learning points particular to each case study have been highlighted. These might include emphasis on the importance of complete and detailed asset registers, or the challenging corrosion morphology which makes determination of MRWT using NDT methods difficult.

The case studies demonstrate the value of the approach described in this document which aims to develop a process for trunnion management which, firstly, reduces the likelihood of corrosion initiation. As a result, the trunnion inspection requirement then, most often, becomes a

[1] As far as is reasonably practicable, it should be ensured that trunnion internals are clean and, in particular, dry prior to having the weepholes sealed and plugged.

demonstration of the absence of corrosion, using simple screening methods, rather than the use of advanced NDT (and an appropriate tolerance applied to reported results) to determine the MRWT.

The guidance provided in Sections 5 and 6 has been applied retrospectively to each case study. Note that, in most cases, only limited information about the trunnion has been provided and so the risk, in the example, is "unknown". In practice, duty holders will have access to all of the necessary information to perform a complete risk ranking process using their own categorisation. The tables provided in this section are for demonstration only, they are not intended to provide recommendations of specific risk levels assigned to individual process pipe or trunnion parameters under the conditions in the case studies.

Duty holders would be expected to assess and assign risk categories for process pipes and trunnions using the risk assessment procedures in their own integrity management system.

7.2 Case study 1: Gas leak from 6" carbon steel trunnion

7.2.1 Trunnion detail

A gas sensor on site detected gas during normal operation. The system was shut down and depressurised to allow investigation into the hydrocarbon release. This identified that the gas leak was emanating from a carbon steel trunnion, shown in Figure 7-1. The spool was removed from service and onshore inspection subsequently confirmed the leak to be due to external pinhole corrosion on the pipework within the trunnion.

Figure 7-1: Leaking spool *in situ*.

The trunnion was sectioned and this revealed generalised corrosion of the internal trunnion wall and pitting was found on the external wall of the hydrocarbon pipework which led to a through wall perforation, shown in the images in Figure 7-2. The weephole was in an exposed location (3 o'clock, horizontal trunnion) and the trunnion showed signs of water ingress.

Figure 7-2: Trunnion sectioned to reveal internal corrosion of trunnion and pitting corrosion on process pipe. Image on the right shows trunnion/process pipe internals following blasting.

The post failure investigation highlighted issues which may have contributed: Firstly, the orientation of the vent hole was not the 6 o'clock position to reduce water ingress and the vent hole was not sealed. Secondly, the trunnion had not been identified on the asset master trunnion register which meant that it had not been included in the periodic trunnion inspection scopes for internal inspection.

This case study highlights the degradation mechanism of pin hole (localised) corrosion within generalised corrosion, also the importance of both weephole location/sealant and complete asset registers – the trunnion had not been inspected because it was not identified and included in the periodic trunnion inspection scope.

7.2.2 HOIS guidance applied to case study 1

Risk ranking:
The risk ranking process would be performed initially using parameters associated with process pipe and subsequently on the trunnion itself:

Table 7-1: HOIS guidance applied to case study 1

Case Study 1		Assessed contribution to risk				Comments
		High	**Medium**	**Low**	**Unknown**	
Process pipe	Operating temperature				x	
	Operating pressure				x	
	Location: marine?	x				Offshore
	Location: Likely water sources		x			
	Pipe contents	x				
	Internal corrosion mechanisms active				x	
	Age				x	
	Inspection history	x				No inspection history or baseline
	Corrosion allowance				x	
	Wall thickness			x		WT
Trunnion	Trunnion orientation		x			
	Weephole orientation	x				
	Weephole plugging	x				
	Absence of weephole					N/A
	Trunnion design and inspection history				x	

There are several higher risk factors: process pipe is in a marine environment, contains hydrocarbons, has an unplugged weephole in 3 o'clock position on a horizontal trunnion. This trunnion would therefore be a high priority for inspection.

Inspection:

The guidance for inspection would depend on when in the life-cycle of this component the guidance is being applied: If with severe damage, e.g. just prior to a leak, a borescope inspection through the weephole would have highlighted the presence of a significant volume of corrosion product. This could have been followed up with radiography (access and safety restrictions allowing) to further assess the condition of the process pipe within the trunnion.

However, if this component had been part of an accurate asset register and the risks addressed accordingly, it is likely that a scheduled inspection would have:

(i) highlighted the presence of corrosion at an early stage where remedial action would be possible, or
(ii) potentially addressed the lack of an effective plug in the weephole to prevent moisture ingress leading to corrosion of the process pipe. The condition of the weephole could then be easily monitored visually, and screening tools used to verify the absence of corrosion rather than advanced inspection methods to estimate MRWT.

7.3 Case study 2: Corrosion morphology – generalised corrosion with deeper isolated pits.

7.3.1 Trunnion detail

This case study material is taken from a (redacted) inspection findings follow-up report provided by a HOIS member; no information was provided on how the corrosion was initially identified. The report indicated that a trunnion was removed to allow inspection of the process pipework which had been concealed by the footprint of the trunnion. The process pipework was a 24" NB carbon steel pipe with a 9.53mm nominal wall thickness and had been in-service for an estimated 39 years.

Pit depths were measured using a depth gauge.

Figure 7-3: Trunnion footprint area (most of trunnion pipe removed). Pre-blast cleaning.

Figure 7-4: Trunnion footprint pre-blast cleaning. Pitting found under corrosion material.

The corroded area shown in Figure 7-3 and Figure 7-4 was blasted, which revealed generalised corrosion with isolated deeper pits, as shown in Figure 7-5 and in greater detail in Figure 7-6. Several pits were located close to the remaining trunnion wall which prevented depth measurements.

Numerous supplementary isolated pitting over the whole of the footprint area was noted, with depths measuring ≤2.5mm.

Figure 7-5: Trunnion footprint after blast cleaning (pit depth measurements in red).

Figure 7-6: Isolated pits: Left: 7mm, Centre: 3mm deep 5x5mm, Right: 4mm deep 8x6mm

The remaining trunnion wall was then removed and ground back to sound material shown in Figure 7-7. Additional UT wall thickness measurements could then be taken from sound material directly adjacent to the deepest pitted areas using a 5mm button probe. Four measurements were taken along the side of the pit: 8.52mm, 8.45mm, 8.48mm and 8.49mm.

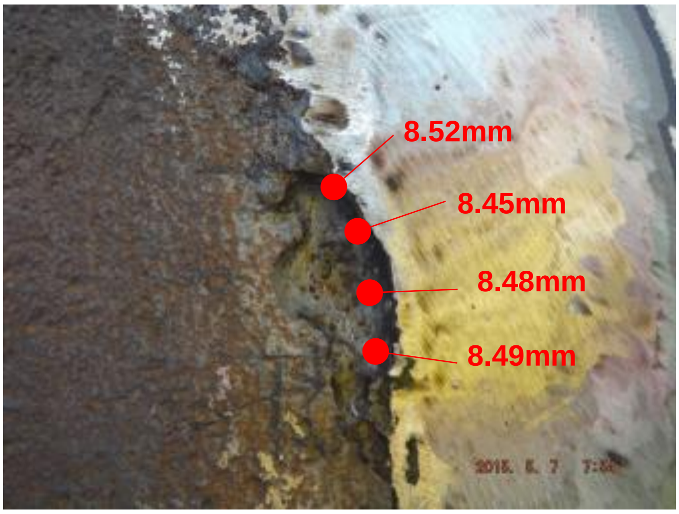

Figure 7-7: Four UT wall thickness spot readings adjacent to pitted area

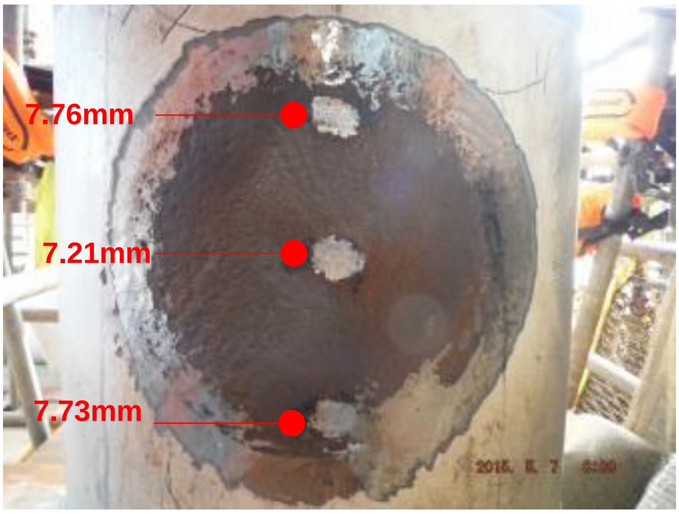

Figure 7-8: Three UT wall thickness spot readings from footprint area

Three areas from the centre of the trunnion footprint area (Figure 7-8) were also ground flush to allow UT wall thickness measurements. These were: top: 7.76mm, middle: 7.21mm and bottom: 7.73mm.

The depth of the deepest pit was remeasured using a straight edge and digital depth gauge: 6.76mm, which resulted in a minimum remaining wall thickness of 1.69mm compared to the local sound wall thickness measurements. This met the minimum requirements for hoop stress as per ASME B31.3 (1.7 > 1.1mm), the maximum pressure of the system was known to be 5barg.

A replacement horizontal trunnion was relocated to another area (to reduce external stresses) and a plate was welded over this trunnion footprint area which fully encompassed the defect area arresting future corrosion by sealing it. The plate was not designed for pressure retention but as a sealant and to protect against external impact damage. The line was due to become a process deadleg within 6 months which would reduce the maximum operating pressure and therefore the minimum allowable wall thickness.

This case study highlights the challenge of the corrosion morphology – detecting isolated pits within general corrosion close to the trunnion wall/weld.

7.3.2 HOIS guidance applied to case study 2

Risk ranking:
The risk ranking process would be performed initially using parameters associated with process pipe and subsequently on trunnion itself:

Table 7-2: HOIS guidance for risk ranking applied to case study 3

Case Study 2		Assessed contribution to risk				Comments
		High	Medium	Low	Unknown	
Process pipe	Operating temperature			x		-10C
	Operating pressure			x		Back pressure
	Location: marine?				x	
	Location: Likely water sources				x	
	Pipe contents			x		Vent system
	Internal corrosion mechanisms active				x	
	Age	x				468 months
	Inspection history	x				No inspection history or baseline
	Corrosion allowance	x				1mm
	Wall thickness		x			9.53mm
Trunnion	Trunnion orientation		x			
	Weephole orientation				x	
	Weephole plugging				x	
	Absence of weephole				x	
	Trunnion design and inspection history				x	

The information on this case study would suggest several higher risk factors: age, lack of inspection history, small corrosion allowance.

Inspection:
A borescope inspection through the weephole would have highlighted the presence of a significant volume of corrosion product which would require follow up, as described in the case study detail.

If this component had been part of an accurate asset register and the risks addressed accordingly, it is likely that a scheduled inspection would have either highlighted the presence of corrosion at an early stage where remedial action would be possible. Or earlier identification would have resulted in action to address the lack of an effective plug in the weephole to prevent moisture ingress leading to corrosion of the process pipe. The condition of the weephole could then be monitored visually, and screening tools used to verify the absence of corrosion rather than advanced inspection methods to estimate MRWT.

7.4 Case study 3: Corrosion morphology – generalised corrosion with deeper isolated pits.

7.4.1 Trunnion detail

As with case study 2, this case study is taken from a redacted inspection findings follow-up report. No information was provided on how these trunnions were originally assessed. The two vertical trunnions of concern are on 3" carbon steel piping with a nominal wall thickness of 11.1mm (Sch.

160) which had been in service for ~ 20 years. Note the challenging access requirements in Figure 7-9.

Figure 7-9: Side view of vertical trunnion supports.

The trunnion endcaps were removed, and external delaminating corrosion was located on the external and internal surfaces of the trunnion pipe supports. The depth of the scale on the inside of both trunnions was estimated to be between 5 and 6mm. The scale was removed, and UT spot readings were performed where possible. Blasting revealed pitting corrosion over the whole trunnion footprints with more severe pits, as shown in Figure 7-10 and Figure 7-11.

