FOREWORD

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G) Asset Operation
H) Marine Operations
J) Cleaner Energy
O) Subsea Systems
Acknowledgements

This recommended practice was formulated principally by the HOIS joint industry project. It is based on a number of preceding documents and as such the permission of the previous authors to incorporate their work is hereby gratefully acknowledged. In particular, we would like to thank members of the HOIS collaborative project for their contributions and comments during the production of the recommended practice, Mitsui Babcock for their permission to incorporate elements of the GSP235 report covering aspects of the inspection planning procedure and summary of inspection methods, and ESR Technology Ltd for compiling the original text for this recommended practice.

Since its initial publication in 2007, increased experience with practical application to pressure vessels has led to the identification of a number of areas for improvement in the RP. A project was run by HOIS to make a number of improvements, these covering specifically changes to the sections on dealing with evaluation of inspection (Section 6) and adjustment of inspection intervals (Section 7). A new section has also been added covering deferral, rather than full replacement, of internal visual inspection (Section 8). These changes have been reviewed and agreed by the HOIS membership and are aimed at making the document more useful to industry.

CHANGES

• General
This document supersedes DNV-RP-G103, October 2007.

• Main changes in January 2011:
Section 6 has been subject to some changes to include a definition of Conformance Levels and guidance on assignment of Conformance Levels.

Section 7 has been revised to include a more quantitative adjustment of intervals following NII that includes non-conforming elements in the inspection achieved. These changes are aimed at ensuring greater consistency in application. The previous version of the document was focussed on NII as a full alternative to internal visual inspection but there is an industry need for NII in support of deferral of internal visual inspection. This is addressed by the addition of Section 8 to the document. This provides information on when use of NII in support of deferral of internal visual inspection is acceptable and how to determine acceptable deferment periods.

Section 8 has been added.
Executive summary

Pressure vessels and pressure systems are required to undergo periodic, statutory inspection to ensure continued safe and reliable operation. Traditionally this has been achieved by means of an internal visual inspection (IVI), however, there can be very high costs associated with shutting down a vessel (loss of production), isolating it and preparing it for entry. Indeed, these costs can be much higher than the cost of the inspection itself. Furthermore, the mechanical disturbances involved in preparing the vessel for internal inspection and reinstating it may adversely affect its future performance. Finally, and by no means least, man access may also be hazardous. There can, therefore, be significant advantages if inspections are performed from the outside of the vessel without breaking containment i.e. non-invasively. However, there needs to be a balance between achieving these benefits and obtaining the information required to ensure continued safe and reliable operation.

While it may often be the preferred option, non-intrusive inspection (NII) represents a relatively new approach by comparison to IVI and many engineers responsible for inspection planning have yet to build up experience with and confidence in its application. In addition, there are a wide variety of techniques available, each with its own specific capabilities and limitations.

This has been recognised by industry and has led to the development of a number of guidance documents aimed at assisting plant operators to plan and justify NII. This recommended practice is intended to bring these documents together under a single cover, and to provide a consistent and logical approach at all stages of the non-intrusive inspection process.

This recommended practice is primarily intended for those with responsibilities in the planning, implementation and acceptance of vessel inspections. It is aimed at the inspection of welded vessels constructed from metals, and related items, fittings and connections associated with them, although the document is equally applicable to forged/spun metal pressure vessels, which contain no welds, as well as storage tanks and large diameter pipelines. Although not intended to be covered by this document, some aspects of this recommended practice may also be applicable to vessels manufactured from other materials and plant items other than pressurised equipment, in which case some of the general principles developed may well still apply.

The recommended practice provides guidance for:

i) determining when NII is appropriate in principle
ii) information requirements to plan for NII
iii) defining the requirements for the NII method(s) to be selected
iv) selecting methods that meet the requirements
v) evaluating the results of the inspection
vi) documentation requirements.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>7</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>7</td>
</tr>
<tr>
<td>1.2 Objectives of Non-Intrusive Inspection</td>
<td>7</td>
</tr>
<tr>
<td>1.3 Scope</td>
<td>8</td>
</tr>
<tr>
<td>1.4 Overview of the Recommended Practice</td>
<td>8</td>
</tr>
<tr>
<td>1.5 Definitions</td>
<td>11</td>
</tr>
<tr>
<td>2. Integrity Review</td>
<td>12</td>
</tr>
<tr>
<td>2.1 General Approach</td>
<td>12</td>
</tr>
<tr>
<td>2.2 Equipment Profile</td>
<td>12</td>
</tr>
<tr>
<td>2.3 Risk Based Inspection Approaches</td>
<td>13</td>
</tr>
<tr>
<td>2.4 Corrosion Risk Assessment</td>
<td>13</td>
</tr>
<tr>
<td>2.4.1 Corrosion Risk Assessment Types</td>
<td>14</td>
</tr>
<tr>
<td>2.5 Structural Integrity Assessment</td>
<td>14</td>
</tr>
<tr>
<td>2.6 Operational Experience</td>
<td>14</td>
</tr>
<tr>
<td>3. The decision guidance process</td>
<td>15</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>15</td>
</tr>
<tr>
<td>3.2 Screening</td>
<td>15</td>
</tr>
<tr>
<td>3.3 High-level decision process</td>
<td>17</td>
</tr>
<tr>
<td>3.3.1 Confidence in ability to predict types and locations of degradation</td>
<td>17</td>
</tr>
<tr>
<td>3.3.2 Previous inspection effectiveness</td>
<td>19</td>
</tr>
<tr>
<td>3.3.3 Severity and rate of degradation</td>
<td>20</td>
</tr>
<tr>
<td>3.3.4 NII recommendation</td>
<td>20</td>
</tr>
<tr>
<td>3.3.5 NII in support of deferment</td>
<td>20</td>
</tr>
<tr>
<td>3.4 NII Decision Record</td>
<td>20</td>
</tr>
<tr>
<td>3.5 Examples</td>
<td>21</td>
</tr>
<tr>
<td>3.5.1 Heat Exchanger Vessel</td>
<td>21</td>
</tr>
<tr>
<td>3.5.2 Gas Receiver Vessel</td>
<td>21</td>
</tr>
<tr>
<td>3.5.3 Separator Vessel</td>
<td>22</td>
</tr>
<tr>
<td>3.5.4 Absorber Vessel</td>
<td>23</td>
</tr>
<tr>
<td>4. Inspection planning</td>
<td>24</td>
</tr>
<tr>
<td>4.1 Introduction</td>
<td>24</td>
</tr>
<tr>
<td>4.2 The Planning Team</td>
<td>27</td>
</tr>
<tr>
<td>4.3 Inspection Strategy Type</td>
<td>27</td>
</tr>
<tr>
<td>4.3.1 Type A Inspection</td>
<td>28</td>
</tr>
<tr>
<td>4.3.2 Type B Inspection</td>
<td>28</td>
</tr>
<tr>
<td>4.3.3 Type C Inspection</td>
<td>29</td>
</tr>
<tr>
<td>4.3.4 Selection of Inspection Type</td>
<td>29</td>
</tr>
<tr>
<td>4.4 Definition of Vessel Zones</td>
<td>31</td>
</tr>
<tr>
<td>4.4.1 Identification of Zones</td>
<td>32</td>
</tr>
<tr>
<td>4.4.2 Example</td>
<td>32</td>
</tr>
<tr>
<td>4.5 Definition of Degradation Type</td>
<td>33</td>
</tr>
<tr>
<td>4.6 Inspection Effectiveness</td>
<td>34</td>
</tr>
<tr>
<td>4.7 Required Inspection Effectiveness</td>
<td>36</td>
</tr>
<tr>
<td>4.8 Coverage</td>
<td>36</td>
</tr>
<tr>
<td>4.9 Selection of Inspection Method</td>
<td>37</td>
</tr>
<tr>
<td>4.9.1 Inspection Capability</td>
<td>37</td>
</tr>
<tr>
<td>4.9.2 Inspection Method Selection Flowcharts</td>
<td>37</td>
</tr>
<tr>
<td>4.9.3 Inspection Method Selection Criteria</td>
<td>39</td>
</tr>
<tr>
<td>4.9.4 Statistical Methods</td>
<td>40</td>
</tr>
<tr>
<td>4.10 Preparation of Work-pack</td>
<td>54</td>
</tr>
<tr>
<td>4.11 Inspection Plan Review</td>
<td>55</td>
</tr>
<tr>
<td>5. On-site Inspection Activities</td>
<td>56</td>
</tr>
<tr>
<td>5.1 Preparation for Inspection</td>
<td>56</td>
</tr>
<tr>
<td>5.1.1 Individual Responsibilities</td>
<td>56</td>
</tr>
<tr>
<td>5.1.2 Preparation Tasks</td>
<td>56</td>
</tr>
<tr>
<td>5.2 Performing the Inspection</td>
<td>57</td>
</tr>
<tr>
<td>5.3 Dealing with Non-conformances</td>
<td>58</td>
</tr>
<tr>
<td>5.4 Reporting of Results</td>
<td>58</td>
</tr>
<tr>
<td>5.5 Demobilisation</td>
<td>59</td>
</tr>
<tr>
<td>6. Evaluation of Inspection</td>
<td>59</td>
</tr>
<tr>
<td>6.1 Introduction</td>
<td>59</td>
</tr>
<tr>
<td>6.2 Items to be checked for conformance</td>
<td>61</td>
</tr>
<tr>
<td>6.3 Inspection Method</td>
<td>61</td>
</tr>
</tbody>
</table>
1. Introduction

1.1 Background

Pressure vessels and pressure systems are required to undergo periodic, statutory and other non-destructive testing to ensure continued safe and reliable operation. This generally includes a requirement to inspect vessels for possible internal degradation. This is frequently achieved by means of an internal visual inspection (IVI) coupled with the use of surface flaw detection methods such as dye penetrant inspection (DPI) and magnetic particle inspection (MPI), however, there can be very high costs associated with shutting down a vessel (loss of production), isolating it and preparing for it for entry. Indeed, these costs can be much higher than the cost of the inspection itself. Furthermore, the mechanical disturbances involved in preparing the vessel for internal inspection and reinstating it may adversely affect its future performance. Finally, and by no means least, man access may also be hazardous.

There can, therefore, be significant advantages if inspections are performed from the outside of the vessel without breaking containment i.e. non-invasively. However, there needs to be a balance between achieving these benefits and obtaining the information required to ensure continued safe and reliable operation. The acceptability and benefits of non-intrusive inspection for a particular vessel will depend on a number of factors including:

— vessel geometry
— materials
— potential deterioration mechanisms and modes
— locations and sizes of flaws of concern
— process
— historic inspection data
— confidence in inspection capability
— inspection costs.

Techniques for non-intrusive inspection (NII) of equipment are becoming increasingly sophisticated and more widely available. While it may often be the preferred option, NII represents a relatively new approach by comparison to IVI and many engineers responsible for inspection planning have yet to build up experience with and confidence in its application. For the purposes of this recommended practice, IVI is considered to include the use of surface flaw detection methods such as DPI and MPI where appropriate. In addition to a general lack of experience, there are a wide variety of methods available to non-intrusively inspect equipment, each with its own specific capabilities and limitations.

This has been recognised by industry and a series of structured guidance documents have been developed Ref. [4], [5] and [6] to assist plant operators to justify and plan NII. Each of these documents deals with a specific aspect of the NII process, and there are some minor inconsistencies in notation and approach. This recommended practice is intended to bring all three documents together under a single cover, and to provide a consistent and logical approach at all stages of the non-intrusive inspection process.

Many of the recommendations in this document are not unique to non-intrusive inspection since proper planning and administration is also important for internal inspection. The document should be considered in conjunction with other relevant guidelines such as those contained in the HSE Best Practice for NDT document (Ref. [7]).

1.2 Objectives of Non-Intrusive Inspection

It is essential to be clear about the reasons for performing a non-intrusive inspection. The decision to carry out non-intrusive inspection will normally depend on a number of different factors. A primary advantage is likely to be overall cost reduction, but this may arise not because an internal inspection is replaced, but, for example, when an unscheduled inspection is required and it is hoped to avoid shutting down the plant by carrying out the inspection non-invasively. It is important to clarify the objective of the non-intrusive inspection in advance, as this may have an impact on the approach to the inspection.

Questions that should be addressed may include:

— Is the inspection to complement an internal inspection programme?
— Is the inspection to act in support of deferment of an internal inspection?
— Is the inspection intended to replace an entire internal inspection or an internal inspection regime?

Potential benefits of performing a non-intrusive inspection include:

— Avoids man access which can be hazardous (possibilities of flammable or toxic residues which can be difficult to remove, adequate lighting may be difficult to achieve).
— Planning for turnaround / shutdown. Identifying what remedial work is likely at the next turnaround? Carrying out non-intrusive inspection allows the preliminary inspection to be made before the plant is shutdown, providing an opportunity for the turnaround to be shortened by long-lead time planning and preparation (for repair and maintenance based upon the NDT results) to be made in advance of the start of
the turnaround.

— Shortening the turnaround. Shutdown duration may be reduced by carrying out most or all of the inspection work in advance of the shutdown, allowing the turnaround to be restricted to mechanical work. This also simplifies planning.

— Removal of requirement to break containment. No need to isolate, drain and purge the vessel. This may include partial break of containment, for example access to water/coolant side of a heat exchanger without breaking hydrocarbon containment. This may lead to shortening of the turnaround.

— Minimises disturbances to the vessel which could create new problems.

— It may be possible to avoid the need to shut down the vessel operation entirely. Inspections can be made on a different cycle from any other maintenance, or the inspections may be made at reduced capacity or temperature, rather than having to isolate, drain and purge the vessel.

— Allows the inspection to be carried out when a potential problem is identified, without interfering with other operations. This might occur when either routine surveillance or unusual operating conditions suggest that damage might have occurred.

1.3 Scope

This recommended practice is primarily intended for those with responsibilities in the planning, implementation and acceptance of vessel inspections. It is aimed at the inspection of welded vessels constructed from metals, and related items, fittings and connections associated with them. The document is equally applicable to forged/spun metal pressure vessels, which contain no welds, as well as storage tanks and large diameter pipelines.

Although not intended to be covered by this document, some aspects of this recommended practice may also be applicable to vessels manufactured from other materials and plant items other than pressurised equipment, in which case some of the general principles developed may well still apply.

The recommended practice provides guidance for:

1) determining when NII is appropriate in principle as an alternative to IVI or as a means of deferment of IVI
2) information requirements to plan for NII
3) defining the requirements for the NII method(s) to be selected
4) selecting methods that meet the requirements
5) evaluating the results of the inspection
6) documentation requirements.

The scope is limited by the following constraints.

— It is assumed that the date of the next inspection following NII will be determined in the same way as with any other inspection, based on sound engineering judgement and an understanding of the degradation rates and tolerance of the equipment to degradation. This recommended practice therefore makes no attempt to influence the timing of the next inspection, other than where the intended scope of the NII inspection has not been fully met or where it is used in support of deferment of a comprehensive inspection.

— No consideration is given to the relative cost of different inspection options and the guidance process considers technical issues only.

— The recommended practice is principally for application to pressure vessels.

— The recommended practice does not address legislative requirements, which may in certain countries preclude the use of non-intrusive methods. The recommended practice considers only the technical aspects of the non-intrusive inspection planning process, and the user should confirm that any inspection plan derived using this document satisfies national legislative requirements.

— The recommended practice does not consider the impact of external degradation mechanisms, for which inspections are intrinsically non-intrusive and would be addressed by conventional assessment means.

It is also important to note that the recommended practice does not aim to comprehensively cover every aspect of planning an inspection by NII but rather seeks to provide structured guidance at key stages of the process. Although the document provides guidance on the general principles of non-intrusive inspection it is not intended to be prescriptive, and readers should assess each case point by point against their own criteria, using the document as a guideline. The recommended practice cannot and is not intended to replace sound engineering and commercial judgement by competent personnel.

It should be recognised that with any scheme of examination there is a finite probability of missing flaws or degradation which could lead to failure. This applies to both invasive and non-invasive inspection.

1.4 Overview of the Recommended Practice

Non-intrusive inspections generally require a more sophisticated approach than internal inspections. The recommended practice developed in this document recommends a systematic assessment of each item of equipment to be inspected using NII. This is a staged process which sequentially considers:
1) when and where inspection is required
2) whether NII is appropriate as a full replacement of IVI
3) the inspection plan
4) what inspection methods are appropriate
5) requirements during inspection
6) whether the inspection actually performed is adequate
7) actions when the inspection performed does not meet the requirements
8) approach to use of NII in support of deferment of IVI.

A summary of the recommended NII process is shown diagrammatically in Figure 1-1. The colours used on the flow chart indicate the appropriate section of this recommended practice to which the action relates.

It is important to recognise that a transfer to a non-intrusive inspection strategy is likely to require a step-change in the administration and execution of the inspection. In particular, inspection methods are likely to be more elaborate when compared with internal visual inspection. Therefore the inspection must be controlled more rigorously, with the procedures (i.e. equipment, settings and reporting criteria) carefully scrutinised and monitored at all stages in order to ensure that the inspection objectives are met. As a consequence, it is likely that planning of the inspection will need to be considerably more thorough (this is covered in Sec.4). In addition, the reporting format must be precisely specified. If the results are not requested in the correct form at the outset of the inspection or are inadequately reported, it can be difficult to transform the data to the correct format, and useful information may be overlooked or lost.
Figure 1-1
Overview of NII Procedure.
1.5 Definitions

In the context of this Recommended Practice the following definitions apply. In certain cases these definitions are the same as, or are based on, those which appear in other documents such as those of the British Personnel Certification in Non-Destruction Testing (PCN) scheme.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
<td>Specified zone where inspection will be carried out. In many instances this area will contain a specific feature (e.g. weld) which is of particular interest.</td>
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<td><strong>Capability</strong></td>
<td>Capability is used to qualitatively describe an NDT methods’ ability to detect (POD) and size flaws.</td>
</tr>
<tr>
<td><strong>Certification</strong></td>
<td>Procedure used to demonstrate the qualification of NDT personnel in a method, level and industrial sector, and leading to the issue of a certificate.</td>
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<tr>
<td><strong>Competency</strong></td>
<td>Capability to perform a given task on the basis of education, training, qualification and experience following objective assessment. To achieve the appropriate level of competency might require a team.</td>
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<td><strong>Corrosion risk assessment (CRA)</strong></td>
<td>An assessment of the susceptibility of the structure under investigation to all in-service degradation mechanisms that may affect it. The CRA is not restricted to simply those degradation mechanisms related to corrosion.</td>
</tr>
</tbody>
</table>
| **Coverage**                                    | Defines the proportion of the structure or region thereof under consideration that is actually subject to inspection, i.e. 

\[
\text{Coverage} = \frac{\text{Area inspected}}{\text{Total area under consideration}}
\]

| **Criticality**                                 | A function of the risk associated with the inspected equipment, incorporating likelihood of degradation occurring and associated consequences. |
| **Defect**                                      | A defect is here taken to be a flaw which renders the equipment unfit for its specified service in its current state. |
| **Deferment**                                   | Allowing for inspection at a date later than currently assigned in the integrity planning system. Justification is usually a requirement whenever a deferment is made. |
| **Degradation mechanism**                       | Those mechanisms by which integrity of the pipe or vessel could potentially be impaired e.g. erosion, fatigue, creep, brittle fracture, wall loss etc. |
| **Effectiveness**                               | A qualitative measure of the probability of detecting flaws, taking coverage into account. 

\[
\text{Effectiveness} = f(\text{POD, Coverage})
\]

Three effectiveness categories are used, (high, medium and low), these being defined by comparison to the POD for visual inspection. High implies a higher POD, medium implies a broadly similar POD and low implies a lower POD. |
| **Feature**                                     | Specific part of area to be inspected i.e. weld, nozzle etc. |
| **Flaw**                                        | The physical manifestation of a degradation mechanism, in terms of cracking, pitting or wall loss etc. |
| **Inspection body**                             | The organisation which manages the performance of the NDT inspection (e.g. inspection vendor). |
| **Inspection manager**                          | The plant owner’s representative with overall responsibility for the inspection. |
| **Inspection Method**                           | A specific way of applying a NDT method (e.g. Pulse echo, TOFD, Radiography etc.) |
| **Inspection supervisor**                       | The leader of the site inspection team with overall responsibility for coordinating and supervising the inspection. |
| **Internal Visual Inspection (IVI)**            | This is considered as an intrusive close visual examination of all internally accessible plate material and, where applicable, conventional magnetic particle (MPI) or dye penetrant (DPI) inspection of welds. In the context of this Recommended Practice, the term IVI is not intended to cover a less rigorous general visual examination. |
| **Non-Intrusive Inspection (NII)**              | This refers to any inspection performed from the outside of the vessel without having to break containment and/or not requiring vessel entry. It may be performed on-stream or off-stream. The terms “non-invasive” and “non-intrusive” are often used interchangeably. Note that in the context of this document NII is taken to cover only inspections where the objective is a replacement or deferment of an IVI and the requirements are aligned accordingly. |
| **Operator/technician**                         | Qualified NDT personnel who execute the inspection. |
| **Probability of detection (POD)**              | Probability of detecting a defined flaw type and size in the area covered by the inspection method. |
2. Integrity Review

2.1 General Approach

Internal visual inspection (IVI) remains widely used on the majority of vessels and several accepted procedures exist for the specification of inspection intervals to ensure safe operation. Traditionally, such intervals have been specified on the basis of legislative requirements, but increasingly plant owners take risk considerations into account in order to maximise the cost benefit of inspection. The decision to apply non-intrusive inspection methods for a particular item of equipment can depend critically on the type and extent of flaws or degradation mechanisms expected. Non-intrusive inspection methods are often slower and more expensive to apply than internal visual inspections, so that 100% inspection of a vessel is often impractical. If non-intrusive inspection (NII) is to be used in conjunction with, or as an alternative to IVI, then the inspection requirements should be defined such that the risk levels are not increased. For any given vessel this effectively means that there should not be an increase in the probability of failure (POF) when NII is used. Non-intrusive inspection therefore requires more careful consideration of the parts of the vessel to be inspected, the flaws/degradation to be detected and the inspection methods to be applied than is normally the case for IVI hence many of the traditional and more recent risk based inspection (RBI) planning approaches will remain applicable.

This section of the recommended practice is intended to provide an overview of the various data requirements that are necessary in order to be able to successfully plan for non-intrusive inspection.

| Procedure | A written description of all essential parameters and precautions to be observed when applying an NDT method to a specific test, following an established standard, code or specification. |
| Qualification | Evidence of training, professional knowledge, skill and experience as well as physical fitness to enable NDT personnel to properly perform NDT tasks, which satisfies the requirements of EN 473 (Ref. [1]) and ISO 9712 (Ref. [2]), e.g. PCN (Ref. [3]). |
| Risk based inspection (RBI) | Process of planning inspection requirements through a detailed assessment of the relative probabilities of failure and their associated consequences. |
| Work-pack | A complete package of documents (procedures, drawings, standards etc.) relevant to the inspection outlining scope and details of inspection to be performed. |

2.2 Equipment Profile

The first stage of the non-intrusive inspection planning process is to carry out a detailed review of the equipment. The intention is to ensure that the inspection planners have a comprehensive understanding of the design, operation, current condition and anticipated degradation mechanisms that may affect the equipment in service. This background information should be compiled into an equipment profile, which should form a part of the auditable document trail for the inspection. Background information that should be included in the equipment profile is as follows:

Identity and design

Vessel unique reference number, general arrangement drawings, materials, current design basis (pressure, temperature, corrosion allowance, cycling regime etc.)

Type of vessel and function

e.g. separator, heat exchanger, boiler, storage tank, blowdown vessel, reactor, etc.

Operation and service details

Process fluids and possible contaminants, operating temperatures, operating pressures, loading and temperature cycles, transients, excursions outside normal operating envelope, insulation systems.

Detailed drawings

Number and type of welds, longitudinal /circumferential shell welds, welds on the domed end/dished end, nozzles, man-ways, construction details including saddles, supports and support skirts, flanges, compensating plates, insulation etc.

Modifications and repairs

Has the vessel been modified since its original commissioning? Have any previous flaws or damage been removed or repaired (dates)? N.B. – it is important to maintain records of any such modifications or repairs.

Previous inspection results

Details of known/previously reported flaws/areas of degradation. Inspection methods and coverage.

General experience

Flaws/degradation/failures in other similar vessels (if available).
Complementary information
Information from corrosion monitors etc. providing evidence on whether degradation is occurring.

Accessibility
General accessibility, access limitations. There may be scaffolding requirements stated for each vessel. This sometimes accompanies the data held on vessels or is noted in drawings or isometrics. Though this is primarily a cost issue, there may be occasions when there are overriding factors that preclude satisfactory external access or the construction of suitable scaffolding.

Safety Requirements
Details should be recorded of any safety requirements pertaining to the equipment. Examples of items to consider are listed below, however any other safety related information considered pertinent to the inspection should also be recorded.
- general safety procedures
- site-specific procedures including requirements for local induction courses
- job-specific risk assessments
- local search review requirements for equipment (at stores/safety officer)
- safety testing and certification requirements for equipment – Portable Appliance Testing (PAT) certification etc.
- requirement for “inherently safe” equipment
- restrictions on ionising radiations
- personal protection equipment.

Possible flaws/degradation
Potential failure modes and effects. Possible flaw/degradation locations. Possible flaw/degradation morphology/ sizes. Reporting criteria. (See also Sec.2.3 and 2.4 below).

The following sections describe in brief some of the established techniques used to obtain some of this information.

2.3 Risk Based Inspection Approaches
Current practice is increasingly to consider the risk presented by any particular item of equipment to the plant [8] when establishing an inspection schedule. Risk based inspection (RBI) processes consider the probability of a failure of the equipment and the associated consequences in order to determine an overall risk ranking. The frequency and extent of inspection required are then set on the basis of this risk ranking. Effective RBI depends heavily on a good knowledge of the degradation mechanisms and their growth rates, the inspection history, operating conditions etc. – i.e. much of the knowledge that goes into RBI is the same as that required to enable justification and planning for NII.

2.4 Corrosion Risk Assessment
Different non-intrusive inspection methods have different capabilities for detecting and sizing flaws, and therefore the inspection manager requires a more detailed knowledge of the types and locations of flaws which may be present in a particular item of equipment than is the case for an internal visual inspection. Hence, one of the key sources of information for the NII assessment is the Corrosion Risk Assessment (CRA). In practice, most rigorous integrity management systems will already incorporate a consideration of the type and likelihood of degradation expected for each vessel, as this is also a requirement for most RBI assessments.

The corrosion risk assessment is a formal review of the degradation mechanisms to which a particular plant item may be susceptible, along with a determination of the anticipated degradation rates. Typically the corrosion risk assessment will consider flaws or degradation such as:
- general corrosion over the whole area
- local corrosion
- pitting
- erosion
- general or preferential corrosion of welds (including “grooving”)
- loss of or damage to cladding or lining
- cracking under cladding or lining
- cracking in or near welds
- cracking at or near nozzles or other perforations
- cracking at or from internal fitting welds, nubs etc.
- stress corrosion cracking in parent material
- hydrogen damage (e.g. blistering, stepwise cracking)
- damage to seals, flange gasket, flange faces
- damage to internals (not normally detectable by NII).

In addition, it is important to consider the different and possibly unusual flaw morphologies which can occur
(e.g. microbiological influenced corrosion) since these aspects can influence the selection and capability of non-intrusive inspection methods.

2.4.1 Corrosion Risk Assessment Types

Corrosion risk assessments can be carried out at very different levels within different organisations. Given the importance of the assessment to the NII planning process, it is therefore important to be clear about what level of assessment has been carried out. The following CRA Types have been defined in order to describe the nature and extent of the CRA carried out. These CRA Types are used in the NII decision process later in this recommended practice (Sec.3).

**CRA Type 1**
A basic assessment considering primarily existing inspection results and expected degradation based on experience with other similar vessels. This level of assessment is what would exist as a minimum to meet inspection planning requirements by RBI. It would be carried out and reviewed by competent individuals from appropriate discipline groups including, for example, inspection, metallurgy/materials, process and engineering.

**CRA Type 2**
A more detailed assessment providing documented consideration of at least the following:
- the vessel's condition, based on previous inspections whenever these have been carried out
- the vessel's metallurgy, modification and repair history
- the process fluid composition and operating conditions
- corrosion management
- changes to any of the above factors that may affect inspection requirements
- types of degradation
- growth rates for each type of degradation identified as of concern (or at least some estimate related to severity, e.g. a likelihood type value from a criticality assessment)
- the locations where each type of degradation is likely to be active.

The assessment should consider existing inspection results and theoretical predictions. Theoretical predictions should be based on process and materials information.

**CRA Type 3**
A comprehensive assessment including an in-depth theoretical study based on process and materials information. The following issues need to be addressed:
- types of degradation
- growth rates for each type of degradation identified as of concern
- the locations where each type of degradation is likely to be active
- upset conditions that can lead to accelerated degradation
- potential for incorrect identification or omission of degradation mechanisms.

A Type 3 assessment is carried out in detail on a vessel by vessel basis.

**CRA Type 4**
This meets the requirements of a Type 3 assessment with respect to the theoretical study but also includes consideration of inspection results from the vessel following at least one in-service inspection. Some interpretation/correlation of the predicted degradation and condition found by inspection shall also have been carried out.

2.5 Structural Integrity Assessment

It is important to have an understanding of the equipment’s ability to resist structural damage following degradation. In its simplest form, this can be knowledge of the margins against operating conditions and corrosion allowance incorporated at the design stage. In certain circumstances however, a more comprehensive fitness for service assessment will have been carried out (for example using API 579 [9]) which will provide information on, for example, critical crack dimensions. All such information provides the inspection manager with evidence as to how tolerant the equipment is to degradation, which in turn will influence the effectiveness of inspection required in order to provide assurance that failure will not occur in-service between scheduled inspections.

2.6 Operational Experience

Where the user has extensive experience with the same or similar vessels in the same or similar service, operational experience provides a very useful corroboration of the theoretical assessments described previously. Inspection histories outlining the types and sizes of any flaws found in service (or indeed the absence of flaws), give a clear indication of what inspection requirements are likely to be necessary. Of course, this is only true if the inspection carried out is appropriate for the degradation anticipated.
3. The decision guidance process

3.1 Introduction

Having carried out the integrity review and obtained the necessary information regarding the equipment condition at the time of the last inspection, it is necessary to determine whether the equipment is intrinsically suitable for non-intrusive inspection as an alternative to, or in supporting deferment of, the IVI that would normally be carried out. This decision process is the second stage of the NII planning process, shown in Figure 1-1. Through application of a flow chart, the decision guidance process determines whether NII should be considered for the inspection of a given piece of equipment.

The process can be broken down into two main stages, namely screening and the high level decision process. The process is shown diagrammatically in Figure 3-1, and is described in more detail in the following sections.

3.2 Screening

The purpose of this first stage is to rapidly identify those vessels for which NII should not be considered or where the required information can not be obtained from such an inspection. The screening process is based on the user’s response to each of the following questions.

Is the vessel intrinsically suitable for NII?

Before proceeding any further with the NII decision process, it is necessary to confirm that the equipment is intrinsically suited to inspection by non-intrusive means; that is that there are no immediately obvious impediments to NII being undertaken. These include factors such as where there is no access to the vessel exterior, extreme surface temperatures, geometry constraints and restrictions to access, as well as any requirement for inspection of internal fittings.

Has the vessel previously been inspected and is the history still relevant?

Vessels with no previous in-service inspection history or for which there is reason that the inspection history may no longer be relevant (due for example to a change in process conditions) should not normally be considered for NII. There are two possible exceptions to this recommendation, as covered by the next two screening questions.

Is the vessel designed specifically for NII?

Where a vessel is designed specifically for inspection by NII, such inspection should be considered from the outset or even when conditions may have changed (while remaining within the design intent).
Figure 3-1
NII Screening Procedure

Is the vessel similar to others for which service history exists?

The intent of this question is to identify if there are other vessels whose inspection history may be directly relevant to the vessel under consideration. Hence the answer can only be taken as yes for vessels:

— substantially the same in terms of design, geometry, construction and conditions of service (i.e. normally empty / full, etc.).

and

— for which no factors with potential to cause a difference in the nature, distribution or rate of degradation can be identified.

Similar vessels shall be taken to mean vessels substantially the same in function, geometry, design, material and construction. Similar service shall be taken to mean substantially the same in each of chemistry, fractions and phase(s) of the vessel contents, process type(s), flow rates and temperatures. When classing vessels as similar, justification must be provided.

Is entry scheduled for other reasons?

When the vessel is to be opened for other reasons, advantage should be taken of the opportunity to perform an internal visual inspection. This does not mean that NII should not be done. However, if it is intended to do NII...
in parallel with IVI then this can be done without additional justification.

3.3 High-level decision process

The next step is to decide whether sufficient information exists to plan the non-intrusive inspection and what inspection effectiveness is required. This requires consideration of how confidently potential flaw types and locations can be predicted, the effectiveness of previous inspections, and the severity and rate of any known or predicted degradation. This is achieved using the high-level decision process, which determines whether NII is appropriate in principle, based largely on the use of the decision tree shown in Figure 3-2. This leads the user to a decision on whether NII is appropriate in principle based on the categories selected for each of three factors. The factors and criteria for categorisation are covered below.

3.3.1 Confidence in ability to predict types and locations of degradation

The decision on whether NII is appropriate in principle is based to a large extent on confidence in being able to predict all active degradation mechanisms and hence specify methods capable of identifying the associated flaws. The ability to predict degradation mechanisms relevant to the vessel under consideration and their locations will depend on a number of factors. Evidence can be considered from two main sources, as described below:

theoretical : The nature of the integrity management systems employed

evidential : Evidence available from the same or similar vessels in the same or similar service (as defined previously).
When using evidential information as the basis for predicting types and locations of degradation, it is important that the previous inspection results have been considered in detail at the planning stage for the current inspection and that a Type 1 CRA is in place as a minimum. The credibility of the evidence is directly linked to the amount of evidence available - i.e. number of vessels and previous inspections considered.

The confidence categories have therefore been defined as follows to consider the above factors.

**Figure 3-2**

**High Level Decision Guidance Chart**
**High**

Either of the following factors apply:

1) a thorough assessment of potential degradation mechanisms gives confidence that all relevant mechanisms and their likely locations have been predicted. This assessment has been carried out as part of the integrity management activity by which inspection planning is conducted. This includes as a minimum for each vessel, documented consideration of:

   - the vessel's condition, based on previous inspections
   - the vessel's metallurgy, modification and repair history
   - the process fluid composition and operating conditions
   - corrosion management
   - the degradation types, locations and rates
   - changes to any of the above factors that may affect inspection requirements.

   The integrity management plan ensures consideration of the above factors by a team of competent individuals from appropriate discipline groups including, for example, inspection, metallurgy/materials, process and engineering. The CRA carried out as part of the integrity management activities described above should conform to the requirements of Type 4.

