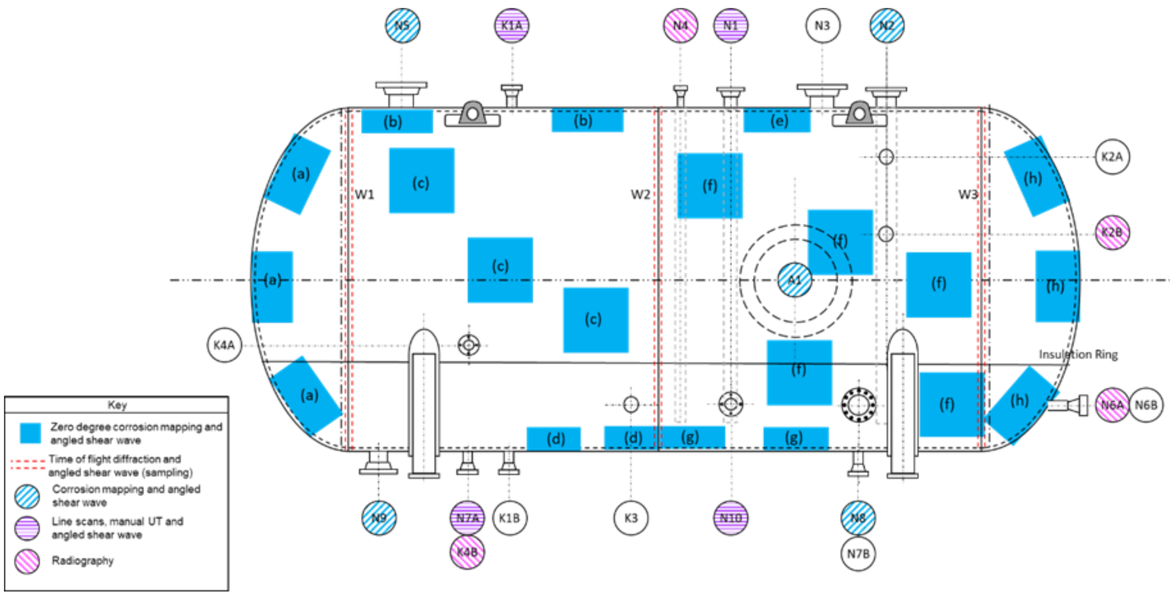

HOIS/OGTC guidance notes for HOIS-RP-103

HOIS-G-103

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Executive Summary

Non-intrusive inspection (NII) is increasingly of interest to operators of pressure equipment as a means of achieving the aims of comprehensive inspection that has traditionally been addressed by internal visual inspection (IVI). NII offers a number of potential benefits compared to IVI. Achieving these benefits without compromising integrity of vessels is reliant on a sound approach to NII. This is particularly important given that pressure vessels are typically high hazard items, failure of which can have severe consequences. The NII Recommended Practice (RP) developed in the HOIS Joint Industry Project and published as HOIS-RP-103 [1], formerly known as DNVGL-RP-G103, is intended to assist industry by providing a structured process for NII. This aims to promote good practice at each stage of the process so that operators can clearly identify where NII is appropriate and then apply it in a manner that does not compromise integrity and delivers the economic benefits.

The process outlined in the RP is comprehensive in both depth and extent. As such, effective application of the process relies on the user becoming familiar with the key elements of the document. These guidance notes, developed within the HOIS Joint Industry Project with additional support from The Oil & Gas Technology Centre, based in Aberdeen, are intended to facilitate this process. The document is aimed at integrity, corrosion and inspection practitioners who will be involved in the assessment, planning, implementation and evaluation phases of NII projects. As such it is expected to be used by pressure equipment owner/operators, integrity service providers and inspection service providers. While the focus is on detailed technical elements, the document also provides an overview intended for owner/operators who include, or are planning to include, NII as part of their integrity management systems.

The guidance notes highlight the key parts of the NII process in Sections 2 to 13. Worked examples of practical application of [1] are given in Appendices 1 to 12. A range of frequently asked questions are addressed in Appendix 13.

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Appendices

1. Introduction

Non-intrusive inspection (NII) is increasingly of interest to operators of pressure equipment as a means of achieving the aims of comprehensive inspection that has traditionally been addressed by internal visual inspection (IVI). NII offers a number of potential benefits over IVI, these being mainly as follows:

- A reduction in the impact of pressure vessel inspection requirements on plant availability, this means production uptime can be increased.
- Avoiding the hazards associated with confined space entry.
- A reduction in the overall cost of performing the inspection.
- Quantitative information on the condition of equipment that can feed into more effective and efficient integrity management.

Achieving these benefits without compromising the integrity of vessels is reliant on a sound approach to NII. This is particularly important given that pressure vessels are typically high hazard items, failure of which can have severe consequences. The NII Recommended Practice (RP) developed in the HOIS Joint Industry Project and published as HOIS-RP-103 [1], formerly known as DNVGL-RP-G103, is intended to assist industry by providing a structured process for NII. This aims to promote good practice at each stage of the process so that operators can clearly identify where NII is appropriate and then apply it in a manner that does not compromise integrity and delivers the economic benefits.

The process outlined in the RP is comprehensive in both depth and extent. As such, effective application of the process relies on the user becoming familiar with the key elements of the RP. These guidance notes are intended to facilitate this process. This document highlights the key parts of the process in Sections 2 to 13. Worked examples of practical application of [1] are given in Appendices 1 to 12. A range of frequently asked questions are addressed in Appendix 13.

2. Principles of the NII Process

2.1 Background

The RP addresses specifically cases where the intent is that the NII acts as a comprehensive inspection which replaces a planned IVI or is used as deferment of IVI.

The RP is not intended for situations where the intent is to use externally applied non-destructive inspection methods on an ad-hoc basis rather than as a comprehensive inspection. One aim of the RP is to avoid the use of unstructured and poorly planned NDT approaches, in which integrity may be compromised, being used as a replacement for IVI.

The RP provides guidance on the primary phases of the NII process as follows:

- Integrity review: covering identification, preparation and review of supporting information
- Assessment
- Work scope development
- Inspection
- Evaluation and analysis
- Feedback to the integrity management system (IMS)

It is not intended that any of these can be performed in isolation, i.e. the process should be followed in full in order to demonstrate compliance with the RP. For example, an inspection that is carried out using externally applied non-destructive inspection techniques but for which there is no assessment and work scope development in accordance with the RP or where there is no evaluation cannot be taken as NII in accordance with the RP.

This will require contributions from several discipline groups in order to effectively manage the process including:

- Process
- Corrosion
- Integrity
- Inspection
- Data science.

2.2 Role of NII in Integrity Management System

NII in accordance with the RP is intended to provide information on the condition of pressure vessels to a level that is appropriate to the requirements of the IMS. The RP provides for a structured process, consistent with and recognising the critical role of inspection in supporting integrity of pressure vessels where the consequences of failure may be severe. Effective implementation of NII is therefore largely dependent on the presence of a structured IMS which has been updated to ensure integration and adoption of NII. Further information is provided in Sections 12 and 13 of this document.

It is worth noting that, while NII delivers information on vessel condition to the IMS, this is a two way process and preparation for and implementation of NII is very dependent on information that should be available in the IMS. This includes, for example, information covering the corrosion risk assessments, risk based assessments, the RBI system, equipment design, process descriptions, process histories and inspection history. The extent to which this information is available (including ease of access), the reliability of the information and the level of detail all affect the ability to make cases for NII and how straightforward making these cases is. In general, NII can be readily integrated and more widely implemented where a sound IMS is in place and appropriately managed.

While the RP addresses NII specifically and is intended to facilitate a structured approach to NII, the value of IVI in the integrity management process continues to be recognised and should be acknowledged in the IMS. As such the IMS should highlight that opportunities for IVI should still be taken when they arise, e.g. when entry is planned for other reasons, even where NII has been assessed as appropriate.

2.3 Principles

The aim of the approach in the RP is to ensure that NII is only carried out when it delivers information which supports the same or an improved level of assurance of integrity compared to IVI. As such there should be no increase in relative risk when NII is carried out in place of IVI.

This aim is met in the RP not by replicating in detail the capability of IVI (with respect to POD, coverage and locations) but by addressing the impact on risk for the vessel.

As explained in Section 2.1 the RP covers the complete process. The approach recognises that completion of the inspection itself does not constitute completion of an NII project and that the information generated following evaluation and analysis is a key output. NII carried out in accordance with the RP provides information for use within an integrity management system (IMS). It is not a replacement for risk-based inspection or assessment (RBI/ RBA) or for the IMS.

2.4 Differences between NII Methods and Visual Inspection

There are substantive differences in capability between techniques used for NII and visual inspection. The most important difference is that visual inspection is typically capable of identifying a range of flaw types without being reliant on up front knowledge of what to look for. Whereas, an NII is usually specific to the flaw type (degradation mechanism and morphology).

Coverage with techniques used in NII is also sometimes restricted, e.g. due to access or economic drivers, compared to what would be achieved with IVI.

The above points mean that successful NII is dependent on a greater understanding, at the planning stage, on the types and potential locations of degradation. This is a fundamental consideration in the RP that is addressed at key points in the process.

When comparing the effectiveness of NII against IVI, the limitations of IVI must also be taken into account. For example, it is difficult to assess the effectiveness of visual only inspections, as these rely greatly on the inspector's level of detail in reporting, accuracy with descriptions and measurements, or the quality and resolution of any photographs/ videos. It has been found that NII inspections can produced more quantitative, accurate, and reliable results than IVI (in terms of the sizing of the wall loss due to corrosion) where IVI is not supplemented by NDT [2]. An IVI may also suffer from limitation due to access (e.g. the presence of fixed internal furniture).

3. Roadmap for Implementation

A breakdown of the main steps typically involved in performing an NII project in accordance with the RP is shown in Figure 3-1. The roadmap assumes initial screening of vessels has taken place which aims to remove items that are clearly not suitable for NII (see Section 5.2).

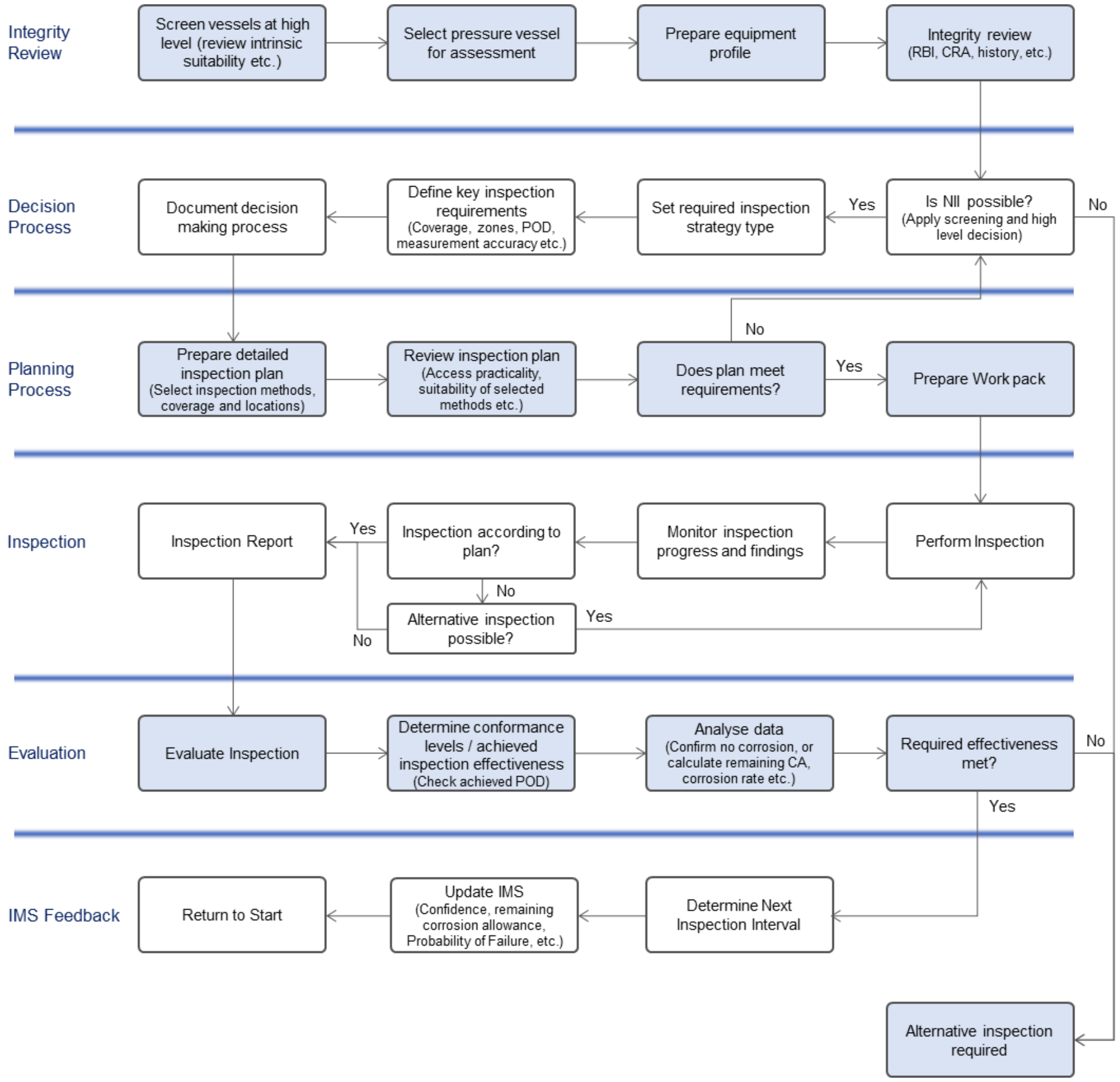

Figure 3-1 Roadmap for NII in accordance with the RP

4. Information Requirements

The RP defines in detail (Section 2 [1]) what information is required in order to complete NII projects. This aims to ensure that there is sufficient information available in each of the following areas to allow effective implementation of the process such that:

- Degradation threats are sufficiently understood (types, morphology, locations and spatial characteristics).
- It is possible to establish the levels of degradation tolerable.
- It is possible to determine the ability to perform inspection with candidate techniques and there is a sufficient understanding of the capabilities and limitations of these techniques under the circumstances specific to each equipment item.

In practice it will often be the case that not all of the information listed in Section 2 [1] will be available and/or there are limitations with respect to the extent and reliability of available information. In general, the limitations arising from insufficient input information will become evident at each stage of the process, as will actions to be taken to address these in order to allow progress to be made. When IVIs are undertaken, one of the aims should be to collect the information needed to support NII at a later stage (e.g. sketches of degradation location recorded, photo records of inspection, 3D scan etc.).

Note that the information that is necessary to support NII is largely the same as would be expected within typical modern integrity management processes. Where significant information relating to equipment integrity is not available, e.g. accurate GA drawings, a clear definition of the operating environment etc., this would normally point to shortcomings in the integrity process that need to be addressed before NII can be considered.

The one area where additional information is most likely to be needed is the corrosion risk assessment. This is because of the added emphasis in NII on understanding the degradation threats, their likely locations and spatial characteristics.

5. Assessment for NII

5.1 Introduction

The aim of the assessment is to determine, for each candidate vessel whether NII is appropriate in principle. This is based on consideration of whether NII would be able to provide the same or better impact on risk compared to an IVI. The assessment consists of two main stages:

- Screening.
- Detailed assessment.

5.2 Screening

The screening phase is used to identify candidate vessels for consideration for NII in Section 3.2 of [1]. Although not explicitly covered in the RP, in most cases the first part of the screening process will consider the potential economic benefits of NII. The detailed planning phase of NII requires time and resource, or external costs if employing a third party, hence it is useful to undertake a high-level screening of vessels. Vessels for which there is no economic or risk benefit to doing NII can be removed from the candidate list. The approach should consider intrinsic suitability for NII and whether there are other factors that would drive vessel entry. Typical items for consideration are listed below:

- Economic benefits. The overall economic benefit should be considered. For example, a vessel that can be inspected outside of shutdown without the need for PPE may be of less benefit to one where shutdown and cleaning is required.
- Safety benefits of avoiding confined space entry. While the improvements to safety of inspectors is a consideration, it cannot be taken a primary driver for NII. Careful consideration should be given to the Major Accident Risk associated with equipment failure.
- Intrinsic suitability. The main consideration here is blockers to performing NII that can provide a suitable level of information on the internal condition of the pressure boundary. This typically includes factors such as:
    - Access for inspection, e.g. heating coils or double walls preventing access.
    - Surface coatings that limit inspection capability, e.g. certain types of passive fire protection or situations where insulation cannot be removed for inspection in-service.
    - Operating temperature. The performance of techniques commonly used for NII can be affected at high temperatures to the extent that data quality is severely compromised. There are also physical and safety limits on temperatures at which inspection is possible.
    - Type of equipment item, e.g. plate or spiral type heat exchangers are not suitable.
    - Internal linings – this does not prevent NII, but close to 100% coverage is required and currently it is not possible to inspect for the condition of the lining. Instead, inspection will only show where corrosion has initiated following lining failure. This must be taken into account when considered NII over IVI for lined vessels.
    - NII to support partial IVI (or vice versa) should also be considered, e.g. where only camera access is possible, or there is a requirement to view the internal furniture or check for debris.
- Are there other factors which make vessel entry essential? Examples include a need to remove solids (such as sand), to carry out maintenance and/or repairs of process furniture and to gain access for tube inspection on the channel side of a shell and tube heat exchanger. These factors would not inherently preclude NII as a means of assessing the condition of the pressure boundary but may provide an opportunity for vessel entry for IVI such that NII would not be necessary.

Note that there is a growing trend towards designing pressure vessels specifically to facilitate NII. Such vessels would be considered intrinsically suitable. Design considerations would include, for example, accessibility to the vessel surface, geometry of nozzles, type of internal cladding and level of detail of commissioning inspection. Further details on design considerations for vessels are provided in Appendix 2 of [1].

Since the exact economic policies will vary between Operators, it may be useful to develop an internal process to assist with the screening phase such as in Figure 5-1.

It is worth considering undertaking NII assessments on similar vessels (e.g. A and B vessels, or different trains) at the same time to maximise efficiency and reduce costs. This allows histories of similar vessels to be reviewed at the same time and work scope designed accordingly. See definition of *similar vessels* in Section 5.3.

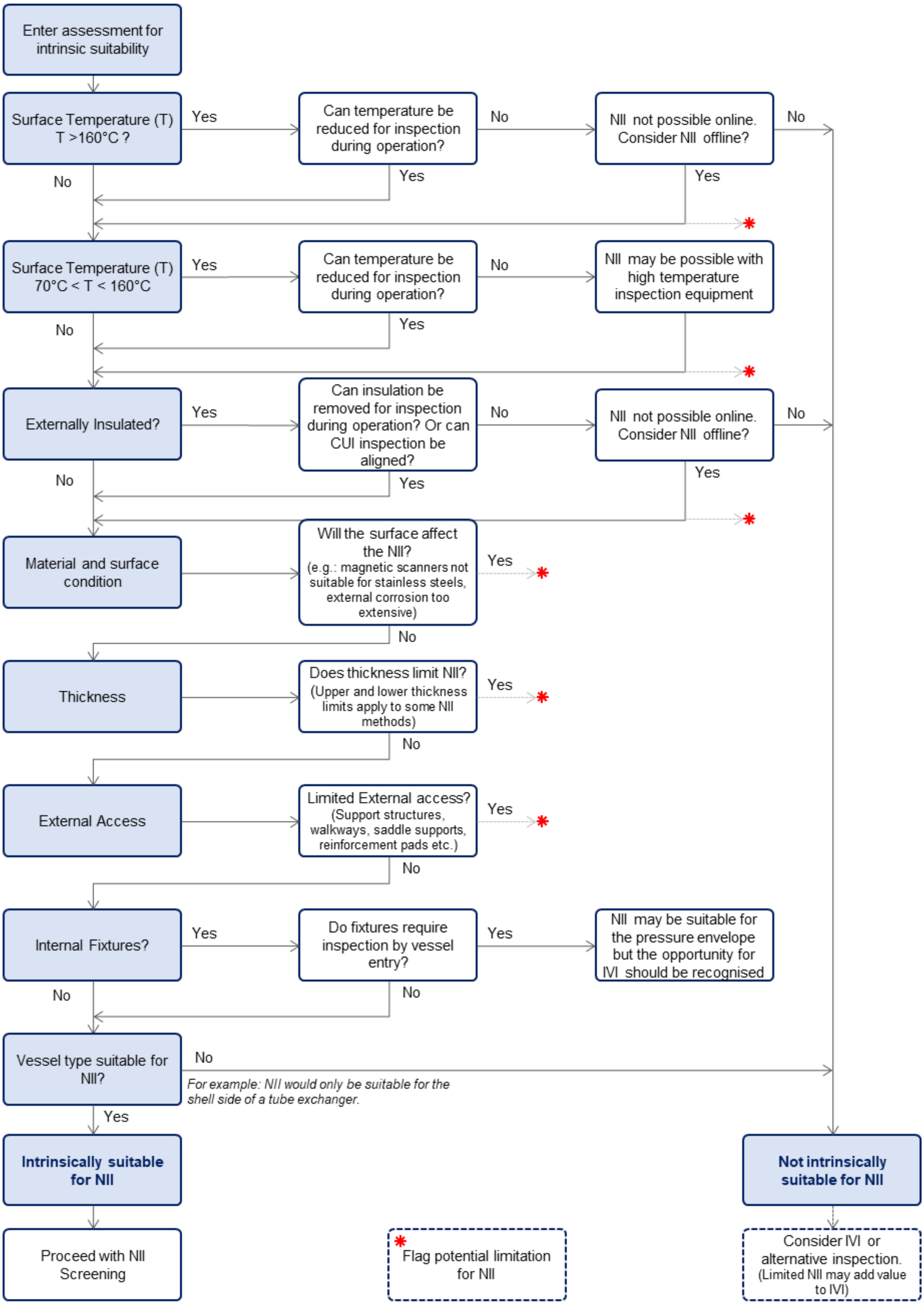

Figure 5-1 Example screening process

5.3 Detailed Assessment

The detailed assessment is based on a flowchart, given in Section 3.3 [1], which considers a categorical response (usually based on information from the IMS/RBI) for three main questions:

- **Confidence in ability to predict types and locations of degradation**

  This is an important measure of whether there is sufficient knowledge of the degradation conditions in order to appropriately develop an inspection plan, i.e. appropriate strategy, techniques, coverage and locations.

  The categorisation can be determined on either a theoretical or evidential basis (see Section 2.4.1 [1]). The theoretical basis considers the corrosion risk assessment within the IMS or RBA. The evidential basis considers primarily the number of previous inspections on the vessel under consideration or others that are considered similar and in similar service. The definition of similar to be used is as from Section 3.2 in [1], i.e.

  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.

  Note that when classing vessels as similar, justification must be provided.

  It is also necessary when using an evidential basis that a Corrosion Risk Assessment meeting at least the Type 1 requirements (see Section 2.4.1 [1]) is in place.

  It is also worth noting that when using the evidential basis, establishing the number of previous inspections is itself not sufficient, it is also a requirement that the results of the inspections have been reviewed and considered with respect to understanding the types of locations of degradation likely. This would normally be evidenced in the assessment by including a summary of the inspection history and reference to the history in summarising the Corrosion Risk Assessment.

- **Previous inspection effectiveness**

  This is used as a further measure of whether there is sufficient knowledge of the likely degradation conditions, specifically taking into account the extent to which the previous inspection would be able to provide relevant information. The categorisation is based on comparison of effectiveness to a conventional internal visual inspection

- **Severity and rate of degradation**

  This factor is included in the assessment to ensure NII is not used in situations where degradation that was not found during the NII could lead to potentially integrity threatening situations within the plant lifetime due to a high corrosion rate. It should consider the worst affected zone of the vessel; i.e. the highest corrosion rate that could be present in the vessel. Note that the three categories (low, medium, high) are not quantitative and are quite broad; as such it is not essential to have accurate estimates of current worst condition, degradation growth rates, and limiting conditions in order to appropriately assign the category. In most cases it is a fairly straightforward decision.

5.4 Documentation

The RP includes detailed specification on documentation of the assessment process. Clear documentation is important for audit purposes, for ready access of information to other elements of the integrity process and for future reference.

6. Strategy Selection

6.1 Background

Once a vessel has been identified as suitable for NII, the process moves on to developing the work scope for the inspection. This begins with defining appropriate strategies. The RP defines three Strategy Types as highlighted in Section 4.3 of [1]. The Strategy Types are linked to the nature of potential degradation and, as such, affect the objectives of the inspection as well as the nature of coverage and inspection performance in order to provide an appropriate degree of assurance. Consideration of different strategies recognises that there is no “one size fits all” NII plan suitable for all situations and different scenarios require a different approach in order to address the twin goals of effective and efficient inspection.