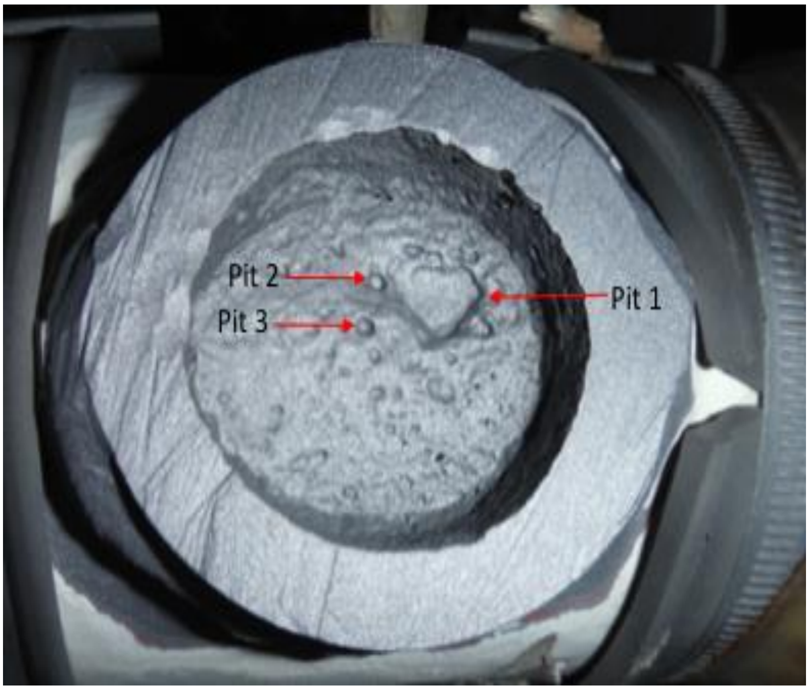

Figure 7-10: Trunnion A post blasting: Pitting of between 0.5mm and 1.0mm over whole footprint with 3 more severe pits.

The UT readings on Trunnion A gave a minimum remaining sound wall thickness of 8.40mm (no information provided on where or how this was measured).

The operator's performance standard used in the report provided by the HOIS member specifically calculated the minimum allowable remaining wall thickness as:

$$Minimum\ allowable\ WT = \frac{2}{3}(Nominal\ WT - Corrosion\ allowance)$$

Note that this is an operator specific definition of a performance standard and should not be seen as generally applicable.

For this particular process pipe the calculation results in a minimum allowable remaining wall thickness of 5.42mm, this from ((11.1 – 3.00) x 0.67) = 5.42mm.

The measured pit depths were subtracted from the minimum remaining sound wall thickness to calculate the minimum remaining wall thickness below each pit to assess whether the performance standard could be met:

Pit 1: 4.0mm deep, 7 x 10mm. Minimum remaining wall thickness = 8.4 – 4 = 4.4mm.
Fails performance standard.

Pit 2: 1.6mm deep, 2mm Ø. Minimum remaining wall thickness = 8.4 -1.6 = 6.8mm.
Meets performance standard.

Pit 3: 1.6mm deep, 2mm Ø. Minimum remaining wall thickness = 8.4 -1.6 = 6.8mm.
Meets performance standard.

The spool was changed out because of the 4.0mm deep pit not meeting the operator's company performance standard.

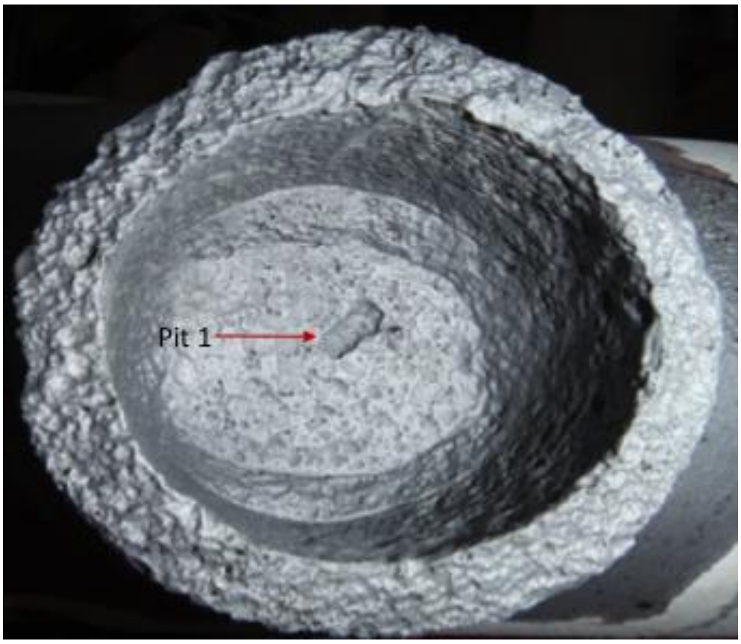

Figure 7-11: Trunnion B post blasting: Pitting of between 0.5mm and 1.0mm over whole footprint with 1 more severe pit.

The UT readings on Trunnion B measured a minimum remaining sound wall thickness of 8.5mm (again, no information was provided on where or how this was measured). The operator's performance standard allows the minimum remaining wall thickness to be 5.42mm, this from (nominal wall thickness – corrosion allowance) x 0.67; (11.1 – 3.00) x 0.67 = 5.42mm.

Pit 1: 2.5mm deep, 9 x 3.5mm. Minimum remaining wall thickness = 8.4 – 2.5 = 5.9mm.
Meets performance standard.

Although the spool met the performance standard, it was still replaced. This was due to the uncertainly of the UT measurements of wall thickness, a result of the surface condition and difficulty accessing the area inside the trunnion.

The pipework under the supports was blasted and coated to full specification to arrest further corrosion whilst awaiting replacement. The replacement spools did not have lower trunnions attached as these were identified as being at an elevated risk of corrosion under insulation.

This case study highlights the complex pitting corrosion morphology and potential challenging access requirements. The case study also demonstrates that corrosion of the process pipe is still a risk on bottom of line vertical trunnions.

7.4.2 HOIS guidance applied to case study 3

Risk ranking:
The risk ranking process would be performed initially using parameters associated with process pipe and subsequently on trunnion itself:

Table 7-3: HOIS guidance applied to case study 3

Case Study 3		Assessed contribution to risk				Comments
		High	Medium	Low	Unknown	
Process pipe	Operating temperature			x		10C
	Operating pressure		x			14.7barg
	Location: marine?	x				Marine
	Location: Likely water sources				x	
	Pipe contents	x				Produced liquids
	Internal corrosion mechanisms active				x	
	Age	x				240months
	Inspection history				x	
	Corrosion allowance		x			3.0mm
	Wall thickness		x			11.1mm (Sch 160)
Trunnion	Trunnion orientation			x		Vertical, bottom of line.
	Weephole orientation				x	
	Weephole plugging				x	
	Absence of weephole				x	
	Trunnion design and inspection history				x	

The information on this case study would suggest several higher risk factors: marine environment, age and the fact that the process pipe contains hydrocarbons.

Inspection:
A general visual inspection of the trunnion and surrounding pipework shows evidence of external corrosion.

A borescope inspection through the weephole would have highlighted the presence of a significant volume of corrosion product which would require follow up.

If this component had been part of an accurate asset register and the risks addressed accordingly, it is likely that a scheduled inspection would have either highlighted the presence of corrosion at an early stage where remedial action would be possible. Alternatively, action would likely have addressed the lack of an effective plug in the weephole to prevent moisture ingress leading to corrosion of the process pipe. The condition of the weephole could then be easily monitored visually and screening tools used to verify the absence of corrosion rather than advanced inspection methods to estimate MRWT.

7.5 Case study 4: Vertical carbon steel trunnion with evidence of corrosion

7.5.1 Trunnion detail

The trunnion in Figure 7-12 was on an offshore asset and identified for investigation because there was evidence of external corrosion to the receiving pipework, trunnion body and end plate. The pipework was isolated, and the trunnion inspected using a borescope. Some example images are shown in Figure 7-13 and Figure 7-14 which were of concern because of the presence of a watery fluid at the base of the trunnion and a black sticky fluid which had some characteristics of crude. The fluid was subsequently sampled and analysed by an offshore chemist who ruled out the presence of hydrocarbons and identified iron sulphide and iron oxide corrosion product as a result of the stagnant water inside the trunnion (thought to be deluge water).

The trunnion was then removed (cold cut) to further assess the condition of the process pipe. Light surface corrosion was identified with no excessive pits as shown in Figure 7-15. The area was cleaned, and wall thickness measurements taken using a button probe and found to be within nominal. A new clamp type support was fitted Figure 7-16.

Figure 7-12: Vertical trunnion on process fluid containing 10” Sch 40 line.

Figure 7-13: Borescope image looking up at process pipe.

Figure 7-14: Borescope image looking down to end plate.

Figure 7-15: Area within trunnion exposed.

Figure 7-16: Clamped shoe arrangement.

This case study highlights that the external condition of the trunnion does not necessarily correlate with the condition of the process pipe within the trunnion. So, it follows that wall loss of a process pipe cannot generally be inferred from wall thickness measurements on the trunnion.

7.5.2 HOIS guidance applied to case study 4

Risk ranking:
The risk ranking process would be performed initially using parameters associated with process pipe and subsequently on trunnion itself:

Table 7-4: HOIS guidance for risk ranking applied to case study 4

Case Study 4		Assessed contribution to risk				Comments
		High	**Medium**	**Low**	**Unknown**	
Process pipe	Operating temperature				x	
	Operating pressure				x	
	Location: marine?	x				Offshore
	Location: Likely water sources	x				Regular deluging
	Pipe contents	x				Crude
	Internal corrosion mechanisms active				x	
	Age				x	
	Inspection history				x	
	Corrosion allowance				x	
	Wall thickness				x	
Trunnion	Trunnion orientation		x			
	Weephole orientation				x	
	Weephole plugging				x	
	Absence of weephole				x	
	Trunnion design and inspection history					

The information on this case study would suggest several higher risk factors: marine environment, process pipe contents and the fact that regular deluging is a likely source of water.

Inspection:
Applying the guidance in Figure 6-4, Figure 6-5 and Figure 6-6 would be consistent with the action taken:

- Initial visual inspection
- Borescopic inspection
- Potential follow-up with advanced NDT.

The inspection results would indicate either no or an acceptable level of wall loss. In this case study the trunnion was removed and replaced with a different type of pipe support with a different inspection challenge.

7.6 Case study 5: Horizontal trunnion on support steelwork

7.6.1 Trunnion detail

This case study material is taken from the Health and Safety Executive Safety Notice HID1-2013 [3] which was produced to describe the danger of undetected corrosion in trunnion supports of pipework containing hazardous substances.

A release of liquefied petroleum gas (LPG) occurred on a UK refinery leading to a controlled shutdown and isolation of the associated vessel and pipework. The subsequent investigation identified that corrosion had occurred within the trunnion support with a gradual loss of wall thickness on the LPG pipe.

The trunnion had an endcap forming a closed end, the weephole was sited directly on support steelwork which gradually drew in moisture which then condensed on the pipe wall. This led to accelerated localised corrosion of the pipe. As this corrosion mechanism was not anticipated, it remained undetected until the pipe wall was eventually ruptured under internal pressure.

The company conducted further investigations on site and have found other instances of the same corrosion. This has led to immediate replacement in some cases. In total, almost 5% of the site population of trunnions had to have some remedial work. An example radiograph is shown in Figure 7-17.