2) the user has extensive experience with the same or similar vessels in the same or similar service and inspection histories outlining the types of flaws existing are available. A detailed review of all previous inspection results has been performed. These findings have been considered in predicting the type and locations of flaws that may be expected in the current inspection. Note that extensive experience is taken to mean that data is available covering at least eight inspections in total and not less than two inspections for the longest serving single vessel used in making the judgement, at least one of which should have been a close visual inspection (internal or external depending on the nature of the degradation). In addition, a CRA shall have been carried out, this conforming at least to the requirements of Type 1.

Note that a vessel for which the operating conditions have changed since the previous inspection can not be classed as High, except where the conditions can be shown to be more benign than previously.

**Medium**

Either of the following apply:

1) a thorough assessment of potential degradation mechanisms is considered likely to predict the majority of relevant mechanisms and their locations but cannot fully rule out the possibility of additional degradation mechanisms being active. This assessment has been carried out as part of the integrity management activity by which inspection planning is conducted. It includes as a minimum for each vessel, documented consideration of:

   - the vessel's condition, based on previous inspections whenever these have been carried out
   - the vessel's metallurgy, modification and repair history
   - the process fluid composition and operating conditions
   - corrosion management
   - the degradation types, locations and rates
   - changes to any of the above factors that may affect inspection requirements.

   The integrity management plan ensures consideration of the above factors by a team of competent individuals from appropriate discipline groups including, for example, inspection, metallurgy/materials, process and engineering. The CRA carried out as part of the integrity management activities described above should conform to the requirements of Type 2.

2) experience, including inspection histories, is available for the same or similar vessels in the same or similar service covering not less than four inspections in total and not less than a single inspection for the longest serving vessel considered in making the judgement. A detailed review of all previous inspection results has been performed. These findings have been considered in predicting the type and locations of flaws that may be expected in the current inspection. In addition, a CRA shall have been carried out, this conforming at least to the requirements of Type 1.

**Low**

Justification for inclusion in the High or Medium categories, as defined above, is not possible.

### 3.3.2 Previous inspection effectiveness

This is included as a further measure of the confidence in ability to predict all relevant flaw types and is also used in defining the effectiveness required for methods used in the current inspection as a means of ensuring the probability of failure is managed. The intent is to compare the effectiveness of the last inspection carried
out relative to that of a conventional internal visual inspection, i.e. consisting of close visual examination of plate material and, where applicable, MPI or DPI.

The following category definitions apply:

**High**
The inspection performed has a better probability of detecting flaws of concern than does internal visual inspection.

**Medium**
The inspection performed offers a probability of detecting flaws of concern broadly similar to that of internal visual inspection.

**Low**
The inspection performed has lower probability of detecting flaws of concern than does internal visual inspection.

In deciding which category to select, the user must consider the following:

1) the probability of detection of the method(s) used with respect to flaws of concern. This is given by the effectiveness assigned to each method for a given flaw type.

2) the inspection coverage and how this relates to the locations of flaws of concern.

Clearly, the user’s knowledge of what flaws are likely to be of concern and where these flaws may be located is important in assigning effectiveness. For example, if it is known that flaws only occur in a particular region of the vessel and this region was fully inspected with a highly effective method then a High inspection effectiveness may be justified. Conversely, if the user has little understanding of what flaws might exist then a high coverage inspection but using only a single method (which may be capable of detecting only one flaw type) may result in a Low ranking.

The user can consider previous inspections on similar vessels in similar service (as defined above) in determining the category to select.

### 3.3.3 Severity and rate of degradation

In making this judgement, the user will consider the worst affected zone of the vessels and the following category definitions apply.

**High**
The degradation and rate thereof is such that failure of the vessel or rejection based on inspection results can reasonably be expected within the remaining plant lifetime.

**Medium**
The degradation and rate thereof is such as to be observable during the plant lifetime but would not be expected to threaten the integrity of the vessel during this period.

**Low**
There is no degradation expected or degradation is superficial.

### 3.3.4 NII recommendation

Having answered the above questions, in conjunction with the flowchart, the suitability of the equipment for inspection by NII can be read from the chart.

### 3.3.5 NII in support of deferment

The decision guidance flowchart (Figure 3-2) covers cases where the NII is intended as a full replacement of IVI. It is possible, in certain circumstances, that NII may be suitable in support of deferment of an IVI even when it is not considered suitable in the flowchart. The requirements specific to NII in support of deferment of IVI are covered in Section 8. Hence, if the outcome of the flowchart is that NII is not suitable but there may be some advantage to using NII in support of a deferment of the IVI for a period less than the assigned interval, then Section 8 should be consulted. Similarly, if the NII is planned from the outset as supporting deferment of IVI (rather than as a full replacement of IVI) then Section 8 should be consulted.

### 3.4 NII Decision Record

As with all matters related to plant safety, it is essential that an auditable record is kept of all factors considered in making decisions throughout the above decision guidance process. Documentation shall cover as a minimum the following:
1) statement of any changes occurring in process that may affect the nature or rate of degradation
2) inspection reports (if not already included in the Equipment Profile)
3) justification for acceptance under screening criteria
4) list of vessels considered to be the same as the one under consideration and justification that degradation can be expected to be the same
5) justification of selection of category for:
   — confidence in ability to predict types and locations of degradation
   — previous inspection effectiveness
   — severity and rate of degradation.

3.5 Examples
A number of examples of application of the decision process are presented in this section.

3.5.1 Heat Exchanger Vessel
A heat exchanger vessel (2-HX-05) has been in service for two years and is scheduled for its first inspection since commissioning. A decision is to be made whether this can be by NII or whether an IVI should be performed.

The following information is relevant:
— material (shell and ends): Carbon steel
— material (tubes): Stainless steel
— process fluid (shell side): Wet hydrocarbon gas with some condensation expected
— process fluid (tube side): Water.

The vessel is designed to ASME VIII Div 1 with a 3.2 mm corrosion allowance. The vessel forms part of a new process stream (Stream 2). This is similar in operation to Stream 1 (in service for a period of 10 years) but has been designed for greater efficiency and higher throughput. The vessel under consideration performs the function of two vessels (1-HX-05 and 1-HX-06) on Stream 1. Both vessels have been subject to inspection every three years. The first two inspections were by IVI but the most recent was by NII, this being regarded as at least as effective as the IVI in identifying the main degradation mechanism. The shells on both vessels are observed to suffer from mild internal corrosion. The average rate has been determined to be approximately 0.15 mm per year. The initial inspections showed that the corrosion rate does vary with position in the vessel. This is believed to be related to the gas flow rate and condensate impingement. On 1-HX-06, for example, the first inspection revealed one area with localised loss of wall thickness of 1.5 mm. An investigation carried out at the time suggested that the problem was occurring in a region of particularly high flow where water droplets were likely to be entrained. This was considered to be sufficient to remove the protective hydrocarbon rich film that would normally be expected on the steel and lead to accelerated CO₂ corrosion. An additional diverter plate was installed during the shut-down. Subsequent inspections revealed that this had resolved the problem and the region was no longer subject to higher corrosion than the remainder of the vessel.

The design of 2-HX-05 is different from that of the two vessels it replaces in requiring a higher flow rate and more complex gas flow path. In addition, the gas exit temperature is lower than that for 1-HX-06, hence the rate of water condensation is expected to be slightly higher. The feedstock for Stream 2 is nominally the same as for that for Stream 1 although it does come from a different source.

Application of the screening process (Figure 3-1):
— vessel has had previous inspection and history is still relevant? No
— vessel designed specifically for NII? No
— vessel is the same as others for which service history exists?

The response here should be No. The two vessels for which service history exists are similar in overall function but different in respect of design and process conditions and hence it is possible that the type and rate of degradation might be different. The No response at this point indicates that NII is not recommended for this vessel for the forthcoming inspection.

3.5.2 Gas Receiver Vessel
A gas receiver vessel is due for its first inspection three years after entry to service. It is one of ten vessels having the same design and function. Gas enters the vessels from a common line and gas take-off is to a manifold. Five of the vessels have been in service for ten years and each has had three previous inspections, the last two of which have been by NII. Inspection reports are available for each inspection performed and these have been reviewed in planning for the current inspection. The reports indicate that mild internal corrosion has been found on the interior at the bottom of each vessel. The corrosion is fairly uniform across this region in each of the vessels, with a maximum loss of wall of 1 mm on one of the vessels (the design incorporates a corrosion allowance of 5 mm). This corrosion is expected as the gas is not completely dry and a certain amount of moisture deposition
occurs at the bottom of the vessel. The recent inspections by NII have included extensive wall thickness readings in the corroded regions and TOFD was undertaken on the vessel welds since fatigue cracking under the pressure cycling was identified as a possible failure mechanism. None of the TOFD tests undertaken have identified any cracking.

A decision on whether the inspection can be by NII is required as this is the preferred option.

Application of the screening process (Figure 3-1):

— vessel has had previous inspection and history is still relevant? **No**
— vessel designed specifically for NII? **No**
— vessel is the same as others for which service history exists? **Yes**, since the vessel is of the same design, is in the same service and there are no factors that would be expected to lead to differences in degradation.
— entry is scheduled for other reasons? **No**.

Proceeding to apply the high level decision guidance flow chart (Figure 3-2):

— confidence in ability to predict types and locations of degradation. Given that there are a large number of vessels of the same design and function and that many of these vessels have long inspection histories, the user can directly consider evidence available from these vessels in selecting the category here. Considering the option 2) (category **High**), in item 3.3.1, High is justified here
— previous inspection effectiveness. The previous inspections by NII on the vessels already in service can be taken as Medium, i.e. broadly equivalent to IVI
— severity and rate of degradation. Corrosion occurring at the same rate as on the vessels in service would not be expected to threaten the integrity of the vessels during the design lifetime, hence Medium is selected here.

Following Figure 3-2 with High, Medium, Medium, one arrives at a recommendation that NII is possible in principle.

### 3.5.3 Separator Vessel

A High Pressure Separator Vessel is due for an inspection. The vessel has been in service for eleven years. Its first inspection was after three years in service. The interval to the next inspection was set at four years and this interval has been retained to the present inspection. A decision on whether this inspection can be by NII is required.

The vessel is constructed of carbon steel that is clad internally with a stainless steel liner. The vessel exterior is fully insulated and the insulation is protected by galvanised steel sheet.

The integrity management plan for the plant includes technical reviews, considering the main threats to integrity, on a vessel by vessel basis. This has identified that corrosion and erosion are the only degradation mechanism of concern here. External corrosion (under the insulation) has been identified as having a higher probability than internal corrosion/erosion. However, if the carbon steel becomes exposed to the process fluids (after breakdown of the stainless steel cladding), corrosion can be very rapid hence integrity of the cladding is important. Corrosion is more likely to be in the form of pitting than of a generalised nature.

Both of the previous inspections have included visual inspection of the vessel interior. This included close visual examination of all accessible internal surfaces. All areas inspected were reported to be in good condition with no visible degradation. This information has been considered in the most recent technical review undertaken in planning for the forthcoming inspection. In order to check for signs of external corrosion, sections of insulation were removed during each of these inspections. The insulation was seen to be dry in each case and mild localised corrosion (<0.5 mm) was observed.

Application of the screening process (Figure 3-1):

— vessel has had previous inspection and history is still relevant? **Yes**
— entry is scheduled for other reasons? **No**.

One can therefore proceed to apply the high level decision guidance flow chart (Figure 3-2):

— confidence in ability to predict types and locations of degradation. The reviews performed as part of the inspection planning process are considered to fall within the option 1) requirements for selection of this factor (see item 3.3.1, category **High**). The High category is selected here given that the initial conclusions of the reviews have been validated by the inspections carried out - i.e. there is now no expectation that further, as yet unidentified, mechanisms may be active
— previous inspection effectiveness. The previous inspections by IVI can be taken as Medium
— severity and rate of degradation. The internal inspections performed did not reveal significant degradation but corrosion (not expected to impact on vessel integrity during the remaining lifetime) was observed on the exterior. A Medium ranking therefore applies here.

Following Figure 3-2 with Medium, Medium, Medium, one arrives at a recommendation that non-intrusive inspection is possible in principle.
This vessel has jacketed external insulation hence NII meeting the efficiency requirement may not be possible unless the insulation is removed.

3.5.4 Absorber Vessel

A gas sweetener drum operates by absorption of H₂S in a zinc oxide bed. The zinc oxide becomes depleted through operation and requires replacement after some time in service. The rate of depletion depends on the nature of the gas and replacement timing is determined by monitoring the effectiveness of the sweetening based on the downstream gas composition. Replacement of the zinc oxide requires shut down of the vessel and is a complex and expensive operation. Entry for internal visual examination requires removal of the zinc oxide beds and this involves a cost almost as high as that for replacement. There are two vessels, referred to herein as A and B, running in parallel and a single vessel is capable of sweetening the entire gas throughput hence there are no production losses associated with a shut down. Nevertheless the costs of removal/replacement mean that considerable savings can be made if entry can be timed to coincide with replacement of the zinc oxide bed when it becomes necessary.

The vessels fall under an integrity management plan that uses a risk based approach to inspection planning. As part of this, an operational risk assessment was performed to identify and assess possible damage mechanisms. This indicated that internal pitting type corrosion in the wet sour gas environment is the main threat to integrity. The rate of corrosion is expected to be moderate however, and wall loss would not be expected to exceed the corrosion allowance through the vessel lifetime. The Risk Based Inspection plan devised at the time of vessel commissioning recommended inspection by IVI at intervals of four years. After the first four years of operation, the zinc oxide showed little degradation in performance and a decision was taken to delay the IVI but perform an interim NII. Both vessels were subject to NII consisting of (a) point thickness readings at 42 shell/head and 24 nozzle locations for which pre-service measurements had been made and (b) Time of Flight Diffraction testing over each of the main longitudinal and girth welds. The thickness gauge measurements did not show any notable changes in wall thickness. No reportable flaws were identified by the TOFD inspection. Based on the results obtained, the inspection plan was revised to perform the first IVI after a further two years in operation (or sooner if a change of the zinc oxide was required).

After this two year period it is evident that the zinc oxide in both vessels has considerable remaining life hence it would be desirable to avoid opening either vessel. The decision guidance process is to be followed to establish if this is possible.

Application of the screening process (Figure 3-1):

— vessel has had previous inspection and history is still relevant? Yes (NII)
— entry is scheduled for other reasons? No.

Proceed to apply the high level decision guidance flow chart (Figure 3-2):

— confidence in ability to predict types and locations of degradation. The integrity management approach and operational risk assessments performed allow option 1) to be considered in determining the category applicable here. While the operational risk assessment has considered in detail the types of degradation likely, the findings cannot be taken to be fully validated by the inspections carried out to date. It is conceivable that further, unexpected, degradation mechanisms might not have been identified by the inspection, given the limited extent of the NII carried out. Hence a Medium ranking is assigned here
— previous inspection effectiveness. The previous inspections (on both vessels) were by NII. The thickness gauge inspection at fixed points is judged as having a markedly lower probability than IVI of detecting the flaw type of most concern (pitting). Hence the previous inspection effectiveness is taken as Low here
— severity and rate of degradation. The thickness gauge measurements did not reveal any clear loss of wall thickness. However, the operational risk study did suggest corrosion can be expected, although not sufficient to exceed the corrosion allowance through the vessel life. Hence a Medium ranking applies here
— following Figure 3-2 with Medium, Low, Medium, one establishes that NII is not recommended
— based on the above recommendation, a decision was made to perform IVI on one of the vessels and vessel B was opened for inspection. This consisted of close visual examination of all internal surfaces and MPI on all nozzle welds and approximately 20% of shell weld length. Most of the internal surfaces showed some minor pitting, with a maximum depth of 0.75 mm. No crack like flaws were identified in any of the welds
— the zinc oxide in vessel A remains in good condition and it would be preferable to continue to operate on the basis of having performed NII rather than opening the vessel for IVI. The decision guidance process is to be followed in determining whether this is a justifiable approach.

Application of the decision guidance process:

— vessel has had previous inspection and history is still relevant? Yes (NII)
— entry is scheduled for other reasons? No

Proceed to apply the high level decision guidance flow chart:

— confidence in ability to predict types and locations of degradation. Again the option 1) definitions are
considered in determining the category applicable. The same considerations apply here as for vessel B but now the potential existence of unexpected degradation mechanisms can be ruled out based on the findings of the inspection on vessel B. Hence a High is assigned:
— previous inspection effectiveness. The inspection on vessel B was by IVI and the results are relevant to vessel A hence Medium applies here.
— severity and rate of degradation. The thickness gauge measurements did not reveal any clear loss of wall thickness but the internal visual inspection on vessel B showed pitting up to 0.75 mm depth. Hence a Medium ranking applies here.

Following Figure 3-2 with High, Medium, Medium, one arrives at a recommendation that NII can be performed on this vessel in principle.

4. Inspection planning

4.1 Introduction

The principal objective of inspection planning is to establish a cost effective strategy which provides a satisfactory level of confidence in the vessel’s safe and reliable operation until the next inspection. Inspection planning is a complex task that demands consideration of a broad spectrum of issues, ranging from detailed technical assessments of the impact of vessel operating conditions on degradation through to budget planning and allocation. As well as the technical considerations, it is generally also necessary to satisfy certain legislative requirements. While this aspect is not covered specifically in this recommended practice, since the requirements are usually country specific, it remains an important part of the planning process.

The non-intrusive inspection plan for a vessel defines which parts of the vessel should be inspected, what inspection methods should be used, and what coverage is required. This section of the recommended practice provides guidance on determining the most effective non-intrusive inspection plan for a given vessel, in terms of establishing an appropriate balance between vessel integrity and inspection cost/duration. In particular it addresses the question of how to establish an appropriate balance between sensitive but relatively slow (and therefore expensive) inspection methods, and rapid (and therefore less expensive) but less sensitive screening methods.

Approaches to planning will vary from company to company but, typically, the plan will define at least the following:
— timing for the inspection
— type of inspection method(s) to be used
— regions of the vessel to be inspected
— shortlist of inspection service provider(s)
— qualifications of inspectors. Reporting requirements
— requirements from plant operations (e.g. shut down)
— requirements from plant maintenance (e.g. set up scaffolding)
— safety requirements (equipment and personnel).

Clearly there are many additional considerations that go into the overall inspection planning activity. In particular, consideration should be given to the following:
— whether the inspection to be performed on stream or off stream
— temperature during inspection (high temperature is likely to be the main concern, though difficulties may arise from the build-up of ice on low temperature items).
— whether the inspection is on the critical path of an outage?
— whether the inspection is opportunity driven?
— requirement for comparison with previous/past inspections
— cost and time constraints.

The steps in planning and implementing a non-intrusive inspection are the same, regardless of whether the inspection requirement has been determined using a risk based inspection (RBI) or more prescriptive approach. However, there can be a high degree of synergy between non-intrusive inspection and RBI since both approaches require similar types of information to be available.

The approach developed here is intended to be systematic, thereby promoting a consistent approach between operators. Nonetheless, it does not remove the need for input and review by competent personnel and the results must be reviewed by competent inspection planning personnel to check that the inspection plan is broadly consistent with their engineering judgment.

The main elements in devising an inspection plan are as follows:
Identification and selection of the planning team.

The team to plan, prepare and execute the inspection must be competent across a range of disciplines. These
must be identified and appropriate personnel selected.

**Definition of the inspection strategy.**
The planning approach will depend in part on the intended inspection strategy, i.e. whether the inspection is intended to confirm the absence of degradation, or to establish the depth or extent of known active degradation mechanisms.

**Definition of vessel zones.**
The vessel can be treated as one or more zones, each representing a particular combination of geometry, material, likelihood of degradation etc.

**Selection of inspection methods and coverage.**
Selection of appropriate inspection method(s) and coverage for each of the defined zones (some zones may require no inspection).
Figure 4-1
Inspection Planning Flowchart
4.2 The Planning Team

Inspection planning is generally conducted by a team consisting of people with responsibilities in different areas (e.g. production, process, metallurgy, inspection, maintenance), the objective being to ensure that the inspection is effective within the constraints imposed by sometimes conflicting internal needs.

The development of a non-intrusive inspection plan can be significantly more complicated than is the case for an internal (e.g. visual) inspection. A multi-disciplinary approach is required which is likely to involve appropriate experience in engineering/materials/process operations/non-destructive testing.

The basic team required to assess the requirements for a non-intrusive inspection should consist of personnel with competencies in the following areas:

- general knowledge of the construction of containment vessels and systems, materials and materials processing, fabrication processes etc.
- corrosion or materials technology
- specific knowledge of the systems to be inspected, operational history and ‘general knowledge’, (knowledge of the working practices and history of the system, safety requirements, and the likely conditions at the time of inspection)
- non-destructive testing
- nominated person to coordinate the overall process.

Team members may have more than one of the specified skills; it is not necessary for the team to contain individual specialists in all of the above.

The most effective team is likely to be the smallest team that has the requisite skills, but the team should not be reduced excessively, as items are likely to be overlooked. Personnel to carry out any of these functions should be competent to assess their own level of expertise in the selected area. One member of the team should take responsibility for the overall planning process.

4.3 Inspection Strategy Type

The objective of any inspection, at the highest level, is to give a high degree of assurance that any degradation with potential to threaten integrity is detected before the next inspection. However, how it achieves that ambition will vary according to the specific details of the item under consideration. For example, the inspection regime for a vessel where the corrosion risk assessment has shown no likely degradation mechanisms will be very different from the inspection regime for a vessel where stress corrosion cracking is predicted to be likely.

In the course of defining the inspection schedule the following three, closely linked, aspects must therefore be taken into consideration:

a) Degradation method:
   - nature of degradation, global wall thinning or cracking
   - location of degradation, preferential attack or more random.

b) Potential to threaten integrity (what resistance to degradation is embodied in the design)
   - corrosion allowance
   - critical crack depth.

c) Degree of assurance – feeds into the inspection performance requirements.

Any inspection program specified must also be able to give some degree of assurance that unexpected damage mechanisms are not occurring which might lead to failure of the component.

The above clearly rests on knowing what degradation mechanism to inspect for – once this is determined (through corrosion risk assessment [CRA] or historical evidence) the questions regarding assurance and potential threats to integrity can be addressed through defining where to inspect and how to inspect. These assessments must take into consideration the future operating conditions for the component, and not merely reflect past conditions. For example, where produced fluids are increasingly sour, it would be misleading to base the inspection requirements on a CRA which has assumed low sulphur content, resulting in a downplaying of the importance of inspection for mechanisms such as sulphide stress cracking (SSC).

The starting point in assessing any deviation from the specified inspection plan is an understanding of how the objectives of the inspection might be affected, e.g. does the non-conformance significantly compromise the ability of the inspection to meet the overall objectives. It is therefore important that the objectives be understood, bearing in mind that these may not be defined in detail in the inspection plan itself (as this defines the work scope for the inspection team).

As stated above, different vessels will clearly have different inspection requirements, not just in the detail of the “what, where, how”, but also in the basis of the approach. For example, a vessel for which it has been determined that generalised corrosion is the main degradation mechanism of concern but with a low probability would be treated differently to a vessel in which weld cracking by stress corrosion, such as hydrogen induced
stress corrosion cracking (HISCC) or sulphide stress corrosion cracking (SSCC), is seen a high likelihood. The differences on this level can form a useful basis for categorising the type of inspection in a way that facilitates subsequent assessment of non-conformances. To this end, three inspection types have been defined, as described in Table 4-1 below. There is a clear difference in emphasis in each of the inspection types and this provides a useful framework for the establishment of the inspection plan, as well, as later in the process, treatment of any non-conformances. The three categories are discussed in more detail in the following sections, and guidance on the assignment of an inspection type to a particular item is given in Sec.4.3.4.

### Table 4-1  Inspection Type Definitions

<table>
<thead>
<tr>
<th>Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Degradation mechanism NOT expected to occur. Inspection is required to confirm there is no onset of the degradation mechanism.</td>
</tr>
<tr>
<td>B</td>
<td>Degradation mechanism expected, with low / medium progression. Location of degradation can be predicted. Not anticipated to impact on vessel integrity in the medium term (typically at least 2 outage periods). Inspection required to confirm CRA predictions.</td>
</tr>
<tr>
<td>C</td>
<td>Degradation expected with medium / high progression. Location of degradation can not be predicted. MAY impact on vessel integrity in the medium term (two-outage timeframe). Inspection required to confirm absence of flaws of critical size.</td>
</tr>
</tbody>
</table>

#### 4.3.1 Type A Inspection

Type A inspection applies in situations where there is a low probability of degradation based on previous inspection history and / or CRA and if degradation is present it will tend to be general or there is a high confidence that the most likely areas for degradation can be identified. It is also intended to provide a general screening for damage due to degradation mechanisms that might unknowingly be active. The purpose of this type of inspection is therefore primarily to confirm that there is no degradation active. If degradation is found then further steps are required to be taken.

**Example of Type A**

A vessel constructed in Duplex stainless steel and exposed to produced water, oil and gas at moderate temperature. The most likely mechanisms here would be chloride pitting of the shell and chloride SCC of the welds. The probability would typically be very low however, provided the chloride levels are not excessive and the temperature is moderate. In this situation the corrosion assessment would typically indicate that degradation, if it does occur, will tend to be found at the bottom of the vessel (where there is contact with water). Provided exposure to water is similar, there are no other factors leading to preferential degradation. This means there is no need to do a high coverage inspection – a fairly small coverage can give confirmation that degradation is not active. It's important however to ensure that the areas selected for coverage are likely to be representative of the worst areas. If this is possible (based on the findings of the corrosion assessment) then very low coverage may be acceptable. A key inspection performance requirement here is the ability to detect the presence of degradation, even when it is in its early stages.

1) Note that there is a sound statistical foundation for allowing this type of approach. A semi-quantitative Bayesian statistics approach can be used to show that for a situation in which there is a high level of confidence in limited degradation, a lesser amount of inspection can still have significant influence on the “degree of assurance”.

#### 4.3.2 Type B Inspection

Type B inspection applies when there is some degradation expected but it is not expected to be such as to threaten integrity in the medium term. Medium term is in this case taken as being a period equivalent to at least two inspection intervals. This has been adopted as it allows for any missed flaws to be identified at the subsequent inspection, without threatening the integrity of the equipment. This inspection applies at a low/ moderate coverage and its purpose is to provide sufficient information to allow quantified demonstration of the required degree of assurance. If the results of the inspection do not allow this then further action is taken.

**Example of Type B**

A vessel constructed in carbon steel that is exposed to wet gas. Corrosion (pitting or more general) is expected but with a low corrosion rate. The corrosion assessment has defined three zones where corrosion conditions may be different. For this vessel a moderate coverage using corrosion mapping is appropriate, with a certain amount of coverage in each of the three zones. The coverage should be sufficient to allow a quantified statistical assessment that can be used to demonstrate a high confidence in estimating the worst flaw. The accuracy and resolution of the inspection system need to be considered in the same context. Note the shift in emphasis compared to Type A – here one is using the information provided by the inspection to say something about the worst degradation that might exist in the vessel (including the regions not inspected) where in the Type A inspection the emphasis is on identifying the presence (or confirming the absence) of degradation.
4.3.3 Type C Inspection
Type C inspection applies when there is a reasonably high probability of degradation being present and/or degradation may be severe and/or degradation has no preferred locations. This inspection will often apply at moderate/high coverage. Its purpose is to give a high probability that any flaw with potential to threaten integrity is found directly. In the event that such flaws are found, then further action is required in order to accurately size the flaws to allow integrity assessments to be carried out. These more detailed, flaw specific inspections are outside of the scope for the NII inspection. The purpose of NII is primarily to identify and locate these flaws.

It is useful to illustrate, by way of examples, how the approach to inspection on different vessels aligns to the above types.

Example of Type C
A vessel constructed in carbon steel with an internal polymer lining. The process conditions are such that the corrosion assessment identifies a potentially high corrosion rate if there is breakdown of the lining. Breakdown is considered reasonably likely for polymer linings and preferred locations for breakdown cannot be readily determined. Hence there is limited confidence in ability to identify the areas of highest susceptibility. With localised lining breakdown it is possible that corrosion might be severe over a small region with the remainder of the vessel being relatively unaffected. These conditions mean that conventional statistical analysis may not apply. Here the inspection coverage must be high to ensure that the worst flaws are not missed. In this type of inspection coverage will often be more important than system accuracy.

4.3.4 Selection of Inspection Type
Guidance of the selection of a particular inspection type is given in Figure 4-2 below. This considers the likelihood, extent and rate of degradation expected for a particular mechanism (based on the corrosion risk assessment) to determine the appropriate inspection type.

The inspection type categorisation is unique to a particular degradation mechanism and may also vary from one location to another. It is important, therefore that it is re-evaluated for each. For example, a vessel where the CRA has predicted both general wall loss and localised SCC cracking mechanisms might be assessed as shown in Table 4-2.

<table>
<thead>
<tr>
<th>Table 4-2  Example of Inspection Strategy Grading Process.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Above fluid level</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Below fluid level vessel walls</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Nozzle connection</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
The first stage of the assessment is to determine whether degradation of the item is likely to occur. In making this judgment the assessor should consider the worst location of the item, and take account of any previous inspection history or CRA assessment. The following categories then apply:
Mechanism Likelihood

High
Previous inspection has shown the degradation mechanism to have taken place, or the CRA indicates that the mechanism WILL take place during the remaining plant lifetime.

Medium
The CRA assessment has shown that the damage mechanism MAY take place during the equipment lifetime, but inspection history to date has shown no evidence of degradation.

Low
No degradation expected or degradation is superficial.

The next step is to consider the morphology of the damage mechanism. For the purposes of the inspection categorisation, these can be defined as either

Degradation Extent

General
Covers corrosion or erosion, where the loss of wall thickness is uniform or varies slowly within the area under consideration. It also covers crack-like flaws that are numerous and closely spaced within the area considered.

Localised (Clearly identifiable)
This covers corrosion or erosion where the loss of wall thickness is localised or irregular within the area under consideration, pitting or localised cracking which is isolated and does not merge with surrounding flaws. The principal feature is that the location of the cracking is well understood and predictable – i.e. at the weld root, and inspection can be targeted in that location.

Localised (Random)
As above, but may occur anywhere with no particular preference.

Finally, consideration is given to the rate of the degradation. Again for simplicity, the assessor is required to categorise the rate under one of three headings:

Degradation Rate

High
The anticipated rate of degradation is such that failure of the equipment or rejection based on inspection results can reasonably be expected within the remaining equipment lifetime.

Medium
The anticipated degradation rate is such that it would be expected to be observable during the equipment lifetime, but would not be expected to threaten its integrity during that time.

Low
No degradation expected or degradation is superficial.

The resultant inspection type can then be read from the flow chart. As with all aspects of the evaluation process, the result thus obtained should be considered against engineering judgement, and if necessary overruled, in which case a record of the decision process should be maintained.

4.4 Definition of Vessel Zones

4.4.1 Identification of Zones

Non-intrusive inspection methods have different capabilities and limitations for different geometries and materials and can be heavily influenced by aspects such as degradation and flaw types. In addition, it is generally impractical to perform non-intrusive inspection over the entire vessel surface. The approach suggested herein for the selection of methods is therefore based on the concept of “zones” representing different combinations of likelihood of degradation, tolerance to degradation and practicality of inspection. Factors such as geometry, material, likelihood of degradation, type of degradation and previous inspection results should all be considered when identifying these different zones.

This then provides the basis for deciding which parts (zones) of the vessel should be inspected, by which inspection method, and which should be subject to sample inspections. In the case of sample inspection of a zone, it may be possible to use the results to make predictions about the condition of the un-inspected part of that zone, but the results may provide little or no relevant information about the condition of other zones. Examples of features which could be considered when dividing the vessel into zones include:

— longitudinal welds
— circumferential welds
— attachment welds
— nozzle welds
— parent plate with little probability of corrosion/erosion
— parent plate with medium probability of corrosion/erosion
— parent plate with the highest probability of corrosion/erosion (within that particular vessel)
— known corroded area in parent plate
— internal fixings with integrity impact.

Note that these are examples only, and in practice the zones should be determined by considering the detailed design, function, operating conditions and history of the vessel. The underlying principle is that each individual zone should be “homogeneous” so that any given part of a zone is representative of the rest of that zone in terms of likelihood of degradation, type of possible degradation, tolerance to degradation and type of inspection method(s) which can be applied. Inspection method and the basis for sampling (if appropriate) can then be determined individually for each zone.

Zones which are physically separate but otherwise similar can be considered as one, for the purpose of sampling e.g. in many cases no distinction need be made between spherical and cylindrical shell regions.

In order to simplify the process of defining the separate inspection zones, it is recommended that the three main aspects “design”, “operational” and “inspection history” should be considered separately.

Design and manufacturing factors
The vessel is divided into different zones (categories) based on loading conditions and tolerance to flaws. Examples include, but are not limited to: shell plates, heads/dished ends, nozzles (set on, set through and forged nozzle designs might need to be treated separately), inlets, man-ways, longitudinal welds, circumferential welds, internal attachments, internal components. Separate parts might be included in the same zone, e.g. all nozzles might belong to the same zone, welds might be included in the same zone regardless of welding process or geometry.

Operational factors
The vessel is divided into different zones reflecting the extent to which different locations are known or expected to be affected by the operating and process conditions. Considerations include, but are not limited to: service fluids, inlet/outlet locations, locations of mixed phases, high fluid flow rates and turbulence and impingement, vapour/condensation, bubbling/cavitation, pressure/pressure cycling, loading, temperature, oxidizing atmosphere, aggressive abrasive content. This requires detailed knowledge of the operational characteristics, chemical nature of the fluids, metallurgy etc. When considering the zones corresponding to operational conditions, consideration should be given to previous experience from that vessel, experience from similar types of vessel operating under broadly similar conditions, and generic knowledge and experience of how the vessel material behaves under the particular operating conditions (process, temperature, etc.).

Previous inspection factors
The vessel is divided into different zones corresponding to the effectiveness and results of previous inspections. Examples include, but are not limited to: regions where no previous in-service inspections have been performed, regions subjected to internal visual inspection, regions subject to ultrasonic thickness measurements, regions reported to contain flaws / degradation etc.

Note that further subdivisions of zones may be necessary, e.g. regions covered by fire retardant lining, regions with limited access to inspection surface due to adjacent pipework, etc.

4.4.2 Example
The following example is used to illustrate the identification of zones corresponding to the different combinations.

In a partially filled vessel the shell and weld submerged in and out of the liquid and at the interface between liquid and vapour may corrode at different rates. This gives rise to a requirement for the following zones to be considered: A: Liquid zone, B: Interface zone, C: Vapour zone. Often there are specific issues relating to any nozzles or connections to vessels, so these should also be identified as individual zones, D: Inlet nozzle, F: Outlet nozzle. This would normally be sufficient to assess the vessel; however, if previous inspection records had identified a region of more advanced corrosion in a particular area of the shell (for example within the vapour region caused by condensation of vapour accelerating corrosion) then an additional zone (designated “E” in Figure 4-3 below), which is a combination of shell, vapour region, previously detected flaws would be required.

