Inspection/Non Destructive Testing

This document provides detailed and specific guidance on inspection and Non-Destructive Testing (NDT) in support of the Level 2 Criteria:

- 5.2.1.3(29) f
- 5.2.1.6 (38) i
- 5.2.1.11(64)e
- 5.2.2.2(79)
- 5.2.4.1(89)e
- 5.2.4.3
- 5.2.4.4.

Related Technical Measures Documents are Training and Maintenance Procedures.

This document assists in the assessment and inspection of NDT applied on plant and how that supports the continued safe operation of the plant.

- Introduction: a description of NDT, what it can and cannot do and how it fits with safety management.
- Regulatory requirements: how NDT meets the requirements of current regulations and a description of a Written Scheme of Examination.
- COMAH safety report: what information on NDT would be expected in the safety report.
- HSE follow up COMAH Inspection: what the HSE Inspector should look for in the COMAH follow up inspection of the site.

- NDT process & management: a description of how dutyholders should initiate, specify and apply NDT and how the results should be utilised. Also detail on how dutyholders should manage NDT on a site.
- Techniques & capabilities: an overview of the common NDT techniques and the advantages and limitations. Includes a description of common trade names.
- Checklist for the inspection of NDT: Aide Mémoire to assist follow-up HSE site inspection
- Terminology and current trends: Glossary of terms and what they actually mean.
- Case studies: 2 case studies on the adequacy of NDT programmes to detect defects in pressure vessels.
- Sources of further, more detailed, information are given at the relevant position in the text and other significant standards are listed.

1. Introduction

Pressure vessels, storage tanks and other safety critical components (including pipework and valves) are designed to contain liquids, gases and solids such that a loss of containment does not occur. Leaks or the mechanical or structural failure of these items of equipment may result in a major accident on-site.

The presence of flaws in critical components may result in the integrity of such systems being compromised and increase the likelihood of failure.

Non-Destructive Testing (NDT) is the application of measurement techniques in order to identify damage and irregularities in materials. NDT often provides the only method of obtaining information about the current 'health' of process plant.

If done well, NDT can provide useful information to assist in the management of plant safety. If inappropriate NDT is applied or NDT is not applied correctly, then the results are likely to give a false impression of the integrity and safety of the plant.

NDT is a measurement of a physical property or effect from which the presence of damage or irregularity can be inferred. It is not a measurement of an absolute parameter such as temperature or pressure.

The distinction between what would be considered changes in material properties and what would be considered a defect is not distinct. This can lead to NDT missing defects and also producing false calls i.e. a defect is reported when in fact the signal is not produced by a defect. Also, NDT is applied to a greater or lesser extent by human operators who introduce human error and subjectivity into the process.

NDT is rarely 100% effective at detecting defects of concern. Like all measurements, defect positioning and sizing measurements with NDT techniques are subject to errors. As these techniques are often a combination of separate measurements, these errors can be significant.

NDT techniques fall into two categories:

- techniques which only detect and size defects/damage present on the surface of a component;

- techniques which can detect and size defects/damage embodied within a component.

A brief description of the common techniques applied to process plant is given in Techniques. The basic NDT techniques have changed little over the years but with improvements in technology and the demand to maximise plant productivity new techniques and variations on old ones have been developed, along with various approaches to NDT. These are clarified in Terminology and Current Trends below.

The quality of the NDT applied to a component cannot be easily assessed by subsequently observing the component or the results obtained.

Extra steps are required in the development and application of the test to provide confidence in its ability to identify the damage or irregularities of concern. The Inspection Process and its proper Management are discussed in more detail below.

NDT is a primary recovery mechanism for errors in design, construction and operational activities.

Correct selection and application of an NDT technique can provide confidence that a component or piece of plant does not contain defects of the type which the technique was capable of detecting.

When applied in a manufacturing environment it is used to provide confidence that there are no defects of concern over a certain size which may have been introduced by the manufacturing process. In this case NDT is just one of a number of quality control activities aimed at producing a component or piece of plant to a particular specification.

In service NDT provides confidence that the operation of the plant is not causing deterioration in its integrity beyond its design parameters.

If such deterioration is detected then NDT can quantify the damage and provide input to the justification for maintenance or monitoring actions.

Ad hoc NDT can be used to check that unexpected damage mechanisms are not occurring.

All techniques have strengths and weaknesses regarding the types and parameters of the damage mechanism they can detect.

Either the ad hoc NDT needs to be targeted at a hypothetical damage mechanism or the damage mechanism that can be reported as not detected is defined by the capabilities of the technique.

The types of defect / flaw and degradation that can be detected using NDT are summarised as:

- Planar defects - these include flaws such as fatigue cracks, lack of side-wall fusion in welds, environmental assisted cracking such as hydrogen cracking and stress corrosion cracks; cold shuts in castings etc;
- Laminations - these include flaws such as rolling and forging laminations, laminar inclusions and de-laminations in composites;

- Voids and inclusions - these include flaws such as voids, slag and porosity in welds and voids in castings and forgings;
- Wall thinning - through life wall loss due to corrosion and erosion;
- Corrosion pits - these are localised and deep areas of corrosion;
- Structural deformities such as dents, bulges and ovality.

The application of NDT to support the manufacturing requirements or the continued operation of plant is subject to certain Regulations.

There are some common misconceptions regarding NDT which are still prevalent in industry:

2. Regulatory requirements

The requirements of the various general regulations can be summarised as:

Pressure Systems Safety Regulations 2000 cover the operation of pressure systems.

Regulation 4 (2) states that plant should be "properly designed and properly constructed from suitable materials so as to prevent danger."

Regulation 8 (1) requires the "owner or user must have a WSE for the periodic examination by a competent person where:" according to Regulation 8 (1) (b) "a defect may give rise to danger."

WSE is a Written Scheme of Examination which specifies for each part of the pressure system the damage mechanism that may be expected, the examination interval and the method of examination. Any NDT required will be specified on the WSE. Further information on Written Schemes is given in the document Written schemes of examination.

The Pressure Equipment Regulations 1999 cover the manufacture of new pressure vessels in line with the European Pressure Equipment Directive and apply to pressure equipment and assemblies with a maximum allowable pressure PS greater than 0.5 bar. These regulations require:

- Pressure equipment must be designed and constructed so that all necessary examinations to ensure safety can be carried out;
- Preparation of the component parts (e.g. forming and chamfering) must not give rise to defects or cracks
- Permanent joints and adjacent zones must be free of any surface or internal defects detrimental to the safety of the equipment.
- For pressure equipment, suitably qualified personnel must carry out non-destructive tests of permanent joints.
- For pressure equipment of categories III and IV, the personnel must be approved by a third-party organisation recognised by a Member State pursuant to Article 13.
- Pressure equipment must undergo a final inspection to assess - visually and by examination of the accompanying documents - compliance with the requirements of the Directive. Tests carried out during manufacture may be taken into account.

The old British Standard (BS 5500) for the manufacture of pressure vessels has been superseded by a new European Standard BS EN 13445 but the design requirements that were in BS 5500 have been kept as PD5500. This latter document sets defect Acceptance Criteria for the NDT applied at manufacture. The acceptance criteria take into account the capabilities and limitations of the NDT techniques so for Radiography it states "No cracks allowed" whilst for Ultrasonics it states conditions on planar indications based on the height, length and amplitude.

The Control of Major Accident Hazards Regulations 1999 put a general duty on every Operator to take all measures necessary to prevent major accidents and limit their consequences to persons and the environment. The references to NDT that may occur in the safety report are described in COMAH Safety Report.

NDT although not specifically mentioned in the above regulations has a role to play as part of the Operator's demonstration in respect of mechanical integrity, that all necessary measures have been taken. It provides confidence that plant is constructed to the required standard and is in good repair. NDT can provide information to confirm or otherwise that unexpected damage is not occurring.

The Carriage of Dangerous Goods Regulations - Rail & Road. These regulations cover the transport of dangerous goods by rail and road, including the examination and testing of the tanks used. The tanks require to be examined and tested by the competent authority or approved person in accordance with requirements approved and published in the Approved Tank Requirements. A certificate is required to be produced which confirms the examination and test and also that the tank conforms to an approved design and is suitable for the purpose for which it is intended.