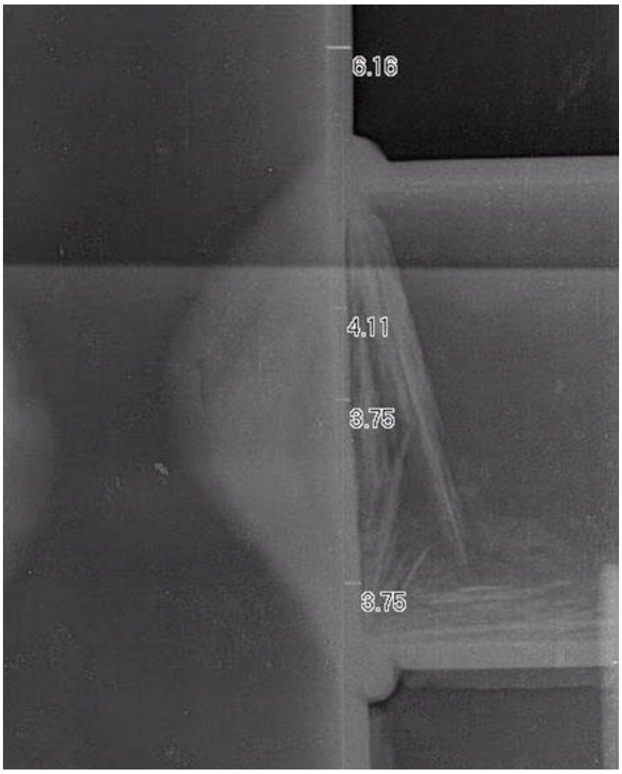

Figure 7-17: Radiography of corroded pipework at trunnion showing wall loss and corrosion product in trunnion.

This case study highlights that an unexpected corrosion mechanism led to failure, emphasising the need for regular inspection to identify corrosion. This failure led to the inspection of other components with similar geometry which resulted in remedial action preventing further failures.

7.6.2 HOIS guidance applied to case study 5

Risk ranking:
The risk ranking process would be performed initially using parameters associated with process pipe and subsequently on trunnion itself:

Table 7-5: HOIS guidance for risk ranking applied to case study 5

Case Study 5		Assessed contribution to risk				Comments
		High	Medium	Low	Unknown	
Process pipe	Operating temperature				x	
	Operating pressure				x	
	Location: marine?			x		
	Location: Likely water sources				x	
	Pipe contents	x				
	Internal corrosion mechanisms active				x	
	Age				x	
	Inspection history					
	Corrosion allowance				x	
	Wall thickness	x				6mm
Trunnion	Trunnion orientation		x			
	Weephole orientation					N/a
	Weephole plugging					Not visible
	Absence of weephole	x				On support steelwork
	Trunnion design and inspection history					

The information on this case study would suggest several higher risk factors: contains hydrocarbons, low wall thickness and weephole not identifiable.

Inspection:

This trunnion would have been categorised as a high priority for inspection due to the apparent absence of a weephole. As such, a borescope inspection would not have been possible nor advisable and radiography would be used to inspect and monitor this trunnion. This would likely have identified wall thinning and highlighted the presence of corrosion product within the trunnion at an earlier stage, prior to a leak, when remedial work would be possible. It would also have hinted at the presence of a concealed weephole for which further work would have been required to reveal. The results of an inspection identifying corrosion would need to be flagged for the risk ranking of other trunnions of a similar geometry.

7.7 Case study 6: Cracking on duplex material

7.7.1 Trunnion detail

Although this guidance document focusses on carbon steel components, this case study, provided by a HOIS member, has been included for awareness. This case study includes details of two examples of chloride stress corrosion cracking failures on duplex stainless-steel trunnion supports leading to hydrocarbon release. One crack initiated from the inside of the trunnion and propagated outwards, the other initiated on the external surface of the trunnion. The former had an unsealed weephole in an unfavourable position which allowed water ingress (horizontal trunnion with weep hole at the 12 o'clock position).

These failures led to platform shutdown, although no injury to personnel. The estimated production losses were 1.4million barrels of oil equivalent.

Figure 7-18: Left: Trunnion and process pipe with flow direction and location of crack indicated. Right: crack.

Figure 7-18 is an example of a crack which has developed on an in-service duplex trunnion.

This case study highlights cracking as a potential failure mechanism in duplex stainless-steel pipework and, again, the key importance of weephole orientation and sealing in assessing the risk. This is information which can only be reliably gathered and maintained by site survey and accurate, up-to-date asset registers.

7.8 Case Study 7: Failure at a vertical trunnion

7.8.1 Trunnion detail

This case study relates to a release of oil which occurred from an oil export line at a carbon steel trunnion pipe support. The line within the trunnion had suffered general wall thinning to the point where it had perforated.

Following an earlier trunnion failure some three years prior, a comprehensive desktop exercise had been carried out to register all trunnions for the purposes of risk ranking, prioritising and inspecting.

The second failure prompted an investigation which revealed that the failed trunnion (in this case), had been missed from the register (together with a number of others), as modifications to the plant had not been reflected in drawing updates. As such, it had never been inspected.

There were three other identical vertical trunnions on the same line which had been inspected three years before using (film) radiography. Interpretation of the radiographs and the vertical orientation of the trunnion led to their risk ranking being lowered.

Following the second failure, the three identical trunnions were inspected initially using a borescope. This reported only superficial surface corrosion on the trunnion bores and process pipe walls. It was later understood that the borescope inspections had only been directed upwards at the process pipe and as a consequence, had failed to observed the large amounts of corrosion product that had fallen and collected at the bottom of the vertical trunnion, as shown following removal of the process pipe and trunnion in Figure 7-19.

Figure 7-19: Left: Corrosion scale leading to a perforation (circled) with relatively superficial appearance. Right: Heavy corrosion scale collected at bottom of vertical trunnion

After the borescopic inspection, radiographs were taken again. This time using digital radiography rather than film as per original inspections. The significantly improved radiographs, shown in Figure 7-20, clearly showed significant wall thinning and greater scale build up, causing the three related trunnions to have Fitness for Service assessments carried out for the interim period to change out.

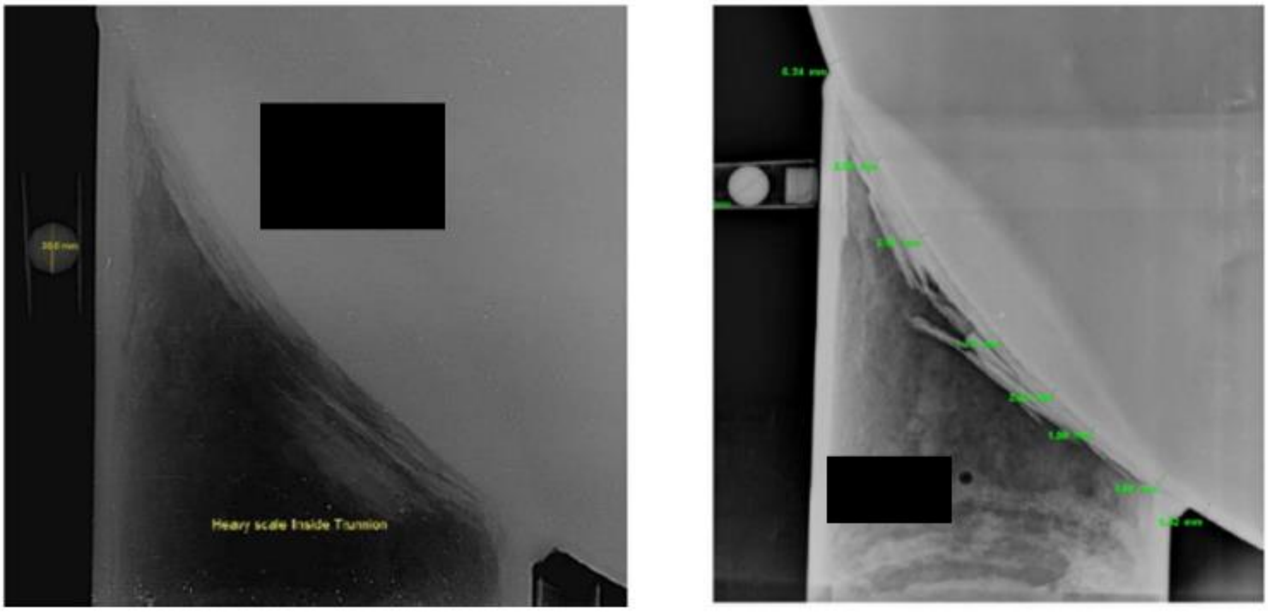

Figure 7-20: Left: Initial radiography. Right: Second radiograph three years later using larger source and digital capture, providing significantly more detail.

This case study highlights several issues:

- **Corrosion of process pipes within vertical trunnions can and does occur. Caution should be used when de-prioritising vertical trunnions for inspection based on their orientation.**
- **Asset registers should be accurately maintained, walking of lines may be necessary to create accurate registers, where none exist.**
- **Where borescope inspection is performed, the whole of the inside of the trunnion should be visually assessed for scale which may have spalled.**

7.8.2 HOIS guidance applied to case study 7

Risk ranking:
The risk ranking process would be performed initially using parameters associated with process pipe and subsequently on trunnion itself:

Table 7-6: HOIS guidance for risk ranking applied to case study 7

Case Study 7		Assessed contribution to risk				Comments
		High	Medium	Low	Unknown	
Process pipe	Operating temperature				x	
	Operating pressure				x	
	Location: marine?	x				
	Location: Likely water sources				x	
	Pipe contents	x				
	Internal corrosion mechanisms active				x	
	Age				x	
	Inspection history	x				No inspection history
	Corrosion allowance				x	
	Wall thickness	x				6mm
Trunnion	Trunnion orientation		x			
	Weephole orientation				x	
	Weephole plugging				x	
	Absence of weephole				x	
	Trunnion design and inspection history				x	

The information on this case study would suggest several higher risk factors: marine environment, contains hydrocarbons, low wall thickness, no inspection history.

Inspection:
A thorough borescope inspection through the weephole would have highlighted the presence of a significant volume of corrosion product on the surface of the process pipe and material which had spalled off. This would be flagged as requiring follow up using radiography. The results of this inspection would need to modify the risk ranking of other trunnions of a similar geometry.

This case study emphasises the importance of assembling an accurate asset register of trunnions (with line walking), together with a comprehensive, initial inspection programme to establish a baseline understanding from which an effective and ongoing inspection scheme can begin.

8 Trunnion design to mitigate risk

The good practice approach to the management of trunnions should begin at the design stage where possible.

Firstly, is a trunnion support the most appropriate solution? Could alternative supporting arrangements avoid the need for inspections using specialist equipment at a later date?

Consideration should be given to reducing the likelihood of moisture ingress into the trunnion (and therefore corrosion) and also to make access for inspection possible.

Factors to be considered include:

Weephole orientation. Ideally 6 o'clock on horizontal trunnions, to limit moisture ingress. Note the HSE safety alert where although the weephole was at 6 o'clock, it was sited directly on support steelwork and, as a result, the void within the trunnion gradually drew in moisture which then condensed on the pipe wall. This in turn led to accelerated localised corrosion of the pipe. As this corrosion mechanism was not anticipated, it remained undetected until the pipe wall ruptured under internal pressure [3].

Weephole plugging. The weephole is designed to vent hot gases during the welding process. It should immediately be plugged, and the location of the weephole recorded so that the condition of the plug monitored – some degrade over time. Consider a programme of weephole plug inspection and maintenance – a simple early intervention of an effectively plugged weephole leads to simpler inspection using screening methods to confirm the absence of corrosion. This would avoid the need to apply advanced NDT methods to try to quantify MRWT and then decide on an appropriate tolerance on the result.

More permanent solutions to weephole plugging, beyond grease or epoxy, such as screwed plugs or plate cover are not recommended. This is because, in the event of a process pipe breach, the trunnion itself could then become pressure retaining (for which it is not designed) and lead to an uncontrolled failure. Furthermore, grease or epoxy plugs can be quickly removed to allow for borescope inspection.

Trunnion access. Design should permit access around the process pipe in the areas of the trunnion to facilitate in-service inspection.

Coating/corrosion prevention. Coating the inside of the trunnion, including the process pipe external surface, during manufacture (such as before the welding of end plate) may prevent or substantially delay corrosion, as long as the coating remains undamaged and intact throughout the installation process. The use of suitably qualified corrosion inhibitor products inside the trunnion might also be considered.

Open ended trunnions would allow for easy inspection and prevent accumulation of water, where structural strength allows elimination of end plates. This can be addressed at the design stage.