As a starting point it is important to understand how the objectives of the inspection, which align to the potential degradation state, relate to the strategy. This can be viewed in the simplest terms as follows:

Type A Objective: Validate absence of degradation.

Type B Objective: Obtain a sufficient sample to make estimates for the zone as a whole.

Type C Objective: Identify directly the worst degradation in the zone.

The above objectives are clearly linked to the nature of degradation as defined by the materials, operating environment, process conditions and history, spatial characteristics and lifecycle phase. A Type C strategy is, for example, applicable when there is a reasonable likelihood of integrity threatening damage in a zone, but the conditions are such the location of the most severe degradation is not readily predicted. A Type A Strategy is clearly not applicable to degradation of this nature.

Identification of the appropriate Strategy Type is key to successful NII, but it is not a complex task for most pressure vessels in typical oil and gas service. The current version of the RP has introduced some simplifications to the approach to Strategy selection and this is now largely a matter of understanding the three Types as defined in Table 4.1 of [1] and the simple flowchart in Figure 4.1 of [1].

Note that the starting point for Strategy selection is a good understanding of the degradation likely to be present. The information to support this should already be available at the time of the NII assessment, i.e. corrosion risk assessment and inspection history, but further, more detailed, review of the information may sometimes be necessary while performing the Strategy selection.

Some worked examples on specific case-study vessels, illustrating the approach to Strategy selection, are provided in Appendix 2, Appendix 3 and Appendix 4.

7. Definition of Inspection Requirements

7.1 Background

The inspection requirements follow from the aims of the inspection and the associated Strategy Type. The requirements address coverage and inspection performance, i.e. probability of detection and accuracy. In previous versions of the RP the requirements related to inspection effectiveness categories but (i) users found this approach potentially subjective and (ii) it did not provide a strong basis for evaluation/validation of performance actually achieved. Consequently, the update in the 2019 version includes detailed quantitative specification of inspection requirements. The requirements are set differently according to the Strategy Type assigned and a depend on a range of equipment item specific parameters.

7.2 Performance (Accuracy and POD)

The accuracy and POD requirements are determined as outlined in Section 4.6.2 of [1]. Note that these are set on a vessel by vessel basis. Determining the requirements relies on having established the applicable Strategy Type and Consequence of Failure (COF). Note that the COF used should be determined as High, Medium or Low in accordance with the definitions in Section 4.6.1 [1]. This is to ensure consistency of approach as the definitions in the RBI systems employed by different operators may be different.

The performance requirements determined for each zone should be clearly documented and accessible for use in the work scope development phase. This should include details on how the requirements were arrived at.

7.3 Coverage Requirements

The coverage requirements are determined as outlined in Section 4.6.3 [1]. These are set according to the Strategy Type and, for Type A and B cases, a number of vessel specific parameters including those given in Table 7-1:

Table 7-1 Parameters affecting coverage requirements for Type A and B Strategies

Parameter	Necessary for Type
Confidence in ability to predict types and locations of degradation	A, B
Degradation density	A, B
Consequence of failure	A, B
Zone area	A, B
Measurement accuracy	B
Tolerance to degradation	B
Spatial homogeneity	B

For Types A and B, the coverage is determined from a base coverage value that is modified by factors dependent on the above parameters. The way these factors should be determined is detailed in Section 4.6.3 of [1] and examples are provided in the worked examples given in Appendix 2, Appendix 3 and Appendix 4.

The RP also defines upper and lower limits to coverage for Types A and B.

Note that in the case of a Type B Strategy, the coverage value can be increased or decreased from that calculated per Section 4.6.3 [1] by performing a comprehensive assessment of the additional factors listed below. Any more thorough assessment must be fully documented with detailed consideration given to each of the listed factors.

- Accuracy of inspection methods
- Type of degradation expected
- Depth of degradation likely to be present
- Role of analysis in decision making
- External surface conditions
- Material condition, e.g. inclusions from fabrication, grain structure.
- Analysis methods.

For Type C the aim should always be to carry out as close as possible to 100% coverage of the zone under consideration. As such no consideration of parameters and associated modifying factors is needed when a Type C strategy applies.

The coverage requirements determined should be clearly documented for each zone and accessible for use in the work scope development phase. This should include details on how the requirements were arrived at.

7.4 Statistical Methods of Inspection Planning

Note that while Sections 4.6.2 and 4.6.3 of [1] are prescriptive in defining how the requirements are to be set, the RP allows the user to specify alternative requirements on the basis of more detailed statistical analysis and simulation. This is covered in Section 4.6.4 [1] which outlines the parameters for consideration and the requirements for justification of an alternative approach. Additional guidance on statistical methods for inspection planning is available in the HOIS RP for Statistical Analysis of Inspection Data [3].

7.5 Data Requirements

As outlined in [1], NII is fundamentally reliant on the data collected during the inspection phase. The inspection data serves a number of critical roles with respect to integrity and inspection quality assurance, these being:

- It is the basis by which the condition of the areas inspected is assessed.
- It allows an assessment of the inspection performance achieved in the field and whether this meets the requirements (e.g. probability of detection, see Appendix 4 of [1]).
- It allows an assessment of the coverage and locations as inspected versus the plan.

Consequently, the requirements for the type and quantity of data collected by the inspection are considered as important in the RP and specified in detail in Section 4.7.2 of [1]. These requirements should be viewed in conjunction with the performance and coverage requirements when specifying the inspection.

8. Work Scope Development

8.1 Background

The RP requires preparation of a work scope covering detailed instructions on how the inspection is to be completed on a vessel by vessel basis. The work scope should include details on the aims of the inspection, the inspection requirements, the techniques to be deployed, locations for inspection and reporting requirements. Details are covered in Section 4.8 of [1]. Specification of techniques is a key element to effective NII per the RP.

8.2 Technique Selection

A variety of factors play a role in technique selection but the most fundamental is that the techniques should be such that the performance and data requirements can be met for the type of degradation and vessel feature under consideration. The other factors such as speed and cost of deployment are secondary. It is useful to understand the link between technique selection and the preceding steps of Strategy Selection and Definition of Requirements. This is illustrated in Figure 8-1.

The 2019 version of the RP provides simple guidelines on techniques likely to meet the requirements. These recognise that the requirements likely to arise for typical vessels can usually be met by a limited number of already available inspection techniques. This is achieved in a practical manner by consideration primarily of the vessel feature and assigned inspection Strategy. These guidelines are provided in Table 4-18 of [1]. This table can be taken as a starting point for technique selection (see Figure 8-1) once the user has a defined strategy and set of performance requirements. It is expected that a competent NDT/ inspection company can provide more detailed advice on technique suitability.

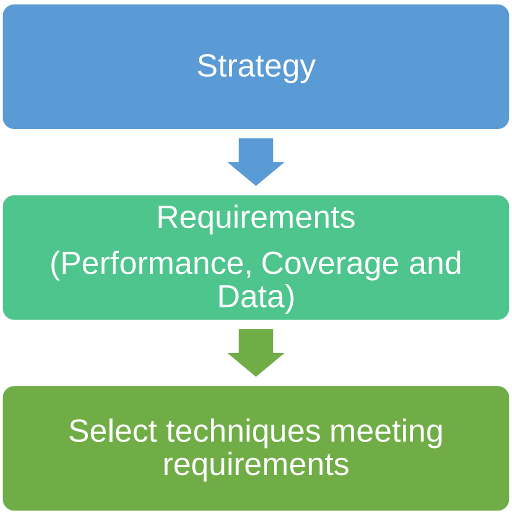

Figure 8-1 Technique selection to meet specified requirements

The table provides options according to feature type, e.g. plate, weld, flange and the applicable Strategy Type. A simple way to work through the techniques required is to start with the vessel drawing and identify, in accordance with vessel zones and applicable strategies, the features for inspection. This leads to options that are likely to meet the inspection and data requirements and which are also likely to be available in practice. The user can then make a selection among the options considering factors such as local availability, previous experience and likely economics.

The RP does not insist on the use of Table 4-18 as a basis for technique selection, e.g. a competent user can separately select techniques, provided these meet the performance requirements. Competent users may or may not be qualified in NDT (e.g. PCN) but should have detailed knowledge and experience of inspection technology and its application in different situations (i.e. on different materials and examining for different degradation mechanisms).

Note that Table 4-18 should be taken as assistance only in identifying candidate techniques for frequently encountered situations. Selection of techniques based on the table does not guarantee they will meet the specific performance requirements for each case under consideration. It remains the user's responsibility, or that of the NDT contractor, having identified a candidate technique, to validate that the selected technique meets the specific performance and data requirements. Additional information on techniques and performance is available in Appendix 1 of [1] and additional advice can also be found in the HSE report RR659 [4].

Inspection techniques and methods of deployment are constantly evolving. New techniques should be reviewed for suitability on a case-by-case basis.

8.3 Work Scope Preparation

A work scope or NII plan is to be completed for each vessel. This document is intended to act as instructions to the team who will perform the inspection on site. It is recommended that the instructions are provided both in written and diagrammatic form, the latter being particularly useful in indicating the locations for inspection. Attention to detail in preparing the work scope is essential and particular care should be taken to ensure the work scope addresses all items necessary and instructions and clear and unambiguous.

Details on the requirements for work scopes are provided in Section 4 of [1]. Many of these elements will be similar to the requirements for inspection work scopes for other applications; however, there are a number of items worth emphasising as specifically important for NII work scopes. These are listed below.

- Prior review of access and other site factors that may impede inspection. This supports the development of scopes which can be achieved in practice and limits non-conformances.
- Scopes structured so as to provide a reliable basis for progress tracking.
- Definition of inspection strategy type and aims of inspection.
- Summary of degradation known to be present or expected.
- Clear statements of coverage requirements.
- Anomaly reporting criteria, when to highlight findings to the integrity team.
- Clear guidance on actions to take to avoid non-conformances (e.g. acceptable alternative locations).
- Non-conformance reporting, when to highlight deviations to scope.
- Inspection team roles and responsibilities.
- Data management requirements.
- Requirements for reporting.

9. Inspection Activity

The inspection phase of an NII project can involve significant amounts of onsite work and is often the largest contributor to project cost. The way this phase is approached impacts on likely success of the NII project, i.e. providing the level of information appropriate for replacement of deferment of an IVI, and also the economics (as dictated by time on site and the cost of the inspection).

Detailed recommendations are provided in Section 5 of the RP [1]. In general, the recommendations cover items that should be addressed in planning for effective delivery of a large NDT based inspection activity. There are however some NII specific points worth emphasising here:

- The inspection will typically rely on advanced techniques that collect and store large amounts of digital data which acts as a record of the inspection achieved and the findings. As such the work will often be carried out by a specialist team who are not usually based at the facility where the vessels are located. This puts extra emphasis on communication between the inspection team, site personnel and those Inspection Engineers involved in planning the NII scope. This should focus on ensuring:
    - The inspection team are sufficiently familiar with site specific conditions and practices and
    - The site personnel are fully aware of any support requirements for the inspection.
- NII activity will often involve collection of a large number of scan files, using a range of different techniques, across a range of locations and feature types and with an associated high volume of digital data. Management of the scan files and data is critical to success of the inspection and in facilitating efficient evaluation of conformance and the data analysis post-inspection. Working processes and procedures will often need updating to accommodate the nature and volume of inspection in NII projects.
- A site survey to identify vessel specific features and any issues that may affect the extent to which the inspection requirements may be compromised is strongly recommended. This should be carried out after the assessment is completed and preferably after a draft work scope has been issued. This work scope then forms the basis for checking each work item in detail during the survey and highlighting if changes to the scope are necessary, e.g. because of access restrictions not identified in the GA drawings or poor surface condition locally. Subsequent non-conformances can be minimised through effective pre-inspection surveys. This has a substantial economic benefit through ensuring the NII is successful and the economic impact of any changes required is minimised. Note that this survey also allows identification of issues that are to be addressed by the site prior to the inspection, e.g. scaffolding or other access requirements and surface preparation.
- A detailed pre-mobilisation briefing between the project manager and the inspectors undertaking the work should be carried out covering:
    - The aims of the inspection for each vessel and the applicable Strategy Types
    - The type and nature of degradation of concern
    - The inspection requirements
    - Review of the inspection work scope
    - Roles and responsibilities of the inspection team
    - Points of contact for the integrity team
    - Key points of interaction with the site staff
    - Reporting requirements (including daily progress)
    - Project specific data management and analysis requirements

    - Requirements for feedback on conformance to the work scope and any degradation found
- The NII work scope will typically be developed around degradation threats and characteristics as are reasonably expected at the planning stage. If the inspection finds there are significant variations from what was expected at the planning stage, e.g. more severe or more isolated corrosion, then the NII work scope originally developed may no longer be appropriate and additional activity, addressing aspects in both inspection and integrity, would be required. These should be addressed as soon as possible with the aim of defining changes that will allow the objectives of the NII to be met. Immediate follow up also ensures any changes can be implemented efficiently, e.g. avoiding the need for a subsequent re-mobilisation. To facilitate this timely follow up, the work scope should include a clear definition of reporting criteria and flaw types, characteristics and size limits which should be highlighted immediately to the integrity team.
- While the aim should always be to avoid non-conformances against the scope by rigorous planning, including steps outlined above, in practice it’s unlikely they will be eliminated entirely. The sooner any non-conformances are identified and dealt with the better (in the sense of avoiding impact on success of the NII and minimising costs associated with any change). Consequently, the work scope should include clear instructions on the need to report back potential non-conformances as soon as possible and this should also be highlighted in the pre-mobilisation briefing. A process should be put in place whereby information on potential non-conformances is fed back to the integrity team as soon as possible.

10. Evaluation

The evaluation phase covers (i) a review of conformance of the inspection achieved vs the work scope and (ii) analysis of the results of the inspection. These activities are usually carried out by the integrity team supporting the NII project, but the way the data is collected, managed and reported by the inspection team plays an important role too.

The integrity team carrying out the evaluation phase should have an in-depth understanding of the RP, and of the inspection techniques used for NII. For the conformance review, they should be able to understand the effect of changes to the work scope (change in POD, change in inspection location etc.). For the analysis of the inspection results, they should be able to understand inspection results (in some cases to the level of signal processing) and be able to undertake statistical analysis. This would usually require some formal training in signal processing, NDT and statistics. Note that some of these capabilities fall outside the “traditional” remit of integrity engineers; hence additional training/development is often necessary. There is benefit to the evaluation team including both data science and inspection disciplines.

10.1 Conformance

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 the same or improved knowledge of equipment condition by comparison to IVI. Deviations from the work scope and requirements should be avoided as far as possible, but the RP recognises there will be cases where non-conformances do arise. A process for dealing with non-conformances is therefore provided in Section 6 of the RP. This is based on classification of non-conformances according to their severity, these classified according to four Conformance Levels. The approach is summarised in Figure 10-1. The outcome and follow up to the NII depends on the conformance Level established. It is therefore essential that a review be conducted, on a vessel by vessel basis, to establish the applicable Conformance Level.

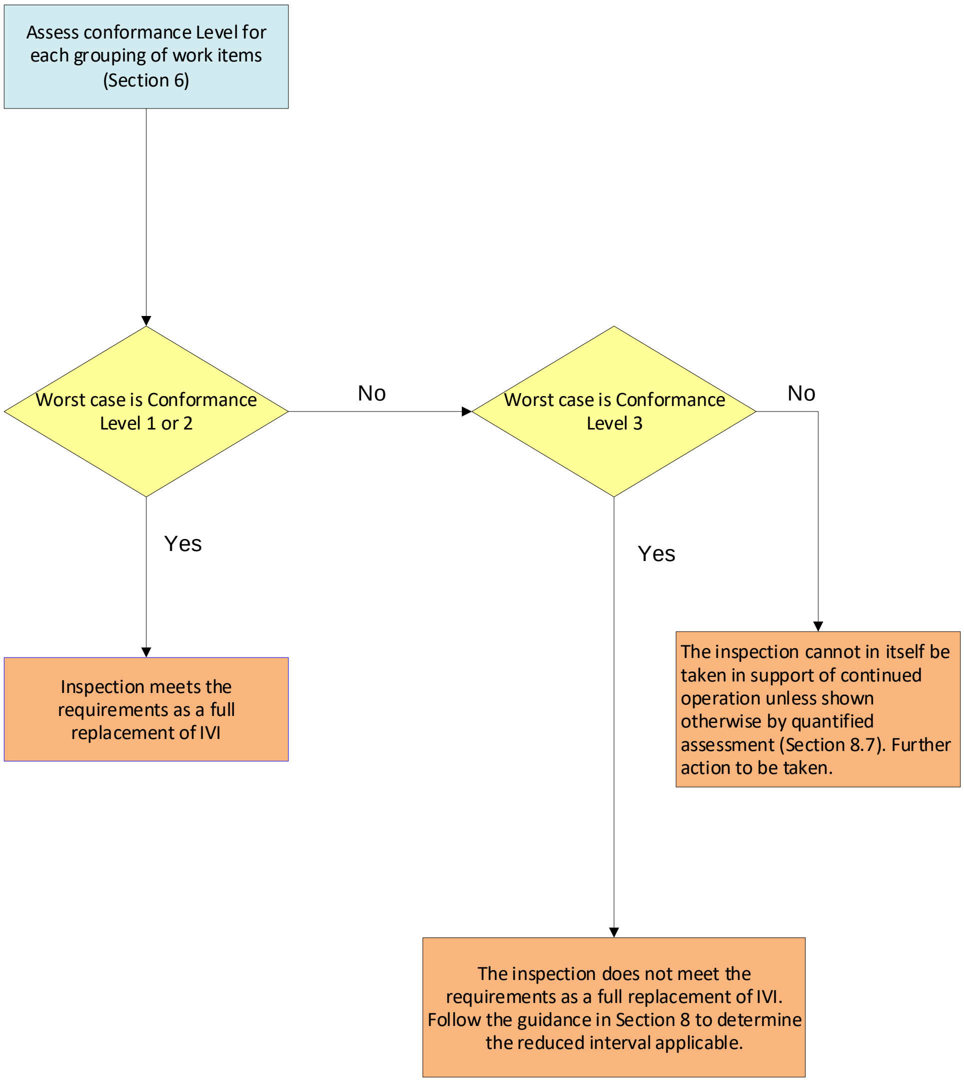

Figure 10-1 Overview of approach to conformance evaluation

The conformance review must consider each work item in the scope and address conformance with respect to the following.

- Method
- Procedure
- Data quality
- Location
- Coverage.

Details on how each of the above should be assessed are provided in Section 6 of [1]. The way in which the Conformance Level is impacted depends on the Strategy Type. The Strategy Type will have been defined on a zone by zone basis prior to the work scope development and this information must be available in order to support the evaluation.

Conformance Levels 3 or 4 represent critical non-conformances which mean the aims of the NII have not been met. For these cases further action will often be necessary. The following is a list of possible actions to be taken where a non-conformance cannot be accepted for the NII as a whole:

- 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.
- Carry out regular 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 CO_2, H_2S or regular checks on corrosion coupons).
- Consider using the NII for the purpose of deferment only if the allowable inspection interval as determined per Section 8 of the RP is suitable.

It is worth emphasising that conformance evaluation usually represents a significant activity with a check on each item in the work scope necessary. Although final responsibility for the evaluation will typically sit with the integrity team, the process can be streamlined by the inspection team confirming conformance for each work item where possible and highlighting any deviations in the inspection report. The way the data is managed and made accessible along with how it is presented in the inspection report has an influence on efficiency of the conformance evaluation. This should be considered in defining the working processes for the inspection and how its reported.

The RP includes four examples of conformance analysis in Section 8.8. These examples illustrate the approach to conformance evaluation.

10.2 Analysis

The data obtained during the inspection phase of NII provides the basis for understanding the condition of the vessel. This is reliant on appropriate analysis of the data, considering both the performance as achieved and any findings. Section 7 [1] covers analysis to be performed in support of the Evaluation phase of NII. As with many other aspects of NII, the approach varies according to the inspection Strategy Type.

The analysis requirements cover two aspects:
- An evaluation of inspection performance as achieved and
- Analysis of the data with respect to clarifying the condition and any degradation.

Key points by Strategy Type are summarised in Table 10-1.

Table 10-1: Overview of analysis requirements in Section 7 of the RP

Strategy	Performance evaluation	Primary focus of analysis
Type A	POD, Measurement accuracy	Validate absence of degradation, even at a low level
Type B	Measurement accuracy, POD	Data is used in a statistical analysis to make estimates for the area not inspected
Type C	POD for screening phase, accuracy for quantification phase	Reliably identify localised degradation and find the worst degradation

Note that the Type B Strategy relies on a sampling inspection approach whereby the zone is partially inspected, and statistical analysis of the data is used to make estimates for the un-inspected area. Details on applicable analysis methods are covered in the HOIS RP for Statistical Analysis of Inspection Data [3].

It is worth noting that the analysis requirements for NII go beyond what is more typical for NDT inspections where the aim would be just to establish a wall thickness for example. In the latter cases there would typically not be any further analysis or documentation other than what is covered by the inspection report which would represent the final deliverable of the inspection. With NII, issue of an inspection report does not represent completion of the process. The process is only completed on issue of the evaluation report which must address both conformance and analysis.

11. Inspection Interval Following NII

In most cases the inspection interval will have been separately determined, very often within a Risk Based Inspection process. The interval will typically be reviewed on completion of the inspection, with an update to the RBI driven by the new information on the condition of the vessel as provided by the inspection. The RP considers this interval is applicable following NII which has met the requirements for a Level 1 or Level 2 conformance. In the case of conformance assessed as Level 3, a reduction in the interval is necessary. In the case of conformance only being Level 4, the NII does not support continued operation unless shown otherwise by a quantified assessment.

The approach to revision of the interval for Level 3 cases depends on the Strategy Type. Detailed recommendations for each Strategy Type are covered in Sections 8.3 to 8.5 of the RP [1]. For Type A and C cases, the changes to interval for Level 3 cases are determined according to the nature of the non-conformance, e.g. whether it is related to POD or coverage, its severity. This results in a reduction factor, linked to the reduction in inspection performance/coverage, which is applied to the RBI interval. For Type B cases, where there is a non-conformance at Level 3 the interval should be determined by consideration of the estimated time to a limiting condition.

Note that for Type B cases the results of the inspection and analysis can be used to make estimates of times to limiting conditions (this on a zone or feature basis). These estimates should be compared to the RBI interval. It is usually acceptable to use the RBI interval where this is less than half of the time to a limiting condition. In some cases, the integrity system may permit a factor different from one half.

12. Update to RBI

The results of the inspection and evaluation of NII provide value beyond simply replacing or deferring an IVI. The nature of techniques relied upon in performing NII and evaluation in accordance with the RP are such that a significant amount of information on the condition of each vessel is obtained. Much of this information is quantitative and, as a consequence, can be used more effectively to support changes to parameters considered in the RBI than is traditionally possible with IVI.

Procedural changes are usually necessary to allow an update to the RBI and supporting corrosion risk assessment in light of the NII results. The following factors are some of those that should be considered in order to maximise the value of NII in the integrity process:

- Damage mechanisms. Are the mechanisms assigned in the RBI present? Are there mechanisms present that were not identified in the RBI? Are some of the mechanisms considered credible in the RBI definitely not present?
- Locations for degradation. How well does the actual location of degradation correlate with predictions?
- Spatial characteristics of corrosion. This will typically not have been considered in historical RBI approaches but is an important input for NII. The results of the inspection in Type B cases should be used where possible to update the initial estimates for the density and homogeneity parameters used in setting coverage.
- Depth/severity of degradation. Is this different from the expectation, typically based on the corrosion risk assessment and previous IVI, in the RBI?
- Corrosion growth rates. NII provides an opportunity to establish more representative corrosion growth rates than would typically be available under IVI driven regimes. This is due to the quantity of thickness data recorded during an NII, allowing factors such as as-manufactured thickness variations to be corrected for. These rates should be considered in remaining life estimates, which may directly affect intervals assigned in the RBI, and in updating Probabilities of Failure in the risk assessment.
- Confidence parameters. The results of the NII should be used to update the *confidence in ability to predict type and location of degradation*. In addition, the results may also be used as a basis for updating confidence parameters specific to the RBI.

13. Integration with Integrity Management Processes

In many cases, the existing integrity management process will have been developed around internal visual inspection of vessels. In order to permit straightforward integration of NII, which will yield benefits in terms of reduced shut-down durations, and to maximise the value of information from NII, the integrity process should be updated. This update should address all areas relevant to NII. This would typically address aspects such as:

- Integrity management system documentation should include reference to NII
- A specific NII process document, referring to the RP as necessary, should be developed.
- Revision of the RBI process, associated documentation and databases
- Revision and update of corrosion risk assessments
- Management and storage of reports and data

14. Acknowledgements

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The authors would like to thank HOIS and OGTC members for their support and feedback in the development of this document.