Management of Health & Safety at Work Regulations 1999. These require employers to make suitable and sufficient assessment of the risks to employees and the public arising from the business activities

The Provision and Use of Work Equipment Regulations 1998. These require the employer to ensure that **work** equipment is so constructed or adapted as to be suitable for the purpose for which it is used or provided and that **work** equipment is maintained in an efficient state, in efficient **working** order and in good repair.

3. COMAH safety report

The information given on NDT in the safety report is likely to be in response to Criterion 5.2.4.3: the report should show that systems are in place to ensure, for safety critical plant, that a competent person examines systems at appropriate intervals. The information is likely to be general and details of the NDT techniques would not be expected.

The safety report should provide evidence that Written Schemes of Examination are in place for pressurised plant.

A safety report should declare whether examinations are performed by an in-house organisation or bought in from a 3rd party. If the competent person is in-house then the report should show they are independent from operations and have direct reporting to senior management.

Most of the information pertaining to the NDT applied and the use of the results in supporting the integrity of the plant will need to be gathered during the HSE follow up COMAH inspection on-site.

4. HSE follow up COMAH inspection

The HSE follow up COMAH inspection on site should be used to gather further information on the following NDT activities:

4.1 Justification of Examination Intervals

- The interval between examinations may be based on guidelines offered by such organisations as SAFed, CEOC and IoP.
- However, HSE interpretation of the legislation does not always agree with the advice given in these guidelines. Also, care is required when interpreting these guidelines for specific situations.

Investigate the justification of the examination intervals.

If standard guidelines have been used, look at the reasons for selecting the chosen periodicity and if these are compatible with the operating conditions of the plant.

A risk based inspection (RBI) approach may have been used as an alternative to fixed interval examinations.

In this case damage mechanisms for each plant item should have been established and the item categorised according to risk.

The NDT should then be targeted at the high/medium risk items with a view to reducing the probability of failure and hence the risk.

This process can reduce the amount of NDT required from that based on a fixed interval approach. However, it is then even more important that the correct NDT technique is used:

- to look for the required damage mechanism,
- that the NDT is correctly applied,
- that the capability is understood and
- the results are fed back into the RBI process.

HSE's Best Practice for risk-based inspection can be used for assessing the quality of the RBI process.

4.2 Management of NDT process

NDT needs to be managed correctly to ensure that the theoretical capability of the technique is not unduly impaired by incorrect or poor application. Companies should not only have procedures which cover the management and application of the NDT but also evidence that they are being implemented.

	Procedure
Assess the plant owners' attitude to NDT.	If it is not given sufficient consideration then it is unlikely to be planned properly, good access is unlikely to be provided and contractors are likely to be under undue pressure which will prevent them performing the NDT properly. This is discussed further under Management below.
Check whose quality system the NDT operators are supposed to be applying the NDT under: the plant owners' or the NDT companies'.	Check that this actually happens.
The results of a Non Destructive Test are dependent on the type of damage being sought and the particular NDT technique applied.	Check that the requirements for the NDT are specified and that the records provide sufficient information on what NDT technique was used and how it was applied. Is the technique likely to find the defects of concern and is the capability of the technique known? Further information on the various techniques is given below.
The HSE's Best Practice documents (ultrasonics, surface techniques) give guidance on assessing the role of the NDT and the effectiveness required of it in reducing the risk of component failure.	Where NDT plays a key role in assuring the safety of the component then additional steps should be taken to ensure that all the defects of concern are detected and that the NDT technique is applied correctly.
Finally the results of the NDT should be assessed and acted upon by the plant owner.	The presentation of the NDT results will often influence the subsequent actions. Some reports will just state no defects found or that the NDT was acceptable i.e. there were no indications observed above a certain acceptance criteria. Other computerised techniques allow apparently detailed, colour plots to be produced which create the impression of quality. Both these extremes can disguise the fact that the NDT may have had limitations in defect type detectable or that an insufficient sample area/volume may have been examined. The plant owner should be able to show how the assessment of the NDT results has taken into account the limitations and errors inherent in the technique applied.

These issues are covered by the questions in the Checklist designed to help in the HSE on-site COMAH inspection.

Small companies are likely to buy in the competent person expertise and place reliance on the 3rd party's expert judgement. The Operator should have the statutory records of inspection available, but may not have immediate access to additional information about the examinations or the competence of the 'competent person' organisation.

5. NDT process & management

5.1 NDT process

The start of any NDT process is the identification of plant items which require NDT.

- For pressure systems this will be detailed in the Written Scheme of Examination.
- For non-pressurised but hazardous plant this should be output from the systems which 'ensure that safety critical plant and systems are examined at appropriate intervals by a competent person'.

These two documents should also identify the damage mechanisms which could be expected to occur in the plant item and hence should be detected, if present, by the NDT technique. As with any other purchase or development (in line with ISO 9001) NDT should start with a specification of requirements. For NDT this is a defect specification or description, which includes:

- A description of the damage mechanism - location, type, morphology, orientation;
- Whether the volume or surface requires NDT;
- The size of defect which needs to be detected and the sizing errors that can be tolerated.

NDT can be applied without stating a particular defect to look for.

The defect description is then defined by the capabilities of the technique applied and the plant item can only be passed clean of defects detected by this technique.

Once the specification has been produced then the appropriate method and technique can be selected.

The NDT method should be specified in the Written Scheme of Examination, if relevant, or documented elsewhere.

All NDT should be applied under the control of a procedure which is produced and approved by competent personnel (see Management).

This is likely to be undertaken by the NDT company on behalf of the plant owner. The procedure, which may be supplemented by a plant specific technique sheet, should be sufficiently detailed to define the technique to be applied.

The NDT technique can then be applied by a competent person and the results reported. The report should highlight any restrictions in the application of the technique and should list any changes to the technique which were required by the particular application.

Radiography is a popular NDT technique because the radiographic films provide a hard copy of the results.

The results from large area NDT techniques such as corrosion mapping, floor scanners are often presented as colourful computerised plots. Although these visual outputs look impressive, they do not show the limitations in the technique and are not proof in themselves that the NDT was performed correctly.

NDT is only able to lead to a reduction in the probability of failure if appropriate action is taken in response to the results obtained.

If the result is no defects found, there may still be the need for action taking into account the capability of the NDT technique and the nature of defects which may not have been found.

Standards governing Manufacturing NDT often specify acceptance criteria in terms of the NDT measurement i.e. no indication longer than … or no signal with amplitude greater than…. This simplifies the assessment procedure and puts the responsibility of deciding whether a defect indication is acceptable or unacceptable on the NDT operator.

For in-service inspection, acceptance criteria are not as easy to define. If manufacturing acceptance criteria are used, it should be justified that these capture relevant degradation mechanisms which may be present in operational conditions. They should also be compatible with the both the plant item and the NDT technique used.

The results of NDT can be fed directly in to an Engineering Critical Assessment (ECA) so that the fitness for purpose of the plant can be assessed.

ECAs involve the solution of mathematical formulae and, as a consequence, answers are often quoted to a number of decimal places. However, the errors on the input information obtained from the NDT results are likely to be in the order of millimetres. It is important that the sizing errors in the NDT measurements are estimated and taken into account in the ECA.

A number of codes can be followed to assess flaws and degradation. Many codes that have been prepared take into account the accuracy of the NDT test methods, however, some do not and care should be taken when interpreting the results.

Two of the more important codes are:

- BS7910: 2000 (Guide on methods for assessing the acceptability of flaws in metallic structures) which superseded earlier standards, PD 6493: 1980 (Guidance on some methods for the derivation of acceptance levels for defects in fusion welded joints) and PD 6493:1991 (Guidance on methods for assessing the acceptability of flaws in fusion welded structures).
- API 579 (Recommended practice for fitness for service).

All inputs into the ECA should be justified:

- Have transients or worse case operating conditions been considered?
- Are the values for material properties correct?
- What assumptions have been made?