DET NORSKE VERITAS
Recommended Practice DNV-RP-G103, January 2011
Page 33

4.5 Definition of Degradation Type

The next stage is to identify the type of degradation expected at each location. Degradation type should be defined according to its associated flaw morphology as this is what mostly influences the type of inspection method that will be applicable. In the majority of cases flaws can be categorised as one of the following, although judgement should always be applied as different mechanisms result in flaws with varying detectability using non-destructive methods.

*Generalised loss of wall thickness.*

This covers corrosion or erosion where loss of wall thickness (LOWT) is uniform or varies slowly within the area under consideration.

*Localised loss of wall thickness.*

This covers corrosion or erosion where the loss of wall is localised or irregular within the area under consideration. For the purposes of this recommended practice, localised loss of wall thickness is also intended to include pitting.

*Localised cracking.*

This covers crack like flaws that are typically isolated and do not merge with surrounding flaws. A fatigue crack initiated in a region of stress concentration would typically be considered as localised cracking.

*Generalised cracking.*

This covers crack like flaws which are numerous and closely spaced in the region under consideration.

In addition to the above major categories there are some less commonly encountered flaw types including delamination and blistering.

The user may find it helpful to develop a matrix of features and flaws to ensure that no combinations are overlooked. Table 4-3 gives an example matrix. Note that the list of features selected for inspection may not always include every feature on the vessel. Depending on the coverage requirements, there may be features that do not need to be included in the inspection.

---

Each of the zones A to F would be considered individually for suitability for inspection by non-intrusive means.

### Figure 4-3

**Example of Vessel Zones**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Zone Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid phase</td>
<td>A</td>
</tr>
<tr>
<td>Interface</td>
<td>B</td>
</tr>
<tr>
<td>Vapour phase</td>
<td>C</td>
</tr>
<tr>
<td>Inlet (liquid)</td>
<td>D</td>
</tr>
<tr>
<td>Previously reported corrosion</td>
<td>E</td>
</tr>
<tr>
<td>Outlet (mixed phases)</td>
<td>F</td>
</tr>
</tbody>
</table>

---

**Table 4-3**

Example Matrix
4.6 Inspection Effectiveness

Having identified the different zones within the vessel, and defined the inspection strategy (from Sec.4.3) for each zone, the inspection criticality should be determined on a zone by zone basis. The level of effectiveness which is appropriate for a particular zone will depend on the likelihood of degradation, previous inspection results, tolerance to degradation, and the consequence of vessel failure. Clearly there is likely to be a strong incentive to perform a rigorous inspection (e.g. full coverage using a sensitive inspection method which has a high probability of detecting flaws) for a part of a vessel where likelihood of degradation is high, tolerance to further degradation is low, and consequence of vessel failure is high. However less expensive methods based on rapid (but reduced sensitivity) screening methods or sample inspections might be acceptable for other zones in this vessel, or for vessels where the consequence of failure is low. Some zones may require no inspection.

By way of example, if for a particular zone, the design is such that tolerance to flaws is high, the likelihood of degradation is very low, and previous inspections have not detected any degradation, then there may be a strong justification for deciding that the inspection has a low criticality, and therefore performing only minimal inspection (or no inspection) of that zone. If on the other hand flaw tolerance is low and the likelihood of degradation is high, the inspection is critical, and obviously there is an incentive to do a much more comprehensive inspection in that particular zone.

A decision process based on a flowchart approach is presented (Figure 4-4), which provides guidance on determining the required inspection effectiveness, taking into account for each zone whether degradation has previously been detected, the likelihood of degradation (using the principles of inspection grading), current tolerance to degradation and consequence of vessel failure. The required inspection effectiveness for a particular location is read off from the appropriate strand in the flowchart.

<table>
<thead>
<tr>
<th>Vessel Feature</th>
<th>Flaw type</th>
<th>Localised LOWT</th>
<th>Generalised LOWT</th>
<th>Localised cracking</th>
<th>Generalised cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set on Nozzle N1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell welds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saddle plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4-3 Example of matrix used to define feature and flaw combinations**

<table>
<thead>
<tr>
<th>Vessel Feature</th>
<th>Localised LOWT</th>
<th>Generalised LOWT</th>
<th>Localised cracking</th>
<th>Generalised cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set on Nozzle N1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Shell plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saddle plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4-4**
Inspection Effectiveness Flowchart
**Inspection Grade**

The inspection grading system used here is taken from the principles of grading contained within the Energy Institute (formerly the Institute of Petroleum (IP)) model codes 12 and 13. [10], [11]. Equipment may be allocated a Grade between 0 and 3 based on the number of previous inspections and the rate and predictability of deterioration based on the Energy Institute guidance on the examination of pressure vessels and piping.

*Grade 0*

Items for which:

1) there is no historical evidence to support the judgement, or  
2) the rate of deterioration is high, or  
3) the rate of deterioration is unpredictable.

Items newly installed in a system commence at Grade 0.

*Grade 1*

Items which have:

1) at least one previous examination at Grade 0; and  
2) which show a moderate rate of deterioration which is predictable.

*Grade 2*

Items which have:

1) at least one previous examination at either Grade 0 or Grade 1; and  
2) which show a low rate of deterioration which is predictable.

*Grade 3*

Items which have either:

1) at least one examination at Grade 0 and one examination at either Grade 1 or 2, and which show a low rate of deterioration which is predictable; or  
2) a negligible rate of deterioration in a stable service environment.

**Current Tolerance to Degradation**

The current tolerance to degradation should be considered in terms of whether it is low, medium or high. In the absence of other criteria, the following definitions could apply:

*Low*

The known or predicted degradation and rate thereof in the zone under consideration are such that failure of the vessel (if no remedial action is taken) can reasonably be expected within the remaining plant lifetime.

*Medium*

The known or predicted degradation and rate thereof in the zone under consideration are such as to be observable during the plant lifetime but would not be expected to threaten the vessel during this period or require remedial action.

*High*

There is no degradation expected or degradation is superficial.

**Consequence of Failure**

The consequences of vessel failure must be considered when determining what level of inspection is appropriate for each zone, ref. [12]. For example two vessels of similar design and operating regime will experience similar degradation, however if failure of one vessel resulted in the closure of the plant for an extended period whilst repairs are undertaken, whereas for the other vessel production could continue comparatively unaffected, it is clear that the inspection of the former vessel would be specified more rigorously than that of the second.

In order to simplify the determination of consequence, it is useful to consider the health, safety and environmental consequences separately from the purely business and cost consequences. Having done so, the overall consequence ranking should be taken as whichever of these is the higher. Consequence rankings are generally determined as a part of the risk based methodology, and these can be mapped to the High, Medium and Low categories used here. Alternatively, in the absence of other criteria, the following definitions should apply:
— Health, Safety and Environmental Consequences

**High**
One or more fatalities or serious injuries requiring hospital treatment, or major release of hazardous material or pollution

**Medium**
Injury requiring hospital treatment, or release of hazardous material or pollution but with no significant effect off site.

**Low**
At most, minor injury with full recovery, or minimal release of hazardous material or pollution.

— Business Interruption and Cost Consequences

In the absence of other criteria, the following definitions could apply:

**High**
Major shutdown / turnaround or high costs of repair / replacement

**Medium**
Several days shutdown / turnaround or significant costs of repair / replacement

**Low**
Less than one day shutdown / turnaround or low costs of repair / replacement

### 4.7 Required Inspection Effectiveness

The flowchart provides a “score” which represents the required inspection effectiveness for the zone under consideration. Effectiveness is here defined as a qualitative measure of the probability of detecting flaws, taking coverage into account. Assuming a uniform flaw distribution,

\[
\text{Effectiveness} = f(\text{POD}, \times \text{Coverage}).
\]

Three effectiveness categories are used, (high, medium and low), these being defined by comparison to the effectiveness for visual inspection. High implies a higher effectiveness than visual inspection, medium implies a broadly similar effectiveness and low implies a lower effectiveness.

These requirements should be interpreted as follows.

**Low**: Spot checks. The inspection is performed at a number of discrete locations within the zone, for example manual ultrasonic thickness measurements at 500 mm intervals might be appropriate for monitoring general loss of wall thickness, or at a reduced interval for more localised corrosion/erosion.

**Medium**: 100% inspection of the planned inspection area using a method which has medium efficiency (>70% probability of detection), or sample inspection using a method which has high efficiency (>90% probability of detection).

**High**: 100% inspection of the planned inspection area using a method which has high efficiency, i.e. expected to have a probability of detection exceeding 90% for the degradation or flaws of concern.

In this context, the actual area of the zone inspected should be sufficient to allow meaningful extrapolation of the results to the un-inspected parts of that zone.

Note: The inspection requirements for a zone may need to be increased if flaws or degradation are detected during the inspection. For example if spot checks reveal greater loss of wall thickness than expected, or localised thinning, increased coverage is recommended to properly assess the extent of the thinning. If cracks are detected during a sample inspection, 100% inspection of that zone (and other susceptible zones) may be required.

### 4.8 Coverage

Before proceeding with selecting inspection methods, it is important to establish the nature of inspection coverage required. This, together with several other factors, has an influence on what features should be inspected, which in turn, influences what inspection methods can be selected. The decision process does not seek to guide the user to determining the exact coverage for each region of the vessel, this forms part of the detailed inspection planning activity and is discussed in more detail in Sec.4.4.

A high level recommendation for coverage is provided below; the intent being that this is used to establish the framework into which any detailed decisions on coverage shall conform. A coverage selectiveness requirement is defined, this being such as to ensure coverage consistent with the user’s ability to predict the sites of potential flaws of concern and hence direct inspection accordingly. This is determined according to the response selected for the **Confidence in ability to predict types and locations of degradation** question of decision guidance process, Figure 3-2.

A High confidence will justify a minimum of **Targeted** coverage. Medium confidence will require a minimum
of Targeted plus Exploratory coverage and Low confidence will require Global coverage. The coverage categories are as defined below:

**Targeted**
Inspection can be restricted to the sites where potential degradation has been predicted.

**Targeted plus exploratory**
Sites where potential degradation has been predicted must be inspected. In addition several further areas where it is not possible to rule out the presence of flaws must also be inspected.

**Global**
The entire area/feature of the vessel under consideration should be inspected.

As stated previously, the actual area inspected should be sufficient to allow meaningful extrapolation to remaining areas of the zone, which will be a function of the anticipated type of degradation. i.e. where general loss of wall thickness is expected, it is possible to carry out spot checks, which will rapidly confirm the current status, however where localised wall loss is expected, a more rigorous scan is required to obtain the same degree of confidence.

4.9 Selection of Inspection Method

4.9.1 Inspection Capability

Although routine methods and generic procedures may be appropriate for some zones (e.g. ultrasonic 0 degree wall thickness measurement, ultrasonic examination of butt welds) in other instances (e.g. where access to inspection surfaces is restricted; where complicated flaw orientations/morphologies are sought; difficult material or geometry) it may be necessary to apply specialised methods. The purpose of the inspection plan is to ensure that the correct methods are used in each context (location, degradation type and anticipated extent) in order to ensure the equipment integrity between inspections. A general description of the main inspection methods available for non-intrusive inspection of vessels, and their associated capabilities is provided in Appendix A. A variety of additional sources of information on methods exist, see for example References [13], [14], [15], [16], [17], and internet based software tools such as the HOIS Interactive Knowledge Base [18].

The nature of the degradation expected in each zone is likely to vary, as is the required inspection effectiveness. It is therefore important to consider the applicability of a particular method on a zone by zone basis. The overall objective should be to ensure that the integrity of each zone meets the minimum level needed to ensure the continued integrity required for the vessel as a whole.

4.9.2 Inspection Method Selection Flowcharts

Different NDT methods have differing capabilities, strengths and weaknesses. In order to facilitate the selection of the right method for the application, a number of selection flow charts have been developed for the most commonly used methods in the context of non-intrusive inspection.

The charts are intended to assist the inspection manager to determine the efficiency of a particular method in a given application, as defined by comparison to IVI, for a number of commonly used inspection methods. The method capability is classified in comparison with that of internal visual inspection, taking into consideration the degradation type. Each method is given two capability scores, one for capability in detecting flaws, and the other for the method’s ability to provide quantitative information regarding flaw size or wall thickness. For both factors, three categories are defined, namely, High, Medium and Low. When selecting a method appropriate for the particular application, the inspection manager should use the appropriate capability score (POD / sizing) to compare against the required minimum inspection effectiveness, from Figure 4-4. For example, where a Type A inspection is planned, the dominant requirement is the ability to detect degradation, thus the POD portion of the capability score would be most appropriate; whereas with a type C inspection, the requirement is to determine whether degradation is within expected limits, thus a method with a good ability to provide quantitative information is required and the sizing portion of the capability rating would be more appropriate.

**High**

POD: The method has, in the conditions under consideration, a higher probability of detecting the flaw type than does IVI.
Sizing: The method is able to provide accurate, quantitative information regarding flaw size or wall thickness.

**Medium**

POD: The method has, in the conditions under consideration, a probability of detecting the flaw type broadly similar to that of IVI.
Sizing: The method is able to provide some semi-quantitative or comparative information regarding flaw size or wall loss.
Low POD: The method has, in the conditions under consideration, a lower probability of detecting the flaw type than does IVI.

Sizing: The method is able to provide only limited, generally qualitative information regarding flaw size or wall thickness.

In order to select a method meeting the minimum efficiency requirement, the user consults each of the flow charts, considering each factor sequentially in the following order;

\[ \text{Vessel feature} \rightarrow \text{Flaw type} \rightarrow \text{Surface} \rightarrow \text{Temperature} \rightarrow \text{Thickness} \rightarrow \text{Access} \]

The flow charts allow continuation in cases where the method is applicable for the factor considered and terminate where it is not. In each case of termination, recommendations are made for alternatives that may have a better chance of success. Branches that do not terminate prematurely end with the efficiency rating for the method under the combination of conditions specified.

For each method a flow chart is presented which takes due consideration of vessel features, flaw type, external surface coating, temperature, wall thickness and access requirements in order to determine the likely method efficiency. A brief description of each of these factors is given below.

Features considered

The features for which guidance on the selection of an inspection method can be provided are limited to those on the baseline vessel shown in Figure 4-5 and include:

- seam and girth butt welds
- cylindrical and spherical shells
- set on and set through nozzles
- nozzle compensating plate (not shown on vessel but included)
- saddle plate (external support)
- weir plate (internal)
- lifting lug (external)
- external stiffener.

Note that several of the features are external to the vessel (compensating plate, saddle plate, lifting lug and external stiffener). The inspection method for these is recommended not in terms of assessing their external condition but in terms of the condition of the vessel interior adjacent to the feature.

![Figure 4-5](image)

Baseline Vessel Design (showing features considered).

Flaw types considered

At this stage only four flaw types are considered in making recommendations for inspection method. These are:

- generalised loss of wall thickness (e.g. corrosion/erosion)
— localised corrosion/erosion (e.g. pitting)
— multiple cracking (e.g. stress corrosion cracking)
— isolated cracking (e.g. fatigue cracking in welds).

**External surface coating**

The user selects from one of:

— bare metal
— paint
— flame or thermal sprayed aluminium
— zinc
— thermal insulation
— passive fire protection.

For bare metal it is assumed, in all cases except when considering magnetic flux exclusion, that the exposed surface is sufficiently smooth and continuous for adequate ultrasonic transmission through conventional probes. Bare metal in a corrosive environment will often need some cleaning up before being suitable for ultrasonic inspection.

For paint it is assumed, in all cases except for when considering magnetic flux exclusion, that the coating is less than 2 mm thick and in good condition, i.e. its surface is sufficiently smooth and its body continuous so as to allow adequate ultrasonic transmission through conventional probes.

**Temperature**

Temperature refers to the external surface temperature of the feature under inspection, and therefore the temperature to which the inspection equipment may be exposed.

**Wall thickness**

Wall thickness refers to the wall thickness of the feature to be inspected (either vessel wall thickness or feature thickness as applicable).

**Access requirements**

The access requirements are specified as the minimum length required (i.e. dimension parallel to the surface being inspected) \( \times \) the minimum height required (i.e. dimension perpendicular to the surface being inspected).

### 4.9.3 Inspection Method Selection Criteria

The user works through the flow charts until a method is found having at least the effectiveness rating determined in Sec.4.7. The order in which the flow charts are consulted or, indeed, whether all of the charts should be consulted in every instance cannot be prescribed. There will, for example, be cases in which the user has sufficient knowledge/experience with the inspection requirement under consideration to confidently specify an inspection method that will be suitable. In such cases only the flow chart for the selected method need be consulted, with this serving as confirmation of the selection. There will also be cases where the user can not easily identify suitable methods and in these instances it may be necessary to consult each of the flow charts. It is possible that, for the combination of factors considered, several methods will turn out to have more than the minimum efficiency required. Whilst under ideal circumstances the best method would be selected for each zone, in such cases the decision on which of the acceptable methods to use will be tempered by non-technical considerations such as cost and practicality.

In addition, it is important to consider compatibility with previous inspections. In order to be able to monitor progression of any degradation, there is clearly a need for continuity between inspections. The introduction of different inspection methods may complicate the comparison of results (particularly when changing from an invasive to a non-invasive inspection regime). The impact of any such changes can be minimised with due care in specifying the inspection reporting criteria and format.

The intent of the flow charts is to allow a rapid assessment of method capability in a particular set of circumstances. In meeting this objective they are necessarily simple and can not consider in depth all situations that might arise. There may be circumstances in which capability is significantly degraded by factors not considered in the flow charts, e.g. unusual flaw orientation, obscuration by other flaws etc. Consequently the user should regard the results of the flow charts as a guide only and should review the results obtained for each case in the context of any factors that might play a role in degrading capability in practice. Furthermore, the flowcharts reflect the typical capability of the method described and do not address improvements in performance possible through the use of specialised or custom equipment and advanced techniques.

If no method meeting the minimum requirement is available then it is recommended that the risk associated with not inspecting, or a reduced efficiency inspection of the feature for the flaw type under consideration be reviewed (see Figure 4-1). In order to show that the risk is acceptable, the review must be comprehensive and fully documented. The review should consider as a minimum:

— the probability of flaws with potential to cause failure existing in the feature under consideration
— the findings of previous inspections covering the feature under consideration
— the type and extent of inspection in other regions where degradation can be expected to be similar to that for the feature under consideration
— the potential consequences of failure modes associated with the types of flaw expected in the feature under consideration.

Having identified a method which satisfies the efficiency criterion, it is worth considering whether the chosen method has the ability to size any flaws found during inspection. The outcome here might not affect the decision on whether or not to use NII for the inspection but allows early identification of the approach that may have to be adopted if flaws are found.

The process of method selection is repeated for each degradation type anticipated for the zone under consideration, and then for each zone until a complete inspection plan is established for the equipment.

It is worth noting that, in following the high level decision guidance flowchart, Figure 3-2, the effectiveness of the previous inspection has a direct effect on the requirements for the inspection being planned and may determine whether NII is recommended at all. Consequently, in planning for the current inspection the user should consider the potential implications of the effectiveness likely to be achieved on the requirements for future inspections.

4.9.4 Statistical Methods

In some cases, there is a requirement for the inspection planning process to involve a more quantified assessment of the risks and likelihood of failure occurring, and the impact of inspection on mitigating those risks. In particular, in some industries, there is a requirement to demonstrate that the risk exposure remains below some threshold value, typically quantified in units of probability e.g. number of failures per 10$^6$ years. In such cases, it is necessary to consider the statistical probability that the inspections performed will have found any degradation present, and that the most significant degradation has been accurately assessed. Reference 7 provides an insight into how inspection reduces the risk of failure, where risk of failure is a combination of likelihood of failure and consequence of failure (although Reference 7 specifically addresses ultrasonic inspection, the principles of reducing risk by inspection applies to NDT methods in general). Inspection can only reduce likelihood of failure, not consequence. For a vessel where consequence of failure is high, inspection should have the potential to maintain likelihood of failure at a low level. If the predicted likelihood of failure (without inspection) is high, then there needs to be high confidence in the capability and reliability of the inspection method to detect (and correctly sentence) flaws or degradation of concern.

Further guidance on the use of statistical methods to plan inspection activities and evaluate inspection results is given in Appendix B of this document.
### UT Thickness Gauge

#### Feature
- Butt Weld
- Cylindrical shell
- Spherical shell
- Piping
- Set-on nozzle
- Set-through nozzle
- Compensating pad
- Saddle plate
- Lifting lug
- External stiffener
- Weir plate

#### Defect Type
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

#### Surface
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

#### Temperature (°C)
- < 60 °C
- 60 – 500 °C
- > 500 °C

#### Thickness (mm)
- < 4 mm
- > 4 mm

#### Capability
- All sizes

#### Notes
1. Grind weld flat
2. Consider alternative technique
3. Consider removing coating
4. Equipment must be taken off-line for inspection

Typical probe size down to 20 mm x 20 mm x 20 mm
### Manual 0° UT Mapping

**Feature**
- Butt Weld
- Cylindrical shell
- Spherical shell
- Piping
- Set-on nozzle
- Set-through nozzle
- Saddle plate
- Lifting lug
- External stiffener
- Compensating pad
- Weir plate

**Defect Type**
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

**Surface**
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

**Temperature (°C)**
- < 60 °C
- 60 - 200 °C
- > 200 °C

**Thickness (mm)**
- < 2 mm
- 2 mm
- > 2 mm

**Capability**
- HT equipment available?
- POD
- Sizing

---

**Notes**
1. Grind weld flat
2. Consider alternative technique
3. Consider removing coating
4. Consider taking equipment off line for inspection

Typical equipment size:
- Mechanical scanner: from 300 mm x 300 mm x 50 mm high
- Hand-held and camera: from 20 mm x 20 mm x 20 mm plus camera line of sight.
UT Corrosion Mapping

Feature | Defect Type | Surface | Temperature (°C) | Thickness (mm) | Capability
---|---|---|---|---|---
Butt Weld | Generalised LWT | Bare metal | < 60 °C | < 2 mm | POD M
 | Localised LWT | Paint | 60 – 200 °C | > 2 mm | Sizing M
 | Multiple cracking | Flame spray Al | > 200 °C | Y | 2
 | Localised cracking | Zinc | N | 2, 4
Cylindrical shell | Generalised LWT | Thermal insulation | HT equipment available? | Y | 2
 | Localised LWT | Passive fire protection | N | 2, 4
 | Multiple cracking | | | | |
 | Localised cracking | | | | |
Spherical shell | | | | | |
Piping | | | | | |
Set-on nozzle | Generalised LWT | Bare metal | < 60 °C | < 2 mm | POD M
 | Localised LWT | Paint | 60 – 200 °C | > 2 mm | Sizing M
 | Multiple cracking | Flame spray Al | > 200 °C | Y | 2
 | Localised cracking | Zinc | N | 2, 4
Set-through nozzle | Generalised LWT | Thermal insulation | HT equipment available? | Y | 2
 | Localised LWT | Passive fire protection | N | 2, 4
 | Multiple cracking | | | | |
 | Localised cracking | | | | |
Saddle plate | Not Suitable | | | | |
Lifting lug | | | | | |
External stiffener | | | | | |
Compensating pad | | | | | |
Weir plate | | | | | |

Notes:
1. Grind weld flat
2. Consider alternative technique
3. Consider removing coating
4. Consider taking equipment off line for inspection

Typical equipment size:
- Mechanical scanner: from 300 mm x 300 mm x 50 mm high
- Hand-held and camera: from 20 mm x 20 mm x 20 mm plus camera line of sight.
UT Angled Pulse Echo

Feature
- Butt Weld
- Cylindrical shell
- Spherical shell
- Piping

Defect Type
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

Surface
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

Temperature (°C)
- < 60 °C
- 60 – 200 °C
- > 200 °C

Thickness (mm)
- < 8 mm
- > 8 mm

Capability
- HT equipment available?
- POD
- Sizing

Notes
1. Consider alternative technique
2. Consider removing coating
3. Consider taking equipment off line for inspection
4. Consider internal inspection
Typical probe size from 20 mm x 20 mm x 20 mm
### Time of Flight Diffraction

#### Feature
- Butt Weld
- Cylindrical shell
- Spherical shell
- Piping
- Set-on nozzle
- Set-through nozzle
- Compensating pad
- Saddle plate
- Lifting lug
- External stiffener
- Weir plate

#### Defect Type
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

#### Surface
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

#### Temperature (°C)
- < 60 °C
- 60 – 200 °C
- > 200 °C

#### Thickness (mm)
- < 8 mm
- > 8 mm

#### Capability
- HT equipment available?
- POD
- Sizing

#### Notes
1. Consider alternative technique
2. Consider removing coating
3. Consider taking off line for inspection

TOFD requires two probes, one either side of the inspection volume. Separation is dependant on the wall thickness. Typical probe size is 20 mm x 20 mm x 50 mm high.
### Medium Range UT (LORUS)

#### Feature
- Butt Weld
- Cylindrical shell
- Spherical shell
- Piping (general)
- Piping (restricted)
- Compensating pad
- External stiffener
- Saddle plate
- Lifting lug
- Set-on nozzle
- Set-through nozzle
- Weir plate

#### Defect Type
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

#### Surface
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

#### Temperature (°C)
- < 60 °C
- 60 – 250 °C
- > 250 °C

#### Thickness (mm)
- < 4 mm
- 4 – 50 mm
- > 50 mm

#### Capability
- POD
- Sizing

---

**Notes**
1. Consider alternative technique.
2. Consider removing coating
3. Consider taking equipment off-line for inspection

Typical probe sizes from 50 mm x 50 mm x 50 mm

LORUS is particularly suited to locations with limited access and pipe supports. A range of up to 1m either side of the probe can be inspected in one pass.
### Medium Range UT (CHIME)

**Feature**
- Butt Weld
- Cylindrical shell
- Spherical shell
- Piping
- External stiffener
- Saddle plate
- Lifting lug
- Set-on nozzle
- Set-through nozzle
- Compensating pad
- Weir plate

**Defect Type**
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

**Surface**
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

**Temperature (°C)**
- < 60 °C
- 60 – 250 °C
- > 250 °C

**Thickness (mm)**
- < 4 mm
- 4 – 50 mm
- > 50 mm

**Capability**
- HT equipment available?
- POD
- Sizing

**Notes**
1. Consider alternative technique.
2. Consider removing coating.
3. Consider taking equipment off-line for inspection.

Typical probe sizes from 25 mm x 100 mm x 100 mm high.

CHIME requires two probes positioned up to 1m apart.
Notes

1. Consider alternative technique.
2. Consider removing coating.
3. Consider taking equipment off-line for inspection.

Typically requires a ring of probes length 500 mm height 50 mm.
### Magnetic Flux Exclusion

<table>
<thead>
<tr>
<th>Feature</th>
<th>Defect Type</th>
<th>Surface</th>
<th>Temperature (°C)</th>
<th>Thickness (mm)</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical shell</td>
<td>Generalised LOWT</td>
<td>Bare metal</td>
<td>&lt; 80 °C</td>
<td>&lt; 15 mm</td>
<td>POD M</td>
</tr>
<tr>
<td></td>
<td>Localised LOWT</td>
<td>Paint</td>
<td>&gt; 80 °C</td>
<td>&gt; 15 mm</td>
<td>Sizing L</td>
</tr>
<tr>
<td></td>
<td>Multiple cracking</td>
<td>Flame spray Al</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Localised cracking</td>
<td>Zinc</td>
<td></td>
<td>1, 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal insulation</td>
<td></td>
<td>1, 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passive fire protection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spherical shell</td>
<td></td>
<td>Bare metal</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Butt Weld</td>
<td></td>
<td>Paint</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Set-on nozzle</td>
<td></td>
<td>Flame spray Al</td>
<td></td>
<td>1, 3</td>
<td></td>
</tr>
<tr>
<td>Set-through nozzle</td>
<td></td>
<td>Zinc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compensating pad</td>
<td></td>
<td>Thermal insulation</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Saddle plate</td>
<td></td>
<td>Passive fire protection</td>
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<td></td>
<td></td>
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<tr>
<td>Lifting lug</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>External stiffener</td>
<td></td>
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<tr>
<td>Weld plate</td>
<td></td>
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</tbody>
</table>

**Notes**

1. Consider alternative technique
2. Consider removing coating
3. Consider taking equipment off-line for inspection

Typical scanner size 300 mm x 200 mm x 200 mm high
Notes
1 Consider alternative technique
2 Consider removing coating
3 Consider taking equipment off line for inspection.
Particularly suitable for vessels and pipes with lagging or insulation, or thin metallic cladding made from aluminium, stainless steel or low alloy steel. Only suitable for use on low alloy steels.
Typical probe size 200 mm x 200 mm x 100 mm high, although specialist probes available down to 20 mm x 20 mm x 5 mm high.
## Saturation Low Frequency Eddy Current (SLOFEC)

### Feature
- Cylindrical shell
- Spherical shell
- Piping
- Butt Weld
- Set-on nozzle
- Set-through nozzle
- Compensating pad
- Saddle plate
- Lifting lug
- External stiffener
- Weir plate

### Defect Type
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

### Surface
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

### Surface Temperature (°C)
- < 120 °C
- > 120 °C

### Thickness (mm)
- < 35 mm
- > 35 mm

### Capability
- POD
- POD size

### Notes
1. Consider alternative technique
2. Consider removing coating
3. Consider taking equipment off line

Multi sensor scanner typically 150 mm x 150 mm x 200 mm
Passive Thermography

<table>
<thead>
<tr>
<th>Feature</th>
<th>Defect Type</th>
<th>Surface</th>
<th>Temperature (°C)</th>
<th>Thickness (mm)</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bare metal</td>
<td>Non-contact</td>
<td>&lt; 15 mm</td>
<td>POD L</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paint</td>
<td></td>
<td>&gt; 15 mm</td>
<td>Sizing None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flame spray Al</td>
<td></td>
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<td></td>
<td></td>
<td>Zinc</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Passive fire protection</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Thermal insulation</td>
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<td></td>
</tr>
<tr>
<td>Cylindrical shell</td>
<td>Generalised LOWT</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spherical shell</td>
<td>Localised LOWT</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple cracking</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Localised cracking</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Set-on nozzle</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Set-through nozzle</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Butt Weld</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Saddle plate</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Lifting lug</td>
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<tr>
<td>External stiffener</td>
<td></td>
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<tr>
<td>Compensating pad</td>
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<tr>
<td>Woir plate</td>
<td></td>
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</tbody>
</table>

Notes:
1. Consider alternative technique
2. Consider removing coating

For use as an NII technique requires a process transient. Generally used to monitor insulation effectiveness.
### Radiography

#### Feature
- Piping
- Spherical shell
- Cylindrical shell
- Butt Weld
- Set-on nozzle
- Set-through nozzle
- Compensating pad
- Lifting lug
- External stiffener
- Saddle plate
- Weir plate

#### Defect Type
- Generalised LOWT
- Localised LOWT
- Multiple cracking
- Localised cracking

#### Surface
- Bare metal
- Paint
- Flame spray Al
- Zinc
- Thermal insulation
- Passive fire protection

#### Temperature (°C)
- < 60 °C
- > 60 °C

#### Thickness (mm)
- < 85 mm
- > 85 mm

#### Capability
- POD: H
- Sizing: M

#### Special measures required
- Wall thickness
- Tangential thickness
- Use C60 or Betatron source

#### Notes
1. Consider thickness gauge or pulse echo UT
2. Consider internal visual inspection

Requires access to both sides of equipment. Typically requires 100 mm x 100 mm and 250 mm height for source. Radiography not generally used for non-intrusive inspection of vessels due to long exposure times required.
4.10 Preparation of Work-pack

The work-pack is a comprehensive package (electronic or paper based) of all relevant documentation necessary to perform the inspection. It is typically prepared by the Inspection Body (organisation which will manage the performance of the inspection), in conjunction with the owner in advance of the inspection. The work-pack will be based on the requirements of the document vessel inspection plan which defines the overall inspection strategy – see Sec.4.3. (The vessel inspection plan may be in the form of a specification which identifies the zones to be inspected, the inspection methods and the coverage required but will not include detailed procedures). The Inspection Body should review this plan and compile (as a work-pack) all of the documents required for the inspection. Collaboration with other members of the NII planning team (see Sec.4.2) may be useful.

Contents of the work-pack should include the following:

_Equipment Profile_
Details of the equipment design and operation and previous inspection history, as described in Sec.2.2, and including:

- identity and design
- type of vessel and function
- operation and service details
- detailed drawings
- modifications and repairs
- previous inspection results
- general experience
- complementary information
- accessibility
- safety limitations
- viable degradation mechanisms
- anticipated degradation rates and extent.

_NII Decision Record_
Details of the decision confirming that NII is appropriate for the equipment (Sec.3.4) including:

- statement of any changes occurring in process that may affect the nature or rate of degradation
- inspection reports (if not already included in the Equipment Profile)
- justification for acceptance under screening criteria
- list of vessels considered to be the same as the one under consideration and justification that degradation can be expected to be the same
- justification of selection of category for:
  - confidence in ability to predict types and locations of degradation
  - previous inspection effectiveness
  - severity and rate of degradation.

_Inspection Plan_
This is the document produced by the NII planning team which is the basis of the inspection. It should contain the following information:

- details of the inspection strategy and objectives
  - including the associated decision process.
- datum referencing system
- complete list of equipment zones considered and their associated flaw types
  - justification shall be provided for each feature not being considered for inspection.
- inspection criticality and effectiveness
  - including the associated decision process.
- inspection procedures and method sheets for each method
  - inspection procedures must normally be written or approved by a person certified to Level 3/III in NDT
  - details of the standard and extent of surface preparation
  - specification of the temperature at which the inspections are to be performed together with the operating conditions (if plant is live).
- required inspection coverage
— reporting criteria and format (possibly in the form of a reporting template)
— acceptance reporting criteria and format
— well-defined thresholds or dimensions above which indications (interpreted as flaws) are recorded
— wherever possible acceptance criteria should be defined
— the reporting criteria and format should be specified in detail. The format should facilitate repeatability
  of the inspection and facilitate comparison between past, current and future inspection results.

— recording criteria
— when it is inappropriate to define a recording level (e.g. corrosion mapping, thickness measurements)
  then any condition of particular interest (e.g. evidence of wall thinning) should be defined.

Method Statement
The Inspection Body may decide to produce a Method Statement which summarises the inspection strategy and
incorporates or refers to the information described above. This will help to make the work-pack a coherent,
stand-alone document. In addition, this document could account for any areas where a departure from the
recommended Inspection Plan is unavoidable and describe and justify the remedial action. Other records which
should be included are:
— training, qualification and certification requirements for inspection personnel
— names of the inspection team, copies of certificates
— records of any pre-inspection development work and personnel training and qualification requirements
  where specialised methods not covered by the general certification schemes (e.g. Ref. 3) shall be applied.

Programme
An outline of the inspection programme should be included to enable the detailed planning of resources. This
should also include advice on any parallel activities which may impact on the timing or performance of the
inspection.

Once prepared, the work-pack should be formally issued and treated as a controlled document. Relevant
documents which are produced during the course of the inspection, e.g. inspection reports, should be
incorporated in the work-pack, with copies sent to all those issued with controlled copies of the work-pack.
When completed, the work-pack and results, together with the analysis should become part of the vessel
inspection history records.