Weld specification. Managing the trunnion to pipe weld root by specifying a full penetration joint, should result in a more obtuse, smoother profile, thereby reducing the likely occurrence of crevice effects and associated corrosion.

9 Acknowledgements

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This HOIS project has greatly benefitted from expert guidance of the Project Champions: Chris Scales (HSE) and Sieger Terpstra & Victor Vertregt (Shell). Billy Mackay (Total E&P UK Ltd) and Chris Scales (HSE), in particular, are thanked for their helpful comments on early drafts of the guidance document.

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Appendices

Appendix 1 Trunnion inspection methods

Inspection methods are arranged alphabetically.

A1.1 Guided wave testing

A1.1.1 Description of method

Guided wave testing provides a long-range inspection technique for inspection of pipes up to ranges of about 100m in a pulse echo configuration and, as such, is widely used for standard support inspection but can also be applied for trunnion inspection. Data from several trunnions with a similar configuration can help to identify changes that result from isolated material losses rather than signals from the pipe to trunnion weld.

A ring of guided wave sensors is used to generate guided waves in a pipe. Reflections are generated at locations where there is a change of stiffness (for example, at contact supports) or a change of cross-sectional area (for example at girth welds or corrosion patches) along the pipe length. The reflections are directed back towards the sensors, used in receiving mode to detect the echo return, as illustrated in Figure A 1-1 Schematic of a long range guided wave system (courtesy Guided Ultrasonics Limited)

For changes in stiffness, the reflection amplitude is larger at lower frequencies. For this reason, the GWT is normally performed over a range of frequencies (‘frequency sweeping’). In particular, at higher frequencies the reflection coefficient due to the contact loading becomes negligible, or very small, and only reflections caused by the corrosion would tend to be present.

Gathering data over the correct range of frequencies improves the test sensitivity to corrosion by a significant margin; at some frequencies the reflections from the corrosion will be very small (well below the call level) and would almost certainly be missed during a routine inspection. However, the dynamic frequency sweeping capability enables the frequency to be scanned over a wide range to maximise the signals from the corrosion while minimising the amplitude of any signals from the supports.

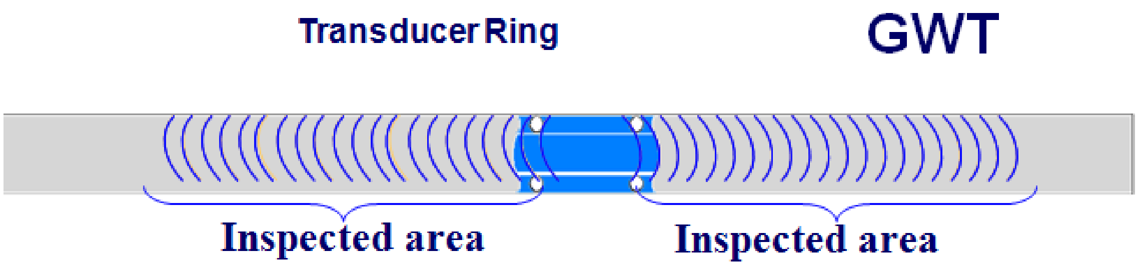

Figure A 1-1 Schematic of a long range guided wave system (courtesy Guided Ultrasonics Limited)

Many different propagation modes are possible for guided waves in pipes, mainly torsional and longitudinal. The guided-wave mode and operating frequency are usually chosen where the guided-wave is non-dispersive or the dispersion effects on the wave packet are minimal. The fundamental torsional mode T(0,1) is dispersion-free, and its properties are independent of pipe diameter and wall thickness. For this reason, it is used for some guided wave inspections. The longitudinal mode L(0,2) is also effectively dispersion-free over a wide range of frequencies and is also used in some instruments.

The arrival time of the echo gives a measure of the axial distance of the reflector from the sensors. The amplitude gives information on the defect severity. The technique is sensitive to reductions in the overall cross-sectional area of the pipe wall and sensitivity is usually quoted as a percentage of this cross-sectional area and may be typically 5% in ideal circumstances. With the latest generations of the technology smaller changes to pipe wall cross section can be found, particularly if repeat tests are carried out from the same position on the pipe and data is compared so as to monitor for changes caused by the pipe condition degrading.

Focussing using data processing methods allows the circumferential distribution of guided wave energy to be determined at any axial support location within the test range. This allows location of both the axial and circumferential (clock) location of touch point corrosion. This can improve the accuracy of corrosion characteristics (change in cross section and approximate circumferential extent) leading to classification of corrosion into groups with the most severe being an estimate of wall loss > 60%.

GWT is most applicable to long, straight pipe runs or above ground pipelines. The presence of elbows, tees and other geometric features limits its applicability and the ability of the technique to provide information over substantial distances from the sensor ring. Guided waves cannot propagate through flanges which may also limit its effective range in some piping systems.

A1.1.2 HOIS trial results

There were no trial results using guided wave testing on trunnions.

A1.1.3 Summary

Table A 1-1: Summary of guided wave testing

Technique:	Guided wave testing method
Basis:	A sensor ring is used to propagate guided waves over long distances in pipes. The trunnion to pipe weld and any material loss due to corrosion reflect back guided waves to the same sensor ring.
Strengths:	• Can cover long lengths of straight pipe runs in one rapid measurement. • Application for screening several trunnions with the aim of identifying the most corroded ones for follow-up with other techniques. • Applicable to a wide range of pipe diameters and wall thicknesses. • Sensitivity to loss of cross-sectional area can be assessed from data. • Can be used for monitoring using a permanently installed sensor ring.
Weaknesses:	• Reflected signals are obtained from the trunnion to pipe weld, so it can be difficult to reliably distinguish between corroded and uncorroded trunnions, although multi-frequency examination and focussing/C-scan displays provide additional information. • Sensitive to loss of cross-sectional area, not % wall loss, so can miss circumferentially localised but deep corrosion pits, especially for larger diameter pipes. • Advantages limited to long straight pipe runs.

	• Propagation of guided waves can be substantially reduced by some forms of coating (e.g. bitumastic) and internal deposits will limit the length of pipe that can be inspected from a single measurement position. • Not applicable to complex geometries. • Guided waves do not propagate through flanges which will limit its range in piping systems. • The accuracy and reliability of the results is strongly dependent on the training and expertise of the inspector and the testing procedures used.
Overall:	Most applicable to screening of large numbers of trunnions on straight pipe runs to identify the most corroded ones for follow up with other techniques.

A1.2 Long range phased array

A1.2.1 Description of method

Phased array (PA) ultrasonic testing has been applied to trunnion inspection. An angled shear-wave PA probe is scanned circumferentially around the pipe with the ultrasound energy travelling axially. This “long range” method requires substantial (~100-200mm) standoff between the probe and the trunnion weld-cap which allows the creation of a complete wave front before hitting any defect. The beam will hit the trunnion weld at different angles, orthogonally when the probe is centrally opposite the trunnion, as shown in Figure A 1-12 and with increasing angles for circumferential positions away from the trunnion centre. Sound energy is reflected back from the weld and potentially from any corrosion of the process pipe inside the trunnion.

Depth sizing is estimated from the echo amplitude. Corrosion of greater wall loss is assumed to reflect more sound energy than shallower corrosion. Reflection amplitude is translated into relative defect depth by comparative measurements on calibration samples with the same material and wall thickness. Zero-degree wall thickness measurements of wall thickness around the trunnion weld can be used to convert this relative estimate of wall thickness loss into millimetres and also remaining wall thickness.

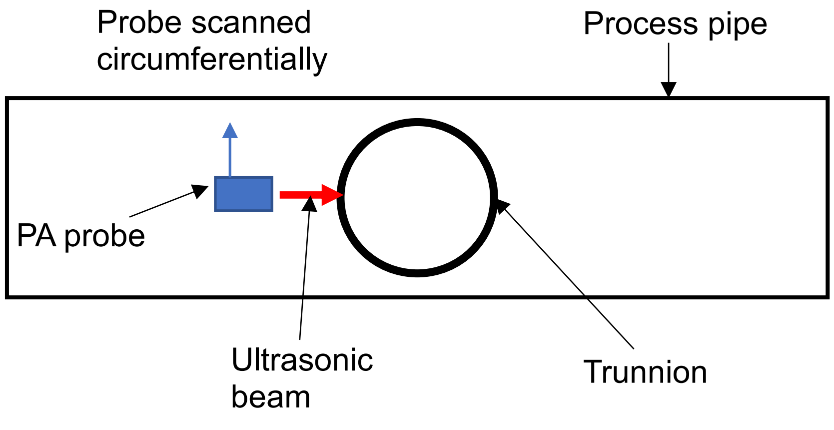

Figure A 1-2: Schematic of the long range PA method

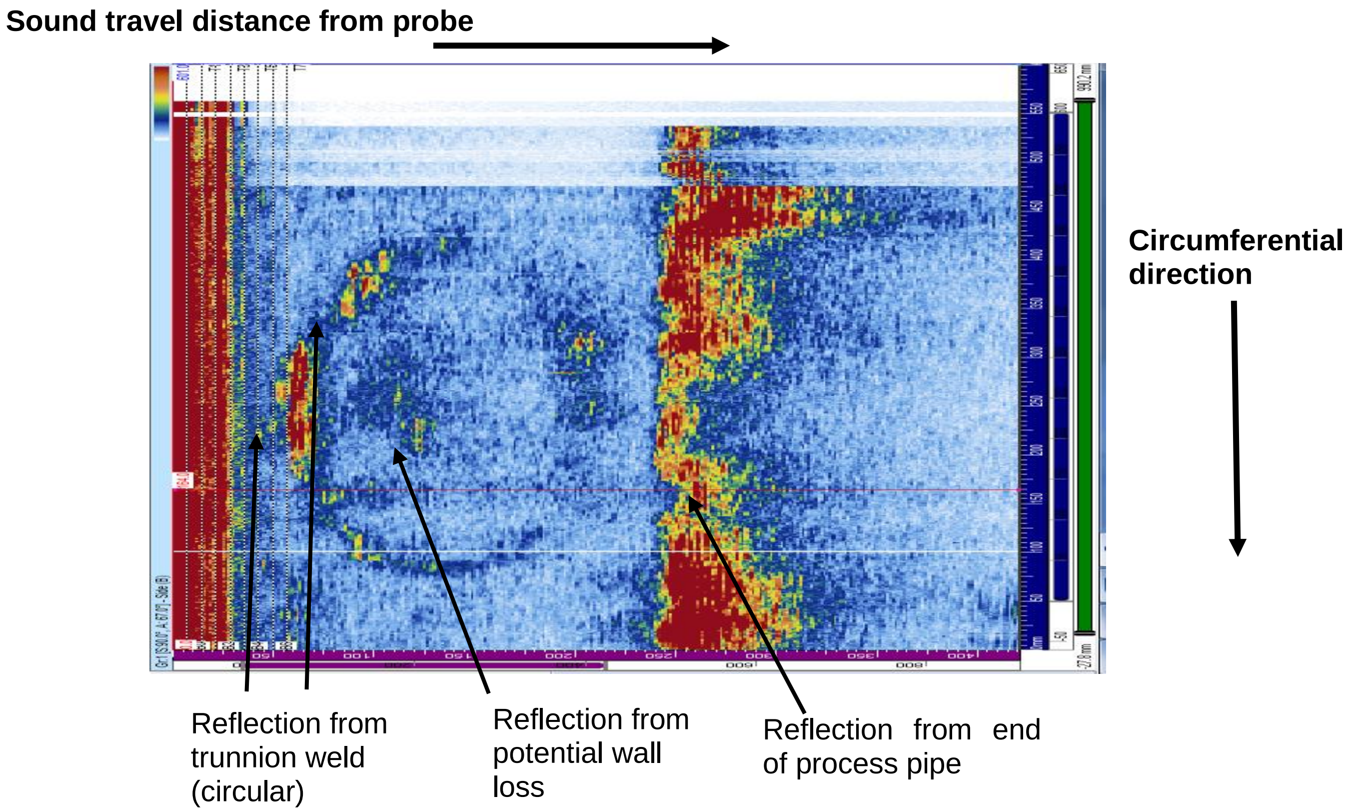

Figure A 1-3: Example results from short length of process pipe with trunnion. Scan data shows reflections from trunnion weld and potential wall loss as well as reflections from the end of the short length of process pipe.