The output from the ECA will determine the course of action the plant owner should take.

If an RBI process is used then the results should be fed back into the risk assessment and appropriate changes made to the required action.

5.2 NDT management

Principle	Information
In order to have confidence in NDT results, it is important that the NDT, as a special process, is applied correctly and the capability of that process is known and understood.	This requires proper management and control. Plant owners who have a certified quality management system will have procedures to control the instigation and purchase of NDT activities. They may also have procedures to cover the application of the NDT although these will often be left to the NDT vendor.
In addition to a certified quality system, UKAS accreditation required to either BS EN ISO/IEC 17025 Testing or EN 45004 Inspection	Shows that NDT companies have the systems in place to adequately control the application of NDT.
However, site practice can be different from the documentation and the nature of NDT activities mean that they are not always subjected to the same control as is applied to other products and services.	Responsibility for the specification and control of the NDT is not always clearly defined between the plant owner and the NDT vendor. An ISO 9000 plant owner can hire in bodies from a UKAS accredited NDT vendor with the result that the operators work under neither quality system. Errors are common in unplanned NDT activities: operators performing a planned job may be asked to 'inspect this item whilst you are here'. In such a case the NDT performed is dependent on the operator's experience; its appropriateness and capabilities are not stated and records to allow future assessment or repetition may not be produced. The control of NDT is discussed in more detail in Best Practice documents for Ultrasonics and Surface Techniques, and Radiography.
NDT personnel are trained and certified under either a central certification scheme (e.g. PCN) or an employer based scheme (e.g. ASNT).	The requirements for centrally administered schemes are laid down in BS EN 473. Their employer should define their training in a written practice. Three levels of competency are defined: • Level 1 - qualified to carry out NDT operations according to written instructions under the supervision of Level 2 or Level 3 personnel. • Level 2 - have demonstrated competence to perform and supervise non-destructive testing according to established or recognised procedures. This includes the ability to define the limitations of application of the testing method and to translate NDT standards and specifications into NDT instructions.

	• Level 3 - qualified to direct any NDT operation for which they are certificated This is a supervisory qualification. Full details are given for the PCN scheme in the Best Practice documents for Ultrasonics, Surface Techniques, and Radiography.
Most NDT techniques require the operators to have good eyesight and to have it checked annually.	This is one aspect which can be overlooked with inevitable consequences for the quality of the NDT performed.
Site NDT should be under the supervision and support of a Level 3 operator and NDT procedures should be approved by Level 3 personnel, or equivalent.	Level 2 qualifications are specific to a NDT method and, in the case of ultrasonics, to a particular geometry. Generic qualifications such as PCN may need supplementation by job specific training for particular NDT technique applications. This was highlighted by HSE's PANI project which investigated the effectiveness of manual ultrasonics as applied on industrial plant.
Where a central certification scheme does not exist for a technique (which is the case for many but not all of the techniques listed under Other Techniques)	The NDT vendor should provide the plant owner with evidence to show that the personnel have sufficient experience and training in the application of that technique.
All NDT should be controlled by a procedure approved by a Level 3, or equivalent.	Some techniques such as magnetic particle inspection or dye penetrant inspection are simple to apply in principle and there is a temptation to just apply them without a procedure. Conversely operators who have a wide experience of the technique may apply advanced techniques and equipment and they may rely on that experience to adjust the many variables instead of recording them in a complete procedure.
NDT is often applied in compliance with a national or international standard.	It is not sufficient to state that a component was inspected in accordance with a standard. Most standards have options on various technique parameters and a procedure or technique sheet should be produced to state what values are to be used. Approval of the procedure by a Level 3 implies that the standard has been assessed in the light of the plant item to be inspected and found to be appropriate.
Some standards have been tried and tested over many years but the data and expertise on which they were based and which defines their capabilities and limitations is often not available.	The harmonisation of standards across Europe has produced many standards which do not yet have a track record to support them. An exception is the Magnetic Particle Standard: "Method for Magnetic particle flaw detection", British Standard BS 6072: 1981 where the supporting information is available as "Magnetic particle flaw detection. A guide to the principles and practice of applying magnetic particle flaw detection in accordance

with BS6072.", British Standard PD 6513: 1985.

NDT can be applied without a written procedure.

But only if all the parameters are recorded so that what has been applied can be subsequently assessed and if necessary repeated.

The HSE's Best Practice documents (ultrasonics, surface techniques) give guidance on assessing the role of the NDT and the effectiveness required of it in reducing the risk of component failure.

Where NDT plays a key role in guaranteeing the safety of the component, additional steps would be expected to be taken to improve the reliability of the NDT, to ensure that all the defects of concern are detected and that the NDT technique is applied correctly.

Such steps include:

- auditing the NDT with independent operators performing repeat NDT on a sample of the volume inspected;
- repeating all of the NDT with different personnel or with different NDT techniques;
- witnessing the inspection by independent third party;
- establishing capability through qualification.

The Best Practice documents also list other important measures that should be considered when looking to ensure a high reliability of inspection.

The capability of an NDT technique to detect and size specified defects can be assessed by the gathering of evidence based on physical reasoning, theoretical modelling, experimental work and previously published work.

This process is known as Inspection Qualification, Validation or Performance Demonstration. The amount of evidence gathered and assessed can be tailored to the importance of the NDT and so need not be prohibitive. Further information is given in the Best Practice documents for Ultrasonics, Surface Techniques, and Radiography.

6. Techniques and capabilities

- 6.1 Visual Inspection
- 6.2 Thickness Measurement
- 6.3 Defect Detection
- 6.4 Other Techniques
- 6.5 Common NDT Technique Trade Names

Detailed information on NDT techniques can be found elsewhere:

- Best Practice RBI document
- Or from The British Institute of Non-Destructive Testing

A brief summary is given below. Terminology other than that relating to specific techniques is given in the Terminology Section. In each section the information is presented in alphabetical order.

6.1 Visual inspection

The simplest and easiest technique to apply and often called by the generic term 'inspection' on process plant.

It is able to detect surface damage and distortion. However, access to the surface is required and the capability relies on the illumination and the eyesight of the inspector.

Many aids are available for visual inspection ranging from a magnifying glass through endoscopes and boroscopes which allow viewing of surfaces inaccessible to the eye alone, to fully remote computerised video systems. In the latter case as 'seeing is believing' care needs to be taken to ensure that the signal processing of the image does not hide any defects.

6.2 Thickness measurement

The commonest damage found on process plant is corrosion and so techniques which allow remaining wall thickness to be measured are widely applied.

Ultrasonics (high frequency sound) provides an accurate point measurement of wall thickness.

The surface on which the transducer is placed needs to be clean and, as it provides a point measurement, the measurement positions need to be selected with consideration of the type of corrosion damage so that the minimum wall thickness can be detected. When using a grid to survey a large surface area, the pitch of the grid needs to be selected so that it will detect the damage of concern.

Care needs to be taken when taking measurements on plant which is painted or coated to ensure that the measurement is just that of the remaining wall. Newer instruments have facilities to assist the operator in this task but older equipment require more care on the part of the operator.

Other thickness techniques include:

Flash Radiography, Magnetic Flux Leakage, Pulsed Eddy Currents and these are discussed below.

These techniques are more limited in their application by material type, accuracy of measurement, wall thickness or geometry than ultrasonics but offer other advantages such as speed of application or the ability to inspect under insulation.

6.3 Defect detection

Defect detection techniques fall into two categories:

- those that can only detect defects on or near to the surface of a component (Surface Techniques);
- those which can detect both surface and embedded defects (Volumetric Techniques).

Surface Techniques

- Dye Penetrant Inspection (PT)
- Eddy Currents
- Magnetic Particle Inspection (MPI or MT)

Dye Penetrant inspection (PT)

Dye is drawn into any surface breaking defects which are then highlighted by the application of a developer which draws the dye back out of the defect.

This NDT method can only detect defects which are open to the inspection surface.

Dye penetrant is the preferred surface technique for non-magnetic materials.

Dye penetrant is better suited to the detection of volumetric defects like pits but is more susceptible to the surface condition than magnetic particle inspection. Detection of tight cracks will require the dye to be left on the surface for a long time.