15. References

[1] HOIS, “HOIS-RP-103: HOIS Recommended Practice for Non-Intrusive Inspection of Pressure Vessels,” HOIS, 2020.

[2] HOIS, HOIS(15)R1: Results of the HOIS NII and IVI Trials on Two Ex-Service Pressure Vessels, Issue 1, 2015.

[3] HOIS, “Recommended Practice for Statistical Analysis of Inspection Data Issue 1,” HOIS, April 2013.

[4] Doosan Babcock Energy Ltd, “RR659: Evaluation of the Effectiveness of Non-Destructive Testing Screening Methods for In-Service Inspection,” HSE, 2009.

[5] S. Papavinasam, Corrosion Control in the Oil and Gas Industry, London: Elsevier, 2014.

[6] HOIS, “HOIS-RP-003: HOIS Recommended Practice for Precision Thickness Measurements for Corrosion Monitoring,” November 2017.

Appendices

Appendix 1 Examples: Introduction

Appendices 2 to 12 provide some worked examples that have been based on real vessels, and NIIs. They provide an example of how the RP may be applied. The examples are illustrative only and, in practice, each vessel should be reviewed for NII using the RP based on its own merits. Some details have been changed to anonymise the data (e.g. vessel thickness, manufacture date, inspection dates, history results). Similarly, the inspection intervals, degradation mechanisms considered etc. should not be considered recommendations for vessels of a similar function. Corrosion risk assessments, RBIs and resulting inspection intervals will take into account individual factors not shown in these examples (e.g. corrosion control measures, process expectations and history etc.). The inspection intervals have been included in these examples in order to allow comparison of inspection interval with inspection histories.

The worked examples include:

- Straightforward examples of a Type A (Appendix 2), Type B (Appendix 3), and Type C (Appendix 4) assessments and inspection.
- The Type B example also shows how a vessel can be zoned and treated using different strategies in a variety of ways (Appendix 3).
- Examples of vessels with limited inspection history resulting in either deferral (Appendix 5) or increased coverage (Appendix 6).
- Examples of vessels where NII was not suitable (Appendix 7 and Appendix 8).
- Example of NII as a First In-Service Inspection (FISI) (Appendix 9).
- Example of an evaluation for a successful Type B inspection (Appendix 10).
- Examples of successful NII where unexpected, or significant degradation, was found (Appendix 11).
- Examples of unsuccessful NII and associated lessons learned (Appendix 12).

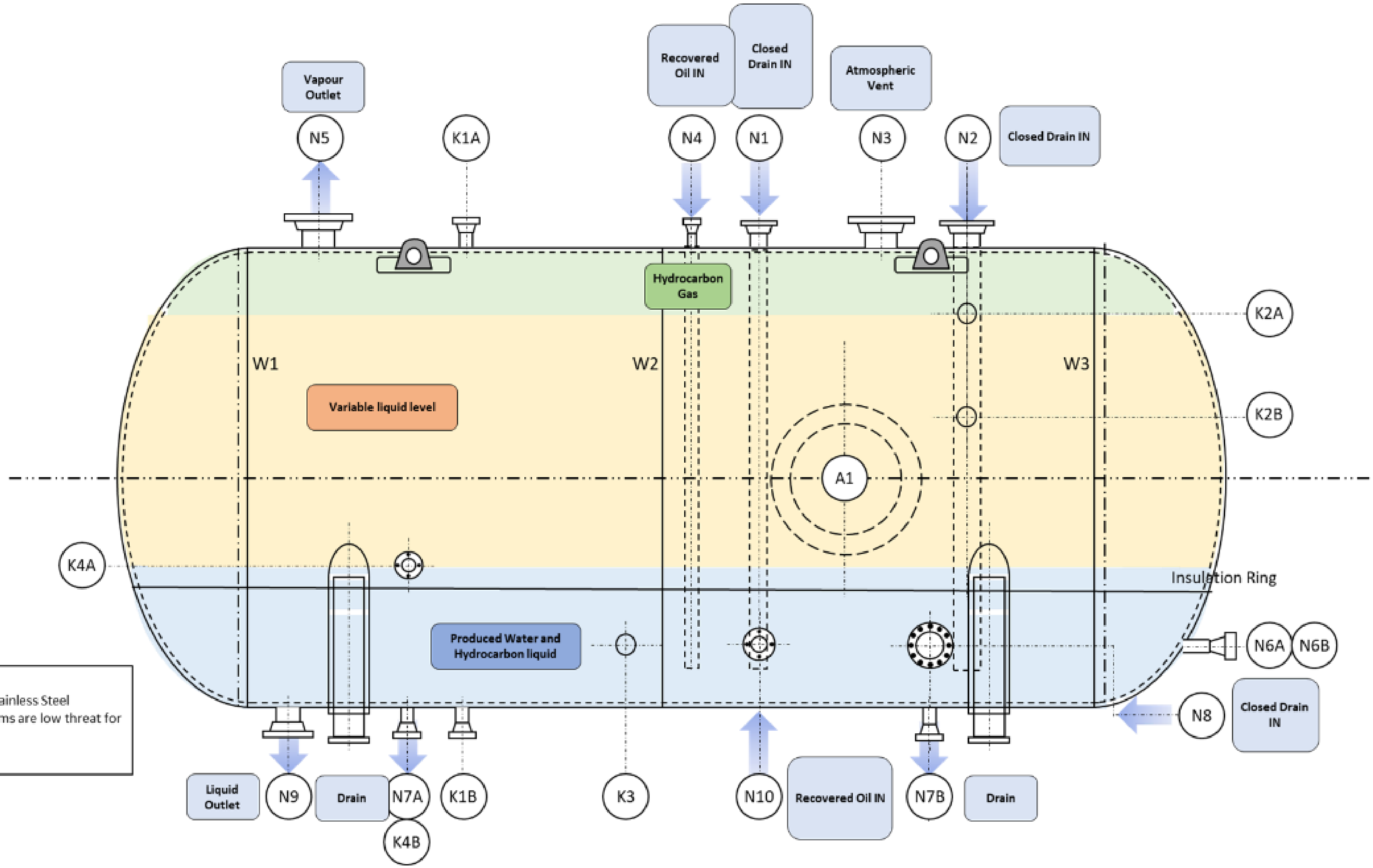
Appendix 2 Worked Example: Type A Strategy

A2.1 Design and Function

Slops Vessel (see Figure A2-1 for process diagram) function - receives fluids before separation and allows gas to flash off.

Table A2-1 Slops Vessel design details

Parameter	Value	Informs
Commission date	2004	Corrosion risk assessment
Design code	PD5500: 2003	Corrosion risk assessment
Contents	Hydrocarbon fluids	Corrosion risk assessment
Material	316L stainless steel	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Insulation	Yes	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Horizontal	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	5000 mm	Coverage calculation
Internal diameter	2468 mm	Coverage calculation
External diameter	2500 mm	Coverage calculation
Wall thickness: Shell	16 mm	Inspection technique selection
Wall thickness: Domed ends	13 mm	Inspection technique selection
Corrosion allowance	0 mm	Inspection performance requirements
MAWT: shell	16 mm	Inspection performance requirements
MAWT: domed ends	13 mm	Inspection performance requirements
Design pressure	5 barg	Corrosion risk assessment
Operating pressure	1 barg	Corrosion risk assessment
Design temperature	110°C	Corrosion risk assessment
Max operating temperature	20°C	Corrosion risk assessment
Internal inspection interval	5 years	Corrosion risk assessment
Next scheduled internal inspection	2021	Corrosion risk assessment



DEGRADATION NOTES: .
1. Vessel is constructed from 316L Stainless Steel
2. All credible degradation mechanisms are low threat for this item.

Figure A2-1 Slops Vessel process diagram

A2.2 Corrosion Risks and RBA Information

Table A2-2 Slops Vessel CRA summary

Degradation Method	Theoretical	Historical
Carbon Dioxide (CO_2)	Low threat	No damage reported.
Hydrogen Sulphide (H_2S)	Low threat	No damage reported.
Chloride pitting	Low threat	No damage reported.
Microbial Mechanisms	Low threat	No damage reported.
Dead-Legs	Low threat	No damage reported.
Galvanic/ Dissimilar Metals	Low threat	No damage reported.
Weld Corrosion (including preferential weld corrosion)	Low threat	No damage reported.
Crevice (including Flange Face)	Low threat	No damage reported.
Fatigue (including Fretting)	Low threat	No damage reported.

Table A2-3 Slops Vessel RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Low*	If corrosion occurred due to upset, likely to be either microbial corrosion (low) or chloride pitting (medium).	Inspection requirements
Homogeneity of degradation	Low*	If corrosion occurred due to upset, likely to be either microbial corrosion (low) or chloride pitting (medium).	Inspection requirements

*Worst case is selected.

A2.3 History

Table A2-4 Slops Vessel inspection history

Date	Inspection Type	Summary
2005	Visual internal and external examination	Vessel was found in satisfactory condition.
2008	Thorough Visual Internal and External	Vessel was found in good condition. No defects were noted.
2011	Thorough Visual Internal and External Examination of Nozzle Bore and Flange Faces	Inspection was carried out with the aid of snake eye inspection for the nozzle bores and flange faces. Vessel found to be in a satisfactory condition. One earth strap broken off.
2016	Thorough Visual Internal and External	Vessel was cleaned before entry. Internal was found in good condition; some debris at bottom of vessel were noted before cleaning. No defects were noted.

A2.4 Assessment

Table A2-5 Slops Vessel NII assessment

Parameter	Reason	Decision
Confidence in ability to predict type and location of degradation	Type 1 risk assessment and at least 4 inspections.	Medium
Previous inspection effectiveness	Last inspection was by IVI	Medium
Severity and rate of degradation	No degradation expected	Low

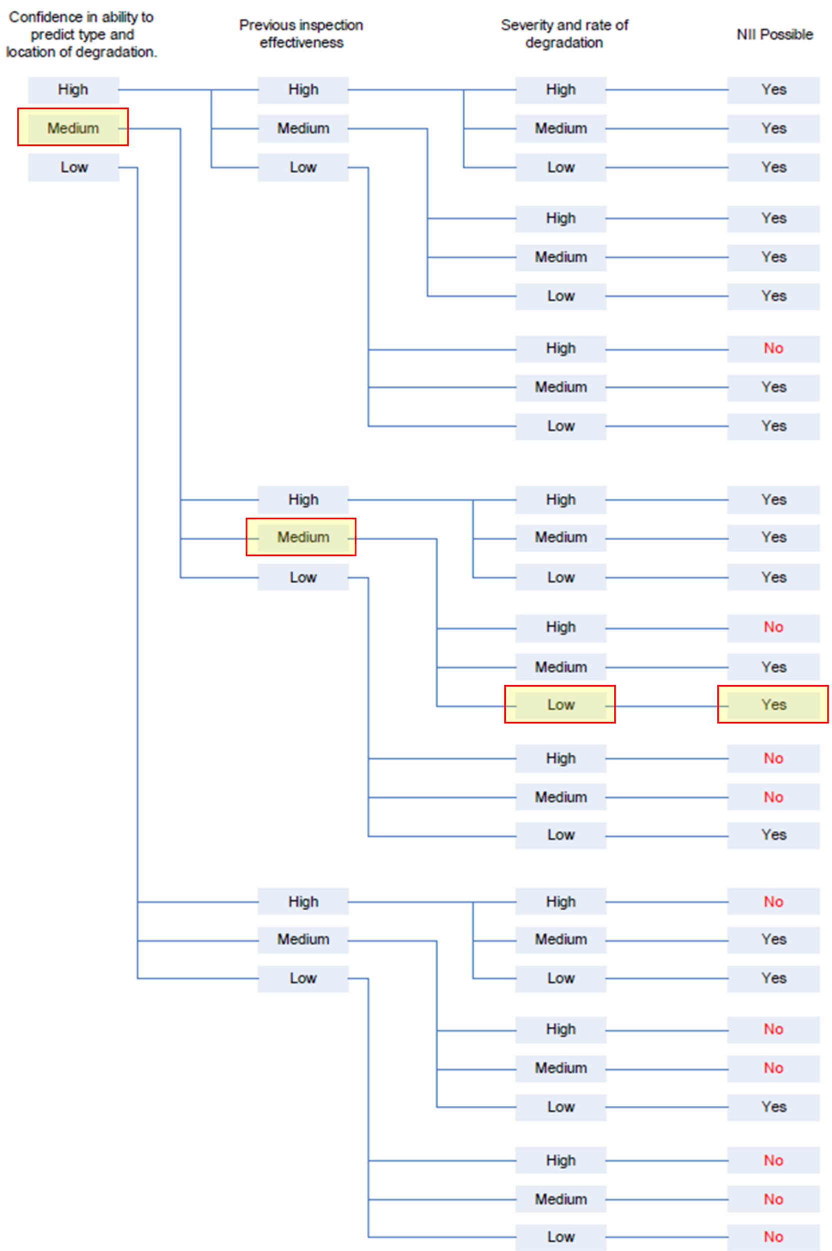


Figure A2-2 Slops Vessel NII assessment

A2.5 Strategy Selection

Table A2-6 Slops Vessel strategy selection

Parameter	Reason	Decision
Degradation likely/ measurable within two inspection intervals?	No degradation expected and no history of corrosion.	No

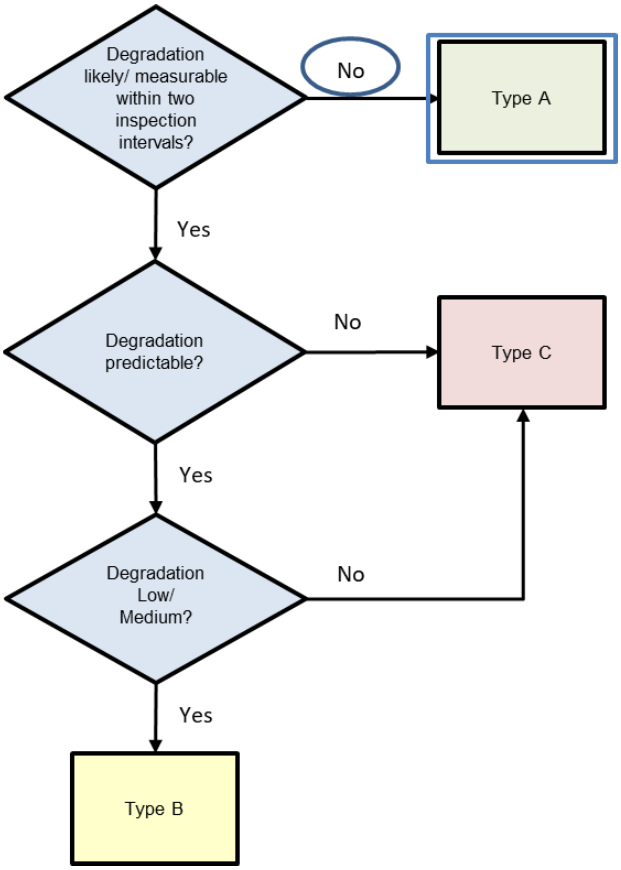


Figure A2-3 Slops Vessel strategy selection

A2.6 Inspection Requirements

Table A2-7 Slops Vessel inspection requirements

Setting	Requirement	Relevant § in [1]
Probability of detection	1.5 mm with aspect ratio of 5	4.6.2
Sizing accuracy	±0.5 mm (80% tolerance)	4.6.2
Coverage	8% see calculation below	4.6.3

A2.7 Coverage Calculation

$$A_{total} = \pi DL + 2(2\pi r^2) = (\pi \times 2.5 \times 5.0) + 2(2\pi \times 1.25^2) = 58.9\, m^2$$

$$C_R = F_{COV} \times F_{CONS} \times F_{ZONE} \times C_1$$

Table A2-8 Slops Vessel coverage calculation (see §4.6.3 in [1])

Factor		Result	Reason
Base coverage	C_1	5	CRA material
Coverage modifier	F_{COV}	2	Medium confidence in degradation prediction (from RBA)
			Low density expected (from RBA)
Consequence of failure	F_{CONS}	1	High (from RBA)
Zone surface area	F_{ZONE}	0.75	Whole vessel considered (A = 50 – 100 m^2)
Coverage required	C_R	8%	$C_R = 5 \times 2 \times 1 \times 0.75 = 7.5\%$

A2.8 Work Scope

Table A2-9 Slops Vessel coverage and locations

	Result	Reason
Coverage	4.7 m^2	As per calculation: 8% of vessel
Inspection areas	30 x400 x 400 mm areas	Many small areas to gather data from across entire vessel.
Locations	Sampling across entire vessel. No inspection under saddles. Sampling of nozzles; focus on process nozzles.	Sampling to confirm absence of degradation. Saddles not required unless evidence of internal corrosion to make inspection efficient.

Table A2-10 Slops Vessel inspection techniques

	Result	Reason
Shell and dome ends	Automated 0°corrosion mapping and…	<20 mm thick.
	Automated angled shear wave inspection	Material is stainless steel; corrosion under upset conditions could be narrow pitting (chloride).
Welds	Time of flight diffraction and…	Geometry of weld.
	Angled shear wave (mono-crystal or phased array)	Required to examine for small defects in weld root and/or cracking.
Nozzles Ø > 6”	0°corrosion mapping and angled shear wave inspection	As per shell and domed ends
Nozzles 3” < Ø < 6”	Line scans, manual UT, and angled shear wave inspection	Small size makes corrosion mapping difficult.
Nozzles Ø < 3”	Radiography	Small size makes use of UT difficult.

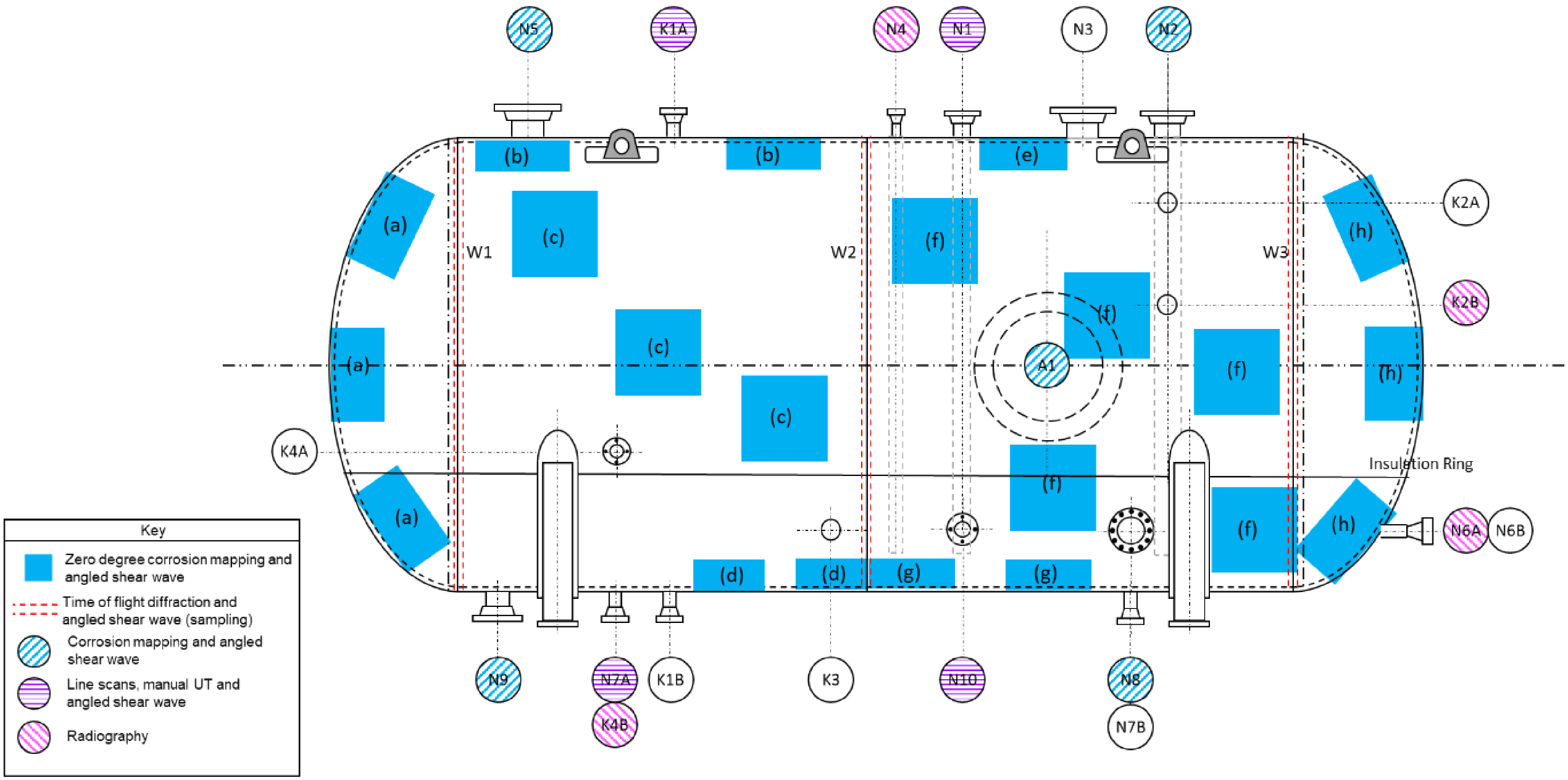


Figure A2-4 Type A example work scope

Table A2-11 Example task descriptions

Task ID	Description
(a) West domed end	Automated 0° corrosion mapping of **five** 400 x 400 mm areas to be spaced out across the full height and width of the west domed end. The exact areas can be chosen for access, but the areas should be well spaced, and one should include the bottom liquid region.
(b) Strake 1	Automated 0° corrosion mapping of **two** 400 x 400 mm areas to be taken at top dead centre of strake 1. The exact areas can be chosen for access.

Appendix 3 Worked Example: Type B Strategy

A3.1 Design and Function

3rd Stage Separator function: a gravity separator that handles fluids from the produced oil system.