A1.2.2 HOIS trial results

This was not included in the HOIS trial programme. However, it was trialled by one HOIS member and was not able to distinguish between superficial and deep corrosion damage.

A1.2.3 Summary

Table A 1-2: Summary of long range phased array

Technique:	Long range phased array
Basis:	An angled shear-wave PA probe is scanned circumferentially around the pipe with the ultrasound energy travelling axially. Sound energy is reflected back from the weld and potentially from any corrosion of the process pipe inside the trunnion. Depth sizing is estimated from the echo amplitude compared to comparative measurements on calibration samples with the same material and wall thickness.
Strengths:	• Applicable to a wide range of pipe diameters and wall thicknesses. • Simple to perform using readily available tools. • For repeat inspections, where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion.

Weaknesses:	• Reflected signals are obtained from the trunnion to pipe weld and so it can be difficult to reliably distinguish between corroded and uncorroded trunnions. • Will be affected by surface condition. • For elbows, it is not clear how ultrasound beam propagates in the axial direction for circumferential locations away from the extrados which may affect interpretation (and therefore reliability) of results. • Not clear how transfer losses between the process pipe and any calibration pipe sections are allowed for. • The accuracy and reliability of the results is strongly dependent on the training and expertise of the inspector and the testing procedures used (including post inspection analysis).
Overall:	Simple to perform. Inspection data can be stored; repeat inspections where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion. Limited trial and field experience.

A1.3 Medium range guided bulk wave techniques

A1.3.1 Description of method

This is a pulse-echo ultrasonic method in which a single high angle shear wave probe, on the process pipe, generates ultrasound waves in the material of the process pipe. These are thought to consist of shear (bulk) waves which experience several reflections off the ID and OD surfaces of the pipe as they propagate along (or around) the pipe. An example scan is shown in Figure A 1-4.

The probe is scanned around the pipe circumferentially with the beam pointing axially towards the trunnion. Where corrosion occurs, part of the guided wave is reflected. The amplitude of the reflected signal is considered indicative of defect depth. The external surface condition of the sample affects the sensitivity. The scans can be encoded, and the inspection data saved for analysis and repeat scans

Multiple inspection service companies offer this inspection method either as a “screening only” technique or, following analysis by a proprietary algorithm, claim a quantitative capability for assessment of wall loss beyond a detection threshold of 25% wall thickness.

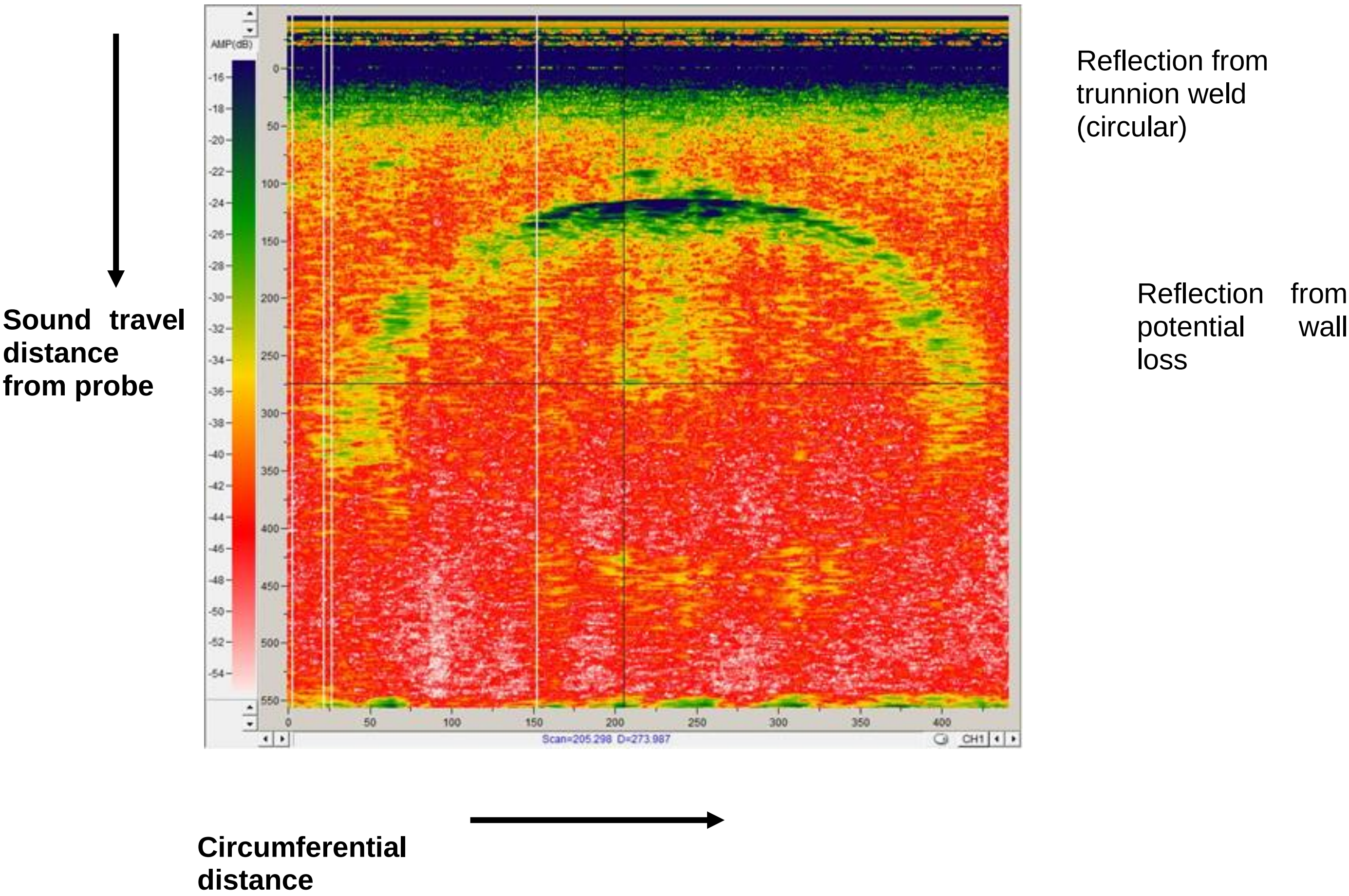

Figure A 1-4: Example inspection result of a guided bulk wave system

This method also finds applications in pipe support, tanks and vessels inspection, although has not been validated in independent HOIS trials.

A1.3.2 HOIS trial results

This approach was used in two HOIS trials performed by two different HOIS members.

One trial was for a screening only tool and reported trunnion condition in categories according to the amplitude of the reflected signal, defect depth is assumed to be proportional to signal strength; the categories were:

- No indications
- "Minor" indications present
- "Major" indications present.

The results of this trial on the manufactured straight components offered no useful information on trunnion condition because trunnions with wall loss >50% could not be distinguished from trunnions with no wall loss present.

A second HOIS member performed trials using a guided bulk wave method on both manufactured and ex-service components. A proprietary algorithm was used for post-scan analysis of results and the inspection company estimated the accuracy to be ±20% WT over a detection limit of 25%WT loss, with reduced sensitivity to gradual wall loss damage (i.e. optimised for pitting wall loss detection). Detection and sizing performance were better on the manufactured components than the ex-service components:

- The POD on the heavily corroded ex-service components was 40%. The POD of corrosion on the manufactured components was 100%.
- The mean difference between reported and benchmark minimum remaining ligament was 8% WT (underestimate of wall loss), the standard deviation was 15%WT. On the ex-service components, the mean and standard deviation were 62% and 40% WT. Note that these figures are on a small sample set (5) and the sizing differences are affected by misses of significant areas of corrosion.

The algorithm is optimised for detection of discrete areas of wall loss rather than generalised corrosion which will often produce very weak pulse-echo responses. This may explain the difference in performance on the two sample sets (for more details on the trials see Section 6.2 and the trial report [1] which is confidential to HOIS members).

For the HOIS trials, the cut ends of test pipes were reference reflectors for amplitude calibration. For in-service inspections it is not clear how any transfer losses between the test component and any calibration pipe sections are allowed for.

A1.3.3 Summary

Table A 1-3: Summary of medium range guided bulk wave technique

Technique:	Medium range guided bulk wave
Basis:	A single high angle shear wave probe on the process pipe is used to generate shear (bulk) waves which experience multiple reflections between the pipe ID and OD as they propagate axially. The probe is scanned circumferentially around the process pipe with the beam pointing axially towards the trunnion. Where corrosion occurs, part of the ultrasound energy can be reflected back to the probe. The amplitude of the reflected signal may be indicative of defect depth.
Strengths:	• Applicable to a wide range of pipe diameters and wall thicknesses. • Can be applied to elbows and straights (over 3" in diameter). • Simple to perform – single probe in pulse echo, can be scanned by hand with wheel encoder or in a frame. • For repeat inspections, where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion.
Weaknesses:	• Reflected signals are obtained from the trunnion to pipe weld and so it can be difficult to reliably distinguish between corroded and uncorroded trunnions. • Will be affected by surface condition. • For elbows, it is not clear how ultrasound beam propagates in the axial direction for circumferential locations away from the extrados which may affect interpretation (and therefore reliability) of results. • Not clear how transfer losses between the process pipe and any calibration pipe sections are allowed for.

	• The accuracy and reliability of the results is strongly dependent on the training and expertise of the inspector and the testing procedures used (including post inspection analysis).
Overall:	Simple to perform. Inspection data can be stored; repeat inspections where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion. Variable detection performance in HOIS trials: Sizing performance was better on the manufactured samples using post-scan data analysis than on heavily corroded ex-service components.

A1.4 Medium range phased array

A1.4.1 Description of method

Phased array probes allow the direction of the sound energy beam to be controlled because the probe is made up of multiple small elements, each of which can be pulsed individually.

Phased array probes can be used on the process pipe each side of the trunnion in order to skip the ultrasonic beam under the trunnion attachment weld and reach the areas of concern. This method is similar to the long range phased array approach in A1.2, except that when applied in the HOIS trials the probe was closer to the trunnion weld and scanned with the beam in both the axial and circumferential directions.

A1.4.2 HOIS trial results

One trial was performed using a medium range phased array method on the straight manufactured components and ex-service components. A phased array probe was scanned in four different directions – the beam axial (at 0 and 12 o'clock) and the beam circumferential at skew angles of 90° and 270°), as shown in Figure A 1-5.

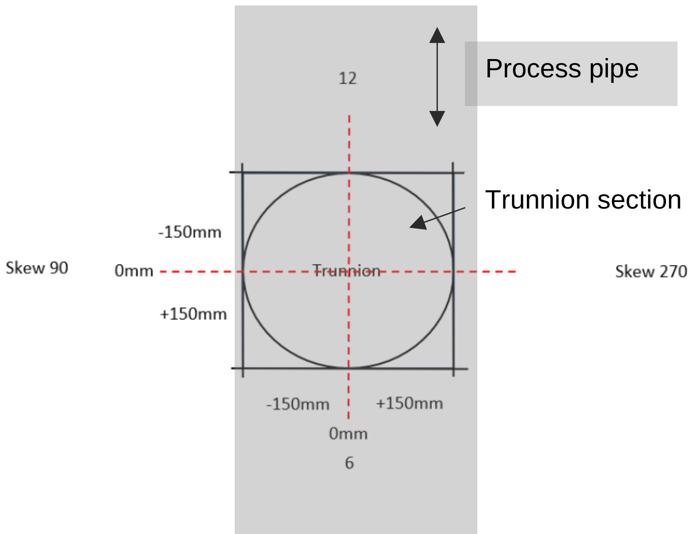

Figure A 1-5: Medium Range Phased Array scan arrangement and nomenclature

The location of areas of suspected wall loss were reported with a corresponding minimum remaining wall thickness at this location.