The component surface needs to be cleaned prior to the application of dye penetrant inspection.

Mechanical cleaning methods can lead to crack openings being closed, subsequently preventing detection. Care needs to be taken with any technique which requires the application of chemicals to plant to ensure that the chemicals are compatible with the plant material. It is particularly important that only chemicals with low halogen content are applied to stainless steel to avoid the initiation of stress corrosion cracking.

Fluorescent dyes are used to increase the contrast of indications making them more visible to the operator and hence increasing the sensitivity of the technique.

The HSE's Best Practice document on the procurement of Surface Techniques gives more details regarding dye penetrant inspection.

Eddy Currents

When an alternating current is passed through a coil close to a component surface, eddy currents are induced and produce a back EMF on the current in the coil.

Any defect in the component which restricts the eddy current flow alters the balance between the applied and back EMFs and can be detected.

The skin depth, which is a function of the permeability of the material and the frequency, determines the depth of penetration of the eddy currents.

In ferro-magnetic material the skin depth is very small and the technique will only detect surface breaking defects. In non-magnetic material it provides some sub-surface capability and can give some indication of the depth of a defect.

Eddy current techniques are widely applied in the NDT of heat exchanger tubing.

Magnetic Particle Inspection (MPI or MT)

Defects on the inspection surface interrupt the lines of magnetic flux.

Magnetic particles sprayed onto the surface are attracted to these defects identifying their position.

This NDT method only detects abrupt changes in the magnetic field and therefore only supplies capability for defects that break the inspection surface. Care needs to be taken to avoid false calls which may arise due to changes in geometry or the presence of residual magnetic fields.

Fluorescent magnetic inks are used to increase the contrast of indications making them more visible to the operator and hence increasing the sensitivity of the technique.

Magnetic particle inspection is generally the preferred NDT method for the detection of surface cracks in ferritic material. The HSE's Best Practice document on the procurement of Surface Techniques gives more details regarding magnetic particle inspection.

Volumetric techniques

- Radiography
- Ultrasonics

Radiography

Radiography is the detection of material loss by the variation in applied radiation, g or x-ray, passing through a component and impinging on a film.

As it is sensitive to material loss, radiography is better suited to the detection of volumetric defects such as slag or porosity. Detection of planar defects or cracks will depend on the gape or opening of these defects and the misorientation of the radiation beam from the axis of the defect. In many cases, cracks will not be detected.

Radiography is liked because it produces a hard copy of the results - the film. It is unable to provide depth information regarding defects without additional specialist techniques (eg profile radiography may give depth information on large volume defects).

Defects are identified by abrupt changes in the density of the developed film: the film density is related to the exposure it has received from the radiation.

The gradient of the curve of density against exposure determines how visible are small changes in exposure. Such changes can arise from the presence of defects and so the ability to detect them through changes in film density is of prime importance.

This characteristic of the film is its contrast. Contrast tends to increase with film density and so high densities are beneficial in the detection of defects. However, viewing high density films requires good lighting conditions such as high light intensity, low background light and film masking and there are practical limits on the level to which density can be increased because of the reduction in transmitted light intensity. Density in the range 2.0 - 3.0 is usually regarded as representing the best compromise between contrast and viewing requirements.

Image quality indicators (IQI) are commonly of the wire type, comprising straight wires of differing diameters sealed in a plastic envelope, or ones which use holes or steps in a block of metal.

The IQI is placed on the object under test and imaged when the radiograph is taken. The smallest wire diameter, hole diameter or step that is visible on the radiograph then gives a guide to the sensitivity achieved.

The IQI type and its position are specified in the appropriate radiographic standard. It should be recognised that the sensitivity established by an IQI relates only to the ability to detect changes in section, wire size etc. This sensitivity is only indirectly related to defect detectability.

The HSE's main concerns are that a significant number of NDT contractors fail to adopt routine working practices capable of keeping radiation exposures of employees as low as reasonably practicable.

Incidents occur because of poor job planning (most notably with site radiography); failure to use adequate local source shielding (collimation); or inadequate systems of work.

The quality and sensitivity of a radiograph are measured by the density of the film and the use of an IQI.

The HSE’s information document on the Procurement of Radiography gives more details on the technique.

Industrial Radiography is covered by the Ionising Radiations Regulations 1999 (IRR99) which mostly came into force on 1 January 2000. Information regarding the requirements of the regulations is available from the HSE website.

Ultrasonics

Ultrasonics is the use of high frequency sound waves in a similar manner to sonar or radar: sound pulses are reflected from interfaces or discontinuities.

In thickness checking the reflections from the wall surfaces are measured. In defect detection reflections from cracks, voids and inclusions are detected and assessed.

The transfer of sound from the ultrasonic probe to the component requires a coupling medium, which is usually water or gel. The condition of the interface determines how much sound is transferred into the component, how much is scattered and how much noise is produced.

Ultrasonics requires a relatively good surface finish.

Manual application over a large area is relatively slow and the technique needs to be tailored to the defects requiring detection. However, ultrasonics is able to provide both length and through wall size information.

Some materials such as corrosion-resistant alloys (eg high nickel alloys and austenitic steels) cause additional problems for ultrasonics and require special techniques and appropriately trained personnel.

Ultrasonics can be automated and hard copy results produced.

6.4 Other techniques (in alphabetical order)

- AC-FM - Alternating Current Field Measurement
- Acoustic Emission
- Creep waves
- Digital Filmless Radiography
- Flash Radiography
- Leak Testing
- Long Range Ultrasonics
- Magnetic Flux Leakage (MFL)
- Phased Array Inspection
- Pressure Testing
- Pulsed Eddy Currents
- Radioscopy
- Remote Field Eddy Currents
- Replication
- Shearography
- Time of Flight Diffraction. TOFD
- Thermography

AC-FM - Alternating Current Field Measurement

This is a non-contacting electromagnetic technique which is used as a surface defect detection alternative to magnetic particle and dye penetrant inspections in conducting materials.

A uniform electric current is induced into the material to be inspected which produces a magnetic field which in turn will be disturbed and flow around the edges of a defect if present. The probes are constructed in order to detect these magnetic field disturbances. Software algorithms allow an estimate of crack depth and crack length to be obtained.

The technique is capable of detecting sub-surface defects on non-magnetic materials.

It can cope with poor surfaces and can test through coatings. However, it requires skilled operators to apply it correctly.

Acoustic Emission

A passive technique in which an array of acoustic sensors are attached around the plant item under test.

Signals originating in the plant item, which are above a specified amplitude threshold, are recorded. Signals from crack propagation, corrosion products and leaks may be identified and located by triangulation.

A common application is in monitoring above ground storage tanks with the sound being generated by the spalling of corrosion products.

This is not a quantitative technique but gives a qualitative assessment of the condition of the tank.

When acoustic emission is used to detect crack growth it faces the challenge of detecting the signal generated by the growth in the presence of operating noise.

Operational noise may not be present when conducting a hydraulic test but the stresses seen by the plant item may be quite different to those seen in service.

Creep waves

This technique is another type of ultrasonic wave which travels along the surface of a component.

As it propagates it converts to a mode which travels into the component at an angle to the surface. This latter wave will convert back to a surface wave if it hits a surface parallel to the surface on which it originated.

The technique is often used for the detection of near surface defects as a complement to the time of flight technique.

Digital Filmless Radiography

Industrial radiography using computer based or "filmless" radiography systems can collect and analyse radiographic data, completely replacing conventional film.

Applications include process corrosion detection and measurement, particularly under insulation and coatings on process pipework.

This technology complements non-projection systems like SCAR to provide a safe, rapid inspection. The system uses flexible, re-usable phosphor plates to capture images. The exposed plate is processed through a laser scanner, delivering the image to a high resolution mono-monitor. After scanning the plate, the digital image is interpreted, reported and digitally stored for future retrieval and analysis.

The flexibility of this approach means that extra control is required of the process to ensure radiographs are traceable and not distorted, deleted or over-written.