Table A3-1 3rd Stage Separator design details

Parameter	Value	Informs
Commission date	1985	Corrosion risk assessment
Design code	BS-1501	Corrosion risk assessment
Contents	Produced oil	Corrosion risk assessment
Material	Carbon steel	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Insulation	No	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Horizontal	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	8400 mm	Coverage calculation
Internal diameter	1960 mm	Coverage calculation
External diameter	2000 mm	Coverage calculation
Wall thickness: Shell	20 mm	Inspection technique selection
Wall thickness: Domed ends	18 mm MAF	Inspection technique selection
Corrosion allowance	5 mm	Inspection performance requirements
MAWT: shell	15 mm	Inspection performance requirements
MAWT: domed ends	13 mm	Inspection performance requirements
Design pressure	125 psig	Corrosion risk assessment
Operating pressure	15 psig	Corrosion risk assessment
Design temperature	125°C	Corrosion risk assessment
Max operating temperature	65°C	Corrosion risk assessment
Internal inspection interval	5 years	Corrosion risk assessment
Next scheduled internal inspection	2020	Corrosion risk assessment

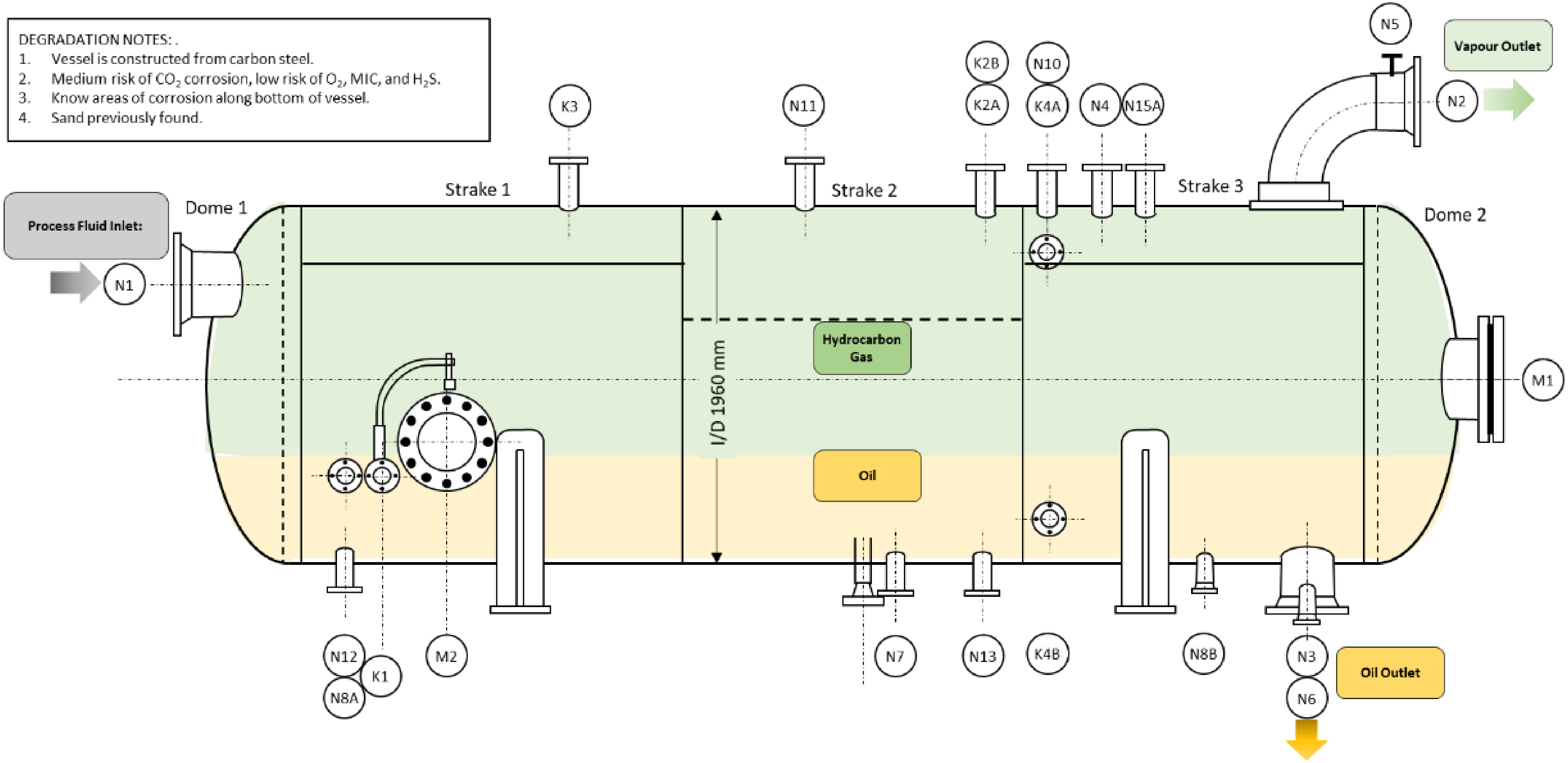


Figure A3-1 3rd Stage Separator function process diagram

A3.2 Corrosion Risks and RBA Information

Table A3-2 3rd Stage Separator CRA summary

Degradation Method	Theoretical	Historical
Carbon Dioxide (CO_2)	Medium threat	Evidence of band of general loss along full length of vessel.
Hydrogen Sulphide (H_2S)	Low threat	Low levels of H_2S measured.
Oxygen (O_2)	Low threat	Low levels of O_2 measured.
Microbial Mechanisms	Low threat	Microbial control in place and low bug count.
Dead-Legs	Low threat	No damage reported.
Galvanic/ Dissimilar Metals	Low threat	No damage reported.
Weld Corrosion (including preferential weld corrosion)	Low threat	No damage reported.
Erosion Mechanisms	Low threat	Sand noted but no damage reported.
Crevice (including Flange Face)	Medium threat	Pitting found along bottom of vessel which may be due to under deposit corrosion.
Fatigue (including Fretting)	Low threat	No damage reported.

Table A3-3 3rd Stage Separator RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Low	Evidence of isolated pitting from under deposit corrosion.	Inspection requirements
Homogeneity of degradation	Low	Evidence of isolated pitting as well as general wall loss.	Inspection requirements

A3.3 History

Table A3-4 3rd Stage Separator inspection history (recent)

Date	Inspection Type	Summary
2000	IVI	Shell and dished ends in generally good order. Thin layer of black deposit on all surfaces.
2005	IVI	Internal surfaces were covered in a thin black deposit that was not removed by water jetting. Band of roughness approximately 500 mm wide at 1/3 height on both sides of the vessel. Maximum loss of ~ 1mm. This was first reported at an IVI 10 years previously.
2015	UT	A UT inspection was carried out in place of a full IVI on the vessel nozzles and four sections along the bottom of the vessel. The domed ends were fully inspected. Four areas of pitting were discovered between the 5 and 7 o'clock positions with the largest pits measuring 2 mm deep.
2018	NDT - monitoring	Localised pitting found in 2015 was verified with no further growth found. However, new pits were discovered up to 2 mm deep.

A3.4 Assessment

Table A3-5 3rd Stage Separator NII assessment

Parameter	Reason	Decision
Confidence in ability to predict type and location of degradation	Type 1 risk assessment and at least 4 inspections. Corrosion can be explained by processes, therefore not unpredictable.	Medium
Previous inspection effectiveness	Last inspection in 2015 was by UT, not NII (i.e. cannot be high), but coverage was reasonable and follow up monitoring has taken place since.	Medium
Severity and rate of degradation	Degradation has been active but there is limited evidence that growth has continued (2018 showed no growth in original pits). Rate of degradation is unlikely to be a cause for concern within two inspection intervals	Medium

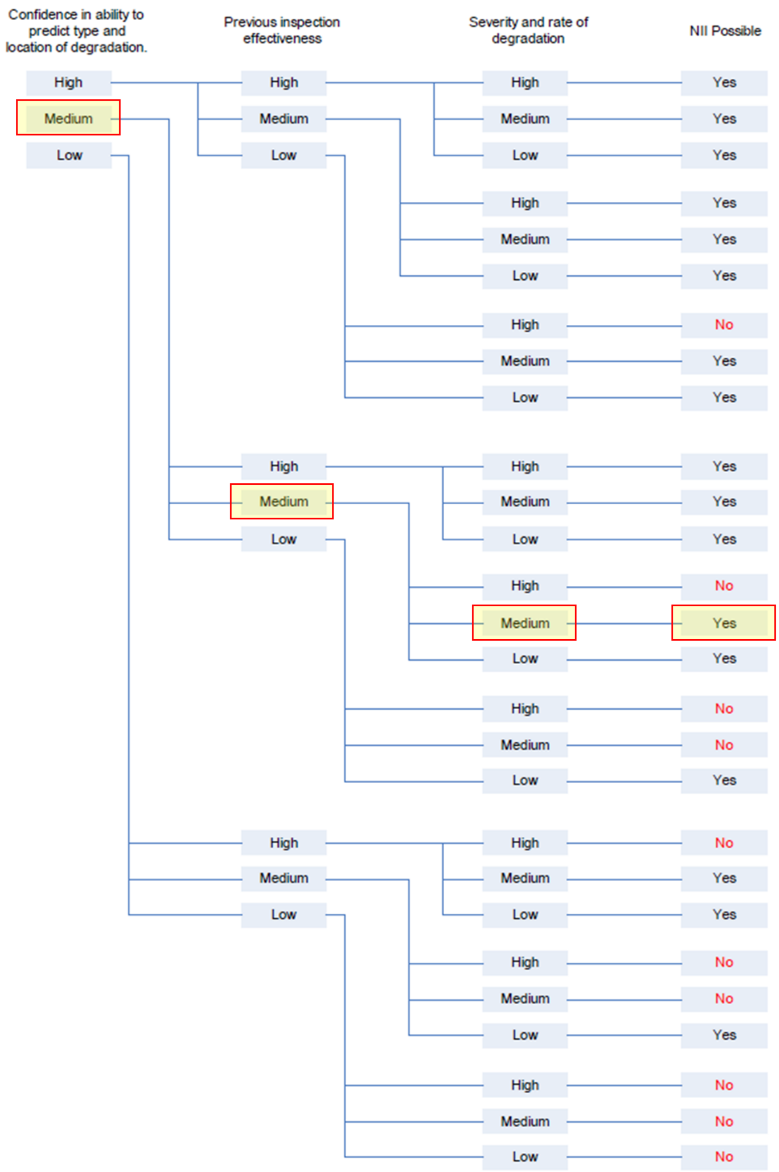


Figure A3-2 3rd Stage Separator NII assessment

A3.5 Strategy Selection

Table A3-6 3rd Stage Separator strategy selection

Parameter	Reason	Decision
Degradation likely/ measurable within two inspection intervals?	Degradation has occurred and could still occur.	Yes
Degradation predictable?	The location and type of degradation that has occurred can be explained by the mechanisms anticipated in the CRA. The areas most at risk can be predicted.	Yes
Degradation Low/ Medium?	The degradation that has been found is unlikely to be a threat within two inspection intervals.	Yes

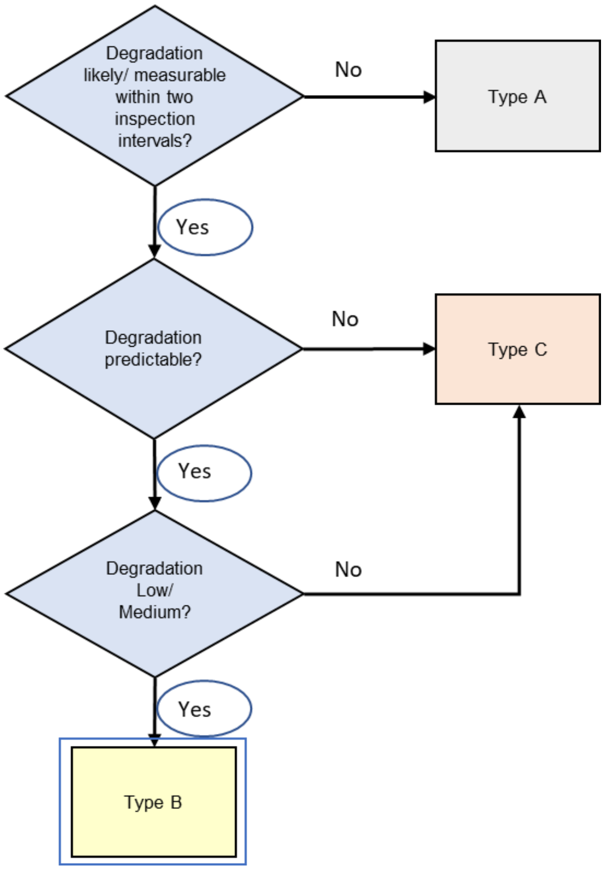


Figure A3-3 3rd Stage Separator strategy selection

A3.6 Inspection Requirements

Table A3-7 3rd Stage Separator inspection requirements

Setting	Requirement	Relevant § in [1]
Probability of detection	1.5 mm with aspect ratio of 10	4.6.2
Sizing accuracy	±0.3 mm (80% tolerance)	4.6.2
Coverage	47% see calculation below	4.6.3

A3.7 Coverage

$$C_R = F_{COV} \times F_{ACC} \times F_{LC} \times F_{CONS} \times F_{SH} \times F_{ZONE} \times C_1$$

Table A3-8 3rd Stage Separator coverage calculation (see §4.6.3 in [1])

Factor		Result	Reason
Base coverage	C_1	25	Fixed value
Coverage modifier	F_{COV}	2	Medium confidence in degradation prediction (from RBA)
			Low density expected (from RBA)
Consequence of failure	F_{CONS}	1	High (from RBA)
Zone surface area	F_{ZONE}	0.75	Whole vessel considered (A = 50 – 100 m^2)
Measurement accuracy	F_{ACC}	1	High (plan to use highly accurate inspection technique)
Tolerance to degradation	F_{LC}	1	Medium (5 mm corrosion allowance at least)
Spatial homogeneity	F_{SH}	1.25	Low (from RBA)
Coverage required	C_R	47%	$C_R = 2\ 5 \times 2 \times 1 \times 0.75 \times 1 \times 1 \times 1.25 = 46.9\%$

A3.8 Work Scope

Table A3-9 3rd Stage Separator coverage and locations

	Result	Reason
Coverage	30.7 m^2	As per calculation: 47% of vessel
Inspection areas	100% coverage between 4 and 8 o'clock (or 1000 mm up each side from BDC) plus three bands 500 mm wide around full circumference. Bottom third of domed ends plus 5 x 500 x 500 areas on each domed end.	Mix of sampling (bands) to examine for corrosion and focused inspection (high coverage along base) to identify any further corrosion and quantify known corrosion.
Locations	Focus on bottom of shell and domed ends. Sampling around full circumference of shell. Sampling on domed ends Sampling of nozzles.	Aim for high coverage along bottom of vessel where corrosion has been found and is most likely to occur. Circumferential bands ensure full coverage of different process areas (e.g. looking for "tide lines").

Table A3-10 3rd Stage Separator inspection techniques

	Result	Reason
Shell and dome ends	Automated 0° corrosion mapping or…	High accuracy technique.
	Automated time of flight diffraction screening	Vessel is > 20 mm thick and TOFD may be more efficient.
Welds	Time of flight diffraction	Geometry of weld.
Nozzles Ø > 6"	0°corrosion mapping	As per shell and domed ends
Nozzles 3" < Ø < 6"	Line scans, and manual UT	Small size makes corrosion mapping difficult.
Nozzles Ø < 3"	Radiography	Small size makes use of UT difficult.

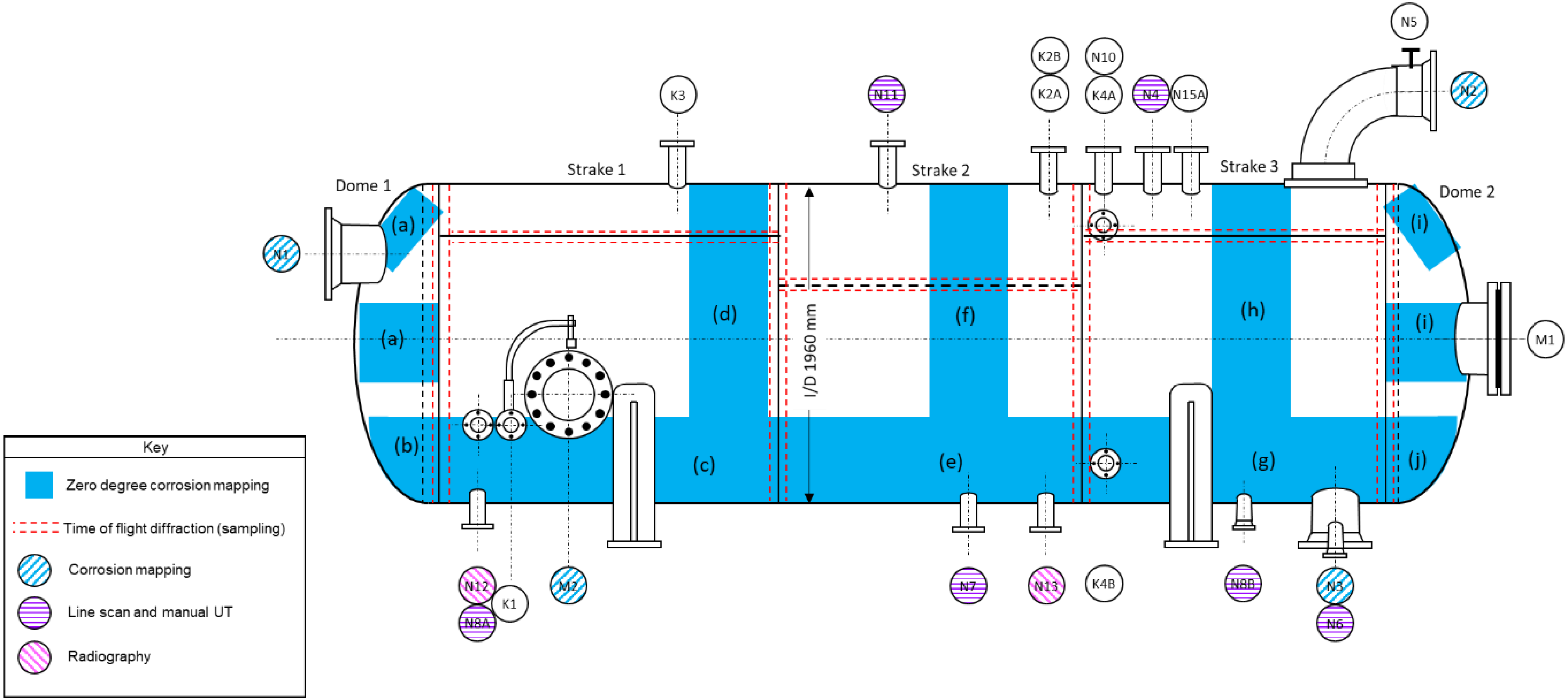


Figure A3-4 Type B example work scope

Table A3-11 Example task descriptions

Task ID	Description
(a) Dome 1	Automated 0° corrosion mapping of **five** 500 x 500 mm areas to be spaced out across the top 2/3 of the domed end. The exact areas can be chosen for access and it is acceptable to form bands of coverage, but the areas should be well spaced or provide good coverage across the top of the domed end.
(c) Strake 1	Automated 0° corrosion mapping or TOFD screening of all accessible material on the bottom third of stake 1. This is effectively 1000 mm up each side of the vessel from bottom dead centre.

A3.9 Alternative Strategies

It should be noted that there are several alternative ways to tackle this vessel, all of which would have provided a similar outcome. For example, the vessel could have been zoned to wetted and unwetted regions if there is knowledge of liquid levels. Or more simply, top half and bottom half. This would be reasonable as the top half of the vessel is more likely to see general corrosion compared to the bottom half which will see less dense, pitting, corrosion. The following sections provide a brief description of what strategies may have been considered if the vessel was zoned.

A3.10 Type B

The two zones could have both been treated as Type B with the following coverages.

Table A3-12 3rd Stage Separator coverages based on zones

Zone	C_1 %	Confidence	Density	F_{COV}	F_{CONS}	F_{CONS}	F_{ZONE}	F_{ZONE}	F_{ACC}	F_{ACC}	F_{LC}	F_{LC}	F_{SH}	F_{SH}	C_R
Top	25	Medium	High	0.75	High	1	10 – 50	1	High	1	Medium	1	High	1	19%
Bottom	25	Medium	Low	2	High	1	10 – 50	1	High	1	Medium	1	Low	1.25	50%

The 50% coverage of the bottom of the vessel would have been focused in between and just beyond the 5 to 7 o'clock positions. The 20% coverage on the top could have been done as bands or small sampling areas.

A3.11 Type B/ Type C

The bottom zone of the vessel could have been treated as a Type C (100% coverage) and the top Type B with 19% coverage (see calculation in Appendix A3.7). Depending on where the vessel is zoned (e.g. split 50/50 or 60/30) this approach may be the higher coverage option, but it would still provide a robust (albeit conservative) inspection strategy.

Appendix 4 Worked Example: Type C Strategy

A4.1 Design and Function

Degasser function: receives produced water from various Hydrocyclones and allows gas to flash off. An internal skimmer removes any residual oil

Table A4-1 Degasser design details

Parameter	Value	Informs
Commission date	1990	Corrosion risk assessment
Design code	BS5500:1988 Cat. 1	Corrosion risk assessment
Contents	Produced water/ oil/ gas	Corrosion risk assessment
Material	Carbon steel	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Internal lining	Yes – glass flake lined	Corrosion risk assessment Strategy decision
Insulation	No	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Horizontal	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	6000 mm	Coverage calculation
Internal diameter	2970 mm	Coverage calculation
External diameter	3000 mm	Coverage calculation
Wall thickness: Shell	15 mm	Inspection technique selection
Wall thickness: Domed ends	15 mm MAF	Inspection technique selection
Corrosion allowance	3 mm	Inspection performance requirements
MAWT: shell	12 mm	Inspection performance requirements
MAWT: domed ends	12 mm	Inspection performance requirements
Design pressure	15 barg	Corrosion risk assessment
Operating pressure	0.1 barg (max.)	Corrosion risk assessment
Design temperature	-5°C to 100°C	Corrosion risk assessment
Max operating temperature	75°C	Corrosion risk assessment
Internal inspection interval	3 years	Corrosion risk assessment
Next scheduled internal inspection	2020	Corrosion risk assessment

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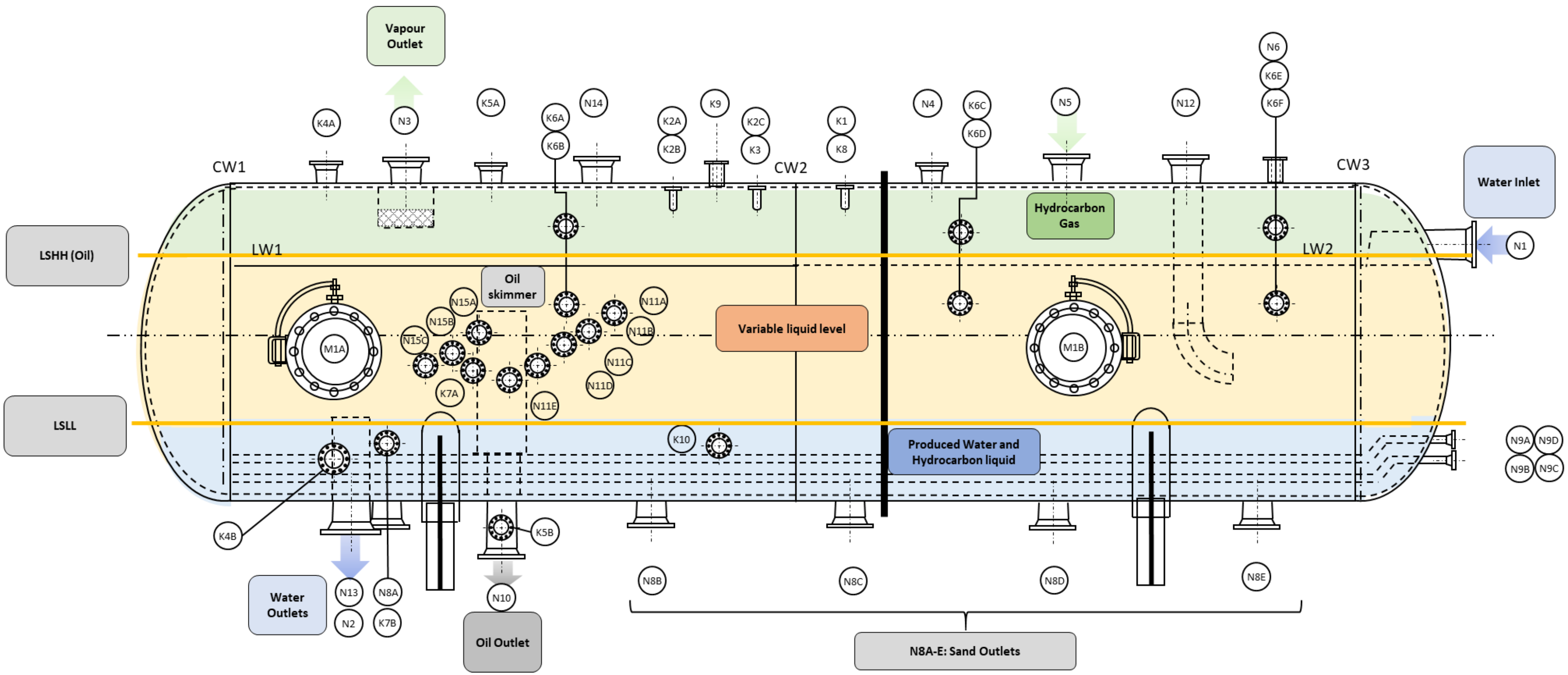

Figure A4-1 Degasser process diagram

A4.2 Corrosion Risks and RBA Information

Table A4-2 Degasser CRA summary (Low to High threat: 1 to 5)

Degradation Method	Theoretical - Mitigated	Historical
Carbon Dioxide (CO_2)	4	Protective scale expected in addition to lining.
Hydrogen Sulphide (H_2S)	4	H_2S corrosion concentration appears to be increasing.
Oxygen (O_2)	N/A	N/A
Microbial Mechanisms	5	Planktonic SRB very low in 2017 survey.
Dead-Legs	4	Redundant level bridles in liquid zones.
Galvanic/ Dissimilar Metals	4	Internals are uncoated 316 stainless steel.
Weld Corrosion (including preferential weld corrosion)	N/A	N/A
Erosion Mechanisms	3	Shell immediately opposite sandwash nozzles susceptible to erosion.
Crevice (including Flange Face)	2	History of recurring flange face corrosion at most nozzles.
Fatigue (including Fretting)	3	Sandwash piping known to have come loose previously.

Table A4-3 Degasser RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Low	Isolated areas of lining loss possible.	Inspection requirements
Homogeneity of degradation	Low	Isolated areas of lining loss possible.	Inspection requirements

A4.3 History

Table A4-4 Degasser inspection history

Date	Inspection Type	Summary
<2011	Various	Inspection data prior to 2011 seen but not summarised here. Vessel inspected every 3 years since 1990.
2011	EVI, IVI and NDT	Externally there was some minor coating breakdown. Internally, coating was found to be in ok condition. Flange face corrosion was found and repaired on nozzles N1, N2, M1A and M1B. All nozzle bores were inspected with UT with no significant deviations from nominal. The vessel was fully recoated with Belzona 1931. 20 holidays were found in testing and repaired with Belzona.
2014	EVI and IVI	External inspection found an isolated area of coating breakdown with external pitting to 1 mm deep. No internal corrosion found.
2017	NII	There are records of an NII taking place, but the report was not available. No information is available on coverage, technique, and conformance levels.