Manufactured components (4 off): Detection performance was excellent (with no false calls) but the mean sizing error was an underestimate of wall loss of ~30% of WT, the largest difference was 45%WT, although the sample size was only 4 components.

Ex-service components (5 off): Detection performance was excellent, with no false calls. The wall loss was consistently underestimated, the mean difference was ~20% WT, the largest difference was ~30%WT.

A1.4.3 Summary

Table A 1-4: Summary of medium range phased array

Technique:	Medium range phased array
Basis:	Phased array probe used to inspect each side of the trunnion in order to skip the ultrasonic beam under the trunnion attachment weld and reach areas of concern.
Strengths:	• Applicable to a wide range of pipe diameters and wall thicknesses. • Simple to apply, rapid scanning using readily available tools.
Weaknesses:	• Affected by surface condition must be relatively free from loose scale. • May be affected by coatings on the pipe. • Difficult to apply to elbows – not clear how ultrasound beam propagates in the axial direction for circumferential locations away from the extrados. • Limited sizing accuracy suggested in HOIS trials, with tendency to undersize. • Will be affected by surface condition.
Overall:	Relatively simple to apply using readily available tools. Good detection capability but limited sizing capability in HOIS trials (small sample set). Limited field experience. For repeat inspections, where comparisons can be made with a baseline scan, may highlight changes in process pipe condition within the trunnion.

A1.5 M-skip

A1.5.1 Description of method

M-skip is an ultrasonic technique that was developed in the mid-2000s [11]. M-skip is based on angled pitch-catch shear wave probes, to avoid mode conversion losses at reflections from the component surfaces. These probes can be separated by the distances required to inspect, for example pipe supports and clamps. The signals travelling between the probes then typically experience many reflections, or skips, between the front and back component surfaces.

M-skip can be applied in two different modes:

1. The ultrasound beam directed axially along the pipe/vessel with the probes scanned circumferentially.
2. The ultrasound beam directed circumferentially around the pipe/vessel wall with the probes scanned axially.

One limitation is that, in common with other ultrasonic techniques, M-skip needs the surface under the probes to be relatively free from loose scale. A second consideration is that the multiple reflections may make it more affected by any coatings on the surface of the pipe which can cause more signal broadening and/or attenuation than pulse-echo techniques.

The lack of any M-skip arc-type indications can provide high confidence in the absence of significant corrosion under a support, provided the signal to noise ratio of the data is sufficiently high. When the wall loss is uniform, analysis of the arrival times of the M-skip signals is needed to confirm the presence or absence of wall loss.

In the presence of corrosion, M-skip can only provide fully quantitative wall loss measurements in certain conditions (either uniform wall loss or isolated pits). The wall loss of extended areas of corrosion may be overestimated, with M-skip providing conservative upper bound values.

M-skip is better suited to inspection of relatively thick-walled components (at least 10mm, with >15mm better). This reduces the numbers of internal and external reflections experienced during the ultrasound propagation between the probes. Also, smaller probe separations are more favourable than larger values.

For corroded components, especially those with thinner walls, the M-skip signals may disappear completely due to scattering at the rough surface, resulting in loss of sizing information, although detection capability is good.

M-skip has been used with some success for in-service inspection of pipe supports on offshore and onshore sites in the UK. Several category 2 HOIS members report applying M-skip to inspection of trunnions, although the effect of the trunnion weld on M-skip signals is not well understood and experience is limited. Note that M-skip could not be used in axial beam mode on an elbow, but circumferential beam may be possible in certain locations, although this would likely be challenging to apply.

A1.5.2 HOIS trial results

One inspection service company performed a trail of M-skip with the axial beam probes scanned circumferentially on the straight manufactured components. It was not performed on any ex-service components, presumably due to the particularly poor surface condition on these components.

Detection of corrosion on a small sample set was excellent, with no false calls. However, the wall loss of the areas of corrosion was generally underestimated, with the mean difference between the reported and benchmark wall losses corresponding to an underestimate of wall loss of ~30% WT (on a small sample set). This may have been due to limited detection of the localised pits present in these test components.

A1.5.3 Summary

Table A 1-5: Summary of M-skip

Technique:	M-skip pitch-catch UT
Basis:	Uses two shear-wave pitch-catch ultrasonic probes. Degradation is detected and sized by a change in signal arrival time and loss of signal amplitude.
Strengths:	• Effective confirmation of lack of corrosion for thin and thick-walled pipes and vessels. • Combination of axial and circumferential beam scanning on straight components may provide more confidence in results. • Rapid scanning. • Quantitative sizing is possible is some cases.
Weaknesses:	• Can be affected by surface roughness and poor surface condition (coating etc.), resulting in loss of signal responses. • Coatings can have very variable effects which need to be assessed on a case by case basis. • Sizing generally only possible on thicker walled pipes only (>15mm). • Sizing information subject to uncertainty depending on the corrosion extent in the along beam direction and profile. • Complete loss of signal (no sizing information) may occur for thin-walled, heavily corroded components. (<10mm) with only moderate levels of corrosion. • The effect of the weld on M-skip signals is not well understood. • Very challenging to apply on elbows, so currently restricted to trunnions on straight lengths of pipe.
Overall:	Can provide confirmation that no corrosion is present, and more quantitative sizing information in some cases, but can be adversely affected by coatings, poor surface condition, and surface roughness. Very challenging to apply around bends. Better on thicker walled pipes (> 15mm). The effect of the trunnion weld on M-skip signals is not well understood. Experience of the application of M-skip to trunnion inspection is limited.

A1.6 Quantitative Short Range guided waves (QSR1)

A1.6.1 Description of method

The basic configuration of the QSR system from GUL is similar to some other guided wave devices. Two EMAT transducers are used, as shown in the schematic Figure A 1-6, to generate and receive circumferential shear-horizontal guided waves that propagate circumferentially around the pipe wall. For trunnion inspections, the transducers would be deployed at approximately the 10 o'clock and 2 o'clock positions of the process pipe, with the centre of the trunnion being at the 6 o'clock position. There are two paths between the transducers: the short path via 12 o'clock which is uncorroded and the longer path via 6 o'clock which includes the potentially corroded section of the pipe. The probes are scanned together in the axial direction across the area of the process pipe onto which the trunnion is welded using a motorised drive with encoded information provided on the transducers' position.

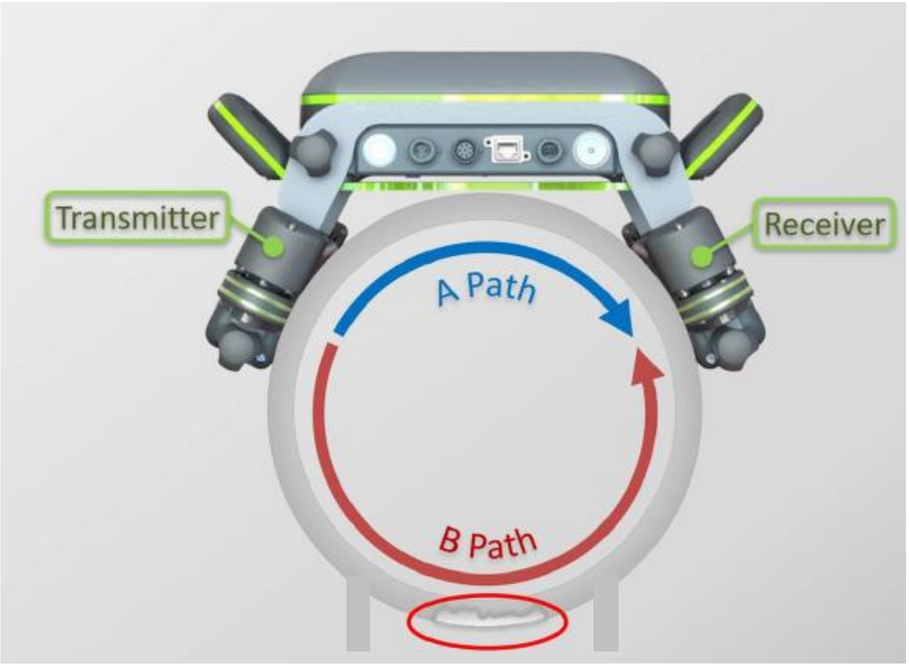

Figure A 1-6: Schematic of QSR1 configuration (courtesy GUL)

The aim of QSR1 is to provide quantitative measurements of remaining wall thickness which is achieved by sophisticated analysis of multi-mode guided wave data, unlike other methods which use simpler measurements of amplitude loss. As the system is scanned along a pipe, an automated routine is used to generate a real-time profile of wall thickness (or remaining wall thickness) which is shown on a laptop connected to the scanner. The raw data is also stored and is then available for review and offline manual analysis once the scan has been completed.

The current limitations of the QSR1 for sizing are expected to be:

- If the wall loss is greater than 50%, the value produced will not be quantitative, but should be reported as >50%
- Under-sizing will occur for small diameter pits (less than the ~40mm beam width)
- The probe beamwidth is stated to be ~40mm but the instrument is said to be capable of sizing localised areas of wall loss down to ~25mm in axial extent. Corroded areas smaller

than this are likely to be undersized. This may be of particular concern for the application of trunnion inspection.

This is a newly developed method specifically for corrosion under pipe support inspection – mainly touch point corrosion with pipes supported by flat beams; it performed well in recent HOIS corrosion under pipe support trials[1]. The method is rapid, and the EMAT transducers are much more tolerant to poor surface condition than conventional ultrasonic probes. Development work continues to increase the capability for thicker pipe and circumferential scanning to allow measurements of both bigger and smaller diameters.

A1.6.2 HOIS trial results

GUL looked at two open trunnion samples in the HOIS trial– one 8" Sch. 40 process pipe and one 8” Sch. 80. No blind trials were performed.

On the thicker walled sample, the tool could transmit in the “thickness gauging mode” through the trunnion but the manufactured pits were too small to resolve (the largest pit on this component was 20mm in diameter, 9mm deep i.e. wall loss of ~70%).

On the thinner walled sample, much of the “thickness gauging mode” was lost and so finding thinning in the process pipe would require further changes to the QSR tool.

A1.6.3 Summary

Table A 1-6: Summary of QSR

Technique:	QSR
Basis:	Two EMAT probes generate a circumferential beam of guided waves, areas of corrosion result in changes in the guided wave signal which are then analysed using sophisticated multi-mode analysis methods. Currently applicable to pipe diameters between 8 and 24" and wall thicknesses between 6 and 14mm.
Strengths:	• EMAT probes are much less affected by surface condition/coatings than conventional ultrasonic probes. • Rapid inspection. • Quantitative indication of defect severity for wall losses <50% provided their axial extent is at least 25mm.
Weaknesses:	• Requires access to the pipe on the opposite side of the trunnion. • Probe beamwidth is stated to be 40mm, but the instrument is said to be capable of reliably sizing localised areas of wall loss down to ~25mm in axial extent. Corroded areas smaller than this are likely to be undersized. • Suitable for wall thickness >6mm, pipe diameter >8inches. • Lack of field experience for trunnion inspection
Overall:	Newly developed technique for quantitative sizing of remaining ligament. Current focus is on developing capability for thicker pipe walls and circumferential scanning to allow measurement of both bigger and smaller diameter. The methods performed well in HOIS CUPS trials, may have some application to trunnion pipe supports where access on the opposite site of the process pipe to the trunnion is possible. Limited field and trial experience for this application.

A1.7 Radiography

A1.7.1 Description of method

Film radiography with x or gamma -rays is one of the earliest NDT techniques to be developed dating back to the early twentieth century. Both x-ray and gamma-ray radiography are well suited to the detection of volumetric defects. Single or double wall radiographic techniques may be used, in which the flaws can be detected by the changes in radiographic density that they produce. Double wall techniques do not provide quantitative information on through wall extent of the flaws.