The master work-pack should be issued to the Inspection Manager who will assume responsibility for
maintaining it. The work-pack should be issued in advance of the inspection to allow adequate time for
inspection preparation.

4.11 Inspection Plan Review
The inspection plan forms the basis for most of the subsequent activity hence it is important that it is reviewed
prior to implementation. It is good practice to include the inspection body (including their inspection
technicians) in this process to ensure that all are fully aware of the issues. As a minimum, this review should
consider the following:
— are all degradation mechanisms identified in the CRA being addressed
— has the location of potential degradation been considered in the inspection plan
— is the inspection plan consistent with the inspection Type(s) identified as applicable
— is the inspection plan consistent with the results of previous inspection(s)
— does the inspection plan include details on:
  — method
  — coverage
  — procedures
  — equipment
  — resolution
  — are there any shortcomings in terms of access, insulation removal, presence of restrictions (e.g. cable
    trays etc.)
  — reporting requirements.

The review process should particularly address any zones where the inspection effectiveness has been down-
graded in order to enable inspection by non-intrusive methods. In particular, the impact on plant risk and
subsequent inspection interval should be considered.

The inspection plans should be made available to the inspection body well in advance of the work being carried
out. The purpose of this is to allow identification of potential problem areas in terms of methods and procedures
specified. Likewise, the inspection plan should be made available to platform personnel as soon as possible to
allow checks on possible access problems (rope access / scaffolding) to be made. It is highly recommended that
a brief visual review should be carried out in order to confirm that access to the specified locations will be possible, and with sufficient space to enable efficient inspections to be performed.

The inspection body should, at this stage, be asked to provide evidence of other similar inspections successfully carried out if new methods or challenging requirements are being considered. In certain instances there may also be a need for the vendor to carry out trials to demonstrate application of the proposed method and procedure e.g. using test blocks. In this eventuality, suitable evidence should be recorded and handed to the inspection manager in order to maintain an auditable document trail.

Detailed records of the review process should be retained and incorporated into the work-pack.

5. On-site Inspection Activities

5.1 Preparation for Inspection

5.1.1 Individual Responsibilities
Preparation for the inspection will require contributions from each of the following members of the inspection team:

Inspection Manager (the plant owner’s representative)

To ensure that all of the parties are aware of what is expected of them, and have access to all of the relevant information. To process and act upon any feedback on the inspection work-pack.

Inspection Supervisor (the leader of the site NDT Team)

This is the key coordinating role. The Inspection Supervisor has many critical responsibilities and there may be a need for more than one supervisor for large scale inspections (or at least for the Inspection Supervisor to delegate some of the tasks to other team members). The Inspection Supervisor should liaise between all parties and ensure good communication.

The Inspection Supervisor should ideally be certified at least to EN473 Level 2 in the methods of NDT to be applied during the inspection. However, Level 3 certification is preferable, particularly when the Inspection Supervisor is not participating directly in the execution of the inspections. Where the method to be used is outwith a certification scheme (e.g. thermography), the supervisor should be suitably experienced in the use of the chosen method.

Other members of Inspection Team

EN 473 Level 2 certification should normally be the minimum requirement for site inspection. However, for NII the requirements are often more specialised than covered by the general Level 2 certificate. The Inspection Body should ensure that the personnel are suitably qualified, experienced and certified where necessary for special applications.

5.1.2 Preparation Tasks
Preparation for the inspection should include the following:

Programming/planning
Provision of adequate resources to meet the scope of work.
Coordination with parallel activities which may impact on the inspection.

Are there any restrictions to working in the area (over-the-side, time constraints, fire watch requirements)?

Team selection
Selection of personnel with the necessary experience, qualifications and certification.

Any job-specific training requirements should be considered and dealt with (e.g. specialised ultrasonic inspection methods such as TOFD). This issue has particular relevance to NII as specialised methods not covered by standard certification schemes may be required. Evidence of general NDT competency (e.g. PCN level 2) is not necessarily evidence of competency in a specialised method and appropriate supplementary training (and occasionally examination) may be appropriate.

Access
Is the area to be inspected accessible for the method to be employed? This includes adequate scaffolding, inspection area within reach and sufficient clearance for personnel to access, power supply available.

Requirements for removal of lagging and insulation and, where appropriate, heat tracing to the required extent.

Facilities
— adequate messing facilities?
— office space for producing reports, PC working?
— storage for equipment, including power for battery charging?
— adequate protection from inclement weather conditions?
— adequate protection for equipment and personnel?
— is the area sufficiently clean and dry?
— any temperature considerations?

Surface Conditioning

Surface requirements stated to be checked by the local inspection supervisor and if not satisfactory then to be reported back to the inspection manager and the plant operator. Remedial action, if needed, will have to be sanctioned by the plant owner/operator, together with any making good of coatings etc. This is a critical issue for NDT, as it has a major influence on the reliability and quality of the inspection.

Safety Issues

Team members should be properly qualified – site safety training is normally mandatory.

Permit requirements: Is the area a designated safe area and are permits required? Are there equipment safety check requirements? (most NDT equipment is not intrinsically safe)

Local safety induction courses or medical clearance may be required prior to going on site.

Check any medical restrictions on personnel.

Pre-mobilisation Briefing

In certain circumstances, particularly difficult or off-shore inspections, it is beneficial to hold a pre-mobilisation briefing in order to familiarise the personnel involved in the inspection with the particular aspects of the inspection.

Mobilisation

Equipment should be checked in advance of shipping to the inspection site. Mobilisation to site/platform may require advance shipping of the equipment. It may be advisable to prepare a checklist of ancillary items that may be needed (tools, reporting materials, markers, spare consumables/IT consumables), check that the requisite software is installed on computers.

The team should ensure that the requirements for the equipment have been met (including calibration and certification) and that everything is in good condition, batteries charged, PAT certification satisfactory etc. before packing and shipping or mobilisation.

Start-up Meeting

All parties should meet prior to the inspection to ensure lines of communication are clear and all understand the inspection requirements and objectives.

The Inspection Team should be familiarised with the inspection, procedures, components, safety issues in a briefing session prior to the inspection.

Known areas of degradation should be identified and quantified to the NDT operator in advance of the inspection (Change in the extent of degradation may be as important as new areas of degradation).

The role of each team member should be clearly defined.

5.2 Performing the Inspection

The Inspection Manager (or an appropriate senior delegate) should coordinate the Permit To Work system and liaise with site personnel and the inspection team.

The Inspection Manager should monitor progress against the programme and take appropriate action where necessary.

The NDT operators should comply with the agreed scope of work, and inform the supervisor of any obstructions or anomalous measurements at the earliest opportunity.

The Inspection Team should practice good housekeeping both during the course of the inspections and on completion of the inspection.

When the inspection is underway, responsibility for ensuring the plan is implemented lies, in the first instance, with the inspection vendor. They should highlight as soon as possible any potential problem areas. These might include:

— access problems
— insulation not removed
— problems with surface condition
— poor sensitivity or excess noise due to material condition
— faulty equipment
— changes to procedure or methods used.

Similarly, platform inspection personnel should monitor progress of the inspection and check off work carried out against the plan. The work items can be checked off directly against the plan in terms of method, location
and coverage. In addition, discussions while the inspection is being carried out should include consideration of data quality and whether this is regarded as acceptable by the technicians. The importance of this regular reporting and feedback cannot be overemphasised as it allows corrective actions to be taken whilst the inspection teams are still on site.

The Inspection Team should be encouraged to produce interim reports on an ongoing basis. These should describe as a minimum the work items completed on the plan, any anomalies detected and any deviations from the plan.

**5.3 Dealing with Non-conformances**

Problems should be reported back to the integrity management team as soon as they arise. The aim should be to ensure that, wherever possible, deviations from the plan are identified prior to or during the inspection rather than when the inspection is complete. This allows direct assessment of the effects of the deviation and suitable alternatives that can be carried out as part of the current inspection to be specified.

The principles outlined in Sec.6 should be applied to dealing with non-conformances at this stage. Every opportunity should be taken to replace any inspection that cannot be carried out to the plan with a substitute inspection, using a different method or in a different location. An understanding of the Strategy Type for the particular inspection (see Sec.4.3) is important at this stage since it affects how best to deal with the substitution. Table 5-1 below summarises the approach recommended.

Documents which evolve as the inspection progresses (e.g. inspection reports) should be added to the work-pack.

**Table 5-1: Summary of approach for defining actions, according to Inspection Type, for dealing with deviations**

<table>
<thead>
<tr>
<th>Deviation</th>
<th>Inspection Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type A</td>
</tr>
<tr>
<td>Area not inspected, e.g. access problem</td>
<td>Substitute with area subject to similar conditions</td>
</tr>
<tr>
<td>Poor technique performance, e.g. procedures not followed, incorrect calibration, poor surface condition</td>
<td>Attempt to correct and redo inspection that is affected. If not then consider substitution by alternative method giving similar performance.</td>
</tr>
</tbody>
</table>

Indications potentially associated with in-service degradation should also be reported to the integrity management team as soon as possible. Such indications may warrant additional inspection or a different approach (see Sec.7).

**5.4 Reporting of Results**

The format for reporting NDT results will have been specified by the Inspection Management Team and defined in the work-pack.

Guidance is provided below.

The reporting criteria and format should be specified in detail. The format should facilitate repeatability of the inspection and comparison between past, current and future inspection results. Proforma reporting formats are recommended to optimise repeatability. These should prompt the operator to enter the same type of information recommended for any routine NDT inspection.

Generally the following information should be included in the report:

1) unique report no.
2) client
3) contract name/number
4) test date(s)
5) component - title/brief description of component under test
6) dimensions - relevant dimensions of component under test
7) drawing no.
8) surface condition
9) material
10) technical details about the equipment and inspection
11) item ref. - reference/identification no. of component under test
12) inspection result - including sketches where appropriate
13) procedure no. - inspection procedure number including issue number
14) acceptance standard - including issue no.
15) test limitations and any remarks
16) clear identification of the ‘sample’ where a sample inspection only has been requested. (for example, where an entire component from a batch of similar components has been tested, the unique identity no. of the component should be reported; where only a percentage of a component has been tested the operator should report the size and location of the ‘sample’ with reference to a datum system)
17) operator’s name, signature and date of report
18) operator’s certification details (e.g. certificate no., type, expiry date)
19) inspection supervisor’s/manager’s approval
20) client approval - if required
21) any other information required by the specified procedure.

Alternatively the report format may be a customised software application, particularly where repetitive statistical information is to be recorded and analysed. Such software programmes should be designed to quickly highlight important measurements.

The Inspection Supervisor should check the reports and the Inspection Manager should evaluate the results as early as possible. This will ensure early warning of any of the following situations and allow more time to take the necessary action:

— any new significant indications
— any significant changes in the inspection result
— any factor which has restricted the inspection
— restrictions to the performance of the inspection in accordance with the procedure
— incorrect application of the procedure
— the need for supplementary inspections.

The inspection reports should be reviewed and approved by the Inspection Supervisor and Manager. The approved reports should be incorporated in the work-pack. Finally, the work-pack shall be archived and available for review prior to and during the next inspection.

5.5 Demobilisation

The Inspection Supervisor should check that all parties are aware of, and satisfied with, the completion of the inspection. All equipment should be checked before packing and shipping.

A debriefing meeting with all parties is recommended. This offers opportunity for feedback, lessons learned, and recommendations for future inspections. Any such recommendations should be documented and stored appropriately, such that it can be retrieved for consideration in future inspection planning stages.

6. Evaluation of Inspection

6.1 Introduction

When carrying out inspection by NII, the inspection plan will have been devised with specific objectives aimed at ensuring that the integrity requirements for the equipment, typically as defined in the RBI, CRA or hazard assessment, are satisfied. This means that, in following the principles of the guidance outlined in this document, inspection carried out to the plan should provide similar or improved knowledge of equipment condition by comparison to IVI.

As covered in Sections 4 and 5, the planning process should include consideration of any factors that can affect the desired inspection effectiveness. The approach should, where possible, be modified accordingly to ensure that (i) the workscopes used meet the requirements and (ii) the potential for non-conformances is minimised. There remain, however, circumstances which can affect the inspection achieved but which cannot always be fully accounted for beforehand. A wide range of factors may play a role here, examples include the following.

— The pre-inspection site survey was unable to fully assess the extent of all access restrictions that limit coverage. This can occur when the survey is conducted before all necessary scaffolding is in place and not all regions are visible during the survey.
— Poor surface condition that means certain areas cannot be inspected or the performance of the inspection
— Material quality, e.g. inclusions, makes for incomplete inspection of the back wall condition.
— Inspection equipment has capability lower than that specified in the NII plan.
— Inspection procedures not followed in full.
— Platform unable to issue permits for confined space inspection.

Given that deviations can occur in practice, it is important to have a means of evaluating work carried out by comparison to the plan. Where there are deviations from the plan these should be dealt with in a consistent way.

This section of the procedure provides guidance on evaluation of NII. It covers primarily the actions to be carried out on completion of the inspection but this guidance is also applicable in assessing changes to be made at the planning stage and during execution of the inspection. Guidance on options for justifying non-conformances and for actions following identification of critical non-conformances is also provided.

The inspection plan generated in meeting the requirements set out in this guidance will define a series of work items, each specifying at least the inspection technique to be used, the location(s) for inspection and coverage (further details may be supplied as necessary). These work items form the basis for the evaluation process covered herein which applies to groupings of work items. Each grouping should include all items where the following are common: technique, degradation zone, feature type. For example, if the workscope includes corrosion mapping over plate in the water wetted zone of a vessel, all regions for such inspection within this zone should be treated as grouping of work items. Likewise, nozzles for which similar degradation conditions can be expected would be considered as a grouping when inspected by a common technique. For each grouping of work items an Inspection Conformance Level is defined as follows.

— Level 1: Requirement is achieved 100%. In the case of a full replacement of IVI the inspection can be considered in supporting re-grading. In the case where the NII is used for deferment the inspection can be taken in support of the planned deferment period.
— Level 2: A small reduction in what was achieved by comparison to the plan. This is assessed as having no impact on the overall effectiveness of the inspection, i.e. the requirements are effectively met and no follow up is needed. In the case of a full replacement of IVI the inspection can be considered in supporting re-grading. In the case where the NII is used for deferment the inspection can be taken in support of the planned deferment period.
— Level 3: A significant reduction in what was achieved by comparison to the plan. This means that the full planned for interval cannot be justified without addressing the non-conformance. Further investigation is necessary and the allowable interval should be determined in accordance with the guidance provided in Section 7. Unless indicated otherwise in Section 7, the inspection cannot be taken to support re-grading.
— Level 4: The inspection achieved is significantly misaligned with the objectives and cannot in itself be taken as support of continued operation. Other action is to be taken to provide assurance of integrity. Unless indicated otherwise following the more detailed assessment in Section 7.7, the inspection cannot be taken to support re-grading.

The applicable level is determined by consideration of the factors defined in the sections that follow.

An overview of the process for assessment of non-conformances and determination of subsequent inspection intervals is provided in Figure 6-1.
6.2 Items to be checked for conformance

On completion of the inspection and delivery of the inspection reports, a thorough review of the reports should
be carried out. This should include consideration of the following for each work item in the inspection plan:

— method
— procedure
— data quality
— location
— coverage.

6.3 Inspection Method

Different methods have differing abilities to identify certain types of flaw. When considering whether an
alternative inspection method is acceptable for a given inspection, it is important to consider the nature of the
degradation expected, if any, and the ability of the new method to detect and characterise it in comparison with the method originally specified.

6.3.1 Type A inspection
A successful Type A inspection relies on a method that is sufficiently sensitive to detect early signs of degradation. If the method applied has similar POD (to that of the method specified) for the type of degradation considered as possible in the CRA, then it would normally be considered as acceptable, i.e. conformance Level 1 or 2.

If, however, the POD is worse than that expected then the deviation may be considered as unacceptable for allowing a full replacement of IVI. In these cases the guidance in Section 7 should be followed in determining the conformance level applicable.

6.3.2 Inspection Types B and C
For inspection Type B, the method is required to sufficiently characterize any degradation present to allow a fitness for service judgement to be made based on a statistical analysis allowing for the level of coverage achieved. Therefore, as long as the data obtained from the new method is sufficient to demonstrate that the vessel has acceptable margins on fitness for service, then in most cases the deviation can be considered acceptable, i.e. conformance Level 1 or 2.

Guidance note:
There is one exception to this, i.e. when the technique and the way it is applied is such that there is a strong systematic overestimation of wall thickness. This possibility, which includes situations in which degradation at shallow depths can be overlooked completely, should be carefully considered in carrying out any statistical analysis of the data.

6.3.3 Type C inspection
For inspection Type C, the method is required to provide a high probability of detection for degradation approaching, with some defined margin, fitness for service acceptance limits. Detection is the primary requirement and accurate sizing is not necessary, i.e. screening techniques can be considered. A change in intended technique is therefore acceptable provided the probability of detection is not significantly reduced for the depths of degradation of interest. It should be noted, however, that while a screening technique may meet the technical requirements, practical considerations may dictate the selection of a technique that goes beyond screening, e.g. use of a technique that can both identify and accurately size degradation may offer a better solution in certain cases through eliminating the need for additional follow up activity.

6.4 Procedure
The procedure used to carry out the inspection is likely to affect a number of inspection performance parameters including POD. The resulting evaluation is therefore very similar to that for alternative inspection methods.

6.4.1 Type A inspection
In a Type A inspection, deviations in the procedure that are unlikely to impact negatively on the POD for small flaws (of the types identified as being possible in the CRA) would normally be acceptable. However, when POD for such flaws is likely to be negatively affected, the deviation will usually be unacceptable and the guidance in Section 7 applies.

6.4.2 Type B inspection
In the case of inspections of Type B, the flaws to be identified are expected to be significantly smaller than the critical size, and therefore precise sizing of degradation is not absolutely necessary. Hence a reduction in inspection performance is often tolerable in a Type B inspection provided it does not affect the validity of the statistical analysis. Changes to the procedure that are likely to result in a situation where there is a strong systematic overestimation of wall thickness or underestimation of crack length will not be acceptable, however, as this affects the validity of the statistical approach.

6.4.3 Type C inspection
The procedure used affects a number of inspection performance parameters including POD. In a Type C inspection it is usually the POD for relatively large flaws that is the primary concern and some compromise in the POD for smaller flaws is often acceptable. Hence, if the deviation in the procedure is unlikely to severely affect the POD for larger flaw sizes (approaching, with some margin, the “fitness for service (FFS)” allowable) it can be regarded as acceptable. When there is a negative impact on POD for flaws of this size the deviation would normally be considered as unacceptable. In these situations the guidance in Section 7 should be applied.

6.5 Data Quality
Identification of degradation relies on interpretation of the inspection data. When carrying out manual inspection this usually has to be done on-line as the data is collected. In this case the procedure provides the
main means of assurance in data quality and there is an expectation that qualified technicians will be able to recognise when problems arise. When data collection is automated, a higher level of assurance is often possible since the data can be examined in detail off-line. It is difficult to define the limits of what constitutes acceptable data quality and this, in itself, is usually determined by the NDT method. However, there are a number of factors not directly defined in the procedure (e.g. poor surface quality, system noise pick up) that can affect the data quality.

6.5.1 Type A inspection

There is an emphasis in a Type A inspection on the ability to detect signs of relatively minor degradation. Hence, reductions in data quality that are unlikely to impact negatively on the POD for small flaws (of the types identified as being possible in the CRA) would normally be acceptable. However, when POD for such flaws is likely to be negatively affected, the deviation will usually be unacceptable. In these situations the guidance in Section 7 should be applied.

6.5.2 Type B inspection

In the case of inspections of type B, the flaws to be identified are expected to be significantly smaller than the critical size, and therefore precise sizing of degradation is not absolutely necessary. Hence a reduction in data quality is often tolerable in a Type B inspection provided it does not affect the validity of the statistical analysis. Changes in data quality that are likely to result in a situation where there is a strong systematic overestimation of wall thickness or underestimation of crack length will not be acceptable, however, as this affects the validity of the statistical approach.

6.5.3 Type C inspection

The data quality directly affects a number of inspection performance parameters including POD. In a Type C inspection it is usually the POD for relatively deep flaws that is the primary concern and some compromise in the POD for smaller flaws is often acceptable. Hence if the data quality is such that it is unlikely to severely affect the POD for larger flaw sizes (approaching the FFS allowable) it can be regarded as acceptable. When there is a negative impact on POD for flaws of this size the deviation would normally be considered as unacceptable. In these situations the guidance in Section 7 should be applied.

6.6 Location

6.6.1 Type A inspection

The locations selected in a Type A inspection will have been determined as being representative of the worst regions in different zones of the vessel. If a location for inspection has been moved (e.g. due to access restrictions) to somewhere subject to similar process conditions and potential for degradation, then the deviation would normally be considered acceptable, i.e. conformance Level 1 or 2 would apply. If, however, the conditions in the new location are likely to be significantly different from those in the location specified then the deviation would be considered unacceptable. In these situations the guidance in Section 7 should be followed.

6.6.2 Type B inspection

The locations selected for a Type B inspection will have been determined as being representative of the worst regions in different zones of the vessel with the objective being to gather (statistically) sufficient data from each zone to enable an estimation of the worst potential flaws in areas not inspected. If a location for inspection has been moved (e.g. due to access restrictions) to somewhere subject to similar process conditions and potential for degradation, then the deviation would normally be considered acceptable. If, however, the conditions in the new location are likely to be different from those in the location specified then the deviation would be considered unacceptable or only justifiable following a statistical analysis that shows sufficient data has been collected for the affected zone.

6.6.3 Type C inspection

In a Type C inspection high coverage over regions or features of concern is usually a primary requirement. This will normally mean that there is little scope for accepting substitution by location.

6.7 Coverage

6.7.1 Type A inspection

The coverage in a Type A inspection will have been determined to allow sufficient sampling of the worst regions in different zones of the vessel to give a high level of confidence that if any degradation is active, its presence is detected. Deviations that locally reduce the coverage by a small amount (<25% relative to that required in the workscope) will normally be acceptable. However, where coverage has been reduced to the point where there is no inspection data from a particular zone or feature of concern, then the deviation would be seen as unacceptable. In these situations the guidance in Section 7 should be applied.
6.7.2 Type B inspection

The coverage in a Type B inspection will have been determined so as to ensure (statistically) sufficient data from each zone to enable an estimation of the worst potential flaws in areas not inspected. The effects of reduced coverage normally feed directly into the statistical analysis, with reduced coverage making it more difficult to demonstrate an acceptable condition. Most instances of small amounts of reduced coverage can be dealt with on this basis. However, where coverage has been reduced to the point where there is no inspection data from a particular zone or feature of concern, then the deviation would be seen as unacceptable. In these situations the guidance in Section 7 should be applied.

6.7.3 Type C inspection

In a Type C inspection high coverage over regions or features of concern is usually a primary requirement. The coverage should exceed 90% of the area for which the conditions are such that a Type C approach applies. Any reduction in coverage below this level would mean that the inspection is not acceptable for a full replacement of IVI and the non-conformance should be dealt with following the guidance in Section 7.

6.8 Conformance Levels

The conformance level should take into account the manner and extent to which the inspection achieved meets or falls short of the requirements outlined in the workscope. It should also consider, from an integrity perspective, the likely implications of any non-conformances. As discussed in the preceding sections, the impact of non-conformances with respect to coverage, technique performance and locations/features inspected is linked to the Inspection Type. Hence this forms an important consideration in the assignment of Conformance Level. Guidance on identification of appropriate Conformance Levels is provided in the Sections that follow.

6.8.1 Type A Inspection

Table 6-1 below should be used as a starting point for determining the conformance levels applicable to different elements of the workscope. As discussed in Section 6.1 a conformance level applies to each grouping of work instructions. The assessment considers what is achieved against expected for each group.

POD in the table refers to the POD as achieved, relative to that planned, for the grouping of work items. This should reflect the “average” performance except in cases where there is a significant variation through a grouping of work items. In such situations the worst performance for any individual work item should be considered. The user should apply judgement here in defining a sound approach, e.g. in a case where the conditions are such that the POD is as expected over most of the area under consideration and the POD is significantly reduced over only a small area it may be preferable to treat this area as lost coverage.

Coverage in the table refers to the total coverage achieved, relative to that planned, for the grouping of work items under consideration and does not take into account the locations of individual work items within the grouping. Coverage will normally be assessed on the basis of physical dimension (achieved vs planned) such as area or length.

Location in the table refers to the number of specific locations or features within a grouping of work items. It covers discrete items such as scan grids, welds, nozzle barrels, nozzle flange faces etc. For example, in a case where the workscope specifies five locations on circ welds within the water wetted zone of a separator for TOFD inspection for preferential weld corrosion, access might restrict any inspection on two of the five locations. This would mean that only 60% of the planned locations have been inspected. If 100% coverage was achieved on each of the three welds inspected, coverage for the grouping of work items would be 60% (3/5).

In this case the value used for coverage and locations inspected is the same. This is not always the case, however, and there are situations in which the values are different. It might be, for instance, that coverage is only 50% of the intended length at one of the three weld locations inspected. This would mean that while 60% of the planned locations have been inspected, the coverage is only 50%.

<table>
<thead>
<tr>
<th>Table 6-1</th>
<th>Categorisation of non-conformances for Type A inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>POD</td>
<td>Coverage</td>
</tr>
<tr>
<td>L1 As expected</td>
<td>As expected</td>
</tr>
<tr>
<td>L2 ≥90% of expected</td>
<td>≥75% of expected</td>
</tr>
<tr>
<td>L3 50% ≤ expected &lt;90%</td>
<td>50% ≤ expected &lt;75%</td>
</tr>
<tr>
<td>L4 &lt;50% of expected</td>
<td>&lt;50% of expected</td>
</tr>
</tbody>
</table>

Note that the conditions above with respect to POD and coverage are intended to be taken individually. If both parameters are simultaneously affected then consideration should be given to increasing the level, e.g. in a case where the POD is approximately 90% of that expected and the coverage is 75% of that expected conformance Level 3 would be considered initially rather than conformance Level 2. The effects of non-conformance with respect to locations for coverage should also be considered in adjusting the conformance level when both POD and coverage are affected.

The above table should be used as a starting point only and the user should apply engineering judgement in
defining the most appropriate categorisation. The applicability of the category assigned in accordance with Table 6-1 should be considered in the context of the factors outlined below and take into account the specific objectives of the inspection plan.

Within a Type A inspection the key issue is the ability to detect the presence of degradation, even when it might be in its early stages. Hence the focus in the Type A inspection will tend to be on inspection performance and this will have been used to specify the inspection method.

Non-conformances that significantly affect the performance (POD) of the inspection compared to that of the system specified will therefore potentially seriously compromise the objectives. If a system with reduced performance is used this can be compensated for to some extent by increasing the coverage but a minimum performance requirement must still be in place.

Non-conformances that relate to coverage are potentially less serious provided it is clear that the reduction/change in coverage does not entail a significant reduction in the area inspected within zones having similar operating characteristics. For example, moving a region for inspection on the bottom of a horizontal vessel longitudinally by a few hundred millimetres to allow easier access would be acceptable provided the conditions are no different to those in the area originally specified for inspection.

In many cases it will be location more than total area covered that is important, i.e. it may be acceptable to reduce coverage in a region of concern rather than moving the inspection to another location where conditions will be less onerous.

It is recommended that if there is doubt about the Conformance Level applicable at the reporting stage, i.e. it is not clear that justification can be made for a particular level, then a conservative approach should be adopted initially. This can be adjusted on application of the detailed consideration of Section 7 of the guidance and/or during the integrity review stage.

6.8.2 Type B Inspection

Acceptance for Type B inspections is dependent on the outcome of statistical analysis of the data. A full assessment of the acceptability of the inspection approach can only be made once the results of the analysis are available. The inspection can, however, be directly assigned conformance Level 4 when one or both of the following apply.

— Inspection technique systematically under-sizes degradation.
— One or more process/corrosion zones have no coverage.

When it is not possible by analysis to demonstrate an acceptable condition (which will generally consider the situation at the end of the subsequent inspection interval) Conformance Level 3 or 4 would apply. This assignment depends on whether or not it remains possible to justify the inspection as supporting a period of deferment.

6.8.3 Type C Inspection

Table 6-2 below should be used as a starting point for determining the conformance level applicable to each grouping of work items.

<table>
<thead>
<tr>
<th>Conformance of non-conformances for Type C inspection</th>
<th>POD</th>
<th>Coverage</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>As expected</td>
<td>As expected</td>
<td>As expected</td>
</tr>
<tr>
<td>L2</td>
<td>≥75% of expected</td>
<td>≥90% of expected</td>
<td>Inspection of ≥90% of expected</td>
</tr>
<tr>
<td>L3</td>
<td>50% ≤ expected &lt;75%</td>
<td>50% ≤ expected &lt;90%</td>
<td>Inspection of between 50% and 90% of expected</td>
</tr>
<tr>
<td>L4</td>
<td>&lt;50% of expected</td>
<td>&lt;50% of expected</td>
<td>Inspection of &lt;50% of expected</td>
</tr>
</tbody>
</table>

Note that, as with the Table 6-1 for Type A inspections, the conditions above with respect to POD and coverage are intended to be taken individually. If both parameters are simultaneously affected then consideration should be given to increasing the level, e.g. in a case where the POD is approximately 75% of that expected and the coverage is 90% of that expected, conformance Level 3 would be considered initially rather than conformance Level 2. The effects of non-conformance with respect to location for coverage should also be considered in adjusting the conformance level when both POD and coverage are affected.

As with Table 6-1, Table 6-2 should be used as a starting point only and the user should apply engineering judgement in defining the most appropriate categorisation. The applicability of the category assigned in accordance with Table 6-2 should be considered in the context of the factors outlined below and take into account the specific objectives of the inspection plan.

Within a Type C inspection the emphasis is on ensuring a high probability of detecting the worst flaw, recognising that degradation may be isolated to particular regions. In many situations the dimensions of a flaw that it is considered essential to detect (i.e. something with potential to grow to a size of concern within the interval to the next inspection) will be large enough to allow a reasonably high probability of detection (assuming the affected area is inspected). For example, in this type of inspection, it may sometimes be sensible...
to use a method that trades off a slightly lower POD for small flaws against ability to cover large areas quickly.

Since coverage will tend to be the key issue in this type of inspection, non-conformances that affect coverage will often be of most concern. There are a number of issues that affect the acceptability of coverage related non-conformances. Several of these are highlighted below:

1) localised reduction in coverage due to local access restriction, e.g. nozzles or pipework blocking access. In many circumstances this may be acceptable and is to be expected. For corrosion type flaws the effects can be assessed relatively simply however by establishing the acceptable loss in wall thickness for the dimensions of the area not inspected. If the metal loss elsewhere is well within the acceptable wall loss, then it may be reasonable to surmise that it is unlikely that unacceptable wall loss will have occurred in the un-inspected region; on the other hand, if measured wall loss is only just within limits elsewhere, it will be more difficult to justify the acceptability of the un-inspected area. This type of approach should take into consideration the findings of the corrosion assessment, i.e. what type of flaws are likely to be present. It will, for example, be less useful when microbial corrosion of a type that may be very localised is active.

2) significant reductions in coverage over particular areas. This will normally be unacceptable – justification here would be primarily on the basis of the corrosion review. This might reconsider the possible nature of degradation in light of the results that are available. A more comprehensive corrosion assessment for the vessel concerned may reduce some of the initial conservatism and allow the non-conformance to be acceptable.

Although inspection performance may typically be less of a concern than coverage in this type of inspection, it remains an important consideration. There will be certain minimum requirements, usually related to tolerable flaw sizes, that must be met. If the inspection system or implementation is such that these requirements are not met then the only scope for demonstrating acceptability will be to refine the definition of tolerable flaw dimensions.

### 6.9 Critical Non-conformance

Non-conformances that mean that the NII cannot be used to justify the inspection interval planned for, e.g. the full replacement interval or a planned deferment interval, are referred to as critical non-conformances, i.e. conformance Levels 3 and 4.

When the inspection includes a critical non-conformance, some action will be required to redress the situation. Each case will be dealt with on its merits but, broadly speaking, the following options, depending on whether a full replacement or deferment was planned, can be considered:

- repeat as soon as possible the inspection work items to which the non-conformance relates. This should address the issues to which the non-conformance applies
- carry out internal visual inspection as soon as possible
- repeat part or all of the NII work-scope on a shorter interval than would normally be applied. This inspection should address the issues to which the non-conformance applies
- carry out internal visual inspection on a shorter interval than would normally be applied
- apply an alternative inspection in the short term
- apply some monitoring of wall thickness over localised areas
- place emphasis on demonstrating that the process is under control and conditions leading to excessive corrosion are not present (e.g. monitor levels of CO2, H2S or regular checks on corrosion coupons)
- consider using the NII for the purpose of deferment only if the allowable inspection interval as determined following the guidance in Section 7 is suitable.

The particular circumstances will determine the best option and the associated timeframes for implementation.

Note that when a full replacement of IVI was planned, assessment of the non-conformances in accordance with the guidance provided in Section 7 may allow continued operation but at a shorter interval, i.e. the NII can be treated in a similar way to a deferment of IVI.

Note that Section 7 provides more detailed guidance on how to assess the impact of non-conformances. It is possible that in some cases the conformance Level can be revised following a review under the guidance provided in Section 7.

Once the conformance levels have been finalised, the following restrictions should apply to the way the information obtained in the inspections can be used.

**Level 3**

- Inspection cannot be used in support of re-grading
- Inspection information from zones of non-conformant inspection not to be used in updating degradation rates, susceptibility etc in the RBI system
- The Inspection Effectiveness should be declared Low for future consideration for NII.
Level 4

— Inspection cannot be used in support of re-grading
— Inspection information from zones of non-conformant inspection not to be used in updating degradation rates, susceptibility etc in the RBI system
— No credit to be taken from this inspection in future consideration of NII.

6.10 Reportable Indications and flaws

In general the procedures relating to flaws are well covered by international standards for fitness for service assessment (such as API 579 [9] and BS7910 [19]) as well as company standards, and will not be dealt with in detail here. However, there are some aspects where the application of NII may lead to differences in approach under some circumstances.

For example, where a Type A inspection has been specified (i.e. no degradation is predicted) however the inspection identifies degradation, albeit below the level that would require action based on a fitness for service evaluation, then further investigation is required.

As with integrity management approaches that rely on internal visual inspection, specific actions are required when flaws are found. The Inspection Type forms a useful basis on which to define the principles governing the nature of action to be taken when flaws are found. A brief summary is provided below.

6.10.1 Type A inspection

A Type A inspection usually applies where degradation is considered unlikely and/or degradation is expected to be superficial. Hence if degradation - beyond some small limit - is found then it is likely to be sign of a process or materials problem leading to corrosion that is more rapid than expected. It may also be an indication of a shortcoming in the corrosion assessment. In any event it is important to gain an understanding of the underlying cause. This will usually depend on a greater knowledge of the nature, size and locations of the degradation than offered by the initial inspection by NII. Furthermore, given that this inspection will typically have relatively limited coverage it is important, from a direct integrity perspective, to ensure that significantly worse degradation is not present in the areas not inspected.