A4.4 Assessment

Table A4-5 Degasser NII assessment

Parameter	Reason	Decision
Confidence in ability to predict type and location of degradation	Type 1 risk assessment and at least 8 inspections.	High
Previous inspection effectiveness	Last inspection was by NII but report was not available so there is no information on what was planned and achieved.	Low
Severity and rate of degradation	Degradation has the potential to be at a medium rate. Provided lining in place, corrosion is unlikely to be of concern before next inspection interval.	Medium

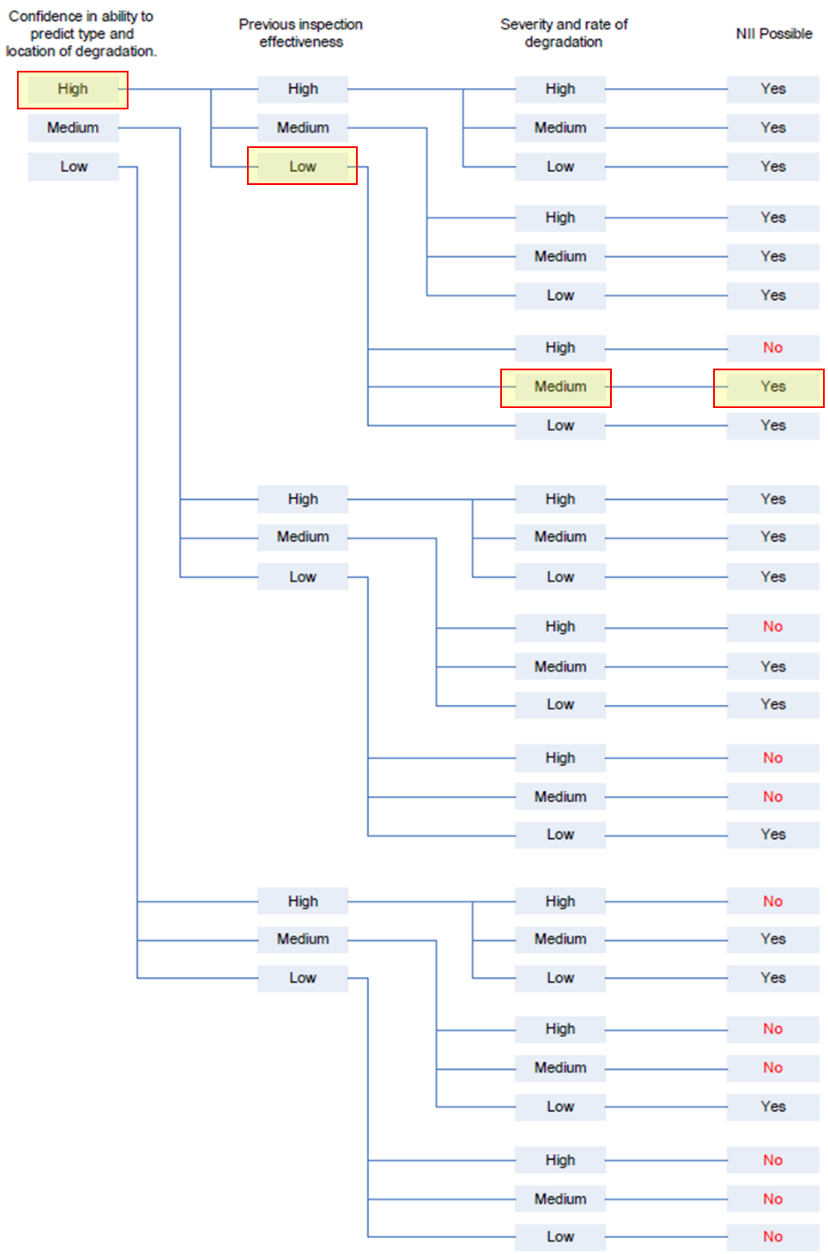

Figure A4-2 Degasser NII assessment

A4.5 Strategy Selection

Table A4-6 Degasser strategy selection

Parameter	Reason	Decision
Degradation likely/ measurable within two inspection intervals?	If lining failure has occurred, degradation would be possible.	Yes
Degradation predictable?	While the corrosion mechanisms are predictable, the locations of where it could occur are not since linings can break down randomly.	No

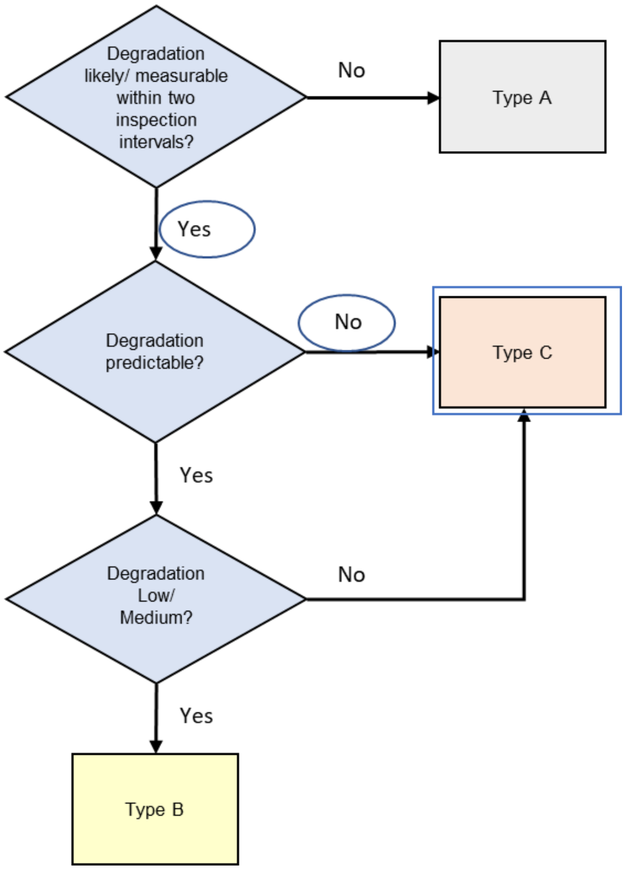

Figure A4-3 Slops Vessel strategy selection

It should be noted that current NDT techniques cannot detect the condition of the lining. This should be kept in mind when dealing with cases where failure of the lining can lead to a very rapid corrosion rate such that integrity may be threatened in less than two inspection intervals.

A4.6 Inspection Requirements

Table A4-7 Degasser inspection requirements

Setting	Requirement	Relevant § in [1]
Probability of detection	1.5 mm with aspect ratio of 10	4.6.2
Sizing accuracy	±0.4 mm (80% tolerance)	4.6.2
Coverage	100%	4.6.3

A4.7 Coverage

100% coverage of all susceptible areas is required for a Type C inspection. In the case of the Degasser, this is 100% coverage of the shell, domed ends, and nozzles.

A4.8 Work Scope

Table A4-8 Degasser coverage and locations

	Result	Reason
Coverage	84.8 m^2	100% of vessel
Inspection areas	N/A 100%	
Locations	100% coverage across all vessel (including under saddles) and all nozzles. Flange faces to be inspected.	No way to predict locations of coating breakdown. Under saddles required in order to help achieve the 100% coverage as access restrictions likely. A site survey helps to make the decision on whether inspection is achievable.

Table A4-9 Slops Vessel inspection techniques

	Result	Reason
Shell and dome ends	Automated 0°corrosion mapping and…	<20 mm thick.
	Multiskip and CHIME at saddle supports	Corrosion equally possible under saddles and high coverage required.
Welds	Time of flight diffraction	Geometry of welds.
Flanges	Phased array flange face inspection	High POD for this type of corrosion.
Nozzles Ø > 6”	0°corrosion mapping	As per shell and domed ends
Nozzles 3” < Ø < 6”	Line scans and manual UT	Small size makes corrosion mapping difficult.
Nozzles Ø < 3”	Radiography	Small size makes use of UT difficult.

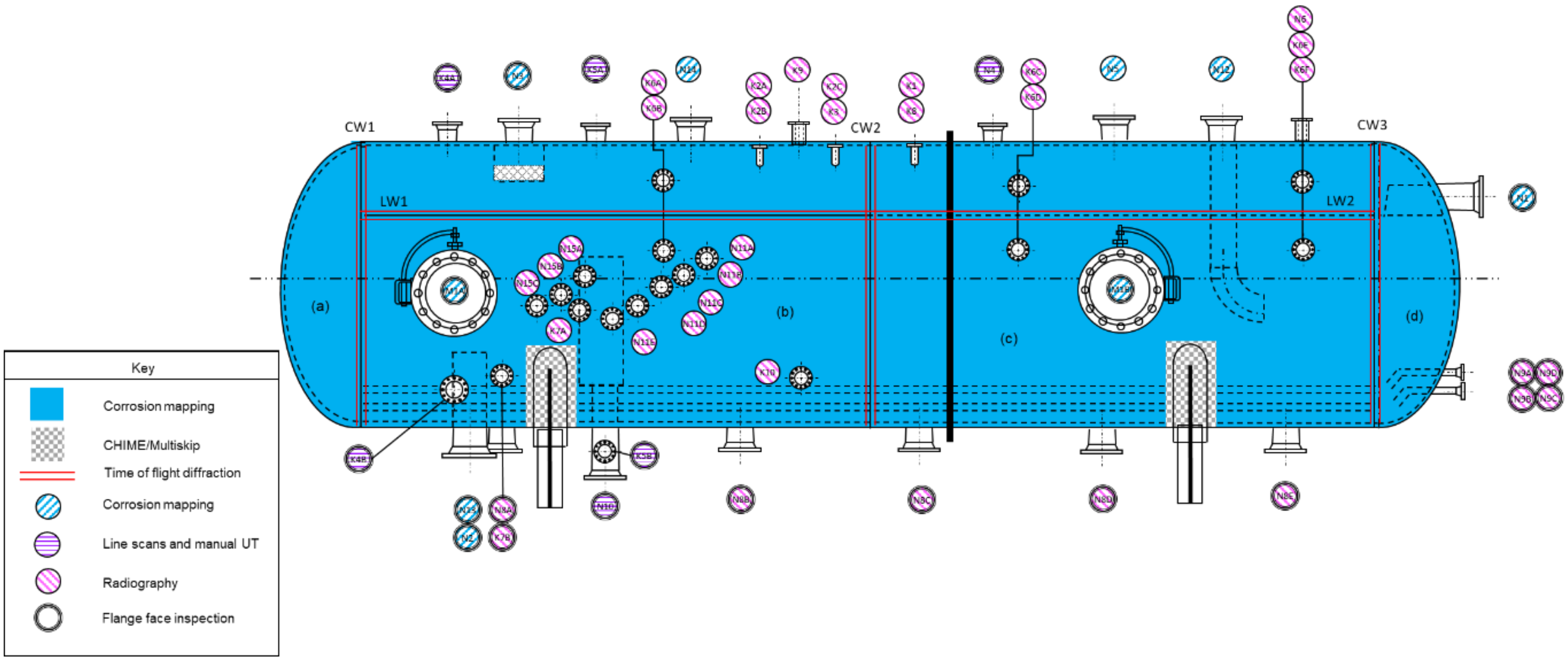

Figure A4-4 Type C example work scope

Table A4-10 Example task descriptions

Task ID	Description
(a) Domed end	Automated 0° corrosion mapping of 100% of the domed end.
(b) Strake 1	Automated 0° corrosion mapping of 100% of strake 1.

Appendix 5 Worked Example: Deferral

A5.1 Design and Function

Flash Drum function: receives fluids before separation and allows gas to flash off.

Table A5-1 Flash Drum design details

Parameter	Value	Informs
Commission date	1990	Corrosion risk assessment
Design code	ASME VIII DIV 2	Corrosion risk assessment
Contents	Rich glycol	Corrosion risk assessment
Material	ASTM 516 Gr 55	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Insulation	Yes	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Horizontal	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	4050 mm	Coverage calculation
Internal diameter	1541 mm	Coverage calculation
External diameter	1581 mm	Coverage calculation
Wall thickness: Shell	20 mm	Inspection technique selection
Wall thickness: Domed ends	22 mm	Inspection technique selection
Corrosion allowance	3 mm	Inspection performance requirements
MAWT: shell	17 mm	Inspection performance requirements
MAWT: domed ends	19 mm	Inspection performance requirements
Design pressure	9.0 barg	Corrosion risk assessment
Operating pressure	6.5 barg	Corrosion risk assessment
Design temperature	63°C	Corrosion risk assessment
Max operating temperature	45°C	Corrosion risk assessment
Internal inspection interval	5 years	Corrosion risk assessment
Next scheduled internal inspection	2022	Corrosion risk assessment

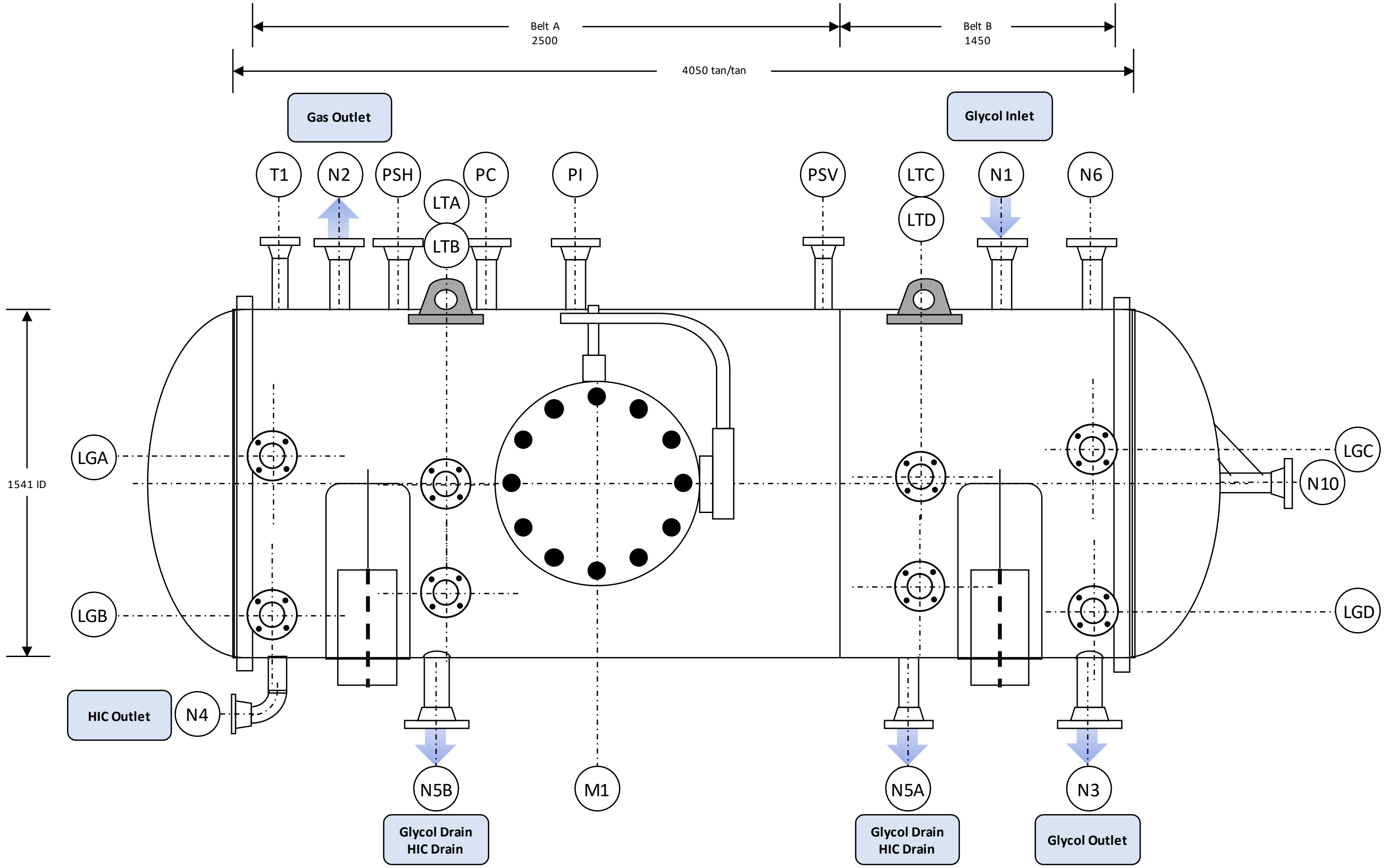

Figure A5-1 Flash Drum process diagram

A5.2 Corrosion Risks and RBA Information

Table A5-2 Flash Drum CRA summary

Degradation Method	Theoretical	Historical
Carbon Dioxide (CO_2)	Low threat	No damage reported.
Glycol	Low threat	No damage reported.

Table A5-3 Flash Drum Vessel RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Medium	If corrosion occurred due to upset, likely to be either CO_2 corrosion (medium) or Glycol corrosion (medium).	Inspection requirements
Homogeneity of degradation	Medium	If corrosion occurred due to upset, likely to be either CO_2 corrosion (medium) or Glycol corrosion (medium).	Inspection requirements

A5.3 History

Table A5-4 Flash Drum inspection history

Date	Inspection Type	Summary
1991	Ultrasonic (UT) Survey	No significant discrepancies
2000	UT Survey	No significant discrepancies
2007	External Visual and UT Survey	Vessel was found in good condition. No notable changed to UT results
2012	UT Survey	Minimum on shell 0.1 mm below nominal. 1.8 mm reduction in minimum at one of the nozzles.
2017	Pulsed Eddy Current (PEC) Survey	3 to 6 o'clock scanned with the lowest recorded reading on the South side of the vessel on Belt A, where wall loss of 2.1 mm from nominal was recorded.

A5.4 Assessment

Table A5-5 Flash Drum NII assessment

Parameter	Reason	Decision
Confidence in ability to predict type and location of degradation	Type 1 risk assessment and at least 4 inspections.	Medium
Previous inspection effectiveness	No record of an IVI, last inspection by PEC through insulation. PEC is not capable of accurate defect sizing and it cannot distinguish between internal and external degradation.	Low
Severity and rate of degradation	Any degradation could threaten integrity within vessel lifetime	Medium

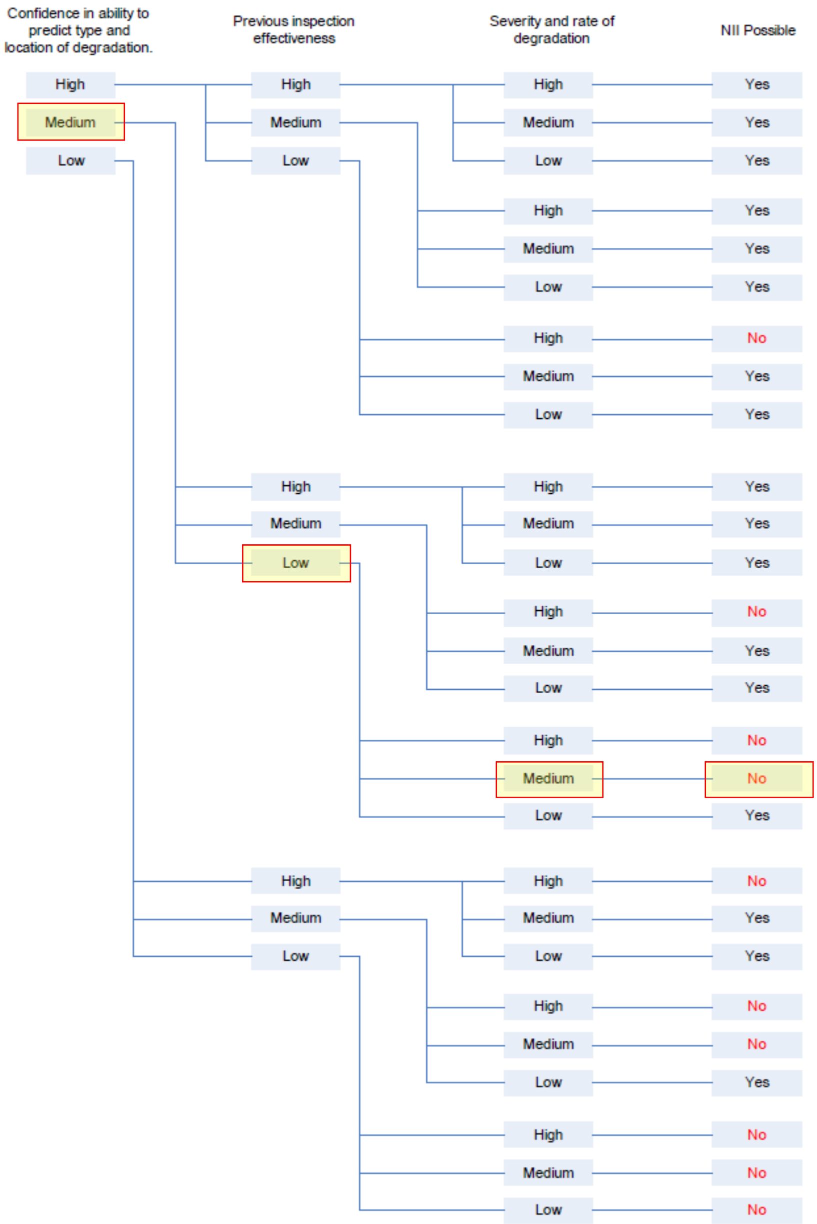

Figure A5-2 Flash Drum NII assessment

NII is not suitable but inspection is permitted for the purposes of deferment of up to 50% of the inspection interval, provided that the deferment interval does not exceed 75% of the estimated remaining life (see Table 9-1 of [1]).

A5.5 Strategy Selection

Table A5-6 Flash Drum strategy selection

Parameter	Reason	Decision
Degradation likely/ measurable within two inspection intervals?	Evidence of degradation during previous UT surveys	Yes
Degradation predictable?	The identified threats in the CRA are likely to occur in predictable locations.	Yes
Degradation Low/Medium?	Medium	Yes

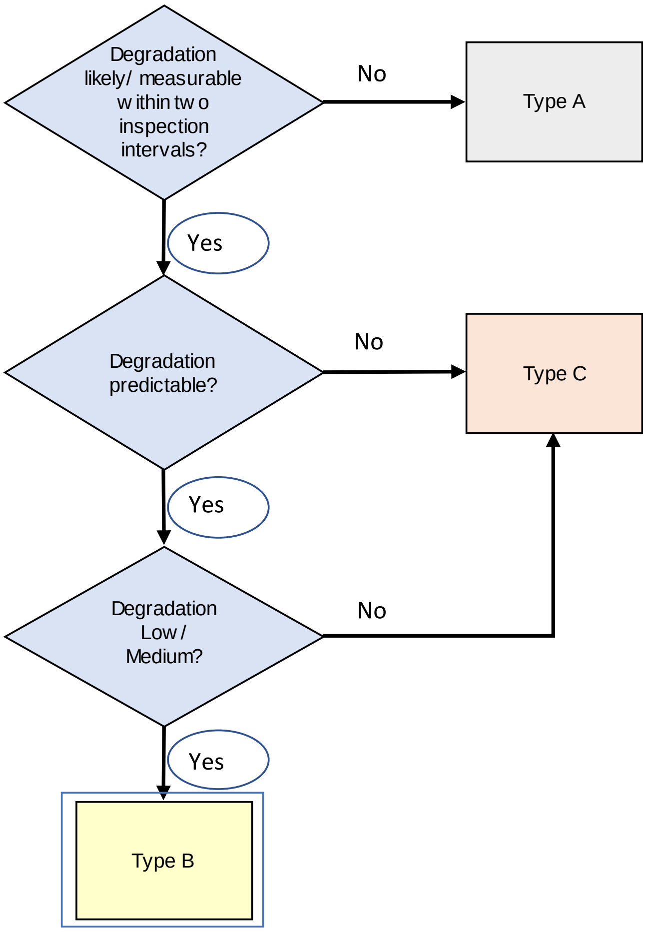

Figure A5-3 Flash Drum strategy selection

A5.6 Inspection Requirements

Table A5-7 Flash Drum inspection requirements

Setting	Requirement	Relevant § in [1]
Probability of detection	1.5 mm with aspect ratio of 5	4.6.2
Sizing accuracy	±0.3 mm (80% tolerance)	4.6.2
Coverage	29% see calculation below	4.6.3

A5.7 Coverage

$$C_R = F_{COV} \times F_{ACC} \times F_{LC} \times F_{CONS} \times F_{SH} \times F_{ZONE} \times C_1$$

Table A5-8 Slops Vessel coverage calculation (see §4.6.3 in [1])

Factor		Result	Reason
Base coverage	C_1	25	Fixed value
Coverage modifier	F_{COV}	1	Medium confidence in degradation prediction (from RBA) Medium density expected (from RBA)
Consequence of failure	F_{CONS}	1	High (from RBA)
Zone surface area	F_{ZONE}	1	Whole vessel considered (A = 10 – 50 m^2)
Measurement accuracy	F_{ACC}	1	High (plan to use highly accurate inspection technique)
Tolerance to degradation	F_{LC}	1	Medium (from NII assessment)
Spatial homogeneity	F_{SH}	1.15	Medium (from RBA)
Coverage required	C_R	28.8%	$C_R = 25 \times 1 \times 1 \times 1 \times 1 \times 1.15 = 28.8\%$

A5.8 Work Scope

Table A5-9 Slops Vessel coverage and locations

	Result	Reason
Coverage	4.35 m^2	29% of 15.0 m^2
Inspection areas	100% coverage between 5 and 7 o'clock (or 450 mm up each side from BDC) plus two bands 200 mm wide around full circumference. 4 x 500 x 500 areas on each domed end.	Mix of sampling (bands) to examine for corrosion based on liquid levels and focused inspection (high coverage along base) to examine for effects of potential debris.
Locations	Focus on bottom of shell and domed ends. Sampling around full circumference of shell. Inspection of area of wall loss from PEC inspection. Sampling on domed ends Sampling of nozzles.	Aim for high coverage along bottom of vessel where corrosion is most likely to occur. Low reading from PEC to be investigated. Circumferential bands ensure full coverage of different process areas (e.g. looking for "tide lines").