For in-service pipe inspection, the source is positioned outside the pipe on the opposite side from the film or imaging plate. When the source is close to one pipe wall the technique is known as double wall single image since the pipe wall adjacent to the source is very blurred and no flaw detail can be discerned on the film. To inspect both pipe walls in a single image the source needs to be moved well away from the pipe and may be offset to allow welds on both sides of the trunnion to be separated on the trunnion radiograph. This is known as double wall double image.

To provide estimates of the remaining wall thickness tangential radiography (also known as profile radiography) is used. A direct radiographic image of the pipe wall is obtained at the position(s) at which the radiation beam forms a tangent to the pipe surfaces, as shown in Figure A 1-7. The technique can be applied with the source symmetrically positioned on the pipe centreline or offset to examine a single wall.

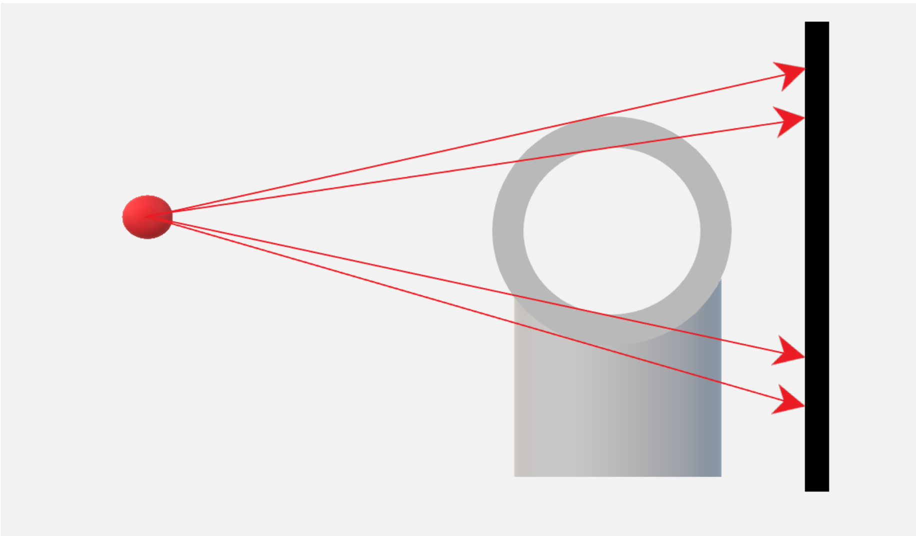

Figure A 1-7: Principle of tangential radiography for inspection of small diameter pipes with trunnion pipe support.

All in-service radiography should be performed in accordance with the international standard ISO 20769:2018 Part 1 (see also the HOIS RP for in-service radiography [16]). Note however the caveats on sizing of external corrosion contained in the HOIS safety notice on this topic [15]. For some external corrosion morphologies (mainly those with localised circumferential extents) significant uncertainties in remaining wall thickness are likely to be obtained when using tangential radiography.

A relevant case study which demonstrates the possible limitations of tangential radiography comes from in-service tangential computed radiography (CR) performed on a trunnion support, but the area of external corrosion was not accurately aligned with the tangent position due to site constraints (adjacent pipework prevented the source and detector being positioned in the optimum locations). As a result, there were difficulties in the interpretation of the image, and no significant corrosion was reported from the CR image (Figure A 1-8: , left) but there was known to be a leak due to corrosion. The pipe and trunnion were cut-out and removed from service. Subsequent CR images were obtained in an exposure bay at different angles to better align the corroded area with the tangent position. The lack of site restrictions on source and plate positioning also allowed the source to detector distance to be increased to reduce the geometric unsharpness. The resulting images obtained for different pipe rotation angles relative to the bend extrados located at the tangent position are shown in Figure A 1-9: . At 0° there is close to zero remaining wall thickness (consistent with the leak) whereas at 30° there is no evidence of major wall loss.

Misaligned in-service CR image (no clear wall loss) — Better aligned CR image showing extensive external wall loss

Figure A 1-8: Computed radiography images of trunnion support: Left: original in-service image. Right: image with source and detector better aligned following removal from service.

There are clues in the left-hand image of Figure A 1-8: to the experienced operator that the image is misaligned and therefore unreliable for wall thickness measurement i.e. the edges of the pipe are not well delineated and the elliptical nature of the trunnion to pipe weld image. Also, there is a significant volume of corrosion product inside the trunnion which should be indicative of a problem.

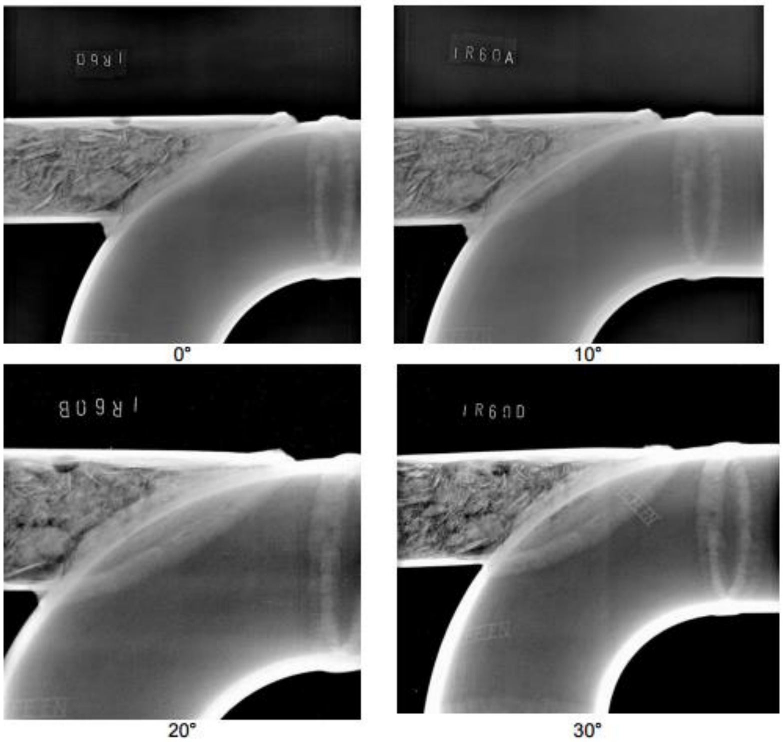

Figure A 1-9: Computed radiography images at different angles.

This example demonstrates that for tangential radiography of trunnions located on elbows, the source and detector should, if possible, be aligned so that the tangent point on the elbow coincides with the extrados, as this corresponds to the centre of the trunnion which is where the greatest wall loss is likely to be present.

A1.7.1.1 Radiation sources for radiography

For in-service site radiography, isotope radiation sources are generally used. The most common is Iridium 192, but others include Cobalt 60 and Selenium 75. Iridium 192 gives gamma rays with mean energy of about 340keV. Selenium 75 has a lower mean energy of about 220keV which gives higher radiographic contrast for thinner walled components. However, Se 75 is significantly less penetrating than Ir 192, a disadvantage for the tangential method. Hence Se 75 is less widely used than Ir 192.

Cobalt 60 gives gamma rays with a significantly higher mean energy than both Ir 192 and Se 75 (circa 1250keV which allows penetration of thicker components. However, the radiological safety issues associated with the use of this high energy source are substantial and for this reason it is seldom used in the UK and Europe.

Isotope sources are often housed in shielded containers from which the active pellet must be withdrawn to perform the radiography. Manual winding methods are usually used, and the pellet is moved rapidly along a flexible tube from the container to the position for the radiography. Often a collimator is used to limit the angle over which the radiation is emitted, to reduce the general dosage in the surrounding area and back scatter on the radiograph.

Alternative source containers with integrated collimators are available for Ir 192 and Se 75 sources. Their advantage is that the source remains within the container and a narrow beam collimator substantially reduces the size of the controlled area needed around the source. Such systems are generally referred to as small controlled area radiography (SCAR) and can reduce radiation safety issues and associated impact on site operations and alarms.

Higher energy (MeV range) portable Betatron sources have been used for specialised applications that require greater penetration than is possible with Ir 192.

A1.7.1.2 Detectors

Although conventional film radiograph is still often used, the deployment of digital detectors over film radiography is becoming more widespread. Digital radiography methods can have advantages over film methods in terms of shorter exposure time, reduced costs and increased exposure latitude. They can be broadly grouped into:

Computed radiography (CR): film is replaced by a photostimulable phosphor imaging plate (IP) which is subsequently read out using a laser scanner.

Digital detector areas (DDA): film is replaced by a two-dimensional array of detectors that produce an image that can be directly read out.

A1.7.2 HOIS trial results

Radiography was performed on both the manufactured (computed radiography only on 4 straights) and ex-service components. The geometry of the manufactured components had specifically been chosen to be beyond the limits of radiography (8" NB, sch 80 process pipe with 6" trunnion welded to them). Radiography is better suited to small diameter pipework because the penetrated thickness on the 8" NB, sch 80 pipes exceeds the recommended limits for wall loss inspection. However, the penetrated thickness at the trunnion/process pipe interface is less than through the process pipe.

Single radiographic shots were performed on the four straight sch 80 components. The radiographs allowed clear identification of the edge of the process pipe inside the trunnions in Figure A 1-10: , although as expected the pipe ID could not be seen. Areas of pitting were also noted in the double wall portion of the image. For the area of generalised wall loss of the process pipe highlighted at the tangent position of the image on the left in Figure A 1-10: , the extent of the wall loss was estimated relative to the adjacent uncorroded process pipe OD. Hence, although a direct measurement of remaining wall thickness was not possible, this wall loss measurement could be combined with a measurement of uncorroded wall thickness adjacent to the trunnion (obtained for example by 0° UT) to provide an estimate of the remaining wall thickness.

For in-service corrosion, it is possible that the corrosion product (or scab) could prevent a clear image of the corroded edge of the process pipe being obtained. However, as the radiographic attenuation due to the corrosion product is substantially less than for steel, this is unlikely to be a major issue. The presence of any localised pitting within the corroded area is more likely to cause measurement unreliability, as covered in ISO 20769:1 (2018).

Accurate measurement of the minimum remaining ligament requires multiple shots to align the point of greatest wall loss with the tangent position.

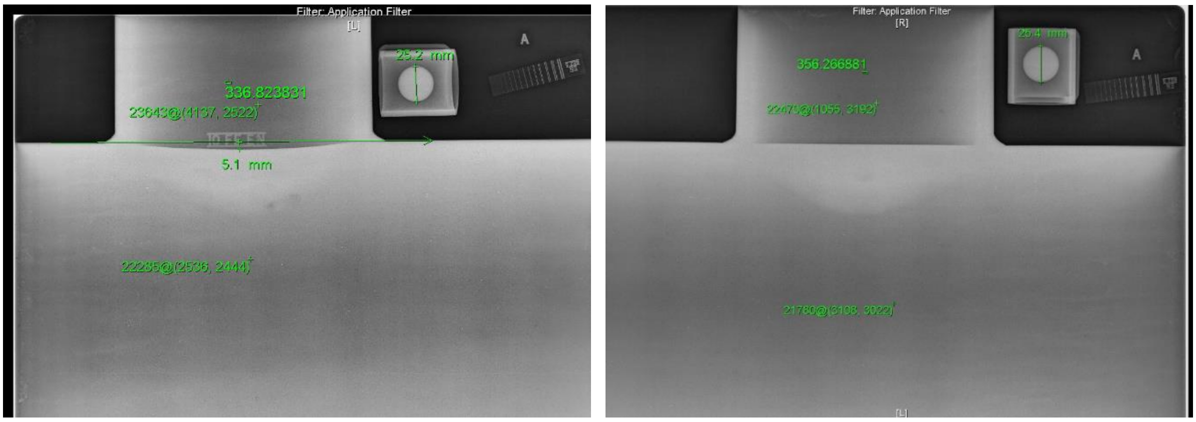

Figure A 1-10: Example CR results: Left – estimated wall loss out with procedure and area of pitting noted. Right: area of pitting noted.

On the heavily corroded ex-service components in the HOIS trials, the mean difference between reported and benchmark minimum remaining ligament was 10% of wall thickness. This was one of the best performing methods used. The maximum sizing difference was up to 40% WT (undersizing wall loss). Improved sizing should have been possible with additional exposures taken at different circumferential angles, as per ISO20769-1.