Given the above concerns, in most instances of flaws being detected in a Type A inspection, additional inspection to be implemented within a relatively short timeframe is warranted. This inspection should seek to increase coverage and provide detailed information on the degradation. In many instances this requirement is best met by internal visual inspection but there may be situations in which further inspection by NII is appropriate.

6.10.2 Type B inspection

An unacceptable situation in a Type B inspection is one where the probability of failure (typically based on the potential for flaws in the areas not inspected) is regarded as excessive. This can be addressed by a number of means, as described below:

— additional inspection coverage using the same method to increase the size of data set (and reduced area for which data is not available)
— inspection with the same coverage but using a method with less inherent variability in wall thickness readings. This will reduce the estimates of the worst flaw sizes
— inspection by NII or IVI with 100% coverage to identify directly the worst flaw size
— additional, more sophisticated, data analysis including correlation of results from different locations.

In many instances the first two options will be more cost effective.

6.10.3 Type C inspection

When flaws are found in a Type C inspection a detailed fitness for service assessment would normally be required unless the flaws can be directly classified as superficial. It may often be the case that the information provided in the initial NII inspection is not in itself sufficient to underpin the FFS study. Hence some additional inspection aimed at more fully characterising the flaws may be needed. This inspection may be by NII or IVI depending on the circumstances. Further action going forward would normally be defined using the findings of the FFS study as a basis.

6.11 Examples

6.11.1 Type A inspection

Example 1: Consider a case of a separator vessel that is fabricated in carbon steel clad internally with corrosion resistant alloy. The NII workscope includes corrosion mapping and shear wave pulse echo inspection over selected regions at the bottom of the vessel. The vessel external condition is found to be poor within the regions inspected since it had suffered CUI at a time when it was insulated. The surface condition is such that the POD for small pitting type degradation (as identified as the main potential degradation mechanism affecting plate material) is considered to be significantly affected relative to what would be achieved with a good scanning surface. The POD is assessed as being somewhere between 50% and 90% of that for a good scanning surface.
Full coverage is achieved over the regions for inspection. In this case Conformance Level 3 would be taken to apply and the full interval following NII would not be justifiable unless other action was taken to address the shortcomings of the inspection. It should be noted that, as discussed elsewhere, effort should be made to avoid situations where performance is reduced, e.g. in this instance a pre-inspection survey would give an opportunity to identify and rectify surface condition. Also during the inspection itself, there may be scope to move some of the inspection areas to cover material with better surface condition while remaining in the zone of interest.

Example 2: For the case above, if the coverage was to approach 75% of planned and POD was considered to be in the low end of the range, i.e. approaching 50% of planned then consideration would be given to assigning Conformance Level 4. If coverage was less than 75% of planned and POD was approaching 50% then there would be a clear case for Conformance Level 4.

Example 3: Assuming now a case where the POD is achieved in full but the coverage is 70% of planned due to an unanticipated access restriction. Table 6-1 would indicate Conformance Level 3 for this situation. However, if it was clear that the 70% achieved still represents a reasonable sampling of the zone under consideration, the coverage includes the regions assessed as being at highest risk, the data collected is of good quality and contains no evidence of degradation, then a case may be made for assigning Conformance Level 2.

6.11.2 Type B inspection

Within a Type B inspection the emphasis will be on gathering sufficient information to allow a quantified statistical assessment that can be used to demonstrate a high confidence in estimating the worst flaw that might exist (including the areas not inspected). Inspection performance and coverage both affect whether the information is sufficient.

If we accept that this type of inspection forms the basis for a statistical analysis whose aim is to allow quantified assessment of vessel condition then this same statistical analysis can be used as a check on the inspection itself. Uncertainties associated with inspection system performance (e.g. poor resolution) and coverage will tend to (but not always) drive an increase in the dimensions of the worst expected flaw.

The nature of the quantified demonstration depends on the coverage and the capability of the inspection technique (measurement accuracy and variability are key concerns here). In general, the requirements are met in a more straightforward way as (i) the accuracy of the inspection technique improves (and/or variability is reduced) and (ii) coverage is increased.

Figure 6-2 serves as an illustration of the effects of measurement error. It shows the 90% confidence estimates for minimum thickness in a situation where an extreme value analysis has been carried out based on an inspection coverage of 20%. The minimum thickness estimate determines acceptance in the current condition and at the end of the planned interval. The effects of measurement error can directly impact on acceptance in the current condition, e.g. assuming 2.5 mm is taken as the acceptance condition (for localised corrosion) in the case to which Figure 6-2 relates, a measurement system with a standard deviation of error of >0.85 mm would not allow demonstration of an acceptable situation at present. Hence to justify ongoing operation, further inspection would be required with either improved accuracy or increased coverage.

![Figure 6-2](image)

**Figure 6-2**

Effect of measurement error on minimum thickness estimates

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1) The minimum thickness for the complete area would be expected to be greater than the value shown in 90% of cases. Note that use of a 90% confidence estimate here should not be taken as a recommendation that this confidence level should always be used. The approach to making estimates of condition based on statistical analysis should be determined as appropriate by the party responsible for such analysis and agreed with the integrity team. Further details on application of statistical analysis are provided in Appendix B of this document.
It should also be noted that the minimum thickness estimate will often be used as a basis for estimating corrosion rates, hence a small reduction in the minimum thickness estimate can have a large effect on the remaining life estimate (the starting thickness is lower and the corrosion rate is higher). To illustrate this consider the situation where (i) the average thickness on commissioning was 8 mm, (ii) the equipment has been in service for 15 years and (iii) the minimum acceptance value is 2.5 mm. The time to reach the limiting condition is shown in Figure 6-3. This time is often used to set the interval, e.g. max interval may be one half of the time to a limiting condition. In this instance an interval of 4 years may be justifiable with a technique with a 0.1 mm standard deviation whereas only 2 years may be justified with a standard deviation of 0.5 mm. The effect of measurement error will vary from case to case but this illustration shows the effects can be significant.

![Figure 6-3](image)

Coverage also has an effect on minimum thickness estimates and whether an acceptable condition can be demonstrated. Figure 6-4 considers effects of coverage for the same case treated in Figure 6-2 but assuming a measurement system with zero error. Increasing coverage is observed to increase the 90% minimum thickness estimate.

As with measurement error, the coverage achieved can affect acceptance in the current condition and impact on acceptable inspection intervals. Figure 6-5 shows the estimated time to a limiting condition based on the results according to coverage achieved. For the case considered here (and using a margin of two on time to a limiting condition) an interval of 4 years may be justified following inspection with 20% coverage but only 2.5 years may be justifiable following an inspection with 10% coverage. The actual effects will vary according to each situation but the example presented here does show the effects can be significant.
As already explained, the workscope for a Type B inspection is only deemed acceptable on completion of the analysis of the results generated by the inspection itself. This will normally involve estimation of minimum thicknesses and times to reach a limiting condition. If the acceptance requirements are not met then further action has to be taken, e.g. more accurate inspection, additional coverage with NII, follow up IVI. Consider for example, that the minimum acceptable time to a limiting condition is 10 years for the situation as outlined in Figure 6-5. An inspection carried out with 20% coverage would not allow an acceptable time to limiting condition to be demonstrated. This would be established by analysis of the data collected during the inspection and would result in the inspection being assigned Conformance Level 3 or 4 depending on whether or not it remains possible to justify the inspection as supporting a period of deferment.
6.11.3 Type C inspection

Example 1: The inspection plan for a carbon steel separator vessel that is lined internally with Glass Flake Vinylester calls for 100% coverage of the shell. There are access restrictions at the bottom of the vessel such that the coverage achieved is only 75% over the water wetted zone. The POD requirements are considered to be met in full. Table 6-2 would indicate Conformance Level 3 from the outset. In this case it would not be possible to justify a change in conformance level since the reduced coverage is significant and in a critical area with respect to the potential for degradation.

Example 2: Considering the vessel in the preceding example, but now with full coverage achieved in the water wetted zone and 75% coverage achieved in the gas zone. Again Table 6-2 would indicate Conformance Level 3 as a starting point. However there may be justification for a change to Conformance Level 2 if the coverage achieved clearly includes all areas of increased susceptibility (e.g. near nozzles and changes in geometry), the inspection results do not show any evidence of any coating degradation and there is no history of coating degradation for the vessel under consideration.

Example 3: Consider a situation as per Example 2 above but where the inspection technique did not deliver the required detection capability such that its POD for isolated degradation (at the defined depths of concern) was something just over 50% of that planned. In this case Table 6-2 would indicate Conformance Level 3 based on either POD or coverage but since both are affected to a reasonably significant extent, Conformance Level 4 should be applied here.

7. Inspection Interval

7.1 Discussion

Section 6 provides guidance on defining acceptability of deviations from the work-scope specified and how they can be overcome or compensated for. Once a non-conformance has been determined to be unacceptable there may be further action that can be taken to show that it remains justifiable. This section outlines briefly the types of action that may be appropriate.

This Decision Guidance Process does not usually require that both a very comprehensive CRA and probabilistic integrity assessment be in place before NII is deemed appropriate. It adopts a pragmatic approach consistent with the level of knowledge/information that will typically be associated with installed pressure equipment and, consequently, the inspection requirements are usually specified conservatively.

There are two approaches that can be used to demonstrate that the inspection carried out can be considered acceptable; firstly, comparison with internal visual inspection (IVI) and secondly, by a quantified (or semi-quantified) statistical assessment of the probability of failure. Whilst the first of these is conceptually simple, it is of necessity conservative, and it may be possible to gain further concession based on a more quantitative assessment. However, the effort and data requirements of a quantitative or semi-quantitative assessment are considerably greater. This document therefore focuses mainly on the use of the first approach but does provide some further guidance on the second approach (see Sec 7.4).

7.2 Intervals adjusted by comparison of capability relative to IVI

The guidance provided in this document aims to ensure that when NII is carried out as a replacement for IVI it provides at least equal performance (in terms of detection of degradation of concern) to that associated with IVI. The NII workscopes generated in following this guidance would normally therefore be such that this objective is met. It should be noted that there are exceptions to this, e.g. where IVI has severe limitations and clearly does not form a suitable benchmark for NII. In these situations the quantified approach to assessment outlined in Section 7.1 and covered in more detail in Section 7.7 should be applied. The main focus of this document is, however, on cases where IVI is used as a benchmark and the objective of the NII is to provide at least equal performance. Consequently, non-conformances that mean this objective is not met require action to be taken to ensure ongoing assurance of integrity. Possible actions in response to non-conformances are covered in Section 6.9. In some cases the most appropriate option available in response to the non-conformance will be to reduce the interval to the next inspection from that assigned in the RBI system (this interval is referred to as $I_{RBI}$).

The reduced interval should consider the impact of the non-conformances and be such that it can be demonstrated that the probability of failure at the end of this interval is less than the probability of failure that would be determined at the end of the RBI assigned interval but assuming IVI was carried out. Calculating intervals on this basis would rely on a complex quantified or semi-quantified approach. This type of approach would not be practical in many instances. Hence, in keeping with the objectives of this recommended practice, a number of simplifying (but necessarily conservative) assumptions have been applied in determining the impact of changes of inspection effectiveness under different scenarios. The guidance provided therefore forms a pragmatic approach to assessing the next inspection interval on the basis of the interval based on the relative effectiveness of the inspection compared to IVI. The assessments should be made on the basis of the most severe non-conformances, as determined by Conformance Level in the first instance. In cases where there is more than one grouping of work items for which there is a critical non-conformance, each case should be
assessed and the interval should be taken as the smallest value determined. Note that this guidance is structured around situations in which a single inspection interval applies to comprehensive inspection to determine the internal condition of the complete vessel. It does not however preclude situations in which the user applies different intervals to different zones of the vessel.

7.3 Intervals following non-conformance in Type A inspections

As explained previously, the emphasis in a Type A inspection is a high POD for early stage degradation. When the POD, for the flaw sizes of interest, is reduced compared to the planned for POD a non-conformance would be declared and for conformance Level 3 (see Section 6) the interval to the next inspection must be reduced. For Type A inspections, conformance Level 3 applies to situations in which the POD is between 50% and 90% of the intended POD.

The allowable interval is reduced linearly according to the POD relative to that expected when the coverage achieved is as planned, such that the interval is zero for ≤50% of the expected POD and the full interval is allowed for ≥90% of the expected POD. The interval should also be adjusted by the coverage relative to that planned and include consideration of whether the non-conformance means any process/corrosion zones have no inspection. Hence the allowable interval should be estimated initially as

\[ I_{\text{allowable}} = I_{\text{RBI}} \times (2.5P_r - 1.25) \times C_r \]  

Eqn 7.1

where

- \( P_r \) is the estimated POD for the inspection achieved, relative to that intended.
- \( C_r \) is the coverage, in the zone to which the non-conformance applies, relative to the planned coverage.

Note that the maximum permitted value of \( I_{\text{allowable}} \) is \( I_{\text{RBI}} \). Furthermore, the minimum permitted coverage (relative that planned) should normally be taken as 50%. With less than this level of coverage the inspection would normally be regarded as unable to sufficiently sample the material condition and inspection would in most cases be assigned Conformance Level 4. As such actions other than changing the interval would need to be taken.

When there is missed coverage, the interval determined above can be revised, by adjustment of \( C_r \), on consideration of the following:

— The expected corrosion conditions in the zone of non-conformance relative to those in areas for which inspection data was obtained and the material is shown to be in good condition. If the missed coverage is in a region where the conditions are expected to be more severe than in other areas the consideration should be given to reducing \( C_r \). Conversely, when the areas of missed coverage are in a zone expected to be less susceptible to degradation than other areas inspected \( C_r \) can be increased (provided the inspection results do not show any signs of degradation in those areas). In these circumstances it is considered reasonable, provided the missed coverage does not fall below 50% of that intended for the zone under consideration, to make the assessment of coverage achieved based on all zones having similar or more severe corrosion conditions to the zone under consideration.

— Does the missed coverage include any specific features likely to have enhanced susceptibility to damage compared to other locations inspected within the same process zone? When it is clear that coverage has been missed near specific features, e.g. adjacent to an outlet nozzle, and no other regions representative of that missed have been inspected, then consideration should be given to reducing \( C_r \) from that determined by proportionate coverage alone. However, when other regions, considered to have similar conditions to those in the region of missed coverage, have been inspected then \( C_r \) may be increased.

— The assessed likelihood of active degradation in the region of missed coverage. In cases where this is assessed as very low, and there is confidence in the assessment through a combination of a detailed CRA and inspection history, then \( C_r \) may be increased. In cases where there is no strong historical evidence supporting the view on likelihood of degradation, i.e. equipment with limited inspection history and/or where conditions have changed, consideration should be given to reducing \( C_r \) from that determined by proportionate coverage alone.

7.4 Intervals following non-conformance in a Type B inspection

Type B inspection applies to cases where some degradation is expected and where zones of common degradation conditions exist. The inspection requirement is to provide sufficient information to allow quantified demonstration of the required degree of assurance. While this document does not aim to provide specific guidance on acceptance criteria since these differ according to company and regulatory requirements, in general the approach will entail assessment of the probability of failure within the interval to the next inspection. This assessment is based on the information provided, on the current condition of the vessel, by the inspection and estimates for degradation rates (based on the inspection results, inspection history and corrosion assessments). The objective will be to demonstrate that the assessed probability of failure remains below some defined limit for safe operation for the duration of the interval to the next inspection.
It is typical industry practice to apply margins to the limiting condition and, in dealing with inspection intervals based on the time to a limiting condition, a factor of two is often applied. Hence the estimated time to the limiting condition should be at least twice the interval planned. In keeping with this approach, a Type B inspection can be taken as fully meeting the requirements when the time to a limiting condition, as estimated based on analysis of the NII data, is at least twice the interval that would normally follow an internal visual inspection.

When the data is such that the estimated time to a limiting condition is less than twice the planned interval then the inspection can be taken as not meeting the requirements. A number of options are available to address the situation in these circumstances. In many cases an increase in coverage from that used initially can lead to an increase in the estimated time to a limiting condition. Other options would include additional inspection with improved data quality or application of more rigorous analysis techniques (that reduce conservatism). Depending on the circumstances it may, however, not be possible to do any additional work and in such cases a downward adjustment of the interval to the next inspection is necessary. The maximum permitted interval is determined as

\[
I_{\text{allowable}} = \frac{\text{Time to a limiting condition}}{2} \quad \text{Eqn 7.2}
\]

It should be noted that the nature of the inspection data should be fully considered in carrying out the quantified evaluation of a Type B inspection. For example, a non-conformance where corrosion mapping is substituted with manual 0 degree ultrasonic inspection would require detailed evaluation of the real coverage achieved with the latter (this may be lower than 20% coverage over areas scanned) and the potential for systematic under-sizing of degradation (as may occur in the case of very small diameter pits).

### 7.5 Intervals following non-conformance in a Type C inspection

The emphasis in a Type C inspection is on coverage since the locations of degradation will usually be random (and unknown beforehand) in situations where this inspection Type applies. When the coverage is less between 50% and 90% of that planned for in the inspection, a non-conformance is declared (Level 3) and, unless other actions are taken, the inspection interval has to be reduced compared to that associated with an IVI.

The interval is reduced linearly according to the coverage achieved relative to that planned, such that the interval is zero for \( \leq 50\% \) of the expected coverage and the full interval is allowed for \( \geq 90\% \) of the expected coverage. The interval should also be adjusted by the POD for the inspection as conducted relative to that planned. In cases where the reduction in POD is similar over all areas inspected within a particular zone then the allowable interval should be estimated initially as

\[
I_{\text{allowable}} = I_{RBI} \times (2.5C_r - 1.25) \times P_r \quad \text{Eqn 7.3}
\]

where

- \( P_r \) is the estimated POD for the inspection achieved, relative to that intended.
- \( C_r \) is the coverage, for the zone under consideration, relative to the planned coverage for this zone.

Note that the maximum permitted value of \( I_{\text{allowable}} \) is \( I_{RBI} \). Furthermore, the minimum permitted POD would normally be taken as 50% relative that planned. With less than this POD the risk of missing significant degradation would typically be approaching unacceptable levels and the inspection would in most cases be assigned Conformance Level 4 (for which actions other than changing the interval need to be taken).

In cases where the reduction in POD is local to specific areas within the zone, two options in terms of approach are recommended, i.e.

i) Consider that the areas of reduced POD give rise to completely missed coverage and recalculate \( C_r \) accordingly. The allowable interval is then determined using Eqn 7.3 with \( P_r \) set to one.

ii) Consider that the coverage in each area of reduced POD is decreased in proportion with the ratio of POD achieved to POD intended. The value of \( C_r \) is then recalculated accordingly.

Note that the first option represents a more conservative approach but is often sufficient for evaluation where the POD is reduced over small areas only.

The interval determined above should be revised on consideration of the following.

- In the case of localised reductions in coverage or POD, the interval determined should also consider whether the affected location has specifically increased susceptibility to degradation, e.g. close to major structural features (where the likelihood of coating breakdown can be expected to be higher). If this is the case the interval should be adjusted downwards from that determined.
- The susceptibility to coating breakdown and subsequent corrosion in the areas where coverage is missed.

The intervals determined by the above equation are considered appropriate when the missed coverage is
predominantly in regions of higher susceptibility, e.g. near changes in geometry and/or exposed to liquids. When the missed coverage is predominantly in regions of lower susceptibility, i.e. continuous plate material in nominally dry gas service, the interval may be increased compared to that determined by the equation. The amount of extension should consider the coverage achieved in the zones of higher susceptibility and the assessed time to a limiting condition in the event of coating breakdown. The maximum increase in interval compared to that calculated should not exceed one quarter of the IVI interval.

— Time that the coating has been in service. In general the longer the coating has been in service the greater the likelihood of failure. If the coating has been in service more than ten years the allowable interval should be adjusted downwards unless there is strong evidence available that indicates the condition of the coating is unlikely to degrade over time in operation.

— Time since the most recent inspection that provided comprehensive information on coating condition. If this exceeds five years then consideration should be given to reducing the interval from that determined, particularly if the missed coverage is predominantly in areas of higher susceptibility.

— History of coating repairs. If there are known repairs in any of the areas of missed coverage consideration should be given to reducing the interval from that determined, particularly if the missed coverage is predominantly in areas of higher susceptibility.

### 7.6 Intervals Assigned

It is important that any inspection interval determined on the basis of the above guidance should be reviewed by competent staff to ensure that all relevant facts have been adequately taken into account in setting the revised interval.

It should be noted that although the intervals arrived at in using the guidance may end up being expressed as some specific percentage of the IVI interval it is not the intent that the allowable interval determined be implemented as such. The allowable intervals should be taken as a guide only, with the final decision taking into account other factors related to planning and synchronisation of work requirements. It would, for example, in the case where an interval has been determined as 32 months, be reasonable to allow for inspection at 36 months (three years). The extent of variation should be assessed by the user on review of the nature of the non-conformance.

In common with all other aspects of the NII process, it is imperative that a record is kept of all factors considered during the evaluation of the inspection. In particular, any decisions relating to the acceptance or rejection of any non-conformances identified, and the subsequent adjustment of the inspection interval must be adequately recorded in order to allow for review and checking as necessary.

The results of the review process and any amendments to the inspection interval should be recorded and retained for QA audit purposes.

### 7.7 Detailed Assessment

Where it is not possible to justify the non-conformance on the basis of comparison with IVI, a quantitative or semi-quantitative approach may enable a given non-conformance to be justified. These assessments cover three main areas, i.e.

— corrosion engineering
— inspection performance
— structural integrity.

A reduced inspection work-scope would usually be justifiable following a very comprehensive CRA and integrity assessment that would consider the worst sizes of flaws expected, the distribution of flaws, growth rates and allowable flaw sizes.

Detailed guidance on how to assess fitness for service (or probability of failure) of a vessel, given information on corrosion conditions and inspection performance, is beyond the scope of this document. Guidance on fitness for service assessment is covered in detail in a number of codes and standards (e.g. BS7910, API 579) and this can form the basis for a probabilistic approach including consideration of inspection performance measures. A number of approaches, different in terms of detail, are applicable and will be appropriate in different circumstances. This document includes a brief summary of the key elements of the type of approach that can be adopted.

The starting point for the assessment will typically be a detailed corrosion review. This would normally consider some or all of the following:

— process conditions (chemistry, temperatures, pressures, dew-points)
— materials
— types of degradation (e.g. pitting, general corrosion)
— locations of degradation
— growth rates
— upset conditions
— effects of controls including inhibitors
— monitoring activities
— inspection and maintenance history.

The aim of the corrosion study should be to provide an informed view on the likely types of degradation, their locations, their distribution and the worst expected sizes at present and going forward over the interval to the next inspection.

An assessment of the performance of the inspection actually carried out with respect to the types of flaw identified in the corrosion review is also usually necessary. The key aspect to be considered is the probability of detection for a range of flaw sizes and distributions. This should include, where possible, consideration of the coverage and likely spatial distribution of the flaws (e.g. is degradation likely to be localised or more randomly distributed). Note that the emphasis will be different according to inspection type however and the following broadly applies:

— in a Type A inspection the key concern is on the ability to detect early signs of degradation. Hence the probability of detection should relate to finding sufficient signs of degradation to conclude that degradation is indeed present (since this is what would trigger further action)
— in a Type B inspection there is a lesser emphasis on POD directly. However, it remains essential that the inspection system is unlikely to systematically overestimate wall thickness. For this reason, it is important to have an understanding of the likely back wall surface morphology and any limitations this can impose on the recording of thickness data (depending on scan increment for example)
— in a Type C inspection it is typically the ability to detect larger flaws that is the primary concern. For such inspections the flaws are potentially isolated so the POD should be related to isolated flaws rather than finding signs of degradation within a larger flaw population.

The integrity assessment brings together the corrosion and inspection information to develop an estimate of the probability of flaws, with potential to threaten integrity of the vessel, having been missed in the inspection. This relies on estimates of the allowable flaw sizes (as defined by fitness for service considerations) and comparison with the flaw sizes that may have escaped detection during the inspection.

The final outcome of the assessment should normally be an estimate of the effects of the inspection actually carried out on the level of assurance. If this is not considered acceptable then further action (usually in the form of inspection) will be required in addressing the non-conformance.

7.8 Examples

The following cases are presented as examples of application of the process for establishing suitable allowable intervals following an inspection where a non-conformance has been identified. For each example, the steps in the evaluation are presented and the resulting reduction in inspection interval considered in comparison with engineering judgement.

Clearly, as with the entire NII process, inspection validation requires engineering judgement to be used at all stages. All available information should be used in order to assess the value of the inspection carried out and sole reliance should not be placed on the mechanistic approach presented in the guidelines. The examples quoted here, however, demonstrate that under normal circumstances the approach will give appropriate assessments.

7.8.1 Missed coverage in a Type A inspection

An inspection of a Separator vessel was required. The vessel is constructed in carbon steel clad internally with high grade corrosion resistant alloy. The corrosion risk assessment indicated a low probability of internal degradation, with chloride pitting/SCC being the main mechanisms of concern. The likelihood of these was determined as very low given the operating conditions. The vessel had been subject to a number of previous internal visual inspections, each of which had indicated good internal condition with no sign of any degradation.

The NII assessment carried out using the guidance provided in this document indicated that NII was applicable. The main requirement for the vessel body was for the inspection to confirm the assumptions regarding corrosion conditions, i.e. no degradation active. A Type A approach was found to apply, i.e. inspection with high sensitivity but over selected representative areas so as to be able to identify if any degradation was active.

The NII plan is summarised in Figure 7-1 in which 0 degree corrosion mapping and 45 degree shear wave inspection was to be carried out over the areas indicated in blue.
A survey was carried out before the inspection commenced. This identified difficult access to the upper part of the vessel, i.e. regions m-q shown in Figure 7-1, due to the presence of structures above the vessel as illustrated in Figure 7-2. Access to the surface at the top of the vessel required removal of gratings/walkway and then removal of insulation. The extent to which this could be achieved was difficult to establish at the time of the survey as it depended on the details of the grating installation. By the time of the inspection it had been possible to provide access at locations m, n and q but access was not possible at locations o and p. This represents a small fraction <5% of the total coverage required for the vessel.

The inspection achieved full coverage in the remaining areas and the technique performance was considered to be as required in the plan. The inspection did not reveal any signs of wall loss or degradation of the cladding surface at any of the locations.

Inspection coverage within the top of the gas zone (upper part of the vessel) was 60% of that planned for. This is assessed as non-conformance (Level 3) following the approach of Section 6. The primary consideration in determining an appropriate inspection interval is the effects of the missed coverage.

The starting point is to consider a coverage factor of $C_r = 0.6$ since 3 out of 5 regions were inspected. This is then adjusted taking into account the issues covered in Section 7.2.1, i.e.

- The missed coverage is in a zone where corrosion conditions are expected to be less severe than those present in the water wetted parts of the vessel. The inspection results for areas inspected within water wetted parts of the vessel do not show any signs of degradation. Hence it is possible to base the coverage factor on the achieved coverage for the vessel as a whole, i.e. a missed coverage of <5%, giving $C_r > 95%$.
- The likelihood of active degradation in the zone where the coverage has been missed has been assessed as very low. The inspection history, including a number of previous interval visual inspections, does not show any evidence of degradation. This would also suggest the use of a higher coverage factor in the assessment.
Based on the above it is considered reasonable in this instance to take the maximum allowable interval as 95% of the intended interval. Note, however, that as discussed in Section 7.3 the actual interval used can be adjusted within reason to align to operational and planning requirements hence in this case the interval could reasonably be extended to that planned in the event of a fully conforming inspection.

It should be noted that, notwithstanding the outcome of the above assessment, whenever possible attempts should be made to achieve the workscope as planned (unless a reduced interval has no impact). The extent to which this can be achieved depends on the particular case, however, in many situations of Type A inspection it is reasonably straightforward to substitute missed coverage with other areas in the same zone and this should be considered as soon as it is evident that the exact coverage per the workscope is not possible.

7.8.2 Reduced POD in a Type A inspection

The preceding situation can also be used as a basis for illustrating how the effects of reduced POD should be dealt with in a Type A inspection. The workscope includes application of 0 degree corrosion mapping and shear wave inspection over the areas indicated in Figure 7-1. For the purposes of illustration let us assume that it was not possible to deploy the shear wave inspection at all but that 100% of the intended coverage was achieved. Inspection with corrosion mapping is subsequently assessed as offering approximately 60% of the POD, for the pitting type degradation of interest, achieved when both techniques are used in combination. (The value of the change in POD here is provided for illustration only and should not be taken as indicative of the real impact on POD for this situation).

The starting point for the allowable interval would, as per Section 7.2.1 be

\[
I_{\text{allowable}} = (2.5P_r - 1.25) \times C_r \times I_{RBI}
\]

\[
= (2.5 \times 0.6 - 1.25) \times 1 \times I_{RBI}
\]

\[
= 0.25 \times I_{RBI}
\]

This interval may be further adjusted, e.g. depending on whether any suspect indications were identified in the corrosion mapping data.
7.8.3 Missed coverage in a Type C inspection

An inspection of a Separator Vessel was required. The RBI programme for the vessel imposed an inspection interval of 3 years based on internal visual inspection. The most recent internal visual inspection had, however, identified severe blistering in the internal polymer based lining as illustrated in Figure 7-3.

![Figure 7-3](image)

Blistering and degradation of the internal coating (as at the most recent IVI)

The blistering was found to affect most of the vessel but was worst at the top, i.e. in the gas zone. Exposure of the carbon steel to the operating environment, particularly in the water wetted lowest part of the vessel, would be expected to lead to reasonably high corrosion rates hence the lining condition was of concern. Repair was not an option at the time the problem was discovered during the IVI.

A decision was made to carry out non-intrusive inspection at half of the normal inspection interval with the intention of identifying any areas of degradation (as might be expected where there was full coating breakdown). The main requirement was to identify any areas of degradation with potential to threaten integrity in the time to the next IVI (and repair of the lining). The condition of the lining indicated a reasonably high probability that there would be some areas of carbon steel exposed to the operating environment and a Type C inspection approach was considered appropriate, i.e. high coverage with a screening type technique that may have limited sensitivity for small levels of degradation but has high POD for any degradation of significance.

The NII plan developed made use of CHIME as the primary screening technique for the vessel shell as shown in Figure 7-4. Note that the CHIME technique was considered suitable in this case since the wall thickness was such that CHIME detection capability would be good for degradation with depths less than the corrosion allowance.

![Figure 7-4](image)

Areas for separator coverage as defined in the NII plan

(Green = CHIME, Blue = Corrosion Mapping at coarse resolution)

Access was dependent on scaffolding but this was constructed such that the upper part of the vessel was not accessible for the CHIME inspection. In addition there were a number of other areas where only partial coverage was possible. The areas for which coverage was not possible by CHIME are shown in yellow in
Figure 7-5. The conditions and set up were such that capability of the technique would be as expected. The area for which inspection was not possible by CHIME represents approximately 15% of the shell with the majority of this being at the top of the shell. The CHIME inspection did not reveal any areas of wall loss exceeding 10% of wall thickness and the minimum thickness measured for the domed ends was above nominal. There were however indications of pitting corrosion, to a depth of less than 2 mm (this being less than 10% of the nominal thickness), in the domed ends. Isolated pitting of small depth was also found by 0 degree compression probe UT inspection that was possible in some areas where the CHIME scanner could not be deployed.

Figure 7-5
Areas for which CHIME inspection was not possible are shown in yellow

The reduced coverage in a Type C inspection should be of some concern as explained in Section 6. The primary concern is missed coverage at the top of the shell, this represents approximately 25% of the area of the gas zone for the vessel, i.e. 75% of coverage intended has been achieved for this zone. As a starting point the allowable interval is determined according to

\[
I_{\text{allowable}} = \left(2.5C_r - 1.25\right) \times P_r \times I_{IVI}
\]

\[
= \left(2.5 \times 0.75 - 1.25\right) \times 1 \times I_{IVI}
\]

\[
= 0.625I_{IVI}
\]

The recent internal inspection indicated that there is damage to the lining in the region of missed coverage. Hence it is reasonable to assume that there will be some exposure of the carbon steel to the process environment. This would normally be taken as an indication that the interval as determined above should be reduced further. However, since the missed coverage is in the gas zone, the corrosion rates following coating breakdown are likely to be less than would be expected in the liquid zone. Hence it would be reasonable to use the allowable interval as determined above as a basis unless an assessment of corrosion rates indicates otherwise. Hence the planned approach, i.e. inspection (and repair of the coating) within one half of the normally assigned IVI interval, is acceptable.

7.8.4 Impaired inspection quality in a Type C inspection – Case 1

This example relates to inspection of a Separator Vessel in which the NII plan included extensive use of the CHIME technique for screening. The material over the lower half of the shell was lined internally with a polymer coating and a Type C approach was therefore applicable. The inspection included coverage of the lower half of the vessel body using CHIME since this was deemed to provide adequate screening capability. A small proportion (<5%) of this area was not accessible for inspection by CHIME but most of these regions were inspected using corrosion mapping, e.g. locally around nozzle locations. The vessel shell included a number of areas of paint breakdown and external corrosion in which it was difficult to maintain strong ultrasonic coupling. One such area is shown in Figure 7-6.
The CHIME signals were affected in a number of these areas. Some CHIME data typical of regions with good surface condition is shown in Figure 7-7.

Figure 7-8 shows two scans, representative of the worst collected, where data quality was clearly degraded. The effects of surface condition are observed to be significant, with a general drop in amplitude and complete loss in amplitude in some areas. If an area of significant amplitude loss was to coincide with the location of a flaw...
it is probable that the flaw could be missed altogether, i.e. a degradation in POD to less than 50% of that for the inspection as planned can be expected for some scans. A total of >200 CHIME scans were collected and approximately 15 of these had visibly reduced data quality (POD < 90% of that expected). Most of these scans were located at the bottom of the vessel.

Following the approach of 7.2.3, given that the areas of degraded POD are localised and the number of affected scans is small relative to the total it is reasonable to take the affected regions as being fully missed in coverage. In this case the coverage factor is (200-15)/200 = 92.5%. Application of Eqn 7.3 then indicates that the full inspection interval is applicable. The inspection can also be considered suitable for re-grading.

The above example is also used as a basis for a number of other scenarios to illustrate further the approach.

7.8.5 Impaired inspection quality in a Type C inspection – Case 2

For the same vessel in 7.8.4 consider the case where the majority of the scans were impaired due to surface condition and it is assessed that for most of these the POD is considered to be less than 50% of that intended. In this situation the non-conformance would, according the guidelines of Section 6.8 be considered as unacceptable, the NII does not provide assurance of integrity for continued operation. In this situation, where there is a high likelihood of significant degradation being missed due to poor inspection performance, further action, see for example Section 6.8, would be required.