Table A5-10 Slops Vessel inspection techniques

	Result	Reason
Shell and dome ends	Automated 0°corrosion	20 mm thick
Welds	Time of flight diffraction and angled shear wave	Geometry of weld.
Nozzles Ø > 6"	0°corrosion mapping	As per shell and domed ends
Nozzles 3" < Ø < 6"	Line scans and manual UT	Small size makes corrosion mapping difficult.
Nozzles Ø < 3"	Radiography	Small size makes use of UT difficult.

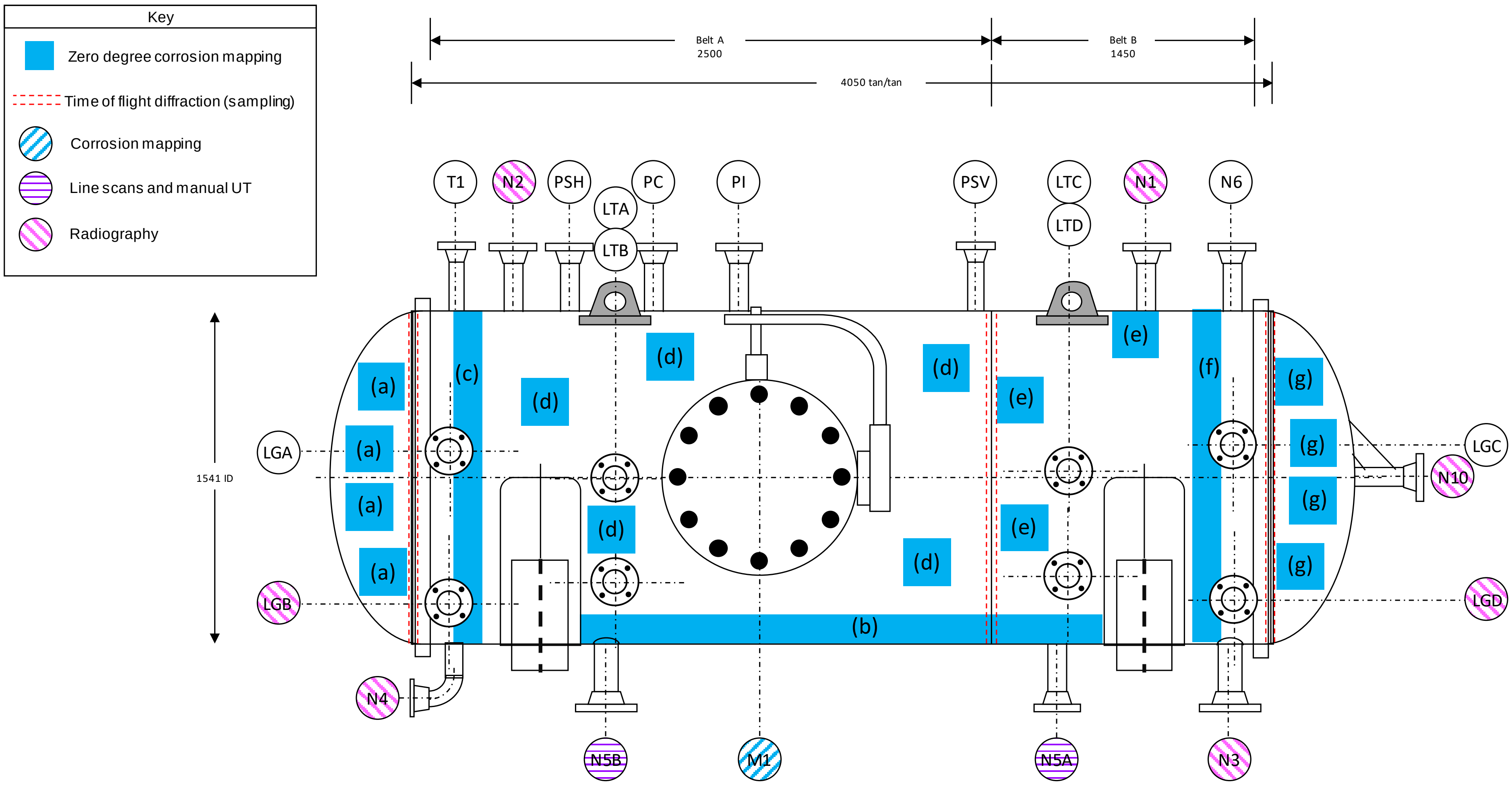

Figure A5-4 Type B deferral example work scope

Table A5-11 Example task descriptions

Task ID	Description
(a) Domed end	Automated 0° corrosion mapping of four 500 x 500 mm areas
(b) Shell	Automated 0° corrosion mapping of a 900 mm wide band centred at BDC, taken between the supports. That is, inspection between 5 and 7 o'clock.
(c) Belt A	Automated 0° corrosion mapping of one 200 mm wide band taken around the full circumference of the vessel, band should be taken to the dome side of the support. If a full band is not possible, smaller areas can be collected until the coverage is achieved with the aim being to collect various height.
(d) Belt A	Automated 0° corrosion mapping of five 500 x 500 mm areas. One area is to cover the region of low thickness recorded by PEC in 2017.

Appendix 6 Worked Example: Limited History

A6.1 Design and Function

Glycol Still Column and Reflux Condenser function: forms part of the glycol regeneration package. Rich TEG enters the packed column meeting hot vapours from the Glycol Reboiler. The TEG flows downwards towards the Reboiler where it is heated to remove water. The hot water vapour (which also contains glycol and fuel gas) passes upwards through the Still Column to the Reflux Condenser where the remaining glycol in the vapour is recovered by condensation and the water/ fuel gas is sent for further separation.

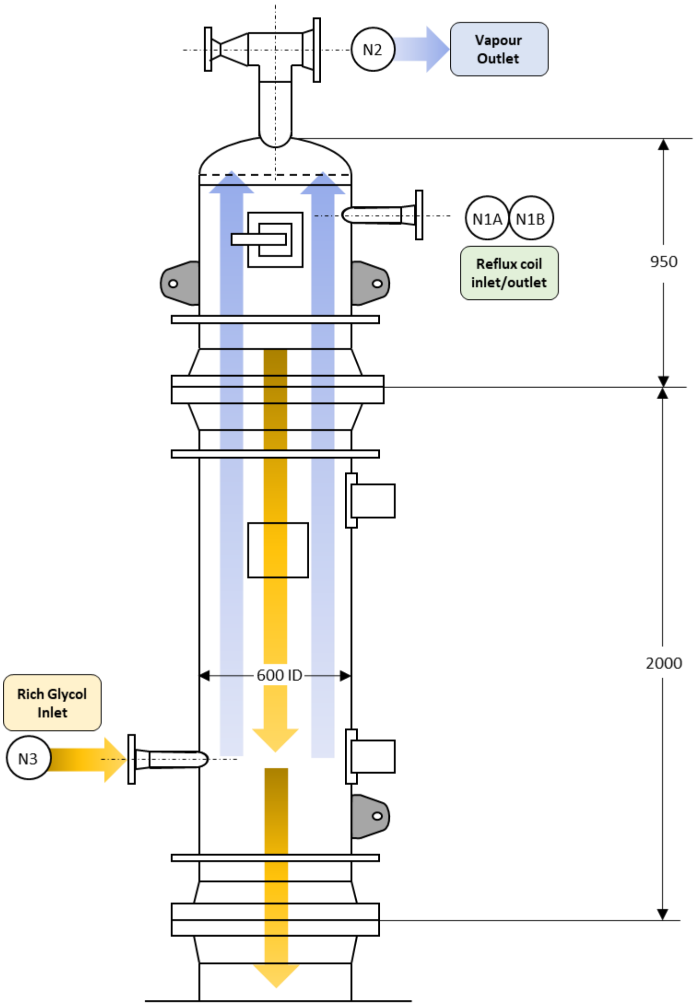

Figure A6-1 Still Column and Reflux Condenser process diagram

Table A6-1 Still Column and Reflux Condenser design details

Parameter	Value	Informs
Commission date	2000	Corrosion risk assessment
Design code	BS5500	Corrosion risk assessment
Contents	Rich glycol	Corrosion risk assessment
Material	UNS 31803	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Insulation	Yes	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Vertical	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	2950 mm (total)	Coverage calculation
Internal diameter	600 mm	Coverage calculation
External diameter	620 mm	Coverage calculation
Wall thickness: Shell	10 mm	Inspection technique selection
Wall thickness: Domed ends	10 mm	Inspection technique selection
Corrosion allowance	0 mm	Inspection performance requirements
MAWT: shell	10 mm	Inspection performance requirements
MAWT: domed ends	10 mm	Inspection performance requirements
Design pressure	3.5 barg	Corrosion risk assessment
Operating pressure	0.04 barg	Corrosion risk assessment
Design temperature	240°C	Corrosion risk assessment
Max operating temperature	204°C (bottom) 101°C (top)	Corrosion risk assessment
Internal inspection interval	5 years	Corrosion risk assessment
Next scheduled internal inspection	2021	Corrosion risk assessment

A6.2 Corrosion Risks and RBA Information

Table A6-2 Still Column and Reflux Condenser CRA summary

Degradation Method	Theoretical	Historical
Carbon Dioxide (CO_2)	Negligible threat	No information
Glycol	Low threat	No information
Chloride pitting	Negligible threat	No information

Table A6-3 Still Column and Reflux Condenser RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Low	Assume worst case for conservatism.	Inspection requirements
Homogeneity of degradation	Low	Assume worst case for conservatism.	Inspection requirements

A6.3 History

Table A6-4 Still Column and Reflux Condenser inspection history

Date	Inspection Type	Summary
2007	IVI	Inspection recorded as having been performed but no report seen. Inspection was limited to boroscope only due to packing.

A6.4 Assessment

Table A6-5 Still Column and Reflux Condenser NII assessment

Parameter	Reason	Decision
Confidence in ability to predict type and location of degradation	Type 1 risk assessment only – poor inspection history and not inspected at intervals in RBA.	Low
Previous inspection effectiveness	Last inspection was by IVI but limited information available.	Low
Severity and rate of degradation	No degradation expected	Low

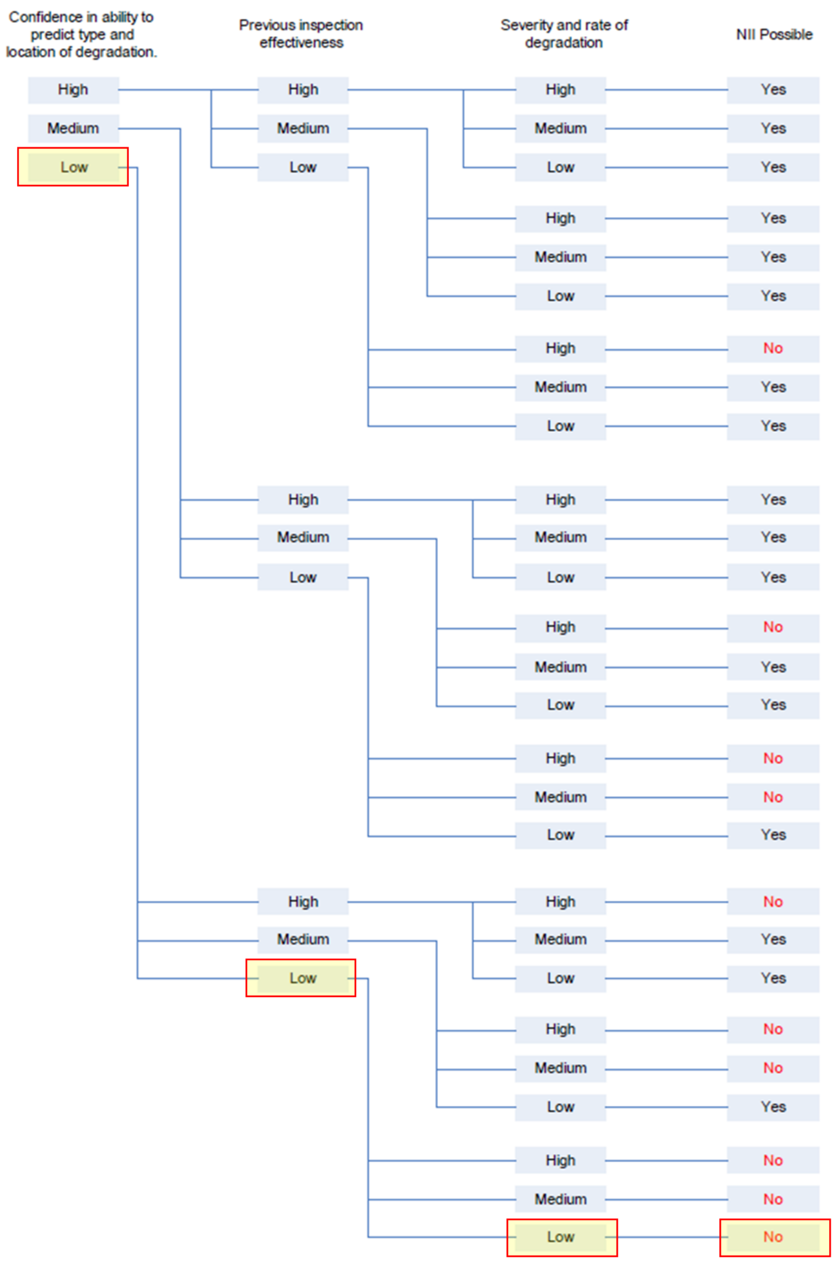

Figure A6-2 Still Column and Reflux Condenser NII assessment

According to [1], NII is not suitable for this vessel. In order to make the vessel suitable, a more detailed corrosion risk assessment could be undertaken to improve the confidence in ability to predict corrosion to medium. For this vessel, however, it is possible to argue for NII on the basis of practicality. The only way to allow a robust IVI, is to remove the Column and Condenser and remove the internal packing and heat exchanger, otherwise the only inspection possible is limited to boroscope. NII, therefore, offers the possibility of an improved inspection over boroscope.

A6.5 Strategy Selection

A full IVI, with the internals removed, would be the preferred option. If, however, a boroscope inspection is the only alternative, then a Type A NII strategy, but with increased coverage, is appropriate.

A6.6 Inspection Requirements

Table A6-6 Still Column and Reflux Condenser inspection requirements

Setting	Requirement	Relevant § in [1]
Probability of detection	1.5 mm with aspect ratio of 5	4.6.2
Sizing accuracy	±0.5 mm (80% tolerance)	4.6.2
Coverage	50% see calculation below	4.6.3

A6.7 Coverage

$$C_R = F_{COV} \times F_{CONS} \times F_{ZONE} \times C_1$$

Table A6-7 Still Column and Reflux Condenser coverage calculation (see §4.6.3 in [1])

Factor		Result	Reason
Base coverage	C_1	5	CRA material
Coverage modifier	F_{COV}	4	Low confidence in degradation prediction (from RBA)
			Low density expected (conservative assumption)
Consequence of failure	F_{CONS}	1	High (from RBA)
Zone surface area	F_{ZONE}	1.5	Whole vessel considered (A = 5 – 10 m^2)
Coverage required	C_R	30%	$C_R = 5 \times 4 \times 1 \times 1.75 = 30\%$

Since this vessel is small, has such limited inspection history and it is likely that all insulation will need to be removed during a shutdown to allow inspection, a higher coverage of 50% is recommended.

A6.8 Work Scope

Table A6-8 Still Column and Reflux Condenser coverage and locations

	Result	Reason
Coverage	3.1 m^2	As per calculation: 50% of vessel
Inspection areas	11 x300 x 300 mm areas. Two full circumferential bands.	Many small areas to gather data from across entire vessel. Examining for run down.
Locations	Sampling across entire vessel. Sampling of nozzles; focus on process nozzles. Sampling of welds. Focus on areas inaccessible by boroscope.	Sampling to confirm absence of degradation. Areas most at risk of being missed by limited IVIs.

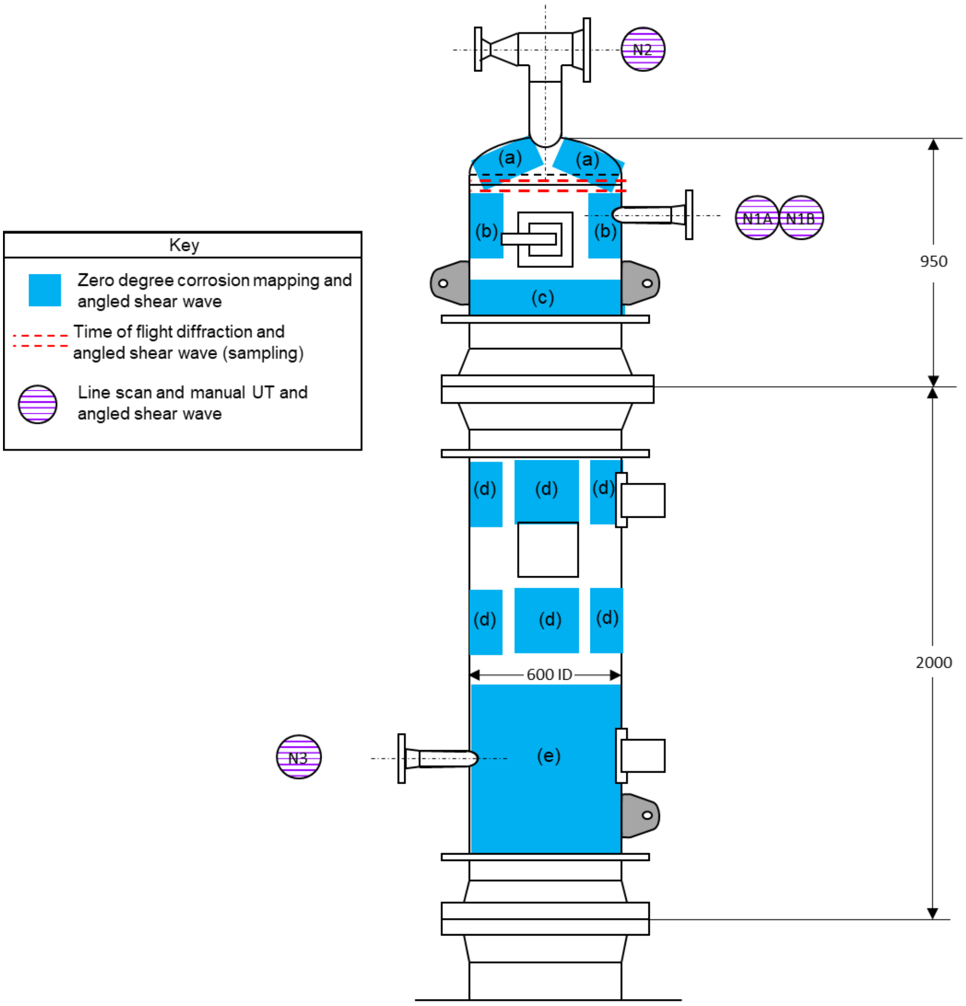

Figure A6-3 Limited inspection history example work scope

Appendix 7 Worked Example: NII Not Suitable

A7.1 Design and Function

Sand Trap function: captures small solid particles from fluid.

Table A7-1 Sand Trap design details

Parameter	Value	Informs
Commission date	1996	Corrosion risk assessment
Design code	Not known	Corrosion risk assessment
Contents	Drilling Fluids/Sand/Cuttings	Corrosion risk assessment
Material	Carbon Steel ASTM A283	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Internal lining	TBC	Corrosion risk assessment Strategy decision
Insulation	Yes	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Vertical	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel dimensions (LxWxH)	4000x1500x3500 mm	Coverage calculation
Wall thickness: Shell	Unknown	Inspection technique selection
Corrosion allowance	Unknown	Inspection performance requirements
MAWT: shell	Unknown	Inspection performance requirements
Design pressure	1 barg	Corrosion risk assessment
Operating pressure	0.1 barg	Corrosion risk assessment
Design temperature	50°C	Corrosion risk assessment
Max operating temperature	10°C	Corrosion risk assessment
Internal inspection interval	6 years	Corrosion risk assessment
Next scheduled internal inspection	2020	Corrosion risk assessment

A7.2 Corrosion Risks and RBA Information

Table A7-2 Sand Trap CRA summary

Degradation Method	Theoretical	Historical
Bacterial	Low threat	No damage reported.
Erosion	Low threat	No damage reported.
Crevice corrosion	Low threat	No damage reported.

Table A7-3 Slops Vessel RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Low	If corrosion occurred due to upset, likely to be either bacterial corrosion (low) or erosion (medium).	Inspection requirements
Homogeneity of degradation	Low	If corrosion occurred due to upset, likely to be either bacterial corrosion (low) or erosion (medium).	Inspection requirements

A7.3 History

Table A7-4 Sand Trap inspection history

Date	Inspection Type	Summary
2002	Visual internal examination	Vessel was found in good condition.
2008	Visual internal examination	Vessel was found in good condition with minor solid deposits.
2014	Visual internal examination	Vessel was found in good condition, mostly clean with some sand stuck to walls. Minor corrosion staining deemed not significant.

A7.4 Assessment

Following analysis of the available information on the vessel and application of the decision guidance procedure, the recommendation was that NII was not applicable as a full replacement of IVI for the vessel and deferment was not recommended.

There was some ambiguity over the presence of an internal coating and the tank could be entered outside of shutdowns. This meant that IVI would be the more cost-effective inspection method. A strong pre-screening process could have removed this vessel before detailed assessment was undertaken.

Appendix 8 Worked Example: NII Not Suitable

A8.1 Design and Function

Separator function: separates three phased (oil, water, and gas) through gravity and a weir.

Table A8-1 Three phase Separator design details

Parameter	Value	Informs
Commission date	1995	Corrosion risk assessment
Design code	BS5500 1997 Cat. 1	Corrosion risk assessment
Contents	Produced water/ oil/ gas/ sand	Corrosion risk assessment
Material	Carbon steel	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Internal lining	Yes – glass flake lined	Corrosion risk assessment Strategy decision
Insulation	No	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Horizontal	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	9000 mm	Coverage calculation
Internal diameter	3000 mm	Coverage calculation
External diameter	3000 mm	Coverage calculation
Wall thickness: Shell	40 mm	Inspection technique selection
Wall thickness: Domed ends	30 mm MAF	Inspection technique selection
Corrosion allowance	3 mm	Inspection performance requirements
MAWT: shell	37 mm	Inspection performance requirements
MAWT: domed ends	27 mm	Inspection performance requirements
Design pressure	27 barg	Corrosion risk assessment
Operating pressure	15 barg (max.)	Corrosion risk assessment
Design temperature	-5°C to 100°C	Corrosion risk assessment
Max operating temperature	60°C	Corrosion risk assessment
Internal inspection interval	5 years	Corrosion risk assessment
Next scheduled internal inspection	2020	Corrosion risk assessment

DEGRADATION NOTES:
1. Vessel fully lined with glass flake lining.
2. Various areas of internal coating breakdown and pitting of up to 5 mm were noted and subsequently repaired.