Flash Radiography

Originally developed to image rapidly moving dynamic events, flash radiography has found application in the detection of corrosion on pipe outside diameters under insulation.

It is normally applied to pipes up to 12" OD but can be applied to items with diameters up to one meter given sufficient source to film distance and radiation output. The technique uses x-ray equipment with a low radiation exposure time, fast x-ray films and intensifying screens, or digital detection media. It saves costs normally attributed to the removal and re-instatement of insulation and associated scaffolding.

The beam is arranged tangentially to the pipe wall and corrosion of the external wall shows up as a variation in the profile of the pipe.

It can also identify where lagging has become waterlogged. Contrast and resolution of the image are not as good as that for conventional radiography because of the limited radiation available, the large grain film and the relatively large focal spot of the sources.

Recent developments have complemented flash radiography.

These involve hand held radiographic systems using a source such Gadolinium-153 in combination with solid-state scintillator which converts the X-rays into electrons. The quality and output of the source determines the maximum length of the beam path in the lagging when looking for under lagging corrosion. Special Gadolinium-153 equipment can allow measurement of pipe wall thickness when shot through the centre of the pipe. The limitations with regard to pipe and lagging diameter will depend on the particular instrument used, notably the length of the fixed arm holding the source opposite the detector and should be known by the NDT vendor.

Leak Testing

This covers a variety of techniques which are used to identify leakage paths through containment.

They include:

- Direct Bubble test - like mending a bike tyre.
- Vacuum Box - a local vacuum is drawn over a small area in the containment. Any leakage path will prevent a full vacuum.
- Tracer Gas Detection - relies on the detection of a tracer gas such as helium or a halogen gas. These techniques are semi-quantitative methods that detect the flow of the tracer gas across a boundary.
- Pressure Change Test - detection of a leak by the monitoring of absolute pressure, pressure hold, pressure loss, pressure rise, pressure decay or vacuum retention.

Long range ultrasonics

This technique has found its main application in pipe NDT.

A particular type of sound wave, Lamb waves, are generated in the pipe wall which acts as a cylindrical wave guide allowing propagation ranges of up to 50 m to be obtained. The waves are reflected back from features including wall loss defects. The frequency is less than that used in conventional ultrasonics at kHz rather than MHz. Interpretation of the signals is complicated because of the different modes of Lamb wave which propagate. The technique is generally used as a screening tool to identify areas worth more detailed NDT with alternative techniques.

Magnetic Flux Leakage (MFL)

This technique relies on the detection of the magnetic flux, which is 'squeezed' out of the metal wall under test by any decrease in the wall thickness.

In order to achieve this, the component wall needs to be close to magnetic saturation. The amplitude of the signal obtained from any wall loss is proportional to the volume that is missing from the region interrogated. This means that the amplitude does not necessarily correspond to the decrease in thickness of the wall. The technique is not able to discriminate between material loss on the near surface and material loss on the far surface.

Surface roughness, surface corrosion, distortion, build up of debris on the magnets and any physical disturbance of the scanning system as it moves across the component will adversely affect the results.

MFL is a qualitative technique and is unable to give an accurate assessment of the remaining wall.

It has found wide use in the NDT of tank floors because it is quick to apply and can detect material loss on both surfaces of the floor. The requirement for the sensor to be placed between the poles of a magnet mean that the technique is unable to give 100% coverage of a floor up to vertical obstructions and side walls. The wall thickness that can be inspected by magnetic flux leakage is limited by the requirement to achieve magnetic saturation.

The high level of set up effort makes the technique susceptible to human error. Procedures need to be clear and sufficiently detailed and operators need to be qualified and experienced in the application of the technique.

Phased array inspection

Technology advances in materials and computers have made it possible for ultrasonic phased array transducers to be manufactured in a similar sized case to conventional transducers.

A phased array transducer enables the ultrasonic beam to be electronically focussed or swept in angle along the length of the array. One phased array transducer can therefore take the place of a number of conventional transducers or reduce the scanning requirement for the transducer.

This is new and advanced technique and operators need training and experience of the technique additional to the conventional ultrasonic qualifications.

Pressure testing

Pressure testing is normally a requirement of design codes and is performed at the start of life and subsequently. It is not always a non-destructive test.

It involves the over pressurisation of a plant item (typically 10 to 50 % over the design operating pressure) with a fluid to see if it is able to withstand the applied stress. A pneumatic test carries more danger than a hydraulic test, releasing 200 times more energy should anything go wrong.

Arguments for and against pressure testing are complex and beyond the scope of this document.

The test may be complemented by the application of acoustic emission with the objective of trying to detect any crack growth, which may be generated during the test.

HSE have a Guidance Note GS4 on Safety in Pressure Testing, which is supported by Contract Research Report CRR168: "Pressure Test Safety", 1998.

Pulsed Eddy currents

This is a technique for detecting corrosion and erosion and measuring average remaining wall.

Unlike ultrasonic thickness measurement it measures average wall loss over an area (footprint).

A transmitter coil produces a magnetic pulse which induces eddy currents within the component wall.

The eddy currents in turn produce a second magnetic pulse which is detected by the receiving coil. The system monitors the rate of decay of the eddy current pulse within the steel wall. The average thickness is derived from the comparison of the transient time of certain signal features with signals from known calibration pieces.

It is important that the operator is given information regarding the component to allow the NDT equipment to be set up correctly and the results to be accurately interpreted.

This technique is quick to apply, can test through non-conductive and non-magnetic material (passive fire protection, concrete) up to 100 mm thick. It is only suitable for low alloy steels and is unable to differentiate defects on the top and bottom surfaces.

Radioscopy

Radioscopy is a digital version of radiography.

The image is produced on a radiation detector such as a fluorescent screen, rather than film, and is then displayed on a television or computer screen. Often such systems work in real time and can provide continuous NDT of objects. The recent advances in detectors and computer technology mean that these systems can offer advantages over the conventional film NDT technique.

Remote Field Eddy currents

This technique provides an alternative to eddy current NDT for ferro-magnetic tube inspection.

The technique monitors the magnetic field produced by induced eddy currents at some distance from the exciting coil. The system gives poorer resolution and has a lower test speed than a high frequency eddy current test. The technique is highly sensitive to gradual wall thinning but detection of localised thinning requires special probes and electronic control.

Replication

This involves the application of a temporarily softened plastic film onto the prepared surface of the item under test so that the surface profile is imprinted into the film.

The film is then removed and examined under a microscope. Details such as cracks, surface inclusions and microstructure can then be observed remotely from the plant item. A hard copy of the results is also obtained.

Shearography

Shearography is used for detection and characterisation of delaminations, debonds, and other defects in fibre reinforced composites, rubber, and rubber/metal parts.

Comparison of two sets of laser images produced before and after the application of a load (thermal, tensile, pressure, vibratory) that causes the item under test to deform allows calculation of relative deformation at each point on the object and highlights local variations in surface deflection. Local variations are characteristic of the defects such as delaminations and debonds.

Time of Flight Diffraction. TOFD

This is an ultrasonic technique which uses the diffracted wave produced by the edge of a planar defect to detect and size such defects.

Sizing can be accurate as the time difference between the signals obtained from the top and bottom edges is used to predict the size. TOFD requires two ultrasonic probes acting as transmitter and receiver to be scanned as a pair either side of a weld.

It is relatively quick to apply compared to the conventional manual pulse echo techniques and a hard copy image can be produced. As a consequence TOFD is replacing radiography as a preferred weld NDT technique.

However, TOFD has a number of drawbacks which need to be considered:

- The diffracted tip wave is relatively small in amplitude so the sensitivity of the NDT needs to be high which can then lead to false calls;
- Other techniques need to be applied to cover the near surface region;
- As the weld thickness increases so does the number of probe separations which are required to cover the inspection volume;
- The technique requires optimisation for the defects of concern;
- Skilled operators are required to operate the equipment and interpret the images.

Thermography

An infrared camera or monitor is used to observe the actual temperature, or the variation over an area, of the surface of a plant item.

Variations in heat transfer through the wall may be attributable to wall thinning or the build up of scale. It may indicate the presence of wet insulation and the potential conditions for corrosion under insulation (CUI).