7.8.6 Impaired inspection quality in a Type C inspection – Case 3

For the same vessel in 7.5.4 consider the case where approximately 30% of the scans collected have significantly impaired quality. In this case, as per the recommendations of Section 7.3, the areas of reduced POD can be treated as missed coverage and a coverage factor of 70% would be used in Eqn 7.3, i.e. a maximum allowable interval of half of the normally assigned interval.

In the event that the quality of the affected scans was not significantly reduced, i.e. POD achieved is considered above 50%, then consideration could be given to decreasing the coverage in each area of reduced POD in proportion with the ratio of POD achieved to POD intended.

8. Application of NII in support of Deferment of IVI

8.1 Introduction

This document is aimed principally at situations in which NII is an effective alternative to IVI. This means that the NII sets out to meet all the objectives of the IVI and delivers equivalent (or better) information to the Risk Based Inspection (RBI) system to allow re-grading and adjustment of the subsequent interval where appropriate.

There is also a need to consider application of NII in support of deferment of IVI. This relates to situations in which there are benefits to extending the interval until the next planned IVI, e.g. to allow operation to planned shut-down, to allow synchronisation of shut-down requirements across a number of vessels on different intervals. Different operators and/or regulatory environments impose different requirements but, in general, the operator is required to justify any deferment by demonstrating that it does not increase the risks of operation in any significant way. There are a number of approaches in this respect, however, given that the role of the IVI is to provide information on the equipment condition, implementation of alternative methods for establishing such information make for a more straightforward case for deferment. Consequently, there is a role for application of NII in support of deferment.

There are two situations in which NII can be used in support of deferment, these being as follows.

i) The objective is to use NII as a full alternative to IVI but the NII assessment, as per the approach of this document, determines that NII is not appropriate as a full replacement for IVI.

ii) NII is assessed as appropriate as a full alternative to IVI, but the requirements in support of deferment can be reduced by comparison to those for a full replacement for IVI.

This section provides guidance on how to deal with the above two situations. An overview of application of this section is provided in Figure 8-1.
Figure 8-1
Overview of the assessment approach for deferment

 Carry out NII Assessment (Section 3) 

 Suitable for NII 

 Yes 

 Develop workscope meeting requirements (full replacement of IVI) 

 Reduce workscope (if required) in accordance with guidance in Section 8.3 

 No 

 Identify key shortcomings and carry out additional action to address if possible 

 Re-evaluate NII Decision (Section 3) 

 Suitable for NII by Section 3 

 No 

 Do any of the criteria in Table 8.1 apply? 

 Yes 

 Determine acceptable deferment period in accordance with Table 8.1 

 Develop workscope (requirements should meet full replacement of IVI) 

 NII cannot be used in support of deferment, other action to be taken 

 No
8.2 Situations in which NII is assessed as not applicable in the Guidance

8.2.1 Background
Section 3 includes a high level process for determining whether vessels are suitable for NII. This considers that the inspection should act as a full replacement for IVI with the same interval being retained following the NII (or, in some cases this being adjusted following re-grading). If the assessment determines that NII is not applicable this does not automatically mean that NII is not suitable as a means of supporting deferment with a shorter interval or that a case for NII cannot be made.

The two most common reasons, when following Section 3, that NII will be assessed as not applicable are:

i) No previous inspections having been carried out and no similar vessels with inspection history.
ii) The flow chart (Figure 3-2) determines NII is not appropriate.

These cases will be dealt with separately.

8.2.2 No previous inspection
Section 3 considers at least one previous inspection on the vessel under consideration or on other similar vessels as essential before NII can be justified. This approach aims to ensure there is sufficient knowledge of potential degradation mechanisms and locations such that inspection techniques and coverage can be appropriately defined. This is consistent with the philosophy of the approach which emphasises the need for verification of assumptions made in development of the inspection plans. In general the expectation would be that there is some relevant internal inspection history for the item under consideration (although this may be derived from other similar vessels). This should, however, not preclude NII as a means of deferment in specific cases. The approach to deferment should follow the guidelines provided in Section 8.4 (special cases for deferment).

8.2.3 Flow chart determines NII not appropriate
The flow chart (Figure 3-2) considers three factors in arriving at the decision on whether NII is appropriate, i.e.

1) Confidence in ability to predict type and location of degradation
2) Previous inspection effectiveness
3) Severity and rate of degradation.

The factors above are rated as being High, Medium or Low depending upon the conditions. NII is not recommended in most cases where “Confidence in ability to predict type and location of degradation” is categorised as Low (the exceptions being where there is a Medium/High “Previous inspection effectiveness” and Low/Medium “Severity and rate of degradation”).

Given the importance of an understanding of the potential degradation conditions in ensuring that a robust approach to NII can be devised, it is recommended that in situations where “Confidence in ability to predict type and location of degradation” is Low, no concessions can be made in situations where NII is not recommended in the flowchart. Hence in these situations there are two options for justification of NII for deferment purposes, i.e.

i) Action be taken to allow re-categorisation of “Confidence in ability to predict type and location of degradation” from Low to Medium or High. This would typically entail a more comprehensive corrosion risk assessment and re-categorisation should be possible in most instances. While carrying out this activity consideration should also be given to “Severity and rate of degradation”, i.e. should this be revised following the more detailed corrosion risk assessment.

ii) NII can be justified by the detailed approach described in Section 8.4.

Note that in cases where action has been carried out to allow re-categorisation of “Confidence in ability to predict type and location of degradation”, there remain four scenarios under which NII is still not recommended by the flow chart. The deferment options for each of these cases are provided in Table 8-1.
Note that the justification described in the table is an important element of the deferment case, particularly so in situations where “Severity and rate of degradation” is categorised as High. The justification should demonstrate that the inspection interval following the most recent inspection (to which a Medium or High effectiveness applied) to the end of the deferment period does not exceed 75% of the time taken to reach a limiting condition considering, (i) the maximum wall loss determined by that inspection and (ii) the worst case corrosion rate. The worst case corrosion rate should be determined by the Corrosion Risk Assessment. The time to a limiting condition should also be checked following the planned inspection, using the actual data obtained.

The permitted deferment period should not exceed 50% of this time. This means that the planned deferment period may have to be reduced in certain cases.

The limiting condition here can be taken as 90% of the Minimum Allowable Wall Thickness (MAWT), as determined by the applicable design code. Note that this is based on consideration of general wall loss using the Fitness for Service (FFS) principles of Part 4 of API 579 which aim to ensure a Reserve Strength Factor of at least 90%.

When the Corrosion Risk Assessment indicates that wall loss is likely to be localised and this is supported by evidence from at least one inspection (whose effectiveness is considered Medium or High), the limiting condition can be based on an API 579 Part 5 Level 1 Local Thin Area assessment. The extent of the region of wall loss used in defining the limiting condition should include consideration of available inspection information but should not be less than the minimum of 100 mm or 5 x the nominal wall thickness.

The above considerations with respect to margins on remaining life refer to degradation leading to wall loss. In situations where the remaining life is likely to be determined by a cracking type mechanism, e.g. fatigue, stress corrosion cracking and hydrogen induced cracking, deferment can follow as above for “Severity and rate of degradation” = Medium. When “Severity and rate of degradation” = High, deferment can only be justified on the basis of the special considerations described in Section 8.4.

The requirements for the NII to be used to defer IVI should be developed in the same way as if the vessel had passed through the process for NII as a full alternative to IVI (see Section 4).

### Table 8-1 Deferment options following re-categorisation

<table>
<thead>
<tr>
<th>Confidence in ability to predict type and location of degradation</th>
<th>Previous inspection effectiveness</th>
<th>Severity and rate of degradation</th>
<th>Deferment option</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Up to 50% of set inspection interval but with justification based on worst case corrosion rate applied since most recent inspection for which a Medium or High effectiveness applied.</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Up to 25% of set inspection interval but with justification based on the worst case corrosion rate applied since the previous inspection.</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>Up to 50% of set inspection interval but with justification based on the worst case corrosion rate applied since most recent inspection for which a Medium or High effectiveness applied.</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Up to 50% of set inspection interval but with justification based on worst case corrosion rate applied since most recent inspection for which a Medium or High effectiveness applied.</td>
</tr>
</tbody>
</table>

### 8.2.4 Example

Consider a vessel for which there have been two previous internal visual inspections and the assigned IVI interval is 4 years. Neither of these inspections found any degradation beyond very light corrosion in certain areas. The initial NII assessment arrives at the following.

**Confidence in ability to predict type and location of degradation:** This is assessed as Low since there are only two previous inspections on the vessel and RBI does not include a detailed corrosion risk assessment.

**Previous inspection effectiveness:** This is taken as Low since the most recent internal inspection missed large areas where access was blocked by internal structures.

**Severity and rate of degradation:** This is assessed as Medium (observable degradation expected but not expected to threaten integrity through the lifetime of the plant).

Following Section 3, the decision is that NII is not applicable. As outlined in Section 8.2.3 it may be possible to justify a change to the categorisation for “Confidence in ability to predict type and location of degradation” if a sufficiently detailed corrosion risk assessment is carried out. If this were such that a High categorisation can be justified then a case for NII as a full replacement for IVI can be made as outlined in Section 3.
In the event that the additional work was such that at most a Medium categorisation applies the NII cannot be taken as a full alternative to IVI. Application of NII may however be possible in support of deferment as indicated in Table 8-1, which recommends “Up to 50% of set inspection interval but with justification based on worst case corrosion rate applied since most recent inspection for which a Medium or High effectiveness applied”.

This would mean the maximum deferment period following the NII would be 50% of the planned IVI interval, 2 years assuming an IVI interval of 4 years. Assuming the worst case corrosion rate has been estimated as 0.3 mm/yr and a wall loss of 6 mm is determined as acceptable, the time to a limiting condition would be 20 years. The time in operation, from the last inspection to which a Medium or High effectiveness applies (8 years ago), to the end of the deferment period (2 years hence) is 10 years. This represents 50% of the time to a limiting condition which is less than the 75% value outlined in Section 8.2.3. This means that the 2 year deferment period is acceptable.

Note that in the above case the time to a limiting condition should be checked on completion of the NII using an update to the current condition and, where necessary, the worst case corrosion rate. The assigned deferment period should be smaller than the updated safe remaining life (with suitable margins in place as outlined in Section 8.2.3).

8.3 Revised inspection requirement in cases where NII is assessed as acceptable

8.3.1 Background

In cases where NII is planned in support of a deferment of IVI (rather than a full replacement) and the assessment according to Section 3 indicates that NII is acceptable, it is possible to justify a reduced NII workscope that is aligned with the reduced interval. This section provides guidance on how changes to the workscope, seen as meeting the objectives of NII as a full alternative to IVI, are to be assessed for suitability for the deferment interval.

8.3.2 Revisions to NII workscope

Following the assessment (Section 3) the initial workscope should be developed as required where the NII is intended as a full replacement for IVI (Section 4). This workscope then forms the baseline for reduction of specific work items. Any changes to this workscope that lead to a reduction in inspection effectiveness should then be considered as impacting on the acceptable interval following the NII, i.e. a reduction to IRBI should be made.

The revised workscope should be treated in the same way as a non-conformant inspection, as per the guidance of Section 7. This means that the changes to the workscope should be such that at worst a conformance Level 3 applies with respect to the workscope for full replacement of IVI.

The revised workscope can be considered acceptable to support the deferment provided the deferment period is less than the allowable inspection interval determined in accordance with the guidance of Section 7. Some basic principles in respect of revision of the workscope for different situations are provided here.

For a Type A inspection reductions in coverage can normally be expected to have less overall impact on the inspection effectiveness compared to reductions in detection capability. This means that revisions to the workscope should consider reducing coverage before allowing changes to the technique or set up that would impact on detection capability. The following points should, however, be considered in making reductions to coverage.

— Coverage should always include material in each of the different degradation zones for the vessel.
— Coverage should not be reduced in regions adjacent to specific features where susceptibility to degradation is considered to be increased e.g. adjacent to an outlet nozzle where an erosion mechanism may be active.
— Coverage should remain aligned to assessed susceptibility, e.g. higher coverage in water wetted zones compared to dry gas zones.
— For plate material reductions in coverage can be achieved in certain situations through reducing the size of individual scan regions, i.e. keeping locations the same but reducing local coverage. This approach should be adopted with caution, however, as the individual scan sizes should be sufficient to provide a reasonable sampling in the area under consideration. It is therefore recommended that it is applied only in cases where it is very clear there is no potential for local variations within a zone for inspection.

For a Type B inspection the acceptability of the deferment period is assessed on the basis of a detailed analysis of the results obtained in the inspection, i.e. it can only be properly assessed once the inspection is completed. The process is summarised in Figure 8-2.
Reductions in coverage and technique performance both impact on the period that can be demonstrated as acceptable following the inspection. It is not possible to provide specific guidance in this respect since each situation is different. However, the following principles apply.

— Changes in technique performance that lead to systematic under-sizing of degradation should not be permitted. For example, in a case where the CRA indicates the potential for small diameter pitting, an increase in the corrosion mapping scan increment should only be permitted on review of the potential effects on consistent sizing error.

— Careful consideration should be given to local coverage effects, e.g. a manual ultrasonic inspection with no means of probe tracking will typically provide a real coverage of significantly less than 100% over the areas inspected (reductions to below 20% coverage are often observed in practice). Hence when changes to the workscope include substitution of manually deployed techniques (with no tracking) the potential impact on real coverage and systematic sizing error should be reviewed before the revised workscope is accepted.

— Changes in the inspection approach that lead to an increase in measurement variability will lead to a reduction in the allowable interval. Attempts should therefore be made to quantify the differences when the inspection system is changed from one for which there is existing information. The main parameter to be considered would normally be the standard deviation of measurement error. The impact, on the interval that can be demonstrated as acceptable, of an increase in standard deviation of measurement error can be significant within the range of typically available equipment and set-ups. Hence caution should be exercised in accepting changes that can affect measurement variability and where necessary the impact of these changes should be assessed by simulation studies before the workscope is accepted.

— Reductions in coverage will lead to a reduction in the allowable interval. The extent of reduction in interval is not linear with the reduction in coverage. The effects of a specific proportionate reduction in coverage are more significant when the initial coverage level is lower, e.g. halving coverage from 30% to 15% would lead to a larger proportionate reduction in inspection interval compared to a reduction in coverage from 60% to 30%. Hence caution should be exercised in reducing coverage significantly when the initially specified coverage is relatively low and reasonable levels of degradation are expected. In these cases simulation studies can assist in identifying the maximum reduction in coverage that is likely to still be acceptable on analysis of the results once the inspection is completed.

For a Type C inspection reductions in detection capability, within the range of degradation depths of concern, can usually be expected to have a lesser impact than reductions in coverage. This means that revisions to the workscope that reduce the coverage should be carefully assessed. The following points should be considered in assessing reductions to the workscope.

— In general a reduction in technique performance will have a lesser impact on the acceptable inspection interval than a reduction in coverage. Hence, if the time taken for the inspection is a driver for reducing the workscope, it may be preferable to accept the reduction in performance associated with a more rapid technique or set-up, e.g. increasing the scan increment for corrosion mapping, rather than allowing a reduction in coverage.

— When changes to the technique or set-up are proposed, a detailed evaluation of the impact on detection capability, for degradation of the type and depths of interest, should be carried out.
— If reductions in coverage are to be made, preference should be given to areas where degradation
susceptibility is considered lowest taking into account the process conditions and likelihood of coating
breakdown. The coverage defined should, however, ensure that material from all different degradation
zones is included.
— If the coating has had known repairs in the past then coverage should include all areas of repair.

8.3.3 Examples

Example 1: A separator vessel fabricated in carbon steel clad internally with corrosion resistant alloy is due
internal visual inspection. The site scheduling requirements would however be better met if the internal
inspection can be deferred for a period of 2 years. The current IVI interval is 4 years. An NII assessment is
carried out and this indicates that NII is acceptable as a full replacement for IVI. The inspection workscope
developed for NII as a full replacement for IVI includes coverage of 20 scan areas along the bottom of the
vessel for inspection by corrosion mapping and angled shear wave. This requirement can be reduced for the
inspection aimed at deferment only. The conditions are such that a Type A inspection approach applies here.
As outlined in Section 8.3.2 reductions in coverage should be considered first for this inspection Type. In order
to ensure the coverage provides sufficient sampling of material the minimum coverage to allow deferment
would normally be 50% of that intended (see Section 7.3).
The coverage requirement should also be evaluated using Equation 7.1. Assuming the POD will be as intended
(P₀ = 1) the coverage (as determined from Cᵣ) that will give an interval of 0.5 x IRBI is given by Equation 7.1
one has

\[
(2.5 \times 1 - 1.25)Cᵣ = 0.5 \Rightarrow Cᵣ = 0.4
\]

This is less than the 50% minimum required hence, as a starting point, the coverage can be reduced to 50% of
that intended, i.e. a total of 10 scan regions of the 20 initially assigned. A key consideration in determining
whether this remains acceptable would be to ensure that the 10 scan regions can still be sufficiently distributed
to ensure that a representative sample is obtained from each location of potentially different susceptibility
within the zone under consideration. This should consider, for example, whether the number of scan regions is
sufficient to allow coverage in plate material adjacent to each nozzle where flow conditions may be slightly
different. It may therefore be necessary to increase the coverage above the 50% level (10 scan regions)
indicated by Equation 7.1 to ensure that all local variations are sampled. As explained in Section 8.3.2 a
reduction in the size of scan regions, i.e. here retaining the 20 scan locations but making each scan area 50% of
the size of that in the original plan, is only applicable in cases where it is certain that local variations within
a zone will not be present.

Example 2: A vessel that is lined internally with a polymer coating is due internal visual inspection and options
for deferment are under consideration. An NII assessment indicates that NII is acceptable as a full replacement
for IVI. The current IVI interval is 5 years and a deferment of 2 years is sought. The NII plan initially developed
for a full replacement inspection includes coverage of all accessible plate material in the liquid zone and the
initial expectation was this would exceed 90% of the area in this zone. Parts of the vessel shell are not accessible
for inspection however and it is evident that only 75% of the planned inspection coverage can be achieved. The
initial NII plan also considered corrosion mapping at a reasonably fine increment. In order to reduce the time
taken to complete the inspection consideration is given to increasing the scan increment for the corrosion
mapping. Equation 7.3 can be used to establish the minimum POD relative to that initially planned, i.e.

\[
(2.5Cᵣ - 1.25)P₀ = 0.5 \Rightarrow (2.5 \times 0.75 - 1.25)P₀ = 0.5 \Rightarrow P₀ = 0.8
\]

Hence the consideration can be given to an increase in the scan increment provided this does not result in the
POD dropping to less than 80% of that expected from the initial planned inspection.

8.4 Deferment as a special case

The preceding sections provide simplified but conservative approaches to the assessment of deferment where
possible. This imposes some limits on the applicability and means that there may be some cases in which this
simplified approach indicates that deferment is not applicable, but a more detailed approach can be used to
justify NII in support of deferment.

Justification in these circumstances depends on a detailed assessment, the requirements of which may vary
according to each specific case. The approach to the assessment, however, should include the following.

1) Detailed review and analysis of potential degradation threats. This would typically include a rigorous
corrosion risk assessment including an in-depth theoretical study based on process, corrosion control/
monitoring and materials information. The following issues would be addressed.

— Types of degradation
— Growth rates for each type of degradation identified as of concern
— The locations where each type of degradation is likely to be active
— Upset conditions that can lead to accelerated degradation
— Potential for incorrect identification or omission of degradation mechanisms.

Furthermore the review should also consider inspection histories for the item under consideration and histories/experience with other equipment items which may be of relevance.

Note that the approach to the corrosion risk assessment should meet the requirement of a Type 4 CRA (see Section 2.4 for definition of CRA levels) where there is inspection history available or a Type 3 CRA where there is no history available.

2) Structural integrity assessment to identify allowable dimensions for potential degradation. This should aim to determine allowable depth/extent combinations for flaws. These should be used as a basis for defining the inspection requirement, i.e. to ensure the inspection has a high probability for detecting and sizing degradation that has the potential to grow to a limiting condition within the inspection interval under consideration. It is important that the assessment be conservative in setting the requirements hence it is acceptable to use simplified approaches (as typified by API 579 Levels 1 and 2) in assessing the limiting conditions.

3) Definition of inspection requirements and approach. The inspection requirements are set on consideration of the sizes determined in the structural integrity assessment. The approach to the inspection, techniques, coverage and locations should be defined on consideration of the results of the degradation review and the integrity assessment. In some cases validation of the inspection approach may be required.

4) Detailed evaluation of the results of the inspection. Justification of the interval for deferment is only possible after the results have been obtained. A detailed assessment should be carried out to demonstrate an acceptable probability of failure at the end of the deferment period.

8.5 Evaluation following NII in support of deferment

Once the inspection as per the revised workscope has been carried out, evaluation should follow Section 6 and any non-conformances should be dealt with in accordance with Section 7 but with two important changes, these being:

1) The interval assigned in the RBI (IRBI) is replaced by the interval determined as acceptable for the deferment.

2) Re-grading is not permitted on the basis of an inspection used for deferment.

8.6 Restrictions on deferment

In general NII should only be used to support a single deferment period, i.e. it is not the intent of this document to allow sequential periods of deferment. This is only considered acceptable in exceptional circumstances and where a detailed justification is made (Section 8.4).

8.7 Statutory requirements

Depending on the country or location of operation, certain statutory requirements may apply to deferment of planned inspections. This guidance should not be seen as allowing exemption from such requirements. Hence it is important that any applicable statutory requirements are understood before planning the use of NII in support of a deferment.

It should be noted, however, that the guidance provided in this document may assist in meeting certain statutory requirements in respect of permitting deferment. For example, in the United Kingdom, the Pressure Systems Safety Regulations 2000 (applicable to onshore pressure equipment) allow for one postponement of the examination specified in the Written Scheme. The enforcing authority (typically the UK HSE) has to be informed of the intended deferment prior to the stated due date. A further requirement is that the postponement of the inspection “does not give rise to danger” and the owner/operator is required to make a declaration to this effect. It is therefore normal practice to carry out a study to (i) assess the risks associated with postponement and (ii) identify mitigations to be put in place to ensure the risks associated with deferment are not significantly higher than those associated with operation following an internal inspection carried out at the due date. In many cases a Non-intrusive inspection can be used as mitigation and the approach outlined in this document can be used as supporting evidence in the case for deferment.
9. References

1) EN 473 General Principles for Qualification and Certification of NDT personnel.
2) ISO 9712 Non-destructive testing - Qualification and certification of personnel.
7) Best Practice for the Procurement and Conduct of Non-Destructive Testing.
   Part I: Manual Ultrasonic Inspection
12) DNV-RP-G101 “Risk Based Inspection of Offshore Topsides Static Mechanical Equipment”.
17) Non-destructive evaluation (NDE) capabilities data-book
   Non-destructive Testing Information Analysis Center (NTIAC) Texas Research Institute, 1997
   Interactive Knowledge Base (IKB) on NDT, HOIS Member Version.
19) Guide on Methods for Assessing the Acceptability of Flaws in Structures
23) Discussion with P Horrocks regarding AEA Technology RBI principles, January 2001
APPENDIX A
REVIEW OF NON INTRUSIVE NDT METHODS

A.1 Introduction
This review gives a brief description of the principles, capabilities and limitations of NDT methods which might be considered as non-invasive inspection methods, including:

1) Ultrasonic Testing
2) Eddy Current Testing
3) Liquid Penetrant
4) Magnetic Particle Inspection
5) Magnetic Flux Leakage
6) Thermography
7) Radiography
8) Backscatter or Compton Imaging
9) Acoustic Emission
10) Remote Visual Inspection
11) Shearography.

A.2 Ultrasonic Testing

A.2.1 Conventional Ultrasonic Testing
Conventional ultrasonic testing is based on the generation of ultrasonic beams by means of probes containing a piezoelectric element excited by an electrical pulse. The piezoelectric element vibrates and generates mechanical waves of frequency typically in the range 1 MHz – 10 MHz. The sound wave propagates into the specimen and discontinuities make the waves reflect back to the same or to a different transducer.

Conventional ultrasonic transducers can generate a variety of angle beams which can provide sufficient coverage for the inspection of the whole thickness of a specimen.

Ultrasonic inspection can be used for the monitoring of corrosion by measuring the wall-thickness of the specimen. It can also detect and size pits.

A poor surface finish, thick paint or inspection at high or low temperature may cause problems for ultrasonics (although more appropriate transducers can be used for particular condition, e.g. specially designed high temperature transducers can be used to inspect hot surfaces).

A.2.2 Ultrasonic Imaging
Ultrasonic imaging systems can be use to improve reliability in detecting and/or sizing flaws.

A.2.2.1 Automated Ultrasonic Imaging
Ultrasonic imaging systems integrate microprocessor technology with non-destructive testing methods and can perform inspections on vessels and piping from the external surface. Wall thickness up to 600 mm can be inspected for both fabrication and service induced cracking, wall thinning or clad delamination in a single pass. The full RF waveforms are collected and reliable repeatability is achieved. Multiple testing allows analysis to be performed while the inspection is carried out.

Applications include erosion/corrosion detection and monitoring, fatigue crack detection and sizing, hydrogen blistering and stepwise cracking and stress oriented hydrogen induced cracking.

A.2.2.2 Ultrasonic Thickness (Corrosion) Mapping
In ultrasonic wall thickness mapping systems, a transducer is linked to a computer so that thickness data for each predetermined measurement position can be recorded. The transducer is scanned manually over the surface and the thickness readings are stored on disk. After the scanning is finished, the data are plotted in a wall thickness map. Each thickness level can be colour coded and wall thinning by corrosion or erosion is more readily recognised than by manual inspection. High reproducibility (typically within 0.3 mm wall loss) enables accurate monitoring and calculation of corrosion rates.

Wall thickness mapping can be applied in-service at temperatures up to about 250°C using special high temperature probes and couplant. Wall thinning, pitting corrosion, flow acceleration corrosion, hydrogen induced corrosion and hot hydrogen attack can be detected and imaged.

Recently there have been significant advances in the technology used for corrosion mapping, which has greatly increased scan speeds and reduced noise levels, allowing more reliable detection of small pitting type flaws. These systems are based on high speed automated scanning systems (crawlers etc.), which are well suited to
scanning large, unobstructed areas such as sections of vessel shells between nozzles etc.

For NII of vessels, corrosion mapping is a widely used method for detection and sizing of internal corrosion/erosion flaws (both localised and generalised loss of wall).

**A.2.3 Time of Flight Diffraction (TOFD)**

TOFD (Time of Flight Diffraction) is an advanced ultrasonic inspection method which can simultaneously detect and size indications. TOFD sizing in the through wall direction is based on the measurement of signal arrival times which is inherently more accurate than methods based on amplitude. With TOFD, through wall sizing accuracy is typically 1 mm or better.

It provides reproducible fingerprints which makes it suitable for condition monitoring. Initial manufacturing flaws can be monitored and service induced flaws detected and progressively monitored. TOFD examination only requires external access to the object to be inspected. TOFD can be applied on hot structure up to 200°C using special transducers. Weld inspection of heavy wall pressure vessels (up to 300 mm wall thickness) has been carried out. Nozzle and flange welds (complex geometry) can be inspected with prior computer simulation modelling to aid inspection planning and result evaluation.

For NII applications, TOFD is often used for inspection of welds for typical welding flaws, including weld root erosion/corrosion, cracks, lack of fusion etc. Recently, there have also been NII applications where TOFD has been used as a rapid scanning method for detection and sizing of backwall pitting type wall loss flaws, as an alternative to more conventional corrosion mapping.

**A.2.4 Creeping Head Inspection (CHIME)**

The CHIME method (Creeping Head Wave Inspection Method) consists of the transmission of an ultrasonic signal between two probes that are placed a distance apart (up to one metre) scanning a parallel (or near parallel) surface.

The transmitter fires a pulse of ultrasound that gives rise to creeping waves propagating along both the surfaces, and critical angle head waves (shear waves) are generated at all parts between the surfaces. As a result, the full wall volume between the probes is covered. The coverage is achieved with little attenuation, allowing the transmitting and receiving probes to be well separated compared to traditional inspection.

Wall thickness up to 40mm at a standard operational frequency of c. 2 MHz and inspection widths (distance between the two probes) of up to one metre have been established. The CHIME scans can provide information about thickness of the sample (by measuring the time interval between successive peaks) or about any flaw which locally changes the thickness.

Flaws due to corrosion or cracking, reduce the CHIME signal magnitude and can change the arrival times of the signal peaks independent of their location between the transmitter and receiver.

The method has tolerance to in-service surface conditions and most coatings. It is sensitive to the presence of corrosion on internal and external surfaces and provides an estimation of the extent of the corrosion area and nominal wall thickness in areas between corrosion. Some approximate information on the through-wall extent of a flaw is also obtained, by the amount of the CHIME signal loss produced.

CHIME has been tested on samples containing general and isolated corrosion, stress corrosion cracking, and hydrogen damage. It has demonstrated reasonable tolerance to surface conditions such as general roughness or thin layers of coating.

For NII applications, CHIME is most often applied to sections of components made inaccessible to conventional ultrasonic methods by geometry, such as pipe supports and pipe clamps. The method also has potential for fast screening for corrosion pits over large areas of vessel shells.

**A.2.5 M-skip**

M-skip method is a new 'medium' range pitch-catch ultrasonic inspection technique developed within the HOIS programme since 2005. The method has some similarities to CHIME, but provides more quantitative information on wall thickness and wall loss via analysis of the arrival times of signals.

M-skip is a variant of the well known TOFD method but is based on angled shear wave probes, separated by the distances required to inspect wider pipe supports and clamps. The signals travelling between the probes then typically experience many reflections, or skips, between the front and back component surfaces.

Measurements of the arrival times of the different skip signals can be used to determine the average wall thickness between the probes. For areas of wall loss on either the front-wall or back-wall surfaces, the signal arrival times which involve reflection/scattering off the flaw will be reduced. Measurements of the differences in the arrival times between the wall-loss signals and the skip signals allows the maximum depth of wall loss to be derived, assuming the number of reflections from the area of wall loss is known. If this number of reflections is unknown, the assumption of a single flaw reflection provides a conservative estimate of the actual depth of the wall loss.

To date, M-skip has been applied to carbon steel plates and pipes with wall thicknesses in the range 7 to about 35 mm, with probe separations up to at least one metre. Typical probe frequencies are 3-5 MHz.
M-skip has been applied to carbon steel components containing generalised and isolated corrosion. For NII, M-skip is applicable to sections of components made inaccessible to conventional ultrasonic methods by geometry, such as pipe supports and pipe clamps. The method also has potential for fast screening for corrosion pits over large areas of vessel shells or long lengths of pipework.

A.2.6 Long Range Ultrasonics

A.2.6.1 LORUS

The principle of the method consists of a high sensitivity angle beam probe used in multi-skip mode to completely flood the wall of the component being inspected. Any changes of the thickness of the pipe at the outer or inner surface can result in reflection of some of the ultrasound back to the transducer. Ranges of over a metre can be achieved. The amplitude of the response provides an indication of severity although it is not possible to measure accurately the through wall dimension of corrosion, or determine whether it is at the inner or outer surface. The surface should be free of impurities and loose deposits to provide sufficient acoustic coupling at the transducer test point. The method is used to detect corrosion at locations with limited access, such as: insulated and (with certain restrictions) clamped pipes, annular plates in storage tanks or under reinforcement plates. The interpretation of the output signals is of prime importance as the signals which reach the transducer include those from welds, supports and other geometrical features and would superimpose over the signals from corrosion areas.

“LORUS” (LOng Range UltraSonics) was developed by RTD. Inspection results are reported in high-resolution colour maps (presented in 3D views: top, side and end images) and corroded areas are listed by angular position and extent with a position accuracy of ±10mm. The LORUS system can be applied to components in the thickness range 6-25 mm. Well-bonded paint coating is acceptable. Heavy corrosion may obscure detection of corrosion at larger distances from the probe in the plate.

Trials have been performed to investigate the capability of LORUS to detect corrosion inside a vessel underneath a nozzle reinforcing plate (which prevents detection using conventional 0° ultrasonic inspection). The trials were performed using two test-pieces manufactured by MBEL. One test-piece was a nozzle welded into a square plate (representing the vessel) and containing a 90 mm wide (radial extent) reinforcing plate. The test-piece contained eleven simulated corrosion sites at various locations under the reinforcing plate. The other test-piece was simplified geometry manufactured from flat plate and containing four simulated corrosion sites. All fifteen simulated corrosion sites were detected.

A.2.6.2 Lamb/Guided Wave Methods

Lamb waves are “guided” or “plate” waves which can exist in plates or pipes where the thickness is the same order of magnitude as the ultrasound wavelength. The wave motion couples both surfaces of the plate together, such that the plate or pipe acts as an acoustic waveguide, allowing the propagation of a series of different Lamb-wave modes, whose velocities depend on the plate thickness and wavelength.

This method is generally applied using a ring of probes which are clamped around the outside of a pipe. The method is pulse-echo and the transducer array is configured such that the test may be carried out in one direction along the pipe and then in the other. Long lengths (ca. 30 m - 50 m or more) of pipe may be examined in both directions from a single test point, although certain pipe coatings (especially soft coatings such as bitumen or tape wrap) can severely attenuate the Lamb waves, and hence reduce the effective range of the method.

Wall loss flaws are detected by the reflected waves they generate. For reliable detection, a wall loss flaw needs to reduce the cross sectional area of the pipe by around 2-5% (this varies depending on equipment used and general conditions of the pipe to be tested). The amplitude of the received flaw echo provides some information on the overall flaw extent, but not on the maximum wall loss.

The detection capabilities at locations close to (or within) pipe features (e.g. under simple supports) depend on the equipment used and the operator skills. In some case detection capabilities are hindered by the presence of pipe features and the user shall refer to the manufacturers' recommendation.

For NII applications, Lamb/Guided inspection is generally used as a fast screening method for the inspection of long lengths of straight pipework, although recent advances allow some inspection around bends. Guided wave techniques have been used to rapidly inspect insulated and clad pipeline corrosion, and the results correlated well with subsequent investigations.

Lamb waves can also be generated in flat or large curvature plates, but these methods are much more developmental than the systems for pipe inspection. Other developments have been used for permanent monitoring of pipes in hazardous areas, and for inspection of heat exchanger or boiler tubes.

A.2.7 Electromagnetic Acoustic Transmission (EMATs)

Electromagnetic acoustic transducers (EMATs) are a relatively new method for generating and receiving ultrasound which offer certain advantages compared to conventional (piezoelectric) probes. However they have much lower sensitivity than conventional probes and are much more expensive.

An EMAT consists of a flat pancake coil of wire carrying a radio frequency current and a magnet which
produces a steady magnetic field. The radio frequency current induces eddy currents in the surface of the specimen and their interaction with the magnetic field results in Lorentz forces or magnetic forces (predominantly magnetostrictive) which cause the specimen surface to vibrate in accordance with the applied radio frequency current. The ultrasonic waves which have been generated at the specimen surface propagate into the specimen in the normal way. They can be detected after reflection from a flaw, for example, by the same transducer or by a separate one using a reciprocal process. Depending on the direction of the magnetic field the EMAT can generate shear (radially, horizontally or vertically polarised), compression or Rayleigh waves.