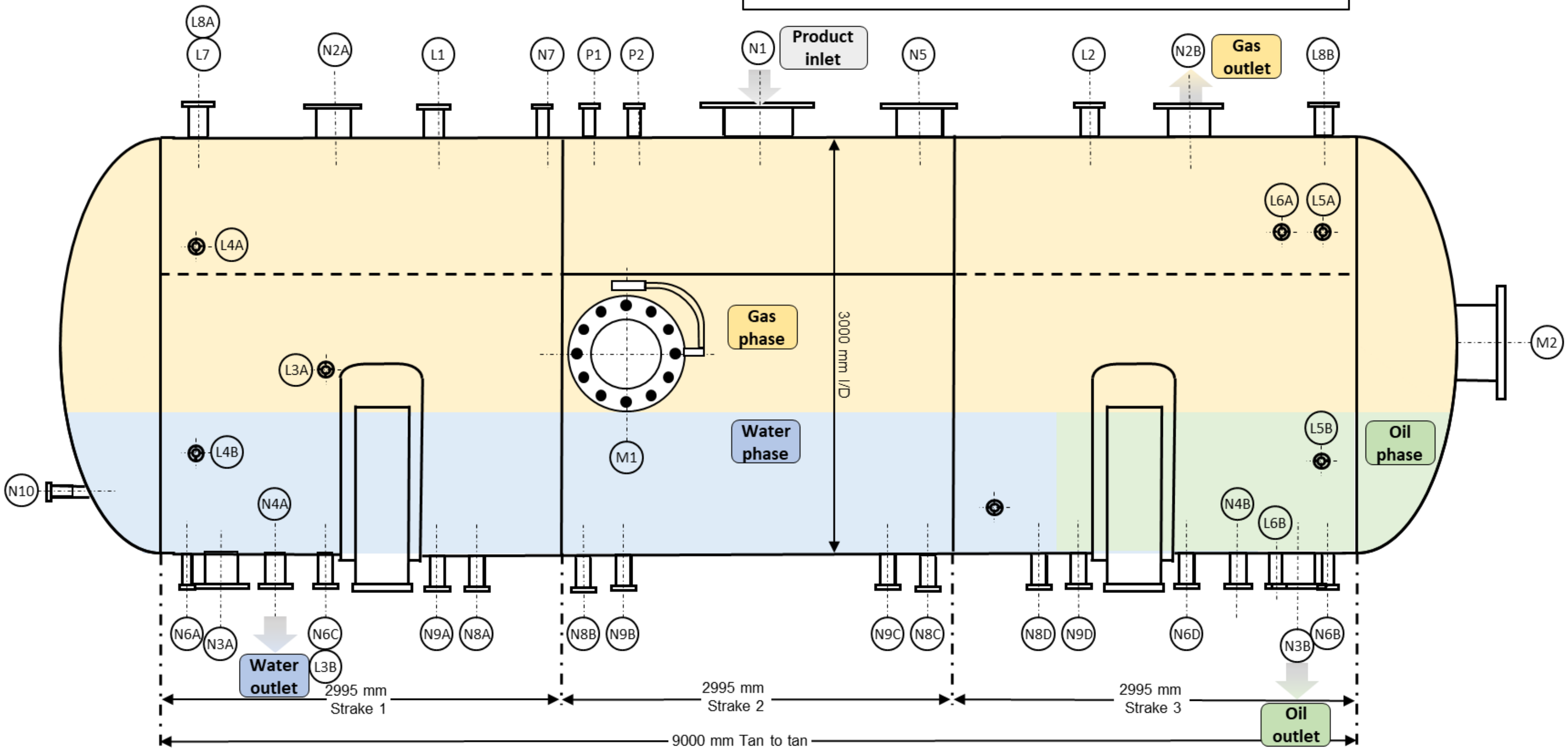

Figure A8-1 Three phase Separator process diagram

A8.2 Corrosion Risks and RBA Information

Table A8-2 Three phase Separator summary (Low to High threat: 1 to 5)

Degradation Method	Theoretical - Mitigated	Historical
Carbon Dioxide (CO_2)	1	Coating breakdown and pitting known. Based on theoretical corrosion rate of 0.5 mm/year, failure unlikely before cease of production due to this mechanism.
Hydrogen Sulphide (H_2S)	1	Coating breakdown and pitting known. Based on theoretical corrosion rate, failure unlikely before cease of production due to this mechanism.
Microbial Mechanisms	3	High bug count and no biociding.
Erosion Mechanisms	3	Sand is a known issue.
Under deposit	3	Sand is a known issue.
Sulphide stress corrosion cracking	1	Constructed from compliant materials.

Table A8-3 Three phase Separator RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Low	Isolated areas of lining loss possible.	Inspection requirements
Homogeneity of degradation	Low	Isolated areas of lining loss possible.	Inspection requirements

A8.3 History

Table A8-4 Three phase Separator inspection history

Date	Inspection Type	Summary
2000	IVI	Internal lining degraded by sand. Large sections of coating disbonded. No corrosion associated with areas of disbond.
2002	IVI	Opportune inspection. Further areas of coating degradation. No associated corrosion.
2005	IVI	Areas of chipped and blistering coating found.
2010	IVI	Coating breakdown found and repaired.
2012	IVI	10 tonnes of solids removed. Coating found to be significantly damaged with associated pitting of up to 5 mm deep.
2015	IVI	Further coating breakdown and additional pitting found.

A8.4 Assessment

Table A8-5 Three phase Separator NII assessment

Parameter	Reason	Decision
Confidence in ability to predict type and location of degradation	Type 1 risk assessment and at least 4 inspections.	Medium
Previous inspection effectiveness	Last inspection was by IVI.	Medium
Severity and rate of degradation	Degradation has been active previously at rates of up to 2.5 mm/year. This is different to the theoretical rate for CO_2 and is likely due to MIC.	High

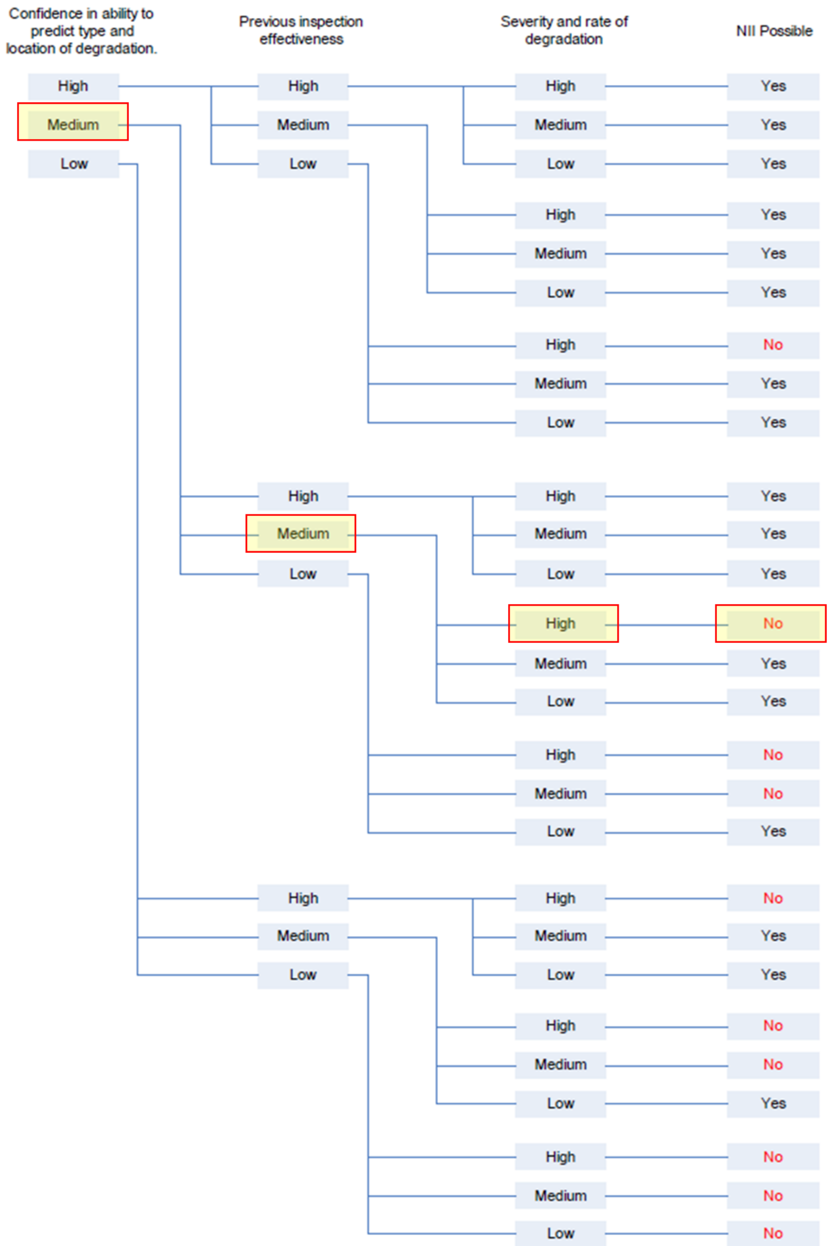

Figure A8-2 Degasser NII assessment

IVIs have taken place at intervals shorter than the set RBI interval and have continually found breakdown of the glass flake lining with corrosion occurring at high rates. Since NII cannot detect the condition of the lining and corrosion rates have been found to be high, NII is unlikely to be suitable as a replacement for IVI. In this case, it is likely that repairs to the lining will be required and potentially repairs to the vessel itself. NII may be useful to allow planning for repairs but this would still require a high coverage and would only allow planning for repairs to the vessel, not the lining.

Appendix 9 Worked Example: NII for FISI

A9.1 Design and Function

Expansion Vessel function: Allows for expansion of the heating medium within the system.

Table A9-1 Expansion Vessel design details

Parameter	Value	Informs
Commission date	2017	Corrosion risk assessment
Design code	ASME VIII Div.1 Ed. 2007	Corrosion risk assessment
Contents	Heating medium	Corrosion risk assessment
Material	Carbon steel	Corrosion risk assessment Inspection technique selection Deployment method selection
External coating	Paint	Inspection technique selection
Internal lining	None	Corrosion risk assessment Strategy decision
Insulation	Yes	Inspection timing (on-line or off-line) Cost efficiency calculations
Vessel orientation	Horizontal	Corrosion risk assessment Inspection technique selection Deployment method selection
Vessel length	12200 mm	Coverage calculation
Internal diameter	4500 mm	Coverage calculation
External diameter	3000 mm	Coverage calculation
Wall thickness: Shell	25 mm	Inspection technique selection
Wall thickness: Domed ends	25 mm MAF	Inspection technique selection
Corrosion allowance	3 mm	Inspection performance requirements
MAWT: shell	22 mm	Inspection performance requirements
MAWT: domed ends	22 mm	Inspection performance requirements
Design pressure	9 barg	Corrosion risk assessment
Operating pressure	5 barg (max.)	Corrosion risk assessment
Design temperature	200°C	Corrosion risk assessment
Max operating temperature	150°C	Corrosion risk assessment
Internal inspection interval	5 years	Corrosion risk assessment
Next scheduled internal inspection	2022	Corrosion risk assessment

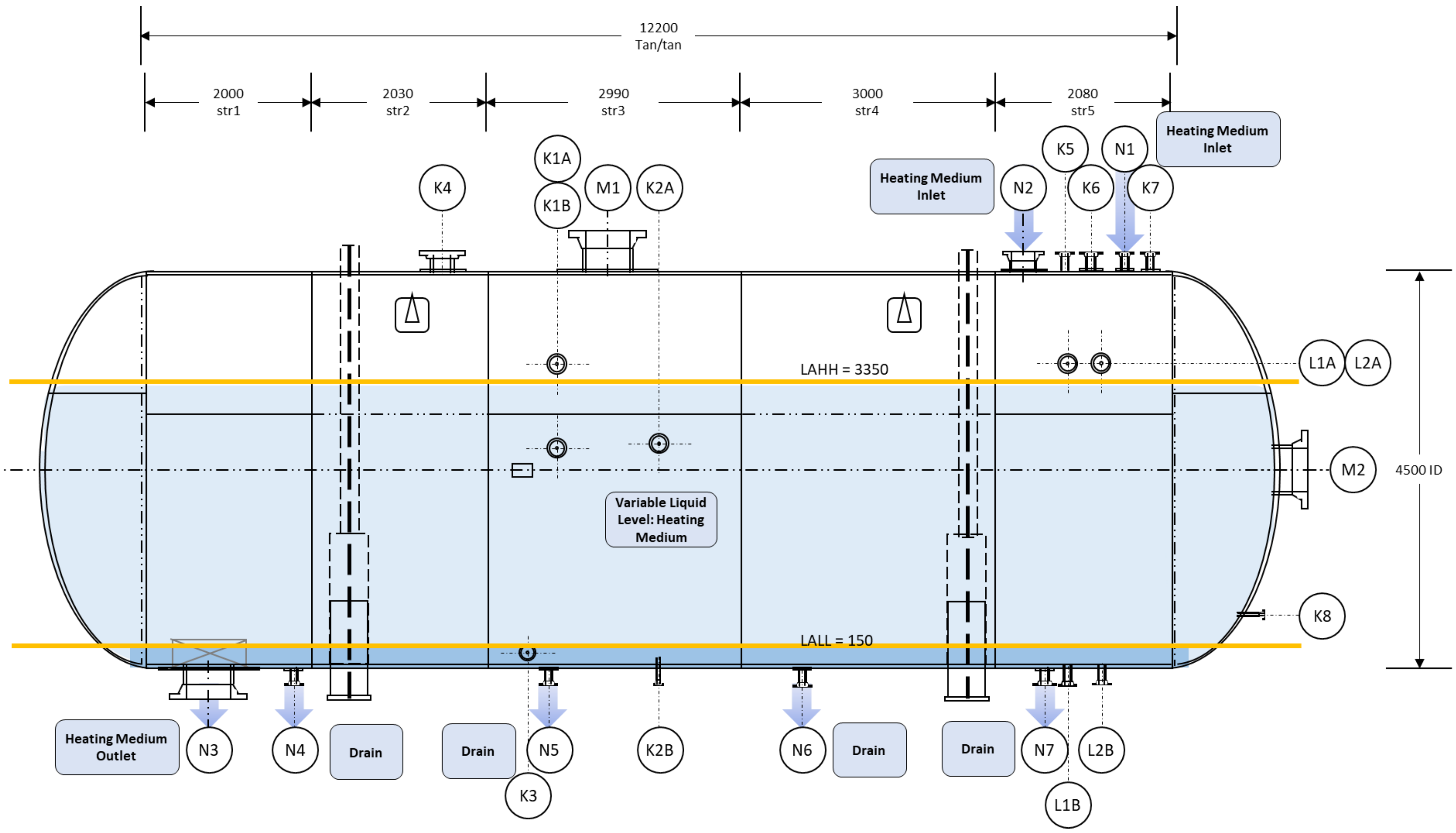

Figure A9-1 Expansion Vessel process diagram

A9.2 Corrosion Risks and RBA Information

No credible degradation mechanisms were identified for this vessel in the RBA. Since this is the first in-service inspection, a more detailed corrosion risk assessment is required which includes looking at the potential impacts of upset conditions. For the heating medium system, there is potential for the medium to fall out of specification (e.g. from overheating) leading to the potential for organic acidic corrosion. Cracked deposits of glycol are likely to collect at the bottom of the vessel which may lead to localised corrosion. A Process Engineer was consulted to confirm that there was no evidence of upset conditions having occurred since commissioning. This included a review of the pH of the heating medium. It is therefore assumed that localised degradation is unlikely.

Table A9-2 Expansion Vessel RBA additional information

		Source/reason	Informs
Consequence of failure	High	RBA	Inspection requirements
Density of degradation	Medium	Localised unlikely.	Inspection requirements
Homogeneity of degradation	Medium	Localised unlikely.	Inspection requirements

Manufacturing related issues must also be considered for FISI. The vessel was designed and manufactured according to internationally recognized standards including quality assurance inspection prior to acceptance for service (certified by a third party). No issues were raised in the pre-service inspection (see History) and no manufacturing issues had been raised from other vessels produced by the same manufacturer. Welds are the most susceptible features to manufacturing flaws and, although commissioning inspection will have examined the welds, the inspection coverage should take account of this.

A9.3 History

Table A9-3 Expansion Vessel inspection history

Date	Inspection Type	Summary
2016	Baseline IVI and UT	All UT readings around nominal. Some light rusting was observed uniformly across the internal shell and domed ends. This suggests the vessel has not had sufficient preservation during storage.

A9.4 Assessment

Table A9-4 Expansion Vessel NII screening

Parameter	Reason	Decision
Is vessel intrinsically suitable for NII?	No access issues, temperature issues, etc.	Yes
Has vessel previously been inspected?	Pre-commissioning inspection only; no in-service inspection.	No
Is vessel similar to others for which service history exists?	No other vessels on same train and of same design with inspection history	No

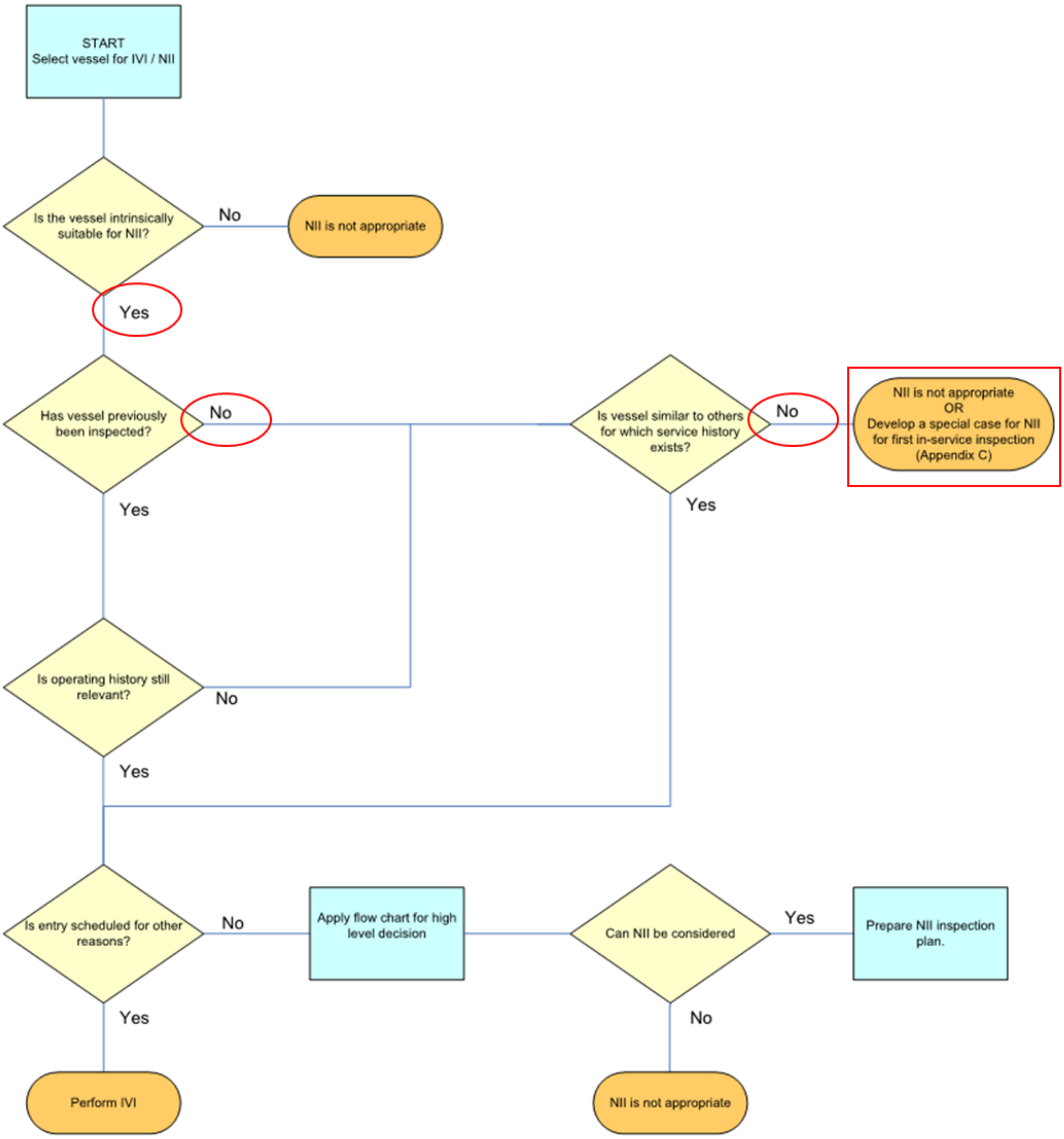

Figure A9-2 NII Screening for Expansion Vessel

Due to the lack of previous inspection history, the high level decision guidance chart (Figure 3-2 from [1]) does not apply for FISI as the "low" previous inspection categorisation would effectively rule out NII. A special case must be made for NII. The additional risks associated with NII for FISI are accounted for in the corrosion review, coverage, and technique selection.

A9.5 Strategy Selection

The primary objective of FISI is to identify and assess any potential degradation that may have occurred within the early stages of operation.

Table A9-5 Expansion Vessel strategy selection

Parameter	Reason	Decision
Degradation likely/ measurable within two inspection intervals?	Vessel is carbon steel and has potential for corrosion.	Yes
Degradation predictable?	Wetted areas along the bottom of the vessel are most at risk.	Yes
Degradation Low/ Medium?	In the event of degradation, it is unlikely to be a threat within two inspection intervals.	Yes

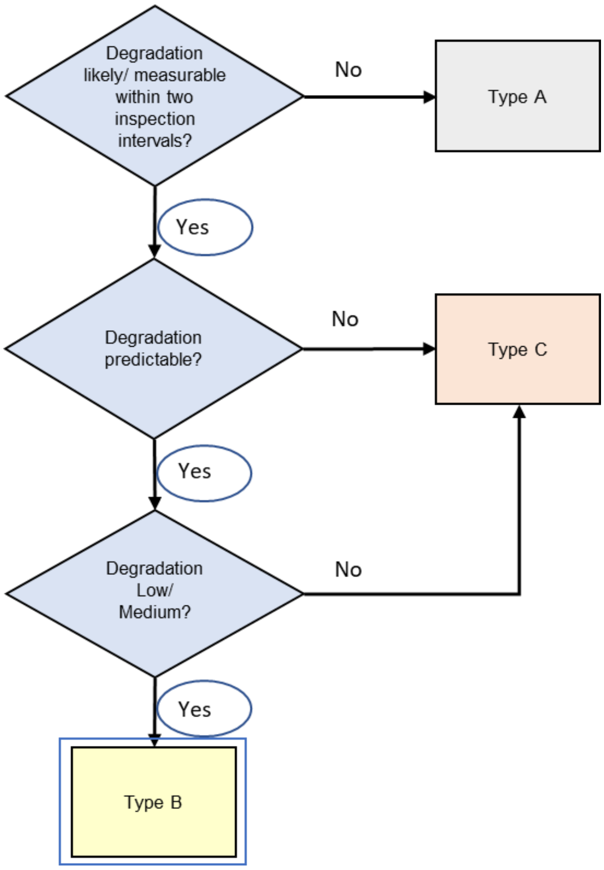

Figure A9-3 Expansion Vessel strategy selection

A9.6 Inspection Requirements

Table A9-6 Expansion Vessel inspection requirements

Setting	Requirement	Relevant § in [1]
Probability of detection	1.5 mm with aspect ratio of 10	4.6.2
Sizing accuracy	±0.3 mm (80% tolerance)	4.6.2
Coverage	30% see calculation below	4.6.3

A9.7 Coverage

$$C_R = F_{COV} \times F_{ACC} \times F_{LC} \times F_{CONS} \times F_{SH} \times F_{ZONE} \times C_1$$

Table A9-7 Expansion Vessel coverage calculation (see Section 4.6.3 in [1])

Factor		Result	Reason
Base coverage	C_1	25	Fixed value
Coverage modifier	F_{COV}	1	Medium confidence in degradation prediction (from RBA)
			Medium density expected (from NII review)
Consequence of failure	F_{CONS}	1	High (from RBA)
Zone surface area	F_{ZONE}	0.5	Whole vessel considered (A > 100 m^2)
Measurement accuracy	F_{ACC}	1	High (plan to use highly accurate inspection technique)
Tolerance to degradation	F_{LC}	1	Medium (3 mm corrosion allowance)
Spatial homogeneity	F_{SH}	1.15	Medium (from NII review)
Coverage required	C_R	15%	$C_R = 2\,5 \times 1 \times 1 \times 0.5 \times 1 \times 1 \times 1.15 = 14.4\%$

Since this is a FISI, it is prudent to increase the coverage to ensure confidence in the inspection. Increasing the coverage to 30% of the shell, and 50% of the welds, will help mitigate some of the residual risk associated with any possible unidentified manufacturing and process issues. **While there is a clear need for increased coverage for FISI, there are no defined rules for this at present. Each case should be considered individually, and the coverage should be commensurate with the consequence of failure.** If the NII confirms the RBA assumptions, further inspections could be at the lower coverage.