A1.7.3 Summary

Table A 1-7: Summary of tangential radiography

Technique:	Tangential radiography to measure remaining wall thickness of pipe at tangent positions, using either film, imaging plate (IP/CR) or direct detector (DDA).
Basis:	Gives direct image of pipe wall thickness at tangent position from which a quantitative measurement of remaining wall thickness can be obtained.
Strengths:	• Direct visualisation of the corrosion. • For small bore pipes (maximum penetrated thickness < 80), an Ir 192 source can provide quantitative (with some caveats) remaining wall thickness measurements for a range of corrosion shapes/profiles but only at the tangent position (which should be aligned with the centre of the trunnion). • For larger pipe diameters and schedules for which full penetration of the pipe wall is not possible (ID not visible on the radiographs), the method of measurement of wall loss, relative to the adjacent uncorroded pipe OD, allows extension of the method to a greater range of pipes than specified in ISO 20769:1.
Weaknesses:	• Radiation safety issues. • Slow. • Generally restricted to small bore pipes (total penetrated thickness of the tangent to the ID, including the trunnion, <80mm for Ir 192), although note the use of the wall loss method to extend the applicability of the method to larger diameters and heavier schedules

	• Circumferential coverage of a single shot is very limited, and corrosion away from the tangential position may be missed or undersized – see ISO 20769:1. • Requires access around the trunnion and may be difficult to image the precise area of interest (i.e. physical constraints in source/detector locations may prevent the tangent point being at the centre of the trunnion).
Overall:	Quite widely used for small bore pipes and is slow with safety implications. One of the best performing methods used in the HOIS blind trial programme. May provide quantitative wall thickness measurements with the correct alignment. But corrosion can be unreliably sized, depending on its morphology (see ISO 20769:1 and caveats highlighted in the HOIS safety notice [15]). Images of corrosion product present inside the trunnion are indicative of corrosion and may be a useful screening technique for severe corrosion if not able to provide quantitative measurement of remaining ligament.

A1.8 Verkade pitch-catch method

A1.8.1 Description of method

The Verkade method use a pitch-catch system based on angled shear wave beams. Two 70° probes (or 45° for heavy wall small bore piping) are used within a frame to ensure correct alignment. One probe emits an ultrasonic pulse which travels circumferentially around the pipe and is received by the second probe; the probes are scanned axially without position encoding. Circumferential scanning of straight process pipes with attached trunnions is also possible, with the travel path of the sound beam in the axial direction.

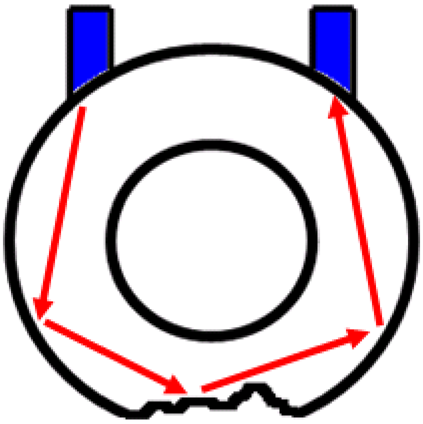

Figure A 1-11: Illustration of Verkade technique using circumferential inspection of a corroded area.

When corrosion damage is present, as shown in Figure A 1-11, the sound beam is likely to be scattered and reflected so that less sound energy reaches the receiving probe. The transmitted signal amplitude on a location with wall loss inside the trunnions (A_1) is compared to the signal amplitude (A_0) at a location on the pipe adjacent to the trunnion with no wall loss. The probes are scanned axially without encoding. The measure of signal attenuation (A_1/A_0) is translated to relative wall loss according to a table in the Verkade inspection procedure.

The uncorroded wall thickness adjacent to the trunnion is measured in several positions using a separate manually deployed 0° probe. This allows the percentage wall loss to be translated into values in millimetres for both wall loss and remaining wall thickness indication.

The Verkade method was included in HOIS CUPS (corrosion under pipe supports) trials where, in common with other amplitude-based methods, it showed good detection but limited sizing capability.

A1.8.2 HOIS trial results

Verkade NDT participated in the HOIS trial programme and inspected both the manufactured and ex-service components.

For the manufactured components, elbows were found to be more challenging than the straights because the inspection of elbows is affected by a limitation of the system – the scanning frame does not permit circumferential scanning of the probes around an elbow, but axial scanning (with sound beams circumferential) is still possible. Verkade NDT missed several areas of corrosion on the elbows which led to a mean difference between reported and benchmark wall loss of ~40% WT (undersize of wall loss) with a standard deviation of ~25%. The largest difference between reported and benchmark wall loss was 85% WT.

For the ex-service (heavily corroded) components, detection capability was improved to a POD of 100%. The sizing performance was also better on the ex-service components, which Verkade NDT anticipated – commenting that manufactured/machined defects with smooth surfaces cause “wrong readings or no readings at all”. On the heavily corroded ex-service components the mean difference between benchmark and reported wall loss was less than 10% WT (an underestimate of wall loss, non-conservative for trunnion condition). The standard deviation was also less than 10% WT, the maximum undersizing of wall loss was <20% WT.

A1.8.3 Summary

Table A 1-8: Summary of Verkade pitch-catch method

Technique:	Verkade pitch-catch method
Basis:	Uses two shear-wave pitch-catch ultrasonic probes. Degradation is detected and sized by a change in signal amplitude.
Strengths:	• Allows confirmation of lack of corrosion for thin and thick-walled pipes and vessels. • Combination of axial and circumferential beam scanning may provide more confidence in results. • Quantitative sizing of MRWT with the highest sizing accuracy of all the ultrasonic methods assessed in the HOIS trials
Weaknesses:	• Can be affected by surface roughness and poor surface condition (coating etc.), resulting in loss of signal responses. • Coatings can have very variable effects and may need to be removed. • Limited to axial scanning only on elbows/complex geometries.
Overall:	May provide confirmation that no corrosion is present, and detection of corrosion with some quantitative sizing information. Can be adversely affected by coatings, poor surface condition and surface roughness etc. More applicable to pipe diameters >3" and <14".

A1.9 Visual and Borescope inspection

The geometry of trunnions with a welded end cap usually prevents a direct visual inspection. However, it may be possible to look for indications of corrosion issues including the coating condition at interfaces and looking for corrosion staining etc.

If there is no end cap in place, then a detailed visual examination should be performed. If it is possible to obtain direct access to the pipe by removal of corrosion product (this may not be possible on live lines), this can be supplemented by a pit depth gauge and other mechanical measurements can be used to quantify the extent of the corrosion under the support.

Detailed photographic records should be kept of visual examination results to assist in the interpretation of any subsequent NDT results obtained.

A1.9.1 Borescopic examination

Borescope or videoscope probes can be inserted into the trunnion through an unplugged weephole (usually of the order of 6-8mm in diameter) allowing inspection using 6 and 4mm nominal scope units. This can be used to visually assess the condition of the external wall of the process pipe inside the trunnion in addition to the internal trunnion condition.

Trunnions can be challenging for borescope technology for the following reasons:

- Manoeuvrability: the tip of the scope has to pass through a small opening (weephole) only slightly larger than the diameter of the tip itself. Passing nominal 4mm tips though weepholes of 4mm diameter or slightly larger risks lens contamination. Articulation of the scope tip determines how fast an inspector can access hard to reach areas.
- Low light conditions: the videoscope's light source needs to be sufficient to illuminate inside the trunnion.
- Glare: shiny metallic surfaces can reflect light which may lead to difficulty in identifying faults on the surface due to the glare.
- Oil/water contamination: in-service inspection may be in wet environments leading to liquid contamination of the tip which can affect image quality.
- Depth of field: During the inspection, moving through a trunnion is easier with a near focus lens, whereas imaging of large spaces works better with a far focus lens. As the tip cannot be replaced inside the trunnion, high depth of field can provide a combination of speed and image quality.
- Build-up of corrosion product on the process pipe and trunnion surfaces masks the extent of any corrosion and associated wall loss.

No direct measurement of remaining wall thickness is possible, but the volume of any corrosion product present is indicative of the severity of the corrosion. This technique can be used to confirm the absence of corrosion and to rank the severity of any corrosion that is present. Example images are shown in Figure A 1-12: Note that in severely corroded trunnions it is difficult to differentiate visually between the trunnion wall and the process pipe wall.

The weephole should be resealed at the end of the inspection to prevent water ingress.

Figure A 1-12: Left: video scope image of an uncorroded trunnion, shows trunnion wall and process pipe, Right: video scope image of a severely corroded trunnion (scope inserted fully into trunnion to view process pipe wall only).

Wall loss measurements may be possible using 3D stereo measurement tools where there is no corrosion product in place. 3D stereo measurement uses stereo optics to match two views of a surface from slightly different perspectives. Advanced calibration and processing algorithms compute a 3D co-ordinate for every matched pixel resulting in a 3D surface map. The software generates a full 3D point-cloud representation of the target surface which can then be viewed, manipulated and analysed. Cursor placement allows measurements to be taken, see for example Figure A 1-13 Care must be taken in establishing a suitable reference surface.

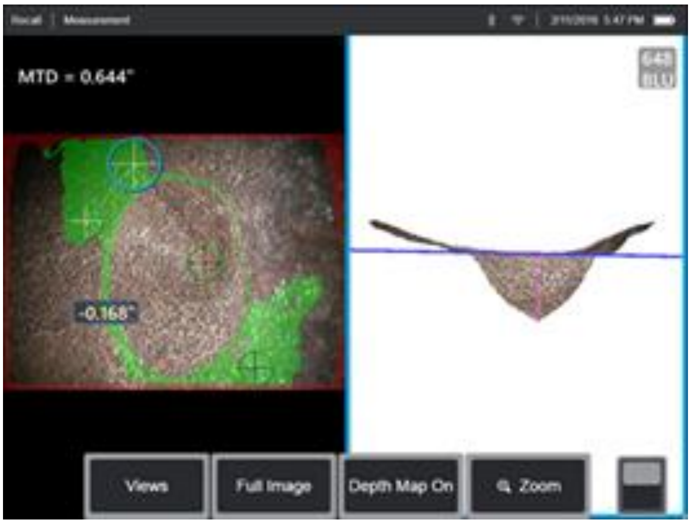

Figure A 1-13: 3D Stereo measurement tools on debris free corrosion pit. Image courtesy of Waygate Technologies.

A1.9.2 HOIS trial experience

Borescope inspection has been shown in the HOIS trials to be a useful method as a first-line inspection method. The videoscope probes used in the trials were effective at identifying the presence of corrosion product, indicative of wall loss on the OD of all the ex-service process pipes (and the ID of the trunnion) for all trunnions where corrosion was present.

However, one limitation of the use of borescopes is that if an internal degradation mechanism (such as internal pitting) is present, it cannot be detected. If the corrosion risk assessment considers that internal degradation mechanism is likely, this would not necessarily be associated with the trunnion and be more widespread, and wall thickness measurements, away from the trunnion, would be able to detect the issue.

A1.9.3 Summary

Table A 1-9: Summary of borescopic examination

Technique:	Videoscopes inserted through unplugged weepholes to visually assess the condition of the pipework within the trunnion.
Basis:	Videoscope can identify the presence or lack of corrosion by looking at the surface condition of the pipework i.e. pitting or corrosion product.
Strengths:	• Direct visualisation of the corrosion. • Rapid and simple to do. • Can confirm the absence of corrosion on external surface of process pipe and possibly rank severity of degradation.
Weaknesses:	• No quantitative measurements of wall loss or remaining wall thickness where corrosion product/debris is in place. • Can be difficult to differentiate between the trunnion wall and process pipe wall on the images.

	• Requires weephole to be unplugged – these must then be refilled to prevent further water ingress after examination. • Will not detect internal degradation mechanisms on process pipe – limited to external pipe surface assessment.
Overall:	Requires access through weephole. Useful rapid screening tool to rule out active corrosion inside the trunnion (by absence of corrosion product) or rank degradation by volume of corrosion product.

Engineering, Safety & Risk

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