EMAT ultrasonic can be a non-contact method since there is no need of fluid couplant and it can be used on rough, scaled or painted surfaces, although any lift-off from the specimen surface reduces the sensitivity still further.

EMAT probes are now available from certain large probe manufacturers for use with conventional manual flaw detectors. However these are intended for a special application, involving thickness gauging of carbon steel components with a magnetite layer which has formed through operation at high temperatures. The presence of this magnetite layer greatly enhances the efficiency of ultrasound generation and detection, via the magnetostrictive effect. For all other steel components, without this coating, EMATs remain a research method only.

EMATs can operate on hot metals, since EMATs are relatively easy to keep below 100°C with simple water cooling. They can be used up to 700°C if they are brought into momentary contact with the sample and up to 460°C in constant contact. Thicknesses from 2 mm up to 150 mm or higher can be inspected. EMATs can also be used on low temperature surfaces (down to liquid nitrogen temperature).

However, when the EMAT is used as a transmitter, problems emerge due to low sensitivity. One recent method used to solve this problem is to use a laser to generate ultrasonic waves and an EMAT as receiver; the EMAT-LASER or EMAT-EMAT method is of high cost compared to more traditional methods, but has proved to be effective for certain specific applications.

EMATs have been used to measure the wall thickness of steel galvanising bottles at their normal operating temperatures that are in excess of 450°C. The kettles are typically fabricated from 50 mm thick steel. The study indicates that it is possible to measure the steel wall thickness to within ±0.5 mm.

EMATs are not typically currently widely applied for NII applications.

A.3 Eddy Current Testing

Eddy current testing is based on inducing electrical currents in the material being inspected and observing the interaction between these currents and the material.

Conventional eddy current testing methods are not suitable for volumetric inspection of vessels since typical penetration depth of the eddy currents is less than 1mm for ferritic material and several millimetres for austenitic material. Advanced eddy current methods can significantly increase penetration depth as described below.

A.3.1 Pulsed Eddy Current Testing

In the pulsed eddy current method, a coil is supplied with a short pulse. The resulting eddy current pulse propagates in the specimen as a heavily attenuated wave of electromagnetic energy with a phase velocity depending on the material and the frequency. For material thickness measurement, a detection coil can be placed close to the transmitter with suitable shielding. Because the wave propagation is highly dispersive, changes in pulse shape occur with distance into the specimen and by measuring the time-amplitude characteristics of the received pulse and comparing them with the time of occurrence of certain signal features from similar calibration tests via a computer, flaw depth can be determined. A change in wall thickness indicates the presence of corrosion or erosion. The probe does not need to be in contact with the component and can therefore be applied through insulation, and also thick coatings or layers of deposit as long as they are non-conductive and non-magnetic.

This method can be used for in-service inspection, has good repeatability (±0.1 mm), is transportable and robust, operates over a wide range of climatic conditions, can be applied on components with temperatures of -100°C to +500°C (above these temperatures, the use of the system is prohibited due to the reduction of magnetic permeability), measures through any non-conductive and non-magnetic material up to 100 mm thickness (in favourable circumstances even up to 150 mm). Ferritic cladding up to a certain thickness (at present 0.8 mm) does not influence accuracy and the transducer can be up to 30 metres from the base unit.

However, typical equipment is limited to inspection of wall thicknesses below 40 mm and pipe diameters over 100 mm, it only detects general corrosion or erosion over relatively large areas, does not detect small isolated pits and can be influenced by the presence of large metal masses nearby.

A.3.2 Saturated Low Frequency Eddy Current (SLOFEC)

This method is based on the eddy current method with DC magnetisation. A magnetising yoke containing an
electromagnet is used to generate a strong magnetic field in the material under test. An eddy current probe senses component metal loss due to the local concentration of the magnetic field.

If the coil is used in differential mode then localised wall loss such as pitting can be detected. General wall thinning can be measured by using the system in absolute mode.

A saturated low frequency eddy current ("SLOFEC") system has been developed by a German company (Kontroll Technik). SLOFEC can provide an improved performance for some applications where classic magnetic flux leakage (MFL) is used, e.g. the inspection of tank floors and pipe inspection.

Two major advantages of SLOFEC compared to classic magnetic flux leakage are that the maximum wall thickness which can be inspected is around 30-35 mm, compared to around 10-15 mm for MFL. Recent studies also suggest that SLOFEC has improved sensitivity to small pitting flaws than MFL. The data from SLOFEC is stored in digital form, and analysis of the signal characteristics provides information on the location of wall loss flaws (backwall/frontwall). Some information on the extent of an indications wall loss is available, but this is less quantitative than that provided by a method such ultrasonic corrosion mapping.

For NII, SLOFEC has considerable potential for the rapid detection/screening of corrosion in vessel shells and pipework.

A.4 Liquid Penetrant Inspection

Liquid penetrant techniques, including dye and magnetic particle variations are low cost methods and are easy to apply and used to detect surface breaking flaws such as cracks, laps and porosity. Large areas can be inspected but liquid penetrant is a slow process in terms of application and flaw indication.

The principle of liquid penetrant method: first, the surfaces to be tested are cleaned – pre-cleaned to remove scale etc., degreased and dried. The chosen penetrant (solutions of coloured or fluorescent dyes in oil-based liquids) is applied to the surface of the specimen and allowed time to soak into discontinuities. The excess penetrant is removed (by water, solvent, water and detergent or by emulsifier). A developer is then applied. After a period of time and if a discontinuity is present, the penetrant seeps out the developer at the discontinuity position, causing a marked local reduction in developer contrast. The surface is examined under appropriate viewing conditions. Finally, the surface is cleaned to prevent corrosion etc.

The sensitivity of penetrant inspection process can be very high and it is possible to detect very small cracks having opening widths of about 1μm.

Liquid Penetrant inspection is only applicable to the accessible component surface, and is not therefore an NII method.

A.5 Magnetic Particle Inspection

Magnetic particle inspection (MPI) is used for the detection of surface and near-surface flaws in ferromagnetic materials. It is one of the most extensively used electromagnetic methods in industry as it is easy to apply and provides a direct visual indication of surface breaking cracks.

The method involves the magnetisation of the component either locally or overall, by application of a permanent magnet, electromagnet or electric current. A magnetic field is produced inside the material. The magnetic field becomes distorted by the presence of a flaw causing a local magnetic flux leakage.

Ferromagnetic particles in the form of dry powder or suspended in a liquid (daylight visible or UV fluorescent particles) are sprayed onto the surface of the specimen to reveal the leakage field. The particles are attracted by the magnetic field and accumulate in the vicinity of the flaw, which is subsequently made visible.

The minimum angle between the magnetic field and the detection of imperfection is 30°. The optimum sensitivity is reached when the magnetic field is perpendicular to the imperfection orientation. Therefore, the flaws must lie between 30° and 90° to the magnetic field in order to be detected. The magnetic field is therefore applied in two directions at right angles to each other.

MPI is only applicable to the accessible component surface, and is not therefore an NII method.

A.6 Magnetic Flux Leakage

The component is locally magnetised and depending upon the level of induced flux density, magnetic flux leakage due to both near and far surface flaws is detected by the voltage induced in a detector coil or a Hall-effect element which is traversed over the surface of the specimen. The method is not limited to surface-breaking or near-surface flaws, although it becomes increasingly sensitive to far-surface flaws with increasing levels of magnetisation. Also, the output from the detector can be amplified, filtered, digitised, etc., and stored to produce automated inspection systems. Multi-element and differential probes can be used, and inspection speeds can be very high.

The method is finding increasing use in the petrochemical industries for providing high-speed inspections of storage tank floors, as well as carbon steel pipes. These systems utilise either permanent or electromagnets to provide localised near-magnetic saturation coupled with induction-coil or Hall-effect sensor arrays for detecting anomalous flux leakage caused by the presence of corrosion flaws (both near and far surface). Many of these systems rely upon the use of an adjustable threshold or amplitude gate to provide the detection of
corrosion in real-time, while some of the more advanced systems, through the use of both advanced electronics and signal processing, are able to provide corrosion-maps of inspected areas similar to the C-scan representation of ultrasonic data.

Maximum wall thickness which can be inspected is around 10-15 mm, and some information is provided on the extent of the wall loss, but MFL is less quantitative than methods such as ultrasonic corrosion mapping. MFL can be used for NII, and crawlers have been developed for inspection of vertical walls, as well as the more conventional floor scanners.

A.7 Thermography

Thermography is based on the measurement of the heat distribution across a surface. The effect of flaws on thermal conductivity and emissivity of test materials can be analysed by a thermographic method.

Passive thermography investigates the heat distribution of a structure with a special infrared camera and looks for hot spots, which could for example be due to loss of wall flaws in a vessel/pipe containing hot products, or a breakdown in thermal insulation.

An alternative method, known as transient or pulsed thermography involves inducing a heat pulse into a component by suddenly raising the temperature of the component surface locally using an external heat source (e.g. flash tube). Within the HOIS programme, an alternative heat source using induction heating was developed to allow the more effective inspection of thicker steel components.

The heat pulse will diffuse into the material. The rate at which the heat front is subsequently dissipated depends on the structure and flaw content below the surface. The surface temperature of the structure is monitored using an infrared camera. Anomalies in the temperature distribution reveal the presence of flaws or local changes in thermal conductivity due to e.g. breakdown in insulation. The method is made more convenient by using a video recorder or computer to store the rapidly changing temperature pattern after the structure surface is heated. Then, flaws in conducting materials that have only a transient effect on the temperature distribution may be detected. Quantification of anomaly size is more usually accomplished by application of a second non-destructive evaluation method as thermography can estimate size only on thin outer layers.

A new method known as lock-in thermography is reported to be much quicker, more accurate and be able to probe deeper than conventional thermographic inspection methods. Lock-in thermography is a method which uses a modulated source to energise the material under test. However, this method is still limited for detection of flaws of several millimetres below a material surface. To date, tests have been carried out at frequencies which allowed depth ranges of 10 mm to be covered.

Transient thermography can be used as a rapid, non-contacting method for detection of sub-surface flaws or voids. However, it becomes less effective in detection of sub-surface flaws as the depth of the flaw increases. Typically for detection, the width of a flaw must be greater than its depth below the inspection surface. Laboratory tests of the induction heater developed in the HOIS programme showed detection of flaws (diameters 15-30 mm) at depths of 10 mm below the inspection surface. Smaller diameter flaws could be detected at smaller depths.

A.8 Radiography

Radiographic inspection is a process of testing materials using penetrating radiation - either electromagnetic radiation of very short wavelength (X-rays, gamma-rays), or particulate radiation (neutron radiation). Radiography is based on the differential absorption of the radiation by the material being inspected. In passing through the material some of the radiation is attenuated depending on the thickness and the density of the material. The unabsorbed radiation that passes through the test-piece can be recorded on an imaging medium, such as film or more recently the film-less plates used in computed radiography. In general, radiography can detect only features which have an appreciable thickness (loss of material) in a direction parallel to the radiation beam.

One radiographic method for inspecting large diameter pipework and even small vessels is a double-wall single image (DWSI) method, where only the section of the wall that is furthest from the source contributes to the radiographic image, although the radiation penetrates both walls. This is achieved by placing the source very close to one wall. Note that DWSI radiography is not suitable for vessels of diameter greater than about 1.5 metres, or where internals obstruct the beam. Also, the presence of liquid products in the vessel further restricts the application of radiography, due to the increased attenuation in the liquid. For water filled components, the additional attenuation obtained is approximately equivalent to an additional penetrated steel thickness of \( ID/7 \), where \( ID \) is the component internal diameter/dimension.

Alternative methods for inspection of smaller diameter pipes and the sections nozzles protruding from vessels, include the double wall double image method (DWDI) where both pipe walls contribute to the radiographic
image, and also importantly the tangential method which gives a direct image of the pipe wall, allowing the extent of any loss of wall flaws to be measured directly from the image (provided appropriate distance calibration methods are used).

Raised surface temperature increases difficulties as the radiographic film cannot be used in contact with the sample surface at temperatures above ±40°C. The film therefore needs to be insulated at higher temperature. However, introducing insulation increases the sample to film distance and can therefore increase the image un-sharpness (blurring of the image), although this effect is likely to be small unless the insulation thicknesses are very large.

Recent developments in the field of in service radiography include the use of collimated sources which allow greatly reduced controlled areas, and allow radiography to continue without plant turnaround, or the need for after hours work.

In addition, computed radiography is now being increasing used. With this technology, traditional film is replaced by film-less plates, which are exposed in a similar manner to film but are then read out (scanned) using a laser scanner, and the resulting digital image is displayed on a computer monitor. Various computerised enhancement and analysis routines can then be applied. Because film-less plates are more sensitive to penetrating radiation than film, computed radiography leads to reduced exposure times, and hence faster inspection.

In addition, the computer based analysis routines greatly facilitate quantitative wall loss measurements using the tangential method. Analysis of image grey level information can also be used to estimate loss of wall flaws to be measured directly from the image (provided appropriate distance calibration methods are used), although this effect is likely to be small unless the insulation thicknesses are very large.

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Recent developments in the field of in service radiography include the use of collimated sources which allow greatly reduced controlled areas, and allow radiography to continue without plant turnaround, or the need for after hours work.

A.9 Backscatter (Compton’s) Imaging

Compton scattering tomography is a relatively new method for industrial non-destructive testing, making use of γ or X-ray photons scattered inside the component under examination. The source emits a finely collimated beam into the material and a finely collimated detector allows measurement of the number of photons that are scattered. The detected signal is largely composed of singly scattered photons from the volume defined by the intersection of the incident beam and the acceptance solid angle of the detection collimator. The amount of scattered radiation produced is directly related to the electron density of the material, which corresponds well to the physical density of the material. The major advantage offered by backscatter imaging is that it can be implemented from one side of the object.

It can provide information even if the object is very massive, or does not permit X-ray transmission through it, or does not permit access to the opposite side. The measurement can be performed in the presence of protective coatings and because the source and the detector are placed on the same side of the test-piece, large components filled (with oil for example) can be inspected at speeds much greater than can be done with conventional through-transmission radiography. Compton backscatter imaging is a non contact method and can therefore be applicable at elevated temperatures.

In Compton scatter imaging a three-dimensional image is built up point by point. The time necessary to obtain an image of a particular volume of interest in the object under study is a function of the size of this volume. The scanning rate varies inversely with the square of the inspection volume. If larger voids are of interest, greater scanning rates are possible and therefore shorter scanning times can be used although there is loss of spatial resolution. A detector array is usually used to cover the entire thickness of specimen traversed by the source beam, for each position of the source. A feasibility study on the use of Compton backscatter gamma-ray tomography for underwater inspections offshore shows that the use of 10 Ci of 60Co should provide a scanning rate of about 35 cm²/min⁻¹. The study showed that this method is capable of detecting 5mm cubical flaws positioned at a depth of 32 mm of steel. Therefore, this method could be an attractive tool to detect corrosion/erosion of the inner surface of vessels. However, this is an expensive method and it might need to be adapted for particular applications.

The major drawbacks of Compton scatter imaging systems has been their high capital costs and very slow scan speeds, which have precluded their application to all but the highest value components.

There have been however some recent developments to this method, especially in the USA, and systems are now being used for certain specialised large area scanning applications (e.g. foam thermal insulation on NASA’s Space Shuttle).

This is not currently a recognised NII method in the oil and gas industry, but there may be some potential for applications such as CUI inspection.

A.10 Acoustic Emission (AE)

Acoustic emissions are pulses of elastic strain energy released spontaneously during deformation of materials. When a body suddenly deforms locally and relieves local stresses, a burst of energy is emitted.

AE can be released by a number of causes such as plastic deformation, inclusion cracking, crack growth, but also by corrosion, phases changes and impact. External factors such as mechanical impacts, friction, machinery vibration, welding operations, can also produce acoustic emission.
These emissions propagate through the specimen and are detected by sensors placed on the surface of the specimen, which in turn convert the energy into electrical signals. These are amplified, stored, processed and displayed. Acoustic emission examination is non-directional as AE propagates in spherical wave fronts. Therefore, a sensor located anywhere in the vicinity of an acoustic emission source can detect the resulting acoustic emission. A large volume of a structure can be monitored at once; it is not necessary to examine specific regions. Since only limited access is required, “active” discontinuities in areas inaccessible to the more traditional non-destructive methods can be detected. Location of the source of the acoustic emission can be accomplished by several search units positioned over the surface area to be tested and monitoring the time of arrival of the signals to the various search-unit locations. Because of the high velocity of sound and the relatively close spacing of search units on a steel vessel, time resolutions must be made in microseconds to locate the source within a centimetre. In most cases, inspection requirements are such that data must be available in a short period of time. Therefore most systems of this type utilise a computer for handling and displaying the data.

The in-service inspection of a pressure vessel may consist of monitoring during periodic proof testing, during normal pressure cycles or continuously during normal operation. When the vessel is pressurised to a level less than that to which it has been previously subjected, little or no acoustic emission occurs. Therefore, on subsequent pressurisations no AE will be generated unless a crack has extended in service because of corrosion or fatigue. On pressurising after crack growth, the stress system at the enlarged crack will be changed from that previously, and further emission will be obtained. The detection of the source of the acoustic emission can be reported to be a relatively straightforward application as stress corrosion cracking produces copious AE. However, the success depends on the particular material tested. Some materials are quiet almost up to the point of failure. Slow, continuous crack growth mechanisms such as active path corrosion are not detectable in themselves, but if general yielding has not occurred, they may be detectable through associated plastic zone growth.

The main advantages of the method are that it allows large area coverage, growing discontinuities can be detected, location of discontinuities is possible, inaccessible area inspection, on-line application (even at high temperature) and non-invasive.

However, not all discontinuities emit detectable acoustic emission, loading methods must be analysed to ensure they promote detectable crack growth, many factors can obscure acoustic signals (geometry, materials, construction, noise), discontinuity size not determinable and special sensors have to be used at high temperature (high temperature sensors are available to operate up to 260°C).

A.11 Remote Visual Inspection

Remote visual inspection using equipment such as boro-scopes, fibre optic boro-scopes and video-scopes is a very useful tool which can give information on the condition of pipes, turbines, heat exchangers, and other critical machinery without costly and time consuming disassembly.

A boro-scope is a long, tubular optical device that illuminates and allows the inspection of surfaces inside narrow tubes or difficult to reach chambers.

Rigid boro-scopes are generally limited to applications with a straight-line path between the observer and the area to be observed – an orbital scan allows the user to view flaws in a 360 degrees arc. The lengths and diameters of the probes can be tailored for optimum results. Typical sizes range in length from 0.15 m up to 30 m and in diameters from 0.9 to 70 mm. Magnification is usually 3 to 4 times although magnifications up to 50 times are available.

Flexible boro-scopes are used when there is no straight passageway to the point of observation. There are two types of flexible boro-scope which are flexible fibre-scopes and video-scopes with a CCD image sensor at the end. The flexible fibre-optic boro-scope carries visual information through fibre-optic cables each of which makes up a picture element of the final image. Articulation controls allow the user to manipulate the end of the scope in the interior of the structure. Special protective coatings allow the boro-scope to operate while submerged in liquid. They are typically available in diameters from 1.4 to 13 mm and in lengths up to 12 m.

Rigid and flexible boro-scopes are available in a wide variety of standard and customised designs and several factors can influence the selection of a scope for a particular application. These factors include focusing, illumination, magnification, working length, direction of view and environment.

Both types of boro-scopes can be manufactured to withstand a variety of environments. Rigid endo-scopes as standard will accept temperatures from -30°C up to 150°C and will withstand pressure up to 6 bars. Flexible endo-scopes will work in temperatures up to 80°C and will withstand pressures of between 2 and 3 bars. Boro-scopes can be tailor made to meet different specifications such as length (up to 18 m), diameter (down to 10 mm), lighting system and the use of a jacket protection to allow the system to be used at higher temperature (up to 1600°C). However, the price of the system is related to these options and would increase rapidly with the quality of performance.

Boro-scopes provide a means of checking in-service flaws in a variety of equipment and are of particular interest for the build-up of corrosion and scale on the internal surfaces of for example heat exchangers. Video-scopes are similar to fibre-optic boro-scopes. The video-scope involves the electronic transmission of
colour or black and white images to a video monitor. The advantage of these devices is their length. Due to light attenuation fibre-optic boro-scopes are limited in length, but some video-scopes can travel as far as 30 m to the inspection site. Other advantages of the video-scope compared to the fibre-optic boroscope are that the display can help reduce eye fatigue, there is no honeycomb pattern and/or irregular picture distortion and the electronic form of the image signal allows digital image enhancement and the potential for integration with automatic inspection systems. It produces generally higher resolution. Video cameras are more sensitive to temperature and will only generally work at temperatures from 0°C to 45°C.

A.12 Shearography

Shearography is a promising relatively new NDT method. It is a non-contact laser based interferometry system that is used to detect areas of stress concentration caused by anomalies in materials.

The method senses out-of-plane surface displacement of an object in response to an applied load. A laser beam is used to coherently illuminate the test sample. The light reflected from the test sample is collected by a photo lens and imaged through an image shearing interferometer onto the sensor array of a CCD video camera. The image shearing interferometer produces a double image on the CCD array. The second image is offset from the first one. The interferogram recorded by the CCD camera is thus indicative of motion toward the camera over an interval of the image shearing distance in the plane of the test sample surface, or the relative slope of the test sample surface. Data are represented in the form of a fringe pattern produced by comparing two states of the test sample, one before and the other after a load is applied.

Shearography can be applied to a variety of materials, including steel, aluminium, plastic and composite. Shearography is a remote, non-destructive, non-contact and very fast method.

It can perform measurements in hazardous conditions such as high temperature, plasma and nuclear radiation. Laser Shearography is very sensitive to slight changes in surface strain due to sub-surface flaws. It can map changes in strains to 0.1 microstrain at video frame rates. However, Shearography is not currently used as an NII method within the oil and gas industry.
### A.13 Inspection Method Capabilities

<table>
<thead>
<tr>
<th>Flaw type</th>
<th>Inspection method</th>
<th>Detection</th>
<th>Through wall Sizing</th>
</tr>
</thead>
<tbody>
<tr>
<td>General wall thickness loss</td>
<td>UT Pulse-echo 0 deg. compression wave</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<tr>
<td></td>
<td>UT mapping (C-Scan)</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<td></td>
<td>UT EMAT</td>
<td><strong>M</strong></td>
<td><strong>M</strong></td>
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<td></td>
<td>Phased Array</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<td></td>
<td>M-skip</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<tr>
<td></td>
<td>Pulsed Eddy Current</td>
<td><strong>H</strong></td>
<td><strong>M</strong></td>
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<td></td>
<td>Film Radiography</td>
<td><strong>M</strong></td>
<td><strong>L</strong></td>
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<tr>
<td></td>
<td>Computed Radiography (tangential on pipes)</td>
<td><strong>M</strong></td>
<td><strong>M</strong></td>
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<tr>
<td></td>
<td>Magnetic Flux Leakage</td>
<td><strong>L</strong></td>
<td>-</td>
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<tr>
<td></td>
<td>Saturated Low Frequency Eddy Current</td>
<td><strong>L</strong></td>
<td>-</td>
</tr>
<tr>
<td>Local wall thickness loss, pitting</td>
<td>UT Pulse-echo 0 deg. compression wave</td>
<td><strong>H</strong></td>
<td><strong>M</strong></td>
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<tr>
<td></td>
<td>UT mapping (C-Scan)</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<tr>
<td></td>
<td>UT TOFD</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<td></td>
<td>Phased Array</td>
<td><strong>H</strong></td>
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<td></td>
<td>M-skip</td>
<td><strong>H</strong></td>
<td><strong>M</strong></td>
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<tr>
<td></td>
<td>Film Radiography</td>
<td><strong>H</strong></td>
<td><strong>L</strong></td>
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<td></td>
<td>Compton Backscatter</td>
<td><strong>H</strong></td>
<td><strong>L</strong></td>
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<td></td>
<td>Computed Radiography (double wall with computerised</td>
<td><strong>H</strong></td>
<td><strong>M</strong></td>
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<tr>
<td></td>
<td>analysis of image grey levels)</td>
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<td></td>
<td>Magnetic Flux Leakage</td>
<td><strong>M</strong></td>
<td><strong>L</strong></td>
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<td></td>
<td>UT CHIME</td>
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<td></td>
<td>Pulsed Thermography</td>
<td><strong>M</strong></td>
<td><strong>L</strong></td>
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<td></td>
<td>UT Long Range (Lamb Wave)</td>
<td><strong>M</strong></td>
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<td></td>
<td>Shearography</td>
<td><strong>L</strong></td>
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<td></td>
<td>Saturated Low Frequency Eddy Current</td>
<td><strong>H</strong></td>
<td><strong>L</strong></td>
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<tr>
<td>Blisters and embedded horizontal cracks,</td>
<td>UT Pulse-echo 0 deg. compression wave</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<tr>
<td>delamination</td>
<td>UT mapping (C-Scan)</td>
<td><strong>H</strong></td>
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<td></td>
<td>Phased Array</td>
<td><strong>H</strong></td>
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<td></td>
<td>Pulsed Thermography</td>
<td><strong>M</strong></td>
<td><strong>L</strong></td>
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<td></td>
<td>Shearography</td>
<td><strong>L</strong></td>
<td>-</td>
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<td></td>
<td>UT TOFD</td>
<td><strong>H</strong></td>
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<tr>
<td></td>
<td>Compton Backscatter</td>
<td><strong>M</strong></td>
<td><strong>L</strong></td>
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<tr>
<td></td>
<td>Acoustic Emission</td>
<td><strong>L</strong></td>
<td>-</td>
</tr>
<tr>
<td>Surface breaking cracks</td>
<td>Eddy Current ACFM (inspection surface only)</td>
<td><strong>M</strong></td>
<td><strong>M</strong></td>
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<tr>
<td></td>
<td>Phased Array</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<td></td>
<td>Liquid Penetrant (inspection surface only)</td>
<td><strong>H</strong></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Magnetic Particle Inspection (inspection surface only)</td>
<td><strong>H</strong></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>UT Pulse-echo Shear wave (backwall &amp; frontwall)</td>
<td><strong>H</strong></td>
<td><strong>M</strong></td>
</tr>
<tr>
<td></td>
<td>UT TOFD (backwall &amp; frontwall)</td>
<td><strong>H</strong></td>
<td><strong>H</strong></td>
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<tr>
<td></td>
<td>Guided Wave</td>
<td><strong>M</strong></td>
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<tr>
<td></td>
<td>Acoustic Emission (backwall &amp; frontwall)</td>
<td><strong>M</strong></td>
<td>-</td>
</tr>
</tbody>
</table>
**Table A-1  Capabilities for Non-intrusive Inspection Methods (Continued)**

<table>
<thead>
<tr>
<th>Flaw type</th>
<th>Inspection method</th>
<th>Inspection efficiency (Low, Medium, High)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Detection</td>
</tr>
<tr>
<td>Embedded cracks</td>
<td>UT Pulse-echo Shear wave</td>
<td></td>
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<tr>
<td></td>
<td>UT TOFD</td>
<td></td>
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<tr>
<td></td>
<td>Phased Array</td>
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<td></td>
<td>Film Radiography</td>
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<td></td>
<td>Computed Radiography</td>
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<tr>
<td></td>
<td>Acoustic Emission</td>
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</tr>
<tr>
<td>Embedded volumetric voids</td>
<td>UT Pulse-echo 0 deg. compression wave</td>
<td></td>
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<tr>
<td></td>
<td>UT Pulse-echo Shear wave</td>
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<td>UT TOFD</td>
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<td></td>
<td>Phased Array</td>
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<td></td>
<td>Film Radiography</td>
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<td></td>
<td>Shearography</td>
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<td></td>
<td>Pulsed Thermography</td>
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<tr>
<td></td>
<td>Computed Radiography</td>
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<tr>
<td>Anomalies</td>
<td>Thermography</td>
<td></td>
</tr>
<tr>
<td>Weld root erosion</td>
<td>UT TOFD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT Pulse-echo Shear wave</td>
<td></td>
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<tr>
<td></td>
<td>UT Pulse-echo 0 deg. compression wave (if weld cap removed)</td>
<td></td>
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<tr>
<td></td>
<td>Phased Array</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT mapping (C-Scan) (if weld cap removed)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pulsed Thermography</td>
<td></td>
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<tr>
<td></td>
<td>Film Radiography (double wall method)</td>
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<tr>
<td></td>
<td>Computed Radiography (tangential on pipes)</td>
<td></td>
</tr>
</tbody>
</table>

- = Not applicable
### Table A-2 Capabilities of Non-intrusive Inspection Methods

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</tr>
</thead>
<tbody>
<tr>
<td>1. UT Pulse-echo Shear wave</td>
<td>6-300</td>
<td>Reduced capability for austenitic and duplex welds</td>
<td>Up to 250°C using special probes</td>
<td>Uniform coating up to 1.5 mm Roughness 6.3µm max. Free of scale, slag, rust, oil and grease at probe location.</td>
<td>1 mm-5 mm depending on geometry</td>
<td>±3mm mean error for weld inspection</td>
<td>Weld 20m/day</td>
<td>High POD values published</td>
<td>ID</td>
<td>Surface and embedded crack, volume</td>
<td>Capability for weld inspection depends on geometry and UT procedure</td>
<td>Small probe</td>
</tr>
<tr>
<td>2. UT Pulse-echo 0° compression wave</td>
<td>2-300</td>
<td>Reduced capability for austenitic and duplex welds</td>
<td>Up to 250°C using special probes Higher temperatures possible for spot checks</td>
<td>Uniform coating up to 1.5 mm Roughness 6.3µm max. Free of scale, slag, rust, oil and grease at probe location.</td>
<td>0.5mm WT typical, depending on thickness</td>
<td>Digital thickness gauge ±0.1mm ideal, ±0.5mm typical</td>
<td>Spot 1 000/day slow</td>
<td>High POD values published</td>
<td>ID/OD</td>
<td>General and local WTL, volume, blistering,</td>
<td></td>
<td>Small probe</td>
</tr>
<tr>
<td>3. UT corrosion mapping C-Scan 0° compression wave</td>
<td>2-300</td>
<td>As pulse-echo UT</td>
<td>Up to 125°C (longer contact)</td>
<td>As pulse-echo UT</td>
<td>0.5mm WT typical, depending on thickness</td>
<td>± 0.1 mm ideal ± 0.5mm typical</td>
<td>2-3 m², 8-12 m² paintbrush, Up to 16 m² mechanized</td>
<td>High POD values published</td>
<td>ID</td>
<td>Local WTL, blistering</td>
<td>Surface</td>
<td>Probe and encoder or mechanized vehicle on magnetic enforced wheels</td>
</tr>
<tr>
<td>4. UT TOFD</td>
<td>8-300</td>
<td>Restricted to fine grain material</td>
<td>As pulse-echo UT</td>
<td>As pulse-echo UT</td>
<td>3mm depending on geometry</td>
<td>±0.5 mm ideal ± 2mm typical</td>
<td>Weld 40m/day</td>
<td>High POD values published</td>
<td>ID, embedded</td>
<td>Embedded and surface crack, volume</td>
<td>Corner welds, complex geometries</td>
<td>Scooter or guiding belt</td>
</tr>
<tr>
<td>5. UT CHIME</td>
<td>Up to 40</td>
<td>As pulse-echo UT</td>
<td>Current applications up to c. 60°C</td>
<td>As pulse-echo UT</td>
<td>Min. c. 10% of WT, lateral dimension &gt; 15 mm</td>
<td>10 mm on position</td>
<td>Scan speed c. 1m/min.</td>
<td>Medium POD values published</td>
<td>No ID/OD discrimination</td>
<td>General and local WTL, cracking</td>
<td>Reinforcement plates, saddles, supports. Also shell screening</td>
<td>Manipulator and probe</td>
</tr>
<tr>
<td>Inspection Method</td>
<td>Wall thickness [mm]</td>
<td>Material</td>
<td>Temperature Range</td>
<td>Surface Finish</td>
<td>Sensitivity/min. detectable flaw</td>
<td>Accuracy / Repeatability</td>
<td>Productivity</td>
<td>Method Maturity</td>
<td>Flaw location</td>
<td>Flaw type</td>
<td>Vessel feature application</td>
<td>Access restriction</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------</td>
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<td>-------------------</td>
</tr>
<tr>
<td>6. UT Long Range (Lamb Wave)</td>
<td>All pipes from 2 to 48 in diameter</td>
<td>Normally carbon steel pipes only</td>
<td>-25°C to 125°C</td>
<td>Similar to pulse-echo UT. Bare metal best.</td>
<td>Min. 5 – 9% of pipe wall circumferential area</td>
<td>Typically 1 km /day</td>
<td>Medium POD values published</td>
<td>No ID/OD discrimination</td>
<td>Local WTL, cracking</td>
<td>Pipes – typically straight (few bends)</td>
<td>Probes form ring around pipe. Access to 0.5 m of bare pipe needed</td>
<td>Works best on straight pipes. Probe ring needs to be at least 1 m from nearest girth weld. Some pipe coatings limit range of method (e.g. Bitumasic)</td>
</tr>
<tr>
<td>7. UT EMAT</td>
<td>10-150</td>
<td>As pulse-echo UT</td>
<td>-200°C to 460°C</td>
<td>Rough surface acceptable in principle but reduces sensitivity even further</td>
<td>As pulse-echo UT under ideal circumstances, typically much poorer</td>
<td>As pulse-echo UT</td>
<td>As pulse-echo UT</td>
<td>Low</td>
<td>ID</td>
<td>As pulse-echo UT</td>
<td>As pulse-echo UT</td>
<td>Small probe</td>
</tr>
<tr>
<td>8. Eddy Current ACFM</td>
<td>N/A</td>
<td>All</td>
<td>Up to 150°C using special probes</td>
<td>Coating allowed with restrictions</td>
<td>Crack depth &gt; 1 mm and length &gt;10 mm ideal, depth &gt;3 mm and length &gt;20 mm typical</td>
<td>±3 mm</td>
<td>Medium</td>
<td>High</td>
<td>OD only</td>
<td>Crack under-coating</td>
<td>Welds, surface limited</td>
<td>Small probe</td>
</tr>
<tr>
<td>9. Pulsed Eddy Current</td>
<td>6-60 (through max. 150 mm insulation)</td>
<td>Low alloy C steel, restricted by ferromagnetic sheeting</td>
<td>-100°C to 500°C contact temperature max. 70°C</td>
<td>Non contact, through insulation</td>
<td>5% WT (relative measurement)</td>
<td>Accuracy 5% WT</td>
<td>Repeatability 2% WT</td>
<td>1,000 points/day</td>
<td>Medium POD values published</td>
<td>When insulated, no ID/OD discrimination</td>
<td>General WTL, volume</td>
<td>Surface spot</td>
</tr>
</tbody>
</table>

Table A-2 Capabilities of Non-intrusive Inspection Methods (Continued)
<table>
<thead>
<tr>
<th>Inspection Method</th>
<th>Wall thickness [mm]</th>
<th>Material</th>
<th>Temperature Range</th>
<th>Surface Finish</th>
<th>Sensitivity/min. detectable flaw</th>
<th>Accuracy / Repeatability</th>
<th>Productivity</th>
<th>Method Maturity</th>
<th>Flaw location</th>
<th>Flaw type</th>
<th>Vessel feature application</th>
<th>Access restriction</th>
<th>Limitations / Comments Testing req.'s</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Saturated Low Frequency Eddy Current</td>
<td>Up to 30 - 35</td>
<td>All, wall thickness for ferromagnetic, reduced capability for other but same as EC.</td>
<td>Up to 60°C</td>
<td>Non contact, max. 8 mm coating</td>
<td>15% WT</td>
<td>10 – 50 m² / day</td>
<td>Medium</td>
<td>ID/OD discrimination possible</td>
<td>Local WTL, volume</td>
<td>Surface</td>
<td>Heavy device due to magnets</td>
<td>Fast large area scanning. Down to 1.4 mm volume wall loss can be detected under favourable conditions</td>
<td></td>
</tr>
<tr>
<td>11. Liquid Penetrant (incl. dye and fluorescent)</td>
<td>N/A.</td>
<td>All, non-porous</td>
<td>10°C to 50°C</td>
<td>Free of scale, slag, rust, oil, grease or paint.</td>
<td>Anything visible</td>
<td>-</td>
<td>20 m per day</td>
<td>OD only</td>
<td>Surface crack</td>
<td>All geometry’s</td>
<td>N/A.</td>
<td>Very clean surface needed. Less reliable than MPI for ferromagnetic material</td>
<td></td>
</tr>
<tr>
<td>12. Magnetic Particle Inspection (incl. fluorescent)</td>
<td>N/A.</td>
<td>Ferromagnetic</td>
<td>Up to 100°C</td>
<td>Free of scale, slag, rust, oil, grease or paint. Smooth surface increases reliability</td>
<td>Anything visible</td>
<td>-</td>
<td>40 m per day</td>
<td>OD only</td>
<td>Surface crack</td>
<td>Depending on yoke</td>
<td>Yoke size 300 mm</td>
<td>Contrast paint can be used. Dry test ‘ink’ for high temperatures</td>
<td></td>
</tr>
<tr>
<td>13. Magnetic Flux Leakage</td>
<td>4-10</td>
<td>Ferromagnetic</td>
<td>Up to 60°C</td>
<td>Max. 3 mm coating, clean surface</td>
<td>Min. 30% WT or 20mm³</td>
<td>-</td>
<td>10 – 50 m² / day</td>
<td>OD only</td>
<td>Surface crack</td>
<td>No ID/OD discrimination</td>
<td>Surface</td>
<td>Medium size device 300 × 300 mm</td>
<td>Fast large area scan. Wall and pipescan, not floorscan</td>
</tr>
<tr>
<td>14. Pulsed Thermography</td>
<td>Surface</td>
<td>N/A.</td>
<td>Non-contact method, -20 to 1000°C</td>
<td>Depends on the surface emissivity</td>
<td>Temperature variations of 0.2°C at 1 m; 10°C at 100 m.</td>
<td>-</td>
<td>Depends on application</td>
<td>High</td>
<td>OD, screening for internal flaws</td>
<td>Anomalies</td>
<td>Surface</td>
<td>N/A.</td>
<td>Screening for anomalies. Depends on the surface emissivity of the specimen and the distance. Filters above 500°C. Line-of-sight required.</td>
</tr>
<tr>
<td>15. Film Radiography</td>
<td>Ir 192 up to c.100 penetrated thickness. Higher with Co60.</td>
<td>All</td>
<td>Max. 40°</td>
<td>2%WT</td>
<td>Slow depends on access and radiation safety regulations. Can be speeded up by use of SCAR or SafeRAD containers</td>
<td>High</td>
<td>ID/OD embedded</td>
<td>Local and general WTL, embedded volumetric flaws</td>
<td>Critical WT locations, welds, nozzles,</td>
<td>2 sided access</td>
<td>Double wall technique limited to vessels diameter below 1.5 m. Tangential technique, on stream possible. Radiation safety restrictions.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
16. Computed Radiography
–Similar to film radiography
All, 2% WT
Generally faster than film radiography subject to sensitivity. Depends on access and radiation safety regulations.