Alternatively, a heat source can be used to heat the surface and the dispersion of the heat observed.

Unexpected changes in the heat flow can be used to identify defects.

For containers containing hot or cold liquid it is possible to observe the level of the liquid in the item non-invasively.

The size of defect which can be detected will depend upon the optical parameters of the system and the resolution of the camera. In assessing the results the emissivity of any paints or coatings on the component need to be considered. Reflections of sunlight can also distort readings.

The technique is non-contacting and only line of sight to the surface under examination is required. It is quick and easy to apply but can only detect defects and or faults which cause a change in heat flow or the surface temperature of the item.

6.5 Common trade names

Fleximat

> This is a thin flexible strip containing an array of ultrasonic transducers which can be permanently bonded to a component to provide continuous corrosion monitoring of fixed locations.

Internal Rotary Inspection System - IRIS

> An ultrasonic technique for the NDT of boiler and heat exchanger tubes consisting of a high frequency ultrasonic immersion probe inside a rotating test head. The system provides coverage of the full circumference and full wall thickness as the probe is scanned axially along the tube. The head can be modified for defect detection if required.

LORUS

> This is an ultrasonic technique which relies on bulk waves and was designed specifically for interrogating the plate under the shell on the annular ring of an above ground storage tank. The probe does not need to be scanned backwards and forwards and so is suitable for use on the restricted surface available on the annular ring.
>
> The sound floods the plate as it travels and is reflected from corrosion defects on the top or bottom surface. The working range is about 1 m but as the plate is flooded with sound it is unable to discriminate between top and bottom defects.

Note: Although the acronym, LORUS, is derived from Long Range Ultrasonic System, when compared to more recent techniques referred to as long-range ultrasonics, the LORUS technique can only be considered medium range (typically up to 1m).

Saturation Low Frequency Eddy Current - SLOFEC

The (SLOFECÔ) technique is very similar to the magnetic flux leakage technique. However, instead of detecting the flux leakage with a passive coil or a hall effect sensor, the SLOFEC technique has an eddy current sensor.

The fact that the eddy currents are used to sense the distortion of the magnetic field in a layer close to the surface of the component means that this NDT system is able to inspect a greater wall thickness and also able to cope with thicker non-magnetic coatings than the magnetic flux leakage NDT system.

When the equipment is used on non-magnetic stainless steels the detection technique becomes solely an eddy current NDT technique.

Small Controlled Area Radiography - SCAR

This is a proprietary radiographic system which operates in a more controlled manner and hence a much smaller area than traditional radiography. Proper application of the system will reduce the controlled area to typically within 3 metres of the emission point. This has the advantages of minimal disruption to adjacent work areas and of reduced dose rates to classified workers

7. Checklist for the HSE Inspection of NDT

This checklist covers the whole NDT process from planning through to assessment of results. It is unlikely to be necessary to apply the checklist from start to finish. It is more likely that specific areas of concern or criticality will need to be selected and addressed. Bold comments help to direct the questions and interpret the answers.

7.1 NDT planning

Identification of plant items which require NDT.

Scope

Is the plant governed by Pressure Systems Regulations?

- If so is there a Written Scheme of Examination for each plant item?

Does the plant contain non-pressure but hazardous fluid?

- If so is it examined at appropriate intervals by a competent person?

Is speculative NDT performed to identify unexpected damage mechanisms?

The defect description will be defined by the capabilities of the technique applied.

The plant item can only be passed clean of defects meeting this capability.

Periodicity of NDT

What are the examination intervals?

What is the justification for the examination intervals?

If standard guidelines:

- What are the reasons for selecting the chosen periodicity?
- Are these are compatible with the operating conditions?

If RBI:

- What are the damage mechanisms for each plant item?
- What is the risk category?
- If High/Medium, is NDT used to reduce risk?
- Are the results fed back into the RBI process?
- If so have appropriate changes been made to the required action?

7.2 Management of NDT process

Plant owners' attitude to NDT.

Is there sufficient independence between the NDT activity and production/operations functions?

Does the NDT play a key role in assuring the safety of the component?

Are additional steps taken:

- To improve the reliability?
- To ensure that all the defects of concern are detected?
- To ensure NDT technique is applied correctly?

Is the plant owner aware of the limitations and capability of NDT?

Is the quality of the results checked in any way?

Does the plant owner act on the results?

Is the plant owner an informed customer?

Q.A.

Is there a certified quality management system?

Are there procedures to control the instigation and purchase of NDT activities?

Are there procedures which cover the management and application of the NDT?

Is the responsibility for the specification and control of the NDT clearly defined between the plant owner and the NDT vendor?

Is there a system for maintaining inspections records?

Whose quality system are the NDT operators applying the NDT under (the plant owners' or the NDT companies')?

Are the NDT companies UKAS accredited to either BS EN ISO/IEC 17025 Testing or BS EN 45004 Inspection?

7.3 NDT Inspection management

Specification

Is there a specification of requirements or defect description?

This should include:

- Location, type, morphology, orientation;
- Volume or surface that requires NDT;
- The size of defect which needs to be detected;
- The sizing errors that can be tolerated.

Is the NDT in compliance with a national or international standard?

Approval of the procedure by a Level 3 operator implies that the relevance of the standard has been assessed for the plant item to be inspected and found to be appropriate.

For pressure systems the NDT method should be specified in the Written Scheme of Examination.

NDT Procedures

Is there evidence of procedures to cover the application of the NDT?

Whose are they [Plant Owners'? NDT vendor?]

Does this match up with the division of responsibilities?

Does a Level 3 approve the procedures?

Is the procedure, which may be supplemented by a plant specific technique sheet, sufficiently detailed to define the technique to be applied?

Is there evidence that the QA & NDT procedures are being implemented?

Practice can be different from the documentation.

Implementation

What additional steps have been taken:

- To improve the reliability?

e.g. different NDT techniques, repeat independent inspections or repeating all of the NDT with different personnel or with different NDT techniques.

- To ensure that all the defects of concern are detected?

e.g. capability established through qualification or auditing with independent operators repeating sample of volume inspected.

- To ensure NDT technique is applied correctly?

e.g. witnessing the inspection by independent third party, audits or measures listed in the Best Practice document.

Are NDT personnel trained and certified?

(e.g. either a central certification scheme such as PCN or employer based such as ASNT)

Is the site NDT under supervision and support of a Level 3 operator?

Are PCN qualifications supplemented by job specific training for particular NDT technique applications?

Where a central certification scheme does not exist for the technique, can the NDT vendor or the plant owner show evidence that the personnel have sufficient experience and training in the application of the technique?

Results

Do reports highlight any restrictions in the application of the technique?

Do they list any changes to the techniques which were required by the particular application?

Are sufficient parameters recorded so that what has been applied can be subsequently assessed and if necessary repeated?

Are the sizing errors in the NDT measurements estimated?

Is appropriate action taken in response to the results obtained?

If the result is no defects found, there may still be the need for action taking into account the capability of the NDT technique and the nature of defects which may not have been found.

Assessment of Results

How are the NDT results assessed?

Acceptance criteria

If manufacturing acceptance criteria are used is there justification for using them?

Are they compatible with the both the plant item and the NDT technique used?

Engineering Critical Assessment (ECA)

Has the assessment of the NDT results taken into account the limitations and errors inherent in the technique applied?

The HSE's information document on Sizing Errors and their Implication for Defect Assessment gives more details.

Has a code been followed to assess flaws and degradation?

(BS7910: 2000 / PD 6493: 1980 / PD 6493:1991 / API 579)

Does the code take into account the accuracy of the NDT test methods?

If not what care is taken when interpreting the results?

All inputs into the ECA should be justified.

Have transients or worse case operating conditions been considered?

Are the values for material properties correct?

What assumptions been made?

8. Terminology & current trends

Testing is the generic term given to a measurement of a property or the performance of an item to assess whether it is fit for purpose.

Inspection is also a generic term but on process plant it is used in relation to the visual assessment of plant condition.