17. Acoustic Emission
All, Normal maximum 60°C
As 1 and 2 local to probes
Only detects growing flaws
Informations on position
Whole vessel
Medium, ID/OD
Local and general WTL
As film radiography
2 sided access, manipulator movement
On stream. Radiation safety restrictions.

Remarks:
Material: Carbon steel, stainless steel (including Inconel), duplex
Productivity: speed under normal conditions
Method maturity: experience with method, (low/medium/high) and POD values known
Flaw location: OD is detect indications on far side, ID is near (probe) side, discrimination of ID/OD flaws possible, embedded flaws can be found
Flaw type: damage description, main character of method. WTL is wall thickness loss. Local WTL is pitting. Cracks can be surface breaking or embedded.
Vessel feature application: type of features suitable for inspection. Welds: butt, corner or complex geometry. Surface with full area access (inspected area is equal to probe access area). Volume means inspected material volume and probe contact location are not necessarily the same.
Access (restrictions): seen from the NDT method, the required access area. In most cases determined by the probe size (detached units).

POD References:
APPENDIX B
STATISTICAL APPROACHES TO NII

B.1 Use of Statistical Methods in NII

B.1.1 Background

A range of statistical methods can be used to help quantify various aspects of the NII inspection procedure. This appendix presents some of the principal methods that can be used to assist in inspection scheduling, as well as the evaluation of inspection data.

The first section discusses a statistically based approach to setting the inspection interval in order to ensure safe operation. Two examples of statistical methods which can be useful tools for evaluation of inspection data from non-intrusive inspection are also provided.

The first method is extreme value statistical analysis, which can be useful for predicting what the maximum corrosion pit depth in a vessel zone is, based on a sample inspection for pitting within that zone. It can also be used to help determine what the sample size should be in order to achieve a particular level of confidence in the conclusions.

The second example covers the use of statistical methods to determine what the probability of detecting at least one flaw (and therefore revealing that a particular degradation mechanism is active) as a function of sample size and how widespread the degradation is.

B.2 Statistical Basis for Inspection Scheduling

Traditionally, inspection intervals are often specified on the basis of legislative requirements. More recently however, risk considerations have been taken into account. If non-intrusive inspection (NII) is to be used in conjunction with or as an alternative to IVI then a sensible basis for the determination of the NII requirements would be to ensure that the risk levels are not increased. For any given vessel this effectively means that there should not be an increase in the probability of failure (POF) when NII is used.

The approach suggested here aims to compare the nature of evolution of the probability of failure under different assumed inspection regimes. This comparison is then used in developing a basis for the determination of an acceptable NII strategy.

B.2.1 Probability of Failure

The probability of failure is determined as the probability that a flaw will exist with a size larger than the critical size. Given a known probability distribution for the sizes of the flaw population and a known critical flaw size, the probability of failure can be calculated as the area under the distribution curve for flaws larger than the critical size.

In many cases the critical flaw size will not vary with time, however, the probability distribution will typically be time dependent as a result of flaw growth by a variety of potential mechanisms. The nature of growth with time therefore has a direct influence on the probability of failure. With growth, there is a greater probability of flaws exceeding the critical size hence the probability of failure will tend to increase with time.

Inspection, aimed at identifying and sizing flaws, along with appropriate action (e.g. repair, rejection) taken when flaws exceed a certain size will have the effect of reducing the probability of failure. This is a consequence of the probability distribution being modified for flaw sizes larger than a defined acceptable limit. The nature of the reduction in probability of failure is directly related to the probability of detection (POD) of the inspection performed. An inspection with a 100% POD of flaws larger than the acceptable limit would reduce the probability failure to zero. Hence the probability distribution, as defined by \( p(x) \), before and after the inspection might appear as shown in Figure B-1.

Note that in practice there would be some modification of the curve for flaws smaller than the acceptable size due to imprecision in the inspection method giving rise to false calls. This, however, will not be considered here and it will be assumed for the present purposes that the inspection method has a 0% false call rate.

![Figure B-1](image-url)

**Figure B-1**
Effect of Inspection with POD = 1 on Probability Distribution
Few inspections will provide a 100% POD hence the case shown in Figure B-1 is not typical. More commonly the POD will be less than one and may be a function of flaw size. Hence inspection will have the effect of reducing in some way the probability of flaws larger than the acceptable size rather than eliminating it. A more typical case is thus as illustrated in Figure B-2.

![Figure B-2](image_url)

**Figure B-2**
**Effect of Inspection with POD < 1 on Probability Distribution**

For a probability distribution before the inspection given by \( p_b(x) \) and a probability of detection defined by \( POD(x) \), the probability distribution after inspection is given by

\[
p_s(x) = p_b(x) \quad \text{for} \quad x \leq x_{\text{accept}}
\]

\[
p_s(x) = (1 - POD(x)) \cdot p_b(x) \quad \text{for} \quad x > x_{\text{accept}}
\]

(1)

The probability of failure before the inspection is given by

\[
POF_b = \int_{x_{\text{accept}}}^{x_{\text{crit}}} p_b(x) dx
\]

(2)

and after inspection by

\[
POF_s = \int_{x_{\text{accept}}}^{x_{\text{crit}}} (1 - POD(x)) p_b(x) dx
\]

(3)

Clearly, the greater the POD of the inspection, the lower the probability of failure after the inspection. This lower probability is retained in part up to the time of the next inspection through the modifying effect on the probability distribution. The way the latter evolves between inspections however depends very much on the nature of flaw growth in addition to its form directly after the inspection. Growth means that the flaw distribution is time dependent and hence so is the probability of failure, which will tend to increase during time intervals between inspections. The shorter these intervals (i.e. the greater the frequency of inspection) the lower the probability of failure will be. In addition to being a function of flaw growth in between inspections, the form of the flaw distribution after an inspection is also dependent on the probability of detection and the margin between acceptable and critical flaw sizes. Hence it can be concluded that the probability of failure is primarily a function of time (which defines the growth processes), the inspection interval, the probability of detection of the inspection and the margins between acceptable and critical flaw sizes.

Since the growth processes are very often dominated by the equipment design and operating conditions, control over the probability of failure is typically only possible through variation of the inspection interval, the probability of detection and the margins between acceptable and critical flaw sizes. The definition of acceptable flaw size is often out of the operator’s hands hence safe management relies largely on a suitable specification of inspection interval and method (as the latter defines the POD).

In order to gain some insight into how the interval and POD may affect probability of failure it is useful to consider some representative examples.

The case to be considered assumes a growth process in which the growth rate is, on average, constant but allows for some variation in rate as defined by a normal distribution. This would be typical of corrosion type processes.

In this scenario, the growth of any flaw over a specified time interval is given by a normal distribution, this being defined by

\[
G(x, \mu, \sigma) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

(4)
where
\[ \mu \] is the average growth
\[ \sigma \] is the standard deviation of the growth

For flaws whose initial sizes are in the range \( x_i \) to \( x_i + \delta x \), the size distribution at the end of the specified interval is given by

\[ F(x, x_i) = f_i G(x, x_i + \mu, \sigma) \]  \hspace{1cm} (5)

where \( f_i \) is the proportion of the total flaw population made up of flaws covering the initial size range. For an initial flaw population distribution given by the continuous function \( p(x) \), the proportion of flaws covering the range \( x_i \) to \( x_i + \delta x \) can be approximated by

\[ f_i = p(x_i) \delta x \]  \hspace{1cm} (6)

In order to determine the flaw size distribution \( S(x) \) at the end of the period, the growth of the entire population of flaws must be considered, this being achieved by summation of the individual distributions as follows

\[ S(x) = \sum_i F(x, x_i) = \sum_i p(x_i) G(x, x_i + \mu, \sigma) \delta x \]  \hspace{1cm} (7)

In the limit as \( \delta x \to 0 \), the above becomes

\[ S(x) = \int_0^x p(y) G(x, y + \mu, \sigma) dy \]  \hspace{1cm} (8)

With no inspection at the end of the period, the starting distribution for the next period is given directly by \( S(x) \) and this can be used in the integration of equation (2) to obtain the distribution at the end of the period.

When an inspection is carried out, the distribution before the inspection is \( S(x) \) and after the inspection it is modified by the reduction in the probability of flaws having size larger than acceptable, as follows

\[ S_e(x) = S(x) \quad \text{for} \quad x \leq x_{\text{accept}} \]  \hspace{1cm} (9)

\[ S_e(x) = (1 - \text{POD}(x))S(x) \quad \text{for} \quad x > x_{\text{accept}} \]

The above values are then used to define the flaw distribution at the start of the next time period. By recursively updating the flaw distribution in this way, the probability of failure can be tracked throughout the life of a vessel and the effects of different inspection strategies (e.g. variations in the interval between inspections and the probability of detection) can be studied.

Figure B-3 shows some typical results which illustrate the effect of variations in the inspection interval and the probability of detection.

The uppermost solid curve shows the situation when there is no inspection performed and, as expected, the probability of failure increases continuously with time. Moving downwards, the next solid curve shows the evolution of POF for the case of inspections with POD=0.5 at every tenth time period. The reduction in POF following each inspection is clearly visible. This reduction is observed to nearly match the rise in POF over the time since the preceding inspection hence, on average, the POF is retained nearly constant under this inspection strategy. The figure shows that a similar average POF can be maintained by adopting an alternative strategy in which the inspection interval is reduced to 5 time periods and the POD also reduced (to 0.3).

The curves for POD=0.5 with an interval of 5 time periods and POD=0.8 with an interval of 10 time periods show, as expected, that the effect increasing POD is to lower the POF. Again it is clear that a given nominal POF at any time can be achieved by variation of either POD or inspection interval. There will however be differences within the time between inspections and a very long inspection interval may lead to an unacceptably high POF even if preceded by a high POD inspection.
B.2.2 Practical considerations

In practice, due to a large number of uncertainties, it will often be very difficult to quantify the probability of failure, as outlined above, with sufficient confidence. Hence such an approach may not always be adequate in providing reliable guidance for the definition of inspection interval and type. There is however a need that these be defined in a systematic manner and this is addressed in a variety of codes of practice (see for examples Refs. [10, 11, 22]) and many organisations have developed their own guidance documents.

Given that internal visual inspection has historically been the primary method, most industry accepted approaches are directed at this type of inspection. However, the principles remain applicable to the specification of NII. A common approach is to base the inspection interval for IVI on the Inspection Grade assigned to the vessel. Guidance on the determination of Inspection Grade may vary according to the code used however it effectively depends on:

— the history of previous inspection intervals
— the confidence in knowledge of the degradation rates
— the maximum degradation rate considered possible.

Grade 0 is the most severe and demands the shortest inspection interval and the interval increases with each Grade until it is a maximum for Grade 3. In order for a vessel to advance a grade it should typically have at least one inspection at the preceding grade. This is where the history of previous inspection intervals plays a role in determining grading.

Reduced confidence in knowledge of the degradation rates has the effect of reducing inspection grade (and hence also shortening the inspection interval). This effectively takes a conservative approach to reducing probability of failure when faced with uncertainty.

Likewise the inspection grade reduces with increasing degradation rate. This is aimed at ensuring the probability of failure remains more or less constant, even for different deterioration mechanisms.

Specification of inspection interval according to grade only does not take risk into account in a systematic way. Risk based inspection (RBI) is becoming increasingly accepted as offering a technically sound yet cost effective means of managing plant safety. Risk is determined as the product of the probability of failure and the consequences of failure and RBI aims to ensure that risk is consistently maintained at an acceptably low level. This can be achieved by a variety of means but the primary variables are inspection interval and inspection type. When internal visual inspection is relied upon, control of risk comes down to specification of an appropriate inspection interval, i.e. high risk items demand a short interval while longer inspection intervals are acceptable for low risk items.

Different guidelines have been developed for the specification of inspection interval according to risk. In many
cases (e.g. Refs. [23, 24]) the interval is not specified according to risk alone but also takes into account the inspection grading. The interval is then defined according to the combination of risk ranking and inspection grade. Typically, rules might be as shown in Table B-1. (Note that these rules are not generic and may vary for different applications, risk ranking definitions etc.)

Table B-1 Inspection intervals (months) according to Criticality and Grade

<table>
<thead>
<tr>
<th>Criticality</th>
<th>Inspection Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
</tr>
</tbody>
</table>

In the table Criticality defines the risk ranking with Criticality = 1 being the highest and Criticality = 5 being the lowest risk rankings respectively. In the above rules, it would be specified that Criticality 1 items cannot be assigned a grade higher than 1 and Criticality 2 items cannot be assigned a grade higher than 2.

Items having high risk and low inspection grade (top left) have short inspection intervals while low risk, high grade (bottom right) items have longer intervals. Taking into consideration the combination of risk and grade in this way may be regarded as doubly accounting for risk. This is true only to the extent that the grade is a measure of the probability of failure. However, grade does not consider the consequence of failure in any way. In addition, risk may not, in general, consider the history of previous inspection intervals. Hence taking a combination of risk and grade into account does allow for a more complete basis for the specification of inspection interval and results in greater differentiation in the requirements for different vessels. In a sense using the combination refines the scale of interval that can be specified compared to the case when only one or the other is considered.

It is important to recognise that the type of inspection has to be considered in determining risk. An inspection having high effectiveness will lead to a reduction in risk and vice versa.

In most cases inspection intervals will already have been specified assuming that IVI will be carried out. Once it has been determined that NII is possible and applicable at a given inspection, the interval following the NII can then be adjusted taking into consideration the inspection effectiveness.

The flow charts set up for use as guidance in selecting an appropriate NII method assign efficiency rankings to each method according to the application. The ranking is defined such that, for areas covered by the inspection:

- **High**: the NII method has a markedly higher POD than IVI
- **Medium**: the NII method has broadly similar POD to IVI
- **Low**: the NII method has a markedly lower POD than IVI.

In keeping with the goal of maintaining a constant long term probability of failure, the decision process uses the effectiveness of the previous inspection as an input to determining the minimum efficiency required of the current inspection. Credit can be taken for a high effectiveness inspection by allowing a low effectiveness for the following inspection (assuming of course that other factors considered allow it). Alternatively, an inspection having a low effectiveness may need to be followed by one having a high effectiveness in order to maintain the desired probability of failure.

Given that at this stage of the project the timing of the inspection is taken as given, all that can be specified is the method efficiency requirement. It is clear, however, that control of the probability of failure could be more effective by allowing for changes in interval according to the method used. This would make for greater flexibility in developing and adapting an NII strategy to meet plant specific requirements. For example, it could allow the user to specify more frequent lower efficiency (and perhaps lower cost) NII while still maintaining a comparable probability of failure to what would be achieved with IVI at longer intervals.

### B.3 Bayes’ Theorem

Bayes’ theorem provides a logical way of updating incomplete knowledge (e.g. 75% confident no degradation present) based on a test or observation which itself may not be 100% reliable (e.g. inspection method detects degradation 90% of the time).

Bayes’ theorem states that given that event B has occurred, the probability that it was due to cause A_i is equal to the probability that A_i should produce that event times the probability that A_j should occur in the first place, all divided by a scaling factor which is the sum of such terms over all causes.

For example, if it is assumed that before inspection of a particular plant item, there is a 75% confidence that
there was no degradation present. If the item is now inspected, using a method with a 90% probability of detecting degradation, with no false calls, and no degradation is reported, Bayes’ theorem can be used to determine the revised probability that there is in fact no degradation.

In this case the event “B” is that no degradation is reported, and the “cause” \( A_j \) is no degradation present. However another possible cause is that degradation is present (but missed).

The notation \( p(A \mid B) \) means “the probability of A, given B”

According to Bayes’ theorem:

\[
\text{(probability no degradation present | none reported) =}
\frac{(\text{prob. none reported | none present}) \times (\text{prob. none present})}{(\text{prob. none reported | none present} \times \text{prob. none present}) + (\text{prob. none reported | present} \times \text{prob. present})} = 1 \times 0.75
\]

\[
= 0.968
\]

i.e. the confidence that no degradation is present has therefore increased from 75% to around 97%.

Bayes’ theorem can also be used to support decisions based on expert judgement even where precise quantitative data on inspection effectiveness or likelihood of degradation does not exist. For example expert judgement could be used to assign a category to inspection effectiveness such as “very high”, “medium high”, “medium” etc. where each category is taken to represent a band such as “better than 90%”, “between 75% and 90%” etc. A similar approach could be adopted to describe initial likelihood of degradation (or degradation rate). The average within each band (e.g. 95% for very high) could then be used to apply Bayes’s theorem. Depending on the band within which the “answer” lay, the revised likelihood of degradation (or degradation rate) could then be interpreted in the original linguistic terms (very high, high etc.)

Note that care should be taken when using probability of detection (POD) data in Bayes’ theorem in cases where a number of discrete flaws (e.g. cracks) may be present. A method with a POD of 90% will have a 90% probability of detecting each individual flaw, but a much lower probability of detecting all of the flaws.

### B.4 Extreme Value Statistical Analysis

There is a common requirement to monitor the condition of plant for reasons of safety or in order to plan the repair or replacement of plant components during their working life. For example a chemical plant may have several vessels that require examination to assess the severity of internal corrosion present. This could be done by carrying out a detailed inspection of the inside of a vessel, and mapping the areas of corrosion. This would inevitably mean that the plant would need to be shut down in order to carry out such an inspection. An alternative would be to carry out an ultrasonic thickness survey of the entire vessel from the outside surface. The advantage of using such a method would be that the plant may not need to be opened or even shut down in order to carry out the inspection. However, the vessel may be large, requiring a long time to carry out the ultrasonic survey. Another way to assess the corrosion present would be to carry out a survey on a representative area of the vessel and use statistical techniques to predict the condition of the entire vessel from the results of the representative area. The advantages of using this technique would be a saving in time and therefore cost of inspection.

The corrosion process can be complicated, with several corrosion mechanisms taking place simultaneously. To fully understand the mechanisms taking place can require extensive testing and analysis in the laboratory. However, corrosion can be classified into two broad categories: uniform and non-uniform (or localised) corrosion. Illustrations of these two categories are shown in Figure B-4.
When a statistical sample is taken a distribution of results is produced from which certain things can be measured, such as the mean and the variance (or Standard Deviation) of the distribution. If we applied this method of sampling to our vessel corrosion problem we could gain valuable information about the severity of corrosion within the vessel and we would also have quantitative information with which to compare previous and future inspections. This type of analysis is useful where the corrosion within the vessel is known to be uniform. In which case we would be more interested in the average or mean depth of corrosion.

If we carried out an ultrasonic thickness survey on a vessel with uniform corrosion we would expect to find a Gaussian or Normal type of distribution from our measurement data. The Gaussian or Normal type of distribution is illustrated in Figure B-5. Our measurements would show a spread of results symmetrically about the mean value.

We could use statistical techniques to measure the mean value and calculate the standard deviation or variance of the distribution. This would provide us with a measure of the spread of values in our distribution.

In the case of non-uniform corrosion we would be more likely to be interested in the deepest extent of the corrosion present, as a single through wall pit will cause the component to leak. If we used the statistical tools we used on the uniform corrosion we may underestimate the seriousness of the deepest corrosion present on the component. A different technique needs to be used in this case; one where we concentrate our measurement and statistical techniques on the most extreme depths of corrosion.

Some corrosion processes occur which are non-uniform where local areas can be subject to extreme degradation (e.g. pitting). With a non-uniform corrosion process we would be much more interested in the most extreme values from our ultrasonic survey, as relying on average or mean values may lead us to be too optimistic in our assessment of plant condition. The branch of statistics which deals with the analysis of these extreme values is “Extreme Value Statistical Analysis” (Ref. 25).

This statistical analysis will be described by way of an example, where we are required to assess the deepest extent of corrosion on the inside surface of a large pressure vessel using ultrasonic thickness measurements. We know that the corrosion occurring in the inside of the vessel is consistent over the entire inner surface but the corrosion is non-uniform in that we know that severe corrosion pitting is occurring. Therefore we can use our extreme value techniques to predict the deepest corrosion likely to be present on the vessel.

B.4.1 Obtaining the Data
When carrying out a survey for Extreme Value Statistical Analysis we place more statistical relevance to the extreme maximum (or extreme minimum) values measured. In terms of a normal statistical distribution we are
in effect analysing the tail of the normal distribution and using statistical techniques to derive probability functions which we can use to gain quantitative information about the most extreme corrosion occurring in the component.

Let us examine the case where we need to carry out a survey of the non-uniform corrosion pitting (or other severe corrosion processes) within a large pressure vessel. We know that the corrosion is non-uniform as there is severe corrosion present generally over the entire inner surface of the vessel. One way of obtaining a statistical sample for extreme value statistical analysis would be as follows:

— choose a representative area of the vessel, say a convenient area of 1 m × 2.1 m. (Note: the area should be “representative” of the condition of the whole vessel or of the part of the vessel being considered)
— split the examination area into sub-areas, say 100 mm × 100 mm squares
— carry out a detailed ultrasonic examination of each sub-area and record only the most extreme value for pitting depth measured in each sub-area.

We now have a sample which we can analyse using extreme value techniques. There are 210 values which we can display in the form of a histogram, see Figure B-6. The x axis measures increasing depth of pitting and the y axis records quantity i.e. number of readings of this depth of corrosion.

![Figure B-6](image)

**Histogram of Results of Ultrasonic Thickness Survey (maximum pit depths)**

### B.4.2 Processing the Data

The histogram showing our results is called a “frequency distribution”. Because it has been produced from a process which concentrates on extreme values however, it does not display the normal or Gaussian symmetrical pattern. The extreme values recorded, tend to trail off at the right hand side of the distribution. In order to process our data we need to find a function which will model our distribution. A distribution function called a “double exponential” or “Gumbel” distribution is commonly used to model such a “maximum” distribution.

The Gumbel distribution function takes the form:

\[
F(x) = \exp \left[ - \exp \left( \frac{x - \lambda}{\alpha} \right) \right] ; - \infty < x < \infty \quad (10)
\]

- \(x\) : Random Variable (corrosion depth)
- \(\lambda\) : Location Parameter (= statistical mode)
- \(\alpha\) : Scale Parameter (related to variance)

Our first step in processing our data must be to check if the data we have recorded will be able to be modelled by a Gumbel distribution function. Processing of the data using PC spreadsheet techniques can make this straightforward, even for large amounts of data.
We should create a table which contains our results as illustrated in Table B-2.

Table B-2 Example data for Extreme Value Statistical Analysis

<table>
<thead>
<tr>
<th>Local Maxima of Pitting/Corrosion (mm)</th>
<th>Frequency A (number)</th>
<th>Probability Density Function ( f = A/(N + 1) )*</th>
<th>Cumulative Distribution Function ( F = \sum f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>19</td>
<td>0.090</td>
<td>0.090</td>
</tr>
<tr>
<td>0.4</td>
<td>40</td>
<td>0.190</td>
<td>0.280</td>
</tr>
<tr>
<td>0.6</td>
<td>43</td>
<td>0.203</td>
<td>0.483</td>
</tr>
<tr>
<td>0.8</td>
<td>43</td>
<td>0.203</td>
<td>0.686</td>
</tr>
<tr>
<td>1.0</td>
<td>31</td>
<td>0.138</td>
<td>0.834</td>
</tr>
<tr>
<td>1.2</td>
<td>15</td>
<td>0.071</td>
<td>0.905</td>
</tr>
<tr>
<td>1.4</td>
<td>12</td>
<td>0.057</td>
<td>0.962</td>
</tr>
<tr>
<td>1.6</td>
<td>4</td>
<td>0.019</td>
<td>0.981</td>
</tr>
<tr>
<td>1.8</td>
<td>2</td>
<td>0.010</td>
<td>0.991</td>
</tr>
<tr>
<td>2.0</td>
<td>1</td>
<td>0.004</td>
<td>0.995</td>
</tr>
<tr>
<td>Total (N)</td>
<td>210</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Using the “Average Rank Method”. See referenced text.

Table B-2 includes two columns containing useful information on our distribution which we will present graphically: The “Probability Density Function” (see Figure B-7) and the “Cumulative Distribution Function” (see Figure B-8). These functions are derived from our recorded data.

![Probability Density Function](image)

**Figure B-7**
Probability Density Function
In order to check that our Gumbel model is a valid description of the distribution it is necessary for us to plot the function:

\[ Y = -\ln[-\ln(F_1(x))] \]

(11)

This has been done for our results presented in Table B-2 and is shown in Figure B-9.

Figure B-9 clearly shows a good linear relationship for the plotted function Y. This linearity indicates that the assumption of a Gumbel function being a good statistical model is valid for our data. The parameters \( \lambda \) and \( \alpha \) from equation (10) can be determined from the graph. \( \lambda \) is the slope of the graph and \( \alpha \) corresponds to the intercept at \( y = 0 \). Knowing parameters \( \lambda \) and \( \alpha \) allows us to construct our model of the distribution using the Gumbel function, see equation (10).
Figure B-10
Comparison of CDF with Gumbel Function

Figure B-10 shows a comparison of our Gumbel function with $F(x)$. If our model matches closely our data plot then we can be reasonably confident in our statistical model and the probabilities we draw from it. In this case, the graph shows a reasonably good match, and the results of our statistical analysis can be used to predict the probability of there being a particular maximum depth of corrosion present in the vessel (or area of the vessel which the sample represents).

If we use the cumulative probability graph (Table B-8) this graph illustrates the probabilities of finding corrosion of a particular maximum depth. For example there is a 99.5% probability that the deepest corrosion present is 2 mm deep. Or conversely, there is a 0.5% probability of there being corrosion greater than 2 mm.

The use of this technique can be a very useful tool in the assessment of non-uniform corrosion, especially when quantitative information is needed quickly and efficiently. Extreme value statistical techniques can be used for a wide range of applications and there is good reference material available which describes the theory behind the technique and provides many examples of its application.

B.4.3 Effect of Paint

Care should be taken when applying extreme value statistical analysis to ultrasonic thickness data measured through painted surfaces. Even if the paint is well adhered, there are likely to be slight changes in paint thickness. Since the velocity of ultrasound in paint is typically 40% of the velocity through steel, a variation in paint thickness of 0.4 mm within the sample may be misinterpreted as a variation of 1 mm in steel thickness if a correction is not applied. If extreme value statistical analysis is then applied to this uncorrected data, the maximum variation in component wall thickness in the un-inspected part of the zone could then be predicted as being significantly greater than 1 mm, even if there was no corrosion or erosion and the thickness of the steel component was perfectly uniform.

Various commercially available instruments are available for measuring the thickness of paint coatings including the “banana gauge” which works on a simple magnetic principle.

B.5 Effects of Sample Size

It is important to understand whether inspection will be able to find at least one instance of any flaw present. Clearly this will depend on the population of such flaws, the effectiveness of the inspection method and the sample size. For localised cracking, spot checks are inappropriate and while sample inspections may help to determine whether a certain type of cracking mechanism is active (Ref. 26), they are unlikely to provide useful information on how many cracks are present in the zone or what their sizes are.

If a vessel zone is genuinely homogeneous, then statistical methods may be useful in determining sample size, and in extrapolating the inspection results from the sample to the whole of that zone. The confidence in the validity of sample inspections depends on the size of the sample compared to the size of the zone. The larger the sample size, the higher the confidence in the extrapolated results.

The validity of spot or sample inspections also depends on the degradation mechanism and the population of flaws present. For a zone susceptible only to uniform corrosion, a few spot checks of wall thickness may provide highly reliable information on the extent of degradation in the whole of that zone. Repeat measurements at the same locations during future inspections can then be used to assess corrosion rates.

If spot or sample checks reveal unexpected degradation, or more severe degradation than anticipated, then increased coverage (possibly up to 100%) is likely to be required.
B.5.1 Analysis Methods

Assume a weld has a uniform random distribution of flaws within its length. This random distribution can be represented as a percentage of flawive weld structure. If a flaw will be detected when the region it is in is inspected (assumes 100% detection capability), the problem is to determine the probability of detecting at least 1 flaw when only inspecting a percentage of the weld volume (and therefore e.g. being alerted to the fact that a particular degradation mechanism is active)

POI: Probability of Inclusion of a Flaw
Cov: Percentage Coverage of the Weld Volume.
Dd: Flaw Distribution as a Percentage.

To assist in calculating the POI, it is assumed that the weld volume is divided into 100 discrete units. The probability that a given unit contains a flaw is: \( P_d = \frac{D_d}{100\%} \). Probability that a unit contains no flaw: \( P_0 = 1 - P_d \)

POI = 1 - PON where PON is the Probability of Detecting No Flaws

Using the above definitions and assumptions a number of models could be used to determine the POI:

B.5.1.1 Simple Evaluation:

Using the following data evaluation, a formula can be determined and extrapolated to 100% coverage.

<table>
<thead>
<tr>
<th>Cov %</th>
<th>PON</th>
<th>PON</th>
<th>PON</th>
<th>PON</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.99</td>
<td>0.98</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>2</td>
<td>0.99</td>
<td>0.98</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>3</td>
<td>0.99</td>
<td>0.98</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>4</td>
<td>0.99</td>
<td>0.98</td>
<td>0.97</td>
<td>0.96</td>
</tr>
</tbody>
</table>

General Formula

\[
PON = \frac{(100 - P_d)^n}{(100 - P_d - Cov)^r} \cdot \frac{100!}{(100 - Cov)!}
\]

B.5.1.2 Binomial Distribution:

\[
POI = 1 - PON = 1 - \left( \frac{n!}{(n-r)!r!} \right) \cdot P_0^{n-r} \cdot P_d^r
\]

where:
\( n = \text{Cov} \)
\( r = \text{flaws to detect} \)

By altering n from 0 to 100% coverage the POI rises from 0 to 1 in a curve.

B.5.1.3 Poisson Distribution:

\[
POI = 1 - PON = 1 - \left( \frac{e^{-\mu} \cdot \mu^r}{r!} \right)
\]

where
\( \mu = nP_d \)
\[ n = Cov \]
\[ r = 0 \text{ flaws to detect} \]

Graphs for all three analysis methods are presented. Generally all three graphs exhibit similar trends. The binomial and Poisson relationship do not provide reliable results for high coverage of welds with a low flaw distribution, since the graphs do not predict a probability of 1 at 100% coverage of the weld with 4% uniform flaw distribution.

A more rigorous treatment, which also addresses the probability of detection (POD) of the inspection method, is provided in the reference below.

**Figure B-11**
Probability of Detecting 1 Flaw Given a Percentage coverage of a Flawive Weld. Simple Distribution

**Figure B-12**
Probability of Detecting 1 Flaw Given a Percentage coverage of a Flawive Weld. Using Binomial Distribution Model
Figure B-13
Probability of Detecting 1 Flaw Given a Percentage coverage of a Flawive Weld.
Using Poisson Distribution Model