Non-invasive inspections

Inspection	Details
Inspecting vessels for possible internal degradation has traditionally been performed from the internal surface, e.g. by visual	This can incur very high costs associated with releasing and emptying the vessel, isolating it and preparing for it for entry. The mechanical disturbances involved in preparing the tank for internal NDT and reinstating it may on

inspection.	occasions adversely affect future performance of the tank. Also, the environment within the empty tank may be hazardous for man access requiring additional precautions to be taken for working in the confined space.
	If they are applied in lieu of internal NDT then evidence should be provided to show that they are capable of achieving the same detection and sizing requirements. This may be in the form of results from both previous invasive and non-invasive inspections showing good correlation or a report on the capability of the non-invasive inspection which can be compared with previous invasive results.
NDT performed from the outside of the vessel, i.e. non-invasively, without breaking the containment have the potential to reduce operating costs significantly.	Alternatively, non-invasive NDT can be applied in addition to the internal NDT prior to an outage and during short shutdowns to assist in the planning of internal NDT or to provide immediate information on an identified potential problem with the minimum of interference with other operations.
	Non-invasive NDT techniques are more complex than the internal NDT techniques and so require better planning, QA and project management procedures. It is important to state the objectives of the non-invasive inspection as this is likely to have an impact on the approach to the NDT.
HOIS2000 and Mitsui Babcock have carried out two research projects into non-invasive inspection.	The HOIS project produced a decision tree to establish if non-invasive inspection was acceptable, and the Mitsui Babcock project detailed the requirement to ensure satisfactory inspection. Results from both of these projects are being reviewed by HSE prior to being recognised as 'Good Practice' documents.

Risk Based Inspection

Risk based inspection is the definition of the NDT requirements based on the risk posed by a particular plant item.

When implementing a risk based approach, safety concerns need to take precedence over other influences such as business interruption and loss of earnings. The RBI approach identifies the potential damage mechanisms and the required interval of inspection: high-risk items requiring frequent NDT; low risk items requiring infrequent or no NDT. This contrasts with the statutory approach of standard fixed inspection intervals irrespective of risk of failure.

To use this approach the plant Operator needs to demonstrate that the risk assessment and NDT planning processes are being implemented in an effective and appropriate manner.

The risk-based approach requires that the quality and veracity of the information is tested and validated.

Information on integrity of plant can be generated from the design, operational experience and NDT records, and from sound knowledge of the deterioration mechanisms and the rate at which deterioration will proceed. The approach is unreliable when there is lack of, or uncertainty in, the key information required to assess integrity.

NDT can then be planned at appropriate intervals using NDT methods that are able to detect the type and level of deterioration anticipated in order to allow an assessment of the current and future fitness-for-service to be made.

Sample inspections

Rather than applying NDT to the total length of welds or number of components, NDT costs can be reduced by inspecting a reduced percentage or sample of the items.

Often a figure of 10% is used. This doesn't necessarily have any scientific basis but is seen as being a reasonable amount without incurring undue cost. Such an approach is only viable if the results from the 10% inspected can be legitimately extrapolated to the 90% which wasn't inspected. i.e. if the damage mechanism is equally likely to occur in all of the 100% and if it can be justifiably assumed that if no defects are found in the 10% examined then there will be no defects in the remaining 90%.

This approach is not applicable if the damage can occur preferentially in one area over another or if random defects can occur.

9. Case studies

NDT Case study 1

A process plant contained two stainless steel vessels which had been operating for 21 years. The contents of the vessels were flammable, mildly toxic and contained 500 ppm of chlorides. The vessels were operated from full vacuum up to 15 psi for 20 cycles per day. They contained an agitator which was used in part of the process. Both vessels had been hydraulically tested to 70 psi when new but had not been subjected to a test since.

The company philosophy was 'Leak before break' but they didn't think that stainless steel would break. No leak detection equipment had been installed and reliance was placed on plant operators noticing the smell or observing drips.

The plant owners hired a Competent Person from a large insurance company who produced the Written Scheme of Examination (WSE) for the vessels. There was no evidence of shared decision making between the plant owner and the insurance company. A generic WSE was put into use. This followed SAFED guidelines on periodicity of inspection which was specified as:

External visual examination supplemented by a hammer test every 2 years.

Was this suitable?

The combination of stainless steel and chlorides immediately raises concerns regarding the possibility of stress corrosion cracking. Whilst the cracks were likely to initiate on the inner surface an external examination could detect the presence of through wall cracks. However, stress corrosion cracks can be very tight and difficult to see with the naked eye. The hammer test offers no benefit - who knows what a good vessel should sound like!

During a thorough examination of one of the vessels the Competent Person called for a small welded repair to an external weld and for this to be followed by a hydraulic test. The vessel developed leaks at 40 psi. Further investigation of the vessel found thousands of through wall cracks. The vessel had not leaked in service because the contents were too viscous to pass through the tight stress corrosion cracks.

The competent person modified the WSE for the 2nd vessel:

- Yearly examination instead of 2 yearly.
- Addition of internal examination from the access way.
- Addition of internal dye penetrant examination using red dye on 10% of welds.

Was this suitable?

The Internal inspection would be carried out from the small access way with agitator still in place.

The failed vessel had shown most throughwall cracks in base. This region could not be inspected on the second vessel from the access way.

Inspection of 10% of welds.

The failed vessel showed through cracks on parent plate and most welds. There was no justification for limiting the inspection to welds only and for just inspecting 10% of them.

Dye Penetrant Inspection using red dye.

With the cracking on the internal surface there was a chance that the cracks may have been filled with product and if this had been the case dye penetrant inspection would not have been effective.

Stress corrosion cracking can be tight and if so the dye penetrant indications would not reveal the defects. Fluorescent dyes give a higher sensitivity and would give much better results in the confined, dark space of the vessel.

Regulation 9 of The Pressure Systems Safety Regulations 2000 requires that a competent person examines those parts of the pressure system included in the scheme of examination within the intervals specified in the scheme. The actions above raise the question of how competent was the competent person? Did they understand the damage mechanisms and the detection requirements?

The competent person, who was independent from the plant owner, did not involve their company NDT expert in amending the WSE. When the expert was finally consulted they estimated that the probability of detection, using the method stated, was less than 30%. In limiting the inspection to just 10% of the welds then the overall probability of detecting a crack in a weld was just 3%. This is unacceptably low. A probability of detection of only 50% may be acceptable for a regularly applied, non-critical inspection whilst for a highly critical inspection the probability of detection would need to be up near 95%.

However, the examination of the second vessel did find two incidences of stress corrosion cracking (SCC): one around the access way nozzle and a star crack in the plate. The nozzle was repaired by welding and the vessel was hydraulically tested to 60 psi. The star crack was to be monitored at the next inspection in a year's time. No further review of WSE was performed and the vessel was put back into service. The Competent person who put the vessel back into service was not the regular surveyor for the site and it raises the question of whether they fully understood the process.

When the poor inspection and quick return to service was questioned the following excuses were offered:

- The client needed the vessel back as quickly as possible.
- We worked day and night for 2 days.
- We have never seen this problem before.
- We follow SAFed guidelines.
- There is no better way to inspect this type of vessel.

Conclusions

- The client placed a high dependency on the competent person to satisfy the 'sufficient' aspect of the WSE.
- The Competent Person may not have understood the process.
- When part of a large company, the Competent Person system relies on the surveyor feeding back information to Head Office which they will not be able to do if they lack understanding.
- The client imposed time pressures on the Competent Person.
- The Competent Person had access to experts in various disciplines but these were not used.
- The initial WSE was poorly thought out.
- The final WSE was even more poorly thought out.
- No attempt was made to estimate critical crack sizes or growth rates and the NDT selected did not have a capability for measuring defect through wall size.

Finally, just because a leading competent person certifies the WSE it does not mean that it is sufficient: the WSE should be scrutinised and the contents challenged wherever there is doubt on their suitability.

NDT case study 2

A number of large LPG storage vessels were due for their first thorough examination after 10 years of use. The vessels had been designed and constructed to BS 5500 Class 1, with radiography used for the detection of volumetric defects. The size of these vessels required that they were site constructed. Site manufacture has the disadvantage that welding and inspection is open to the weather, and in similar vessels Fabrication Hydrogen Cracking (FHC) has occurred, which is very difficult to detect with radiography.

The Operator and Competent Person wished to change the inspection strategy to non-invasive inspection to prevent disruption to operation. The period between inspections was not to be altered.

It has been standard practice to inspect such vessels from the inside. Applying NDT from the outside surface i.e. non-invasively can offer cost savings. However, it is important to ensure that the external inspection achieves the desired detection capability. A relevant joint industry research project (phase 1) had concluded that non-invasive inspection is best used where there was a history of invasive inspections to enable a comparison of the results of the two methods to be made.

In this case there was no previous history, but the Operator had similar vessels on other sites, so considered that they had previous experience in damage mechanisms that could occur.

Was this suitable?

In addition to checking for in-service degradation, the first in-service inspection is also used to show that there are no defects in the vessel which were missed by the manufacturing inspections which could give rise to integrity problems. The competent person and Operator offered no evidence to show that the non-invasive inspection was fit for purpose: there were no results from previous invasive inspections to use as a bench mark; there was no evidence to show that the non-invasive inspection techniques to be used would give the same detection capability as an invasive inspection; no evidence was provided to show that any Fabrication Hydrogen Cracking not detected during manufacture would be detected in the in-service inspection.

The Operator carried out a number of studies to address these concerns. A detailed study of the LPG supply chain was carried out to evaluate if any hydrogen sulphide or other trace components could have been present, which could give additional damage mechanisms.

A test piece was manufactured, to simulate the main weld of the vessels with a number of defects representing in-service defects and FHC. A number of NDT techniques were applied to the test piece, and manual ultrasonic inspection gave the best results. An operator was then qualified on the test piece.

To evaluate the critical crack size, Engineering Critical Assessments were carried out on the vessels. The ECAs assumed the fracture toughness of the material. As the material had a specified Charpy value at -50^{o}C, this value was converted to a fracture toughness and used for the low temperature analysis. A LPG vessel is required to operate though a specific temperature range specified in the LPGA Code of Practice, so assessments had to be made of the tolerable defect size at different temperatures and pressures. The fracture toughness at other temperatures was taken from very limited data available from The Welding Institute. The size of the tolerable defect was quite small, but the NDT trials had demonstrated that defects half the tolerable size could be detected.

A trial inspection was carried out on the smallest vessel. To obtain access to the vessel welds a mobile platform was used, with a target set for inspection of 10% of the weld, in the hope that a greater coverage could be obtained in the period that the mobile platform was available. In addition magnetic particle inspection was to be carried out in the regions of the support legs.

The inspection was carried out in high winds, and the platform was not available for use on two of the days. Only 10 % of the weld length was inspected. The results for the inspection identified a number of planar defects which exceeded the manufacturing ultrasonic acceptance criteria, but were smaller than the maximum allowable size.

Was this suitable?

The NDT of the vessel was performed from a mobile platform in windy conditions.

While the wind speed allowed the inspection to be carried out on 3 days, NDT requires a stable work platform to ensure reliable results.

The ECA was based on material assumptions which had limited validity. The fracture toughness was based on measurements on the parent plate and was then used for the low temperature assessment. For the assessments carried out at different temperatures, parent plate data was taken from a limited database, but, to be conservative, a lower bound value should have been used. If FHC had occurred it would have been in the heat affected zone of the weld, which the work did not address.

Inspection on the other vessels used mechanised ultrasonic inspection, which was not affected by wind, and provided inspection data to a computer, which was analysed later. Only 10% of the weld length was inspected on each vessel. In one case the defect was sized at 4 mm high, compared with the maximum tolerable defect height of 6 mm.

Was this suitable?

The use of mechanised ultrasonic testing was a considerable improvement over the manual technique. However, no allowance was made for the sizing errors of the inspection. The sizing accuracy of the mechanised ultrasonic inspection would have been +/- 2 mm. This means that the 4 mm defects detected could have actually been at the maximum tolerable size of 6 mm. No justification was given for limiting the inspection to 10 % coverage of the weld and this was not extended even when defects near the tolerable size had been detected.

Conclusions

- The Competent Person changed the inspection strategy to non-invasive inspection without the benefit of information from prior invasive inspection or other evidence to justify the decision.
- By use of a test specimen it was demonstrated that the intended non-invasive NDT technique was capable of detecting and sizing in-service and manufacturing defects.
- With no prior inspection data available, inspecting only 10% of the weld does not give a strong demonstration of the vessel integrity. Having detected defects that were on the limit of the tolerable size, increased coverage should have been carried out.
- Allowance should have been made for the sizing error of the NDT technique, and the acceptance criteria set accordingly.
- The ECAs did not use lower bound material properties that may have been present in the welds.

10. Guidance and codes of Practice relating to inspection/NDT

Please note that references quoted are current at June 2003: the originating organisation should be contacted to establish the status and current version.

There are many guides and codes of practice relating to inspection and NDT. These include:

Acceptance Standards and ECA

- BS EN 25817: 1992, ISO 5817:1992, Arc Welded joints in steel. Guidance on quality levels for imperfections.
- BS 7910: 1999, Guide on methods for assessing the acceptability of flaws in metallic structures.

Accreditation

- BS EN 45004:1995, General criteria for the operation of various types of bodies performing inspection.

Personnel qualification

- BS EN 473:2000, Non-destructive testing. Qualification and certification of NDT personnel. General principles
- ISO 9712: 1999 Non-destructive testing - Qualification and certification of personnel.
- PCN/GEN/2000, General requirements for qualification and certification of personnel engaged in Non-destructive testing, BINDT.

Inspection techniques

- BS EN 1714: 1998, Non-destructive examination of welded joints - Ultrasonic examination of welded joints.
- BS EN 1435:1997, Non-destructive testing of welds - Radiographic testing of welded joints
- BS EN 571-1 1997 Non-destructive testing. Penetrant testing. General principles
- BS EN 1290 1998 Non destructive examination of welds: Magnetic particle examination of welds: Method

Information regarding these British Standards can be obtained from the BSI web Site.

American Petroleum Institute guides.

- API 510 Pressure vessel inspection code: Maintenance inspection, rating, repair, and alteration
- API RP 572 Inspection of pressure vessels,
- API RP 576 Inspection of pressure-relieving devices
- API 579 Recommended Practice for Fitness for Service

[Energy Institute](#)

- Institute of Petroleum, Model Code of Safe Practice for the Petroleum Industry: Part 12: Pressure Vessel Systems Examination. 2nd Edition. 1993. ISBN 0471 939366.
- Institute of Petroleum, Model Code of Safe Practice for the Petroleum Industry: Part 13: Pressure Piping Systems Examination. 2nd Edition. 1993. ISBN 0471 939374.

[Safety Assessment Federation - SAFed](#)

- Guidelines for the Production of Written Schemes of Examination and the Examination of Pressure Vessels Incorporating Openings to Facilitate Ready Internal Access Ref: PSG4 April 2003.
- Pressure Systems: Guidelines on Periodicity of Examinations Ref: PSG1 (ISBN 1 901212 10 6). Date of Publication: May 1997
- Shell Boilers: Guidelines for the Examination of Shell-to-Endplate and Furnace-to Endplate Welded Joints Ref: SBG1 (ISBN 1 901212 05)
  Date of Publication: April 1997
- Shell Boilers: Guidelines for the Examination of Longitudinal Seams of Shell Boilers Ref: SBG2 (ISBN 1 901212 30 0). Date of Publication: May 1998

[Engineering Equipment Manufacturers and Users Association - EEMUA](#)

- 159 Users' Guide to the Inspection, Maintenance and Repair of Above-ground Vertical Cylindrical Steel Storage Tanks (3rd edition 2003) ISBN 0 85931 1317

HSE Documents

- Part 1 – Manual Ultrasonic Inspection
- Part 2 – Magnetic Particle and Dye Penetrant Inspection
- Part 3 – Radiographic Inspection in Industry
- Part 4 – Ultrasonic Sizing Errors and their Implication for Defect Assessment

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