A9.8 Work Scope

Table A9-8 Expansion Vessel coverage and locations

	Result	Reason
Coverage	67 m^2	As per calculation: 30% of vessel
Inspection areas	Four 600 x 600 mm areas on domed end. 600 – 800 mm wide bands circumferentially on each domed end and strake. 800 mm wide band along BDC. 50% of welds.	Sampling to examine for corrosion with higher coverage along the bottom of the vessel.
Locations	High coverage of bottom of vessel. Bands around full circumference. Sampling on domed ends Sampling of nozzles. Sampling on welds.	Aim for high coverage along bottom of vessel where corrosion is most likely to occur. Circumferential bands ensure full coverage of different process areas (e.g. looking for “tide lines”). High coverage on welds to examine for manufacturing issues.

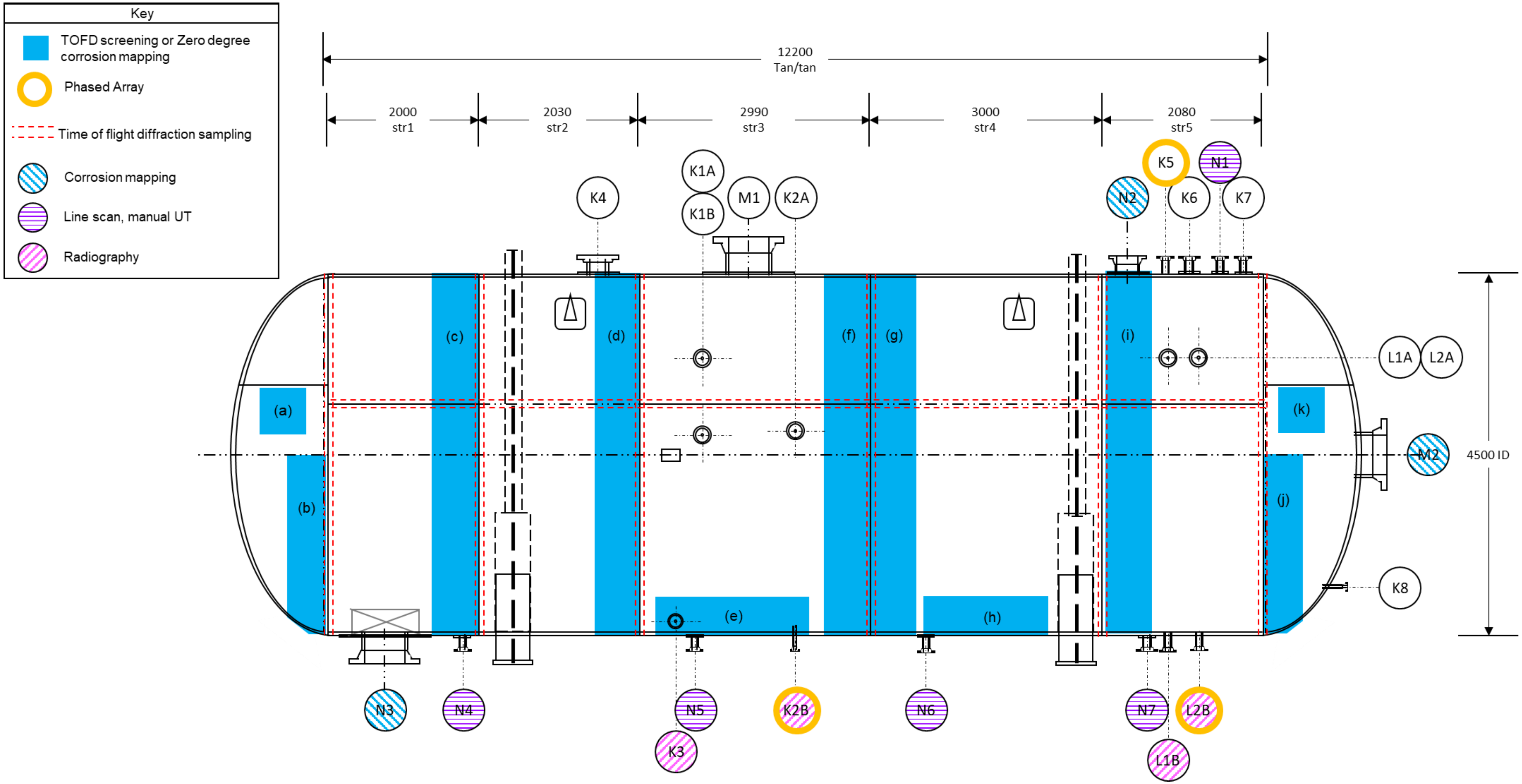

Figure A9-4 FISI example work scope

Appendix 10 Example: NII Evaluation

A10.1 NII Assessment and Scope

A three phase Separator was assessed for suitability for NII. Based on the material, history and corrosion risks, a Type B inspection strategy was recommended. The main inspection technique recommended was corrosion mapping or TOFD screening and the coverage was required to be at least 22%.

A10.2 Inspection Results

The inspection found wall loss along the bottom of the vessel.

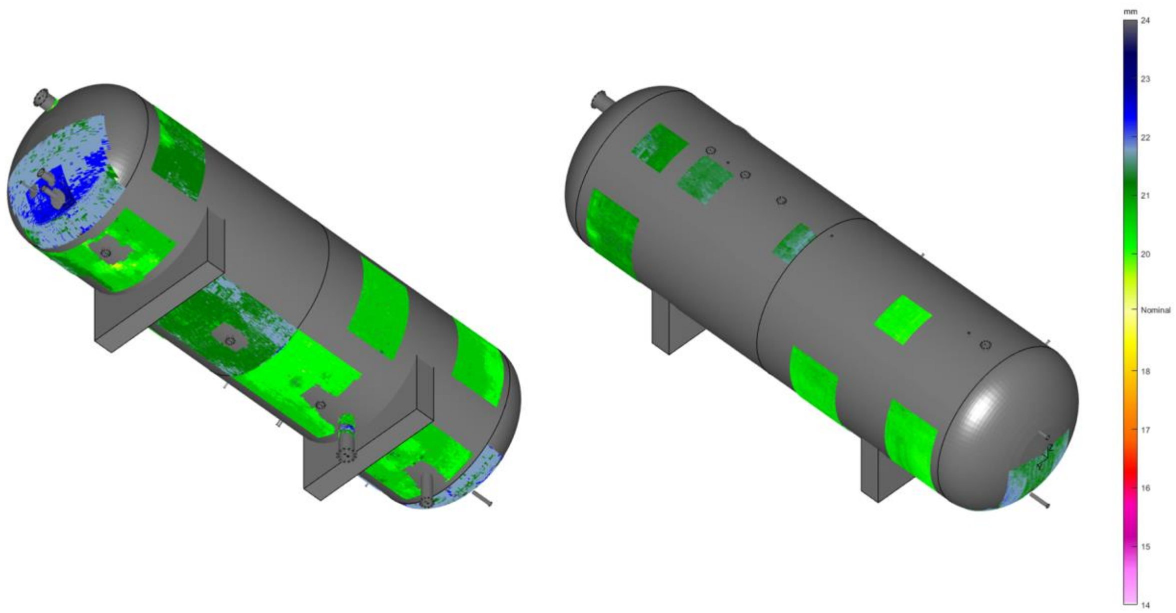

Figure A10-1 Example inspection results for a Type B inspection

A10.3 Conformance

The locations and coverage achieved was reviewed for each individual task. This is summarised pictorially in Figure A10-2. The majority of the inspection was to at least a Level 2 conformance which provides good grounds for replacing IVI.

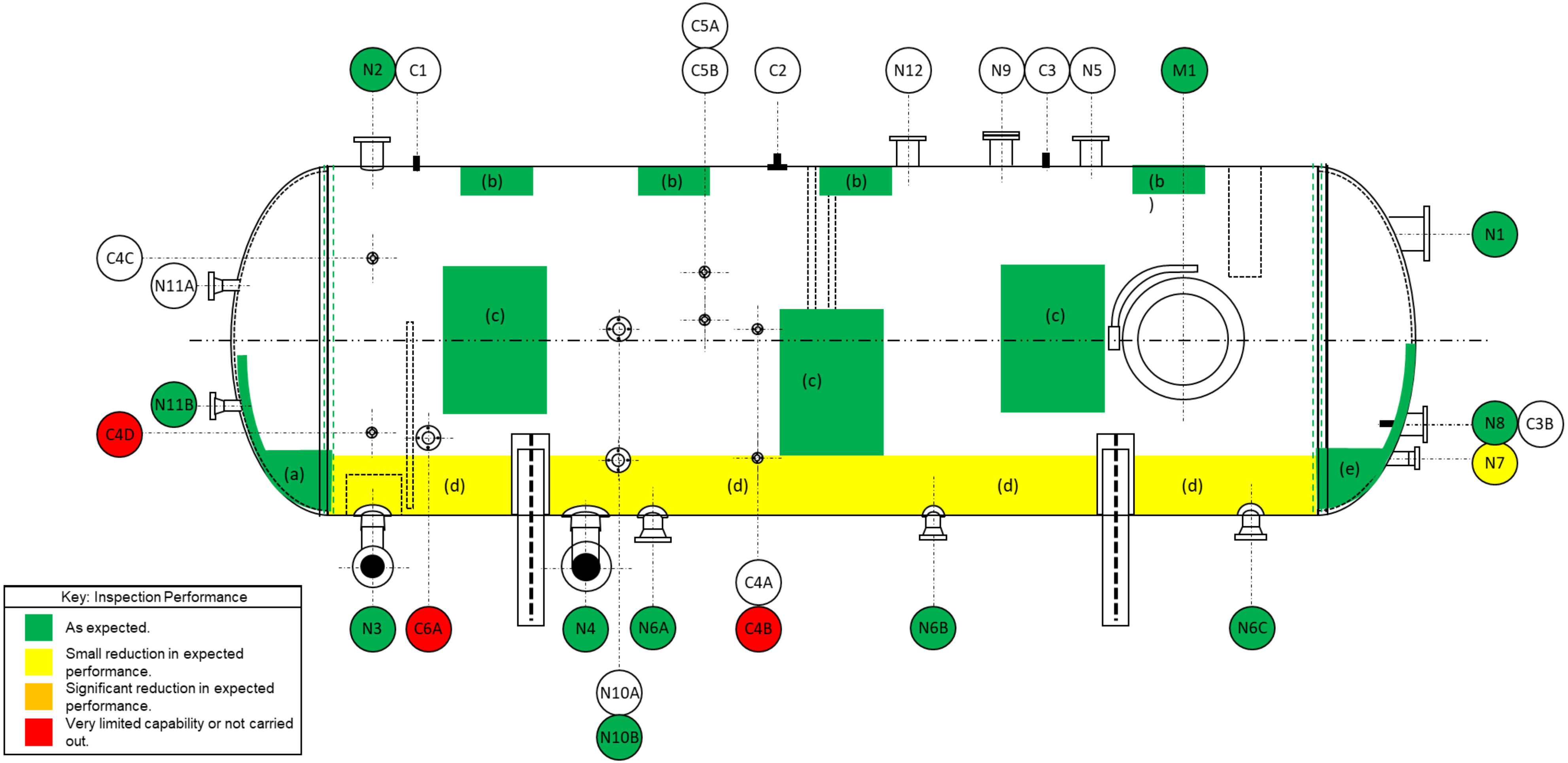

Figure A10-2 Example conformance review

A10.4 Analysis of Data

Each zone was analysed separately (in this case, each domed end, strake, weld, and nozzles). Cumulative thickness distributions were produced for each zone to look for trends in the data. Most areas showed normally distributed data which provides support to the assumption of no degradation. The areas which did have corrosion reported in the inspection report showed a break from normal. Figure A10-3 shows an example of a zone with corrosion. The tail of the distribution deviates at approximately 19 mm; only 0.1% of the data is affected. By fitting to the tail, a conservative minimum in the uninspected regions was estimated to be 17.8 mm (0.2 mm less than the minimum found).

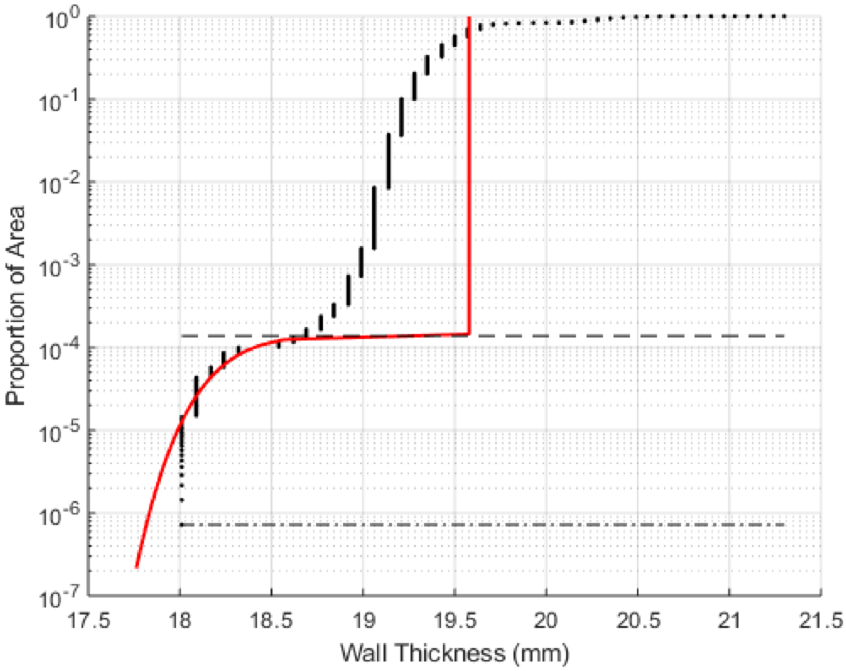

Figure A10-3 Cumulative distribution of thickness values from a strake

Using the extrapolated minimum and assuming corrosion commenced after the last inspection, the calculated average corrosion rate gave a remaining life beyond two inspection intervals.

A10.5 Conclusions of the Evaluation and RBA Update

Conclusions and recommendations from the evaluation included:

- The NII could be used in support of reassessing the inspection grade of the vessel and the RBA could be updated using the information.
- Readings from several nozzles did not match the GA nominal wall thickness. A recommendation was made to confirm the nominal wall thickness.
- Several areas for monitoring were recommended to improve corrosion rate estimates.
- The NII was considered to have been successful in replacing the planned IVI and the full inspection interval could be applied.

Appendix 11 Examples: Successful NII

A11.1 Type C

Glass flake lined vessels require high coverage (close to 100%) as the locations of any breakdown in lining are not predictable. Figure A11-1 shows an example Type C inspection. The main inspection technique was corrosion mapping but where mapping was not possible, i.e. in the white areas of the shell, manual UT was carried out. This highlights why a high coverage is required; the likelihood of sampling inspection locating the small pit would be low. A fitness for service assessment found the vessel was still safe for operation subject to a monitoring programme until a convenient time for repair.

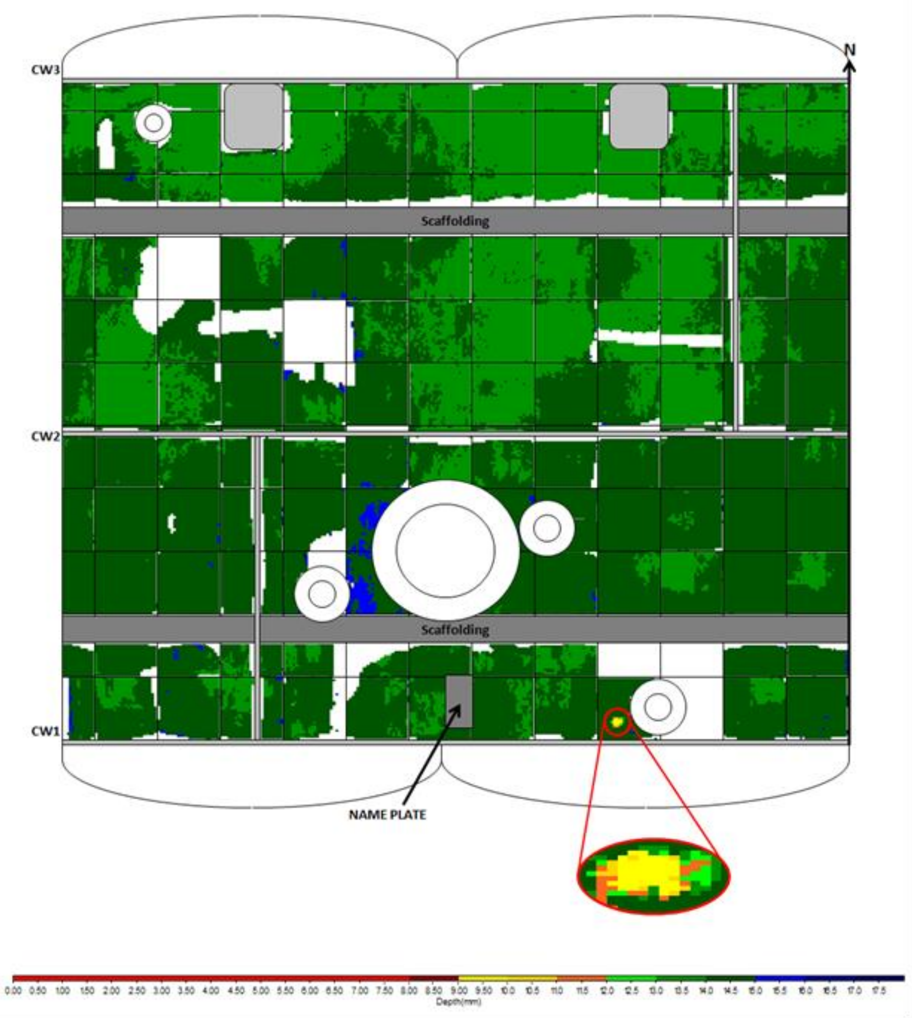

Figure A11-1 Example successful Type C inspection

A11.2 Type B

A Recirculation Vessel at a chemical refinery was assessed as suitable for NII using a Type B inspection strategy. A sampling coverage was recommended across the vessel with high coverage at process regions. The inspection found internal flow related wall loss around an impingement plate as shown in Figure A11-2. The NII successfully identified areas where wall loss was most likely. On-site changes to the scope based on the inspection results allowed the entire area of concern to be inspected in one mobilisation. The NII evaluation considered the

NII to have been successful as a replacement for IVI. Recommendations were made regarding FFS and monitoring of the impingement area.

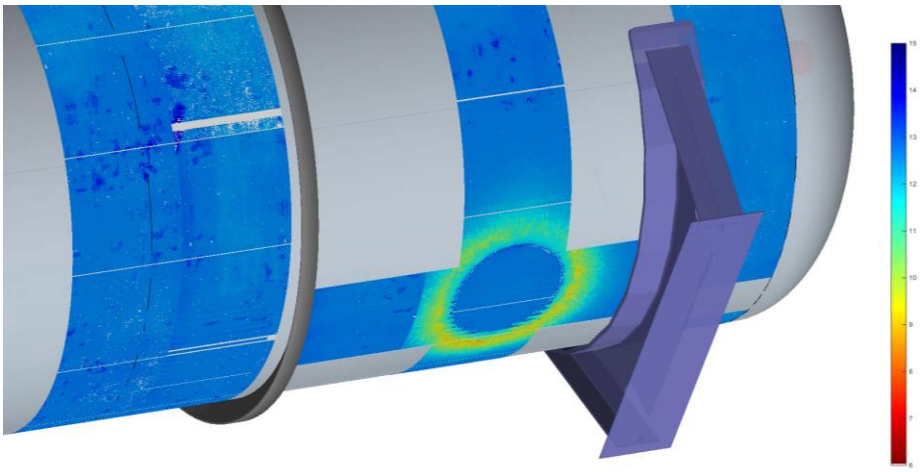

Figure A11-2 Example of successful Type B NII

A11.3 Severe Unexpected Degradation

A Recirculation Vessel at a chemical refinery was assessed as suitable for repeat NII using a Type B inspection strategy. A sampling coverage was recommended across the vessel with high coverage at process regions. The repeat NII found severe corrosion in one of the process regions which has not been anticipated in the corrosion risk assessment. No other region showed corrosion. Recommendations included FFS, monitoring the area and updating the RBA. The NII successfully selected areas where wall loss was most likely. The exact location of the degradation may have meant an IVI would not have been able to identify this due to internal furniture obscuring the view, but IVI supported by NDT may be the more appropriate strategy for the next inspection.

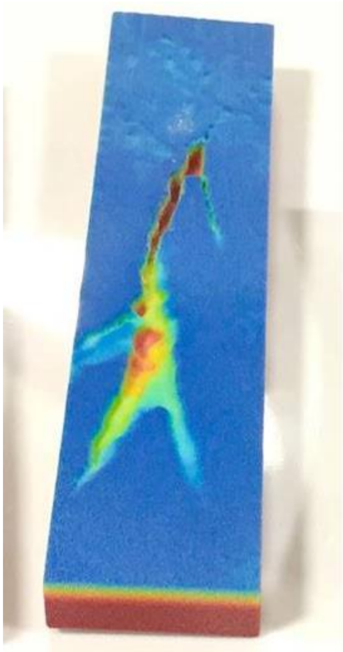

Figure A11-3 3D print of severe wall loss in a Recirculation Vessel

Appendix 12 Examples: Unsuccessful NII

A12.1 Scan Resolution

A glass flake lined Water Skimmer was assessed as suitable for Type C NII. The vessel was inspected using corrosion mapping and manual UT where corrosion mapping was not possible. On review of the inspection results, and after evaluation, the NII was deemed a successful replacement of IVI with no corrosion having been identified. During a subsequent IVI, a deep localised corrosion pit was found. On review it was evident that the inspection had covered the location of the pit. It was considered that the scan resolution had been too coarse to identify the corrosion since it was of small diameter (approximately 20 mm). The following lessons can be taken from this example:

- Resolution of inspection techniques should consider the type of corrosion possible and should be such as to ensure the POD requirements are reliably met.
- Care should be taken when using screening techniques for a Type C inspection.
- NII cannot confirm the integrity of the internal lining. Where high corrosion rates are anticipated if the lining breaks down, such that the vessel could fail within two inspection intervals, IVI may be more appropriate.

A12.2 Insufficient Reporting and Evaluation

A pressure vessel was fully inspected using corrosion mapping. One region was reported back as defective and in need of repair. Upon entry of the vessel during a TAR, numerous areas of significant damage were found that required weld repair. The POD for these types of defects should have been high for the technique used but they were not identified in the NII. A detailed investigation into the inspection revealed that extensive historic CUI damage was not fully reported in the NII inspection report. The external surface would have significantly reduced the reliability of the data and the POD over the areas affected. The following lessons can be taken from this example:

- The inspection report should include all external factors that may have an impact on the inspection.
- The evaluation should review the inspection results including areas of missing data and signal quality.
- As a minimum, a qualitative review of POD should be undertaken in the evaluation.
- While the NII focusses on internal threats, there is a duty of care to report any external degradation that may have an impact on the vessel integrity.

A12.3 Insufficient Coverage for Type C

A glass flake lined horizontal vessel was assessed as suitable for Type C NII, but the inspection work scope limited coverage to the lower part of the vessel only. The inspection did not identify any corrosion of concern. The vessel later failed by a leak at a location above the region of coverage. The following lessons can be taken from this example:

- As close to 100% coverage as possible is required for glass flake lined vessels.
- Where 100% coverage is not achieved, the risk of corrosion in the areas not inspected must be considered and shorter inspection intervals applied if appropriate.
- NII cannot confirm the integrity of the internal lining. Where high corrosion rates are anticipated if the lining breaks down, such that the vessel could fail within two inspection

intervals, internal inspection including methods which can verify the condition of the lining with high reliability may be more appropriate.

A12.4 Incorrect Locations

A horizontal vessel with internal polymer lining was inspected externally with the aim being to replace a scheduled internal visual inspection. The work scope specified corrosion mapping coverage of the 4-8 o'clock region. No damage was identified in this region. The technicians made a decision to extend the coverage selectively, including some regions above the 4 and 8 o'clock levels. An area of significant internal corrosion was found in this additional inspection and vessel entry for repairs was deemed necessary. Note that in this case failure of the vessel was averted but only because the technicians took the opportunity to increase coverage over that specified. The original work scope was not appropriate and had it been followed, with no further activity, a loss of containment may have occurred in the interval before the next planned inspection.

This example highlights the following:

- The need for a structured approach to NII.
- Type C strategy selection for zones with internal polymer linings which aim to protect the carbon steel from corrosion. The need for 100% coverage over such zones is emphasised.

A12.5 Incorrect Locations

A vessel subject to NII later failed at the connection of a set-in nozzle to the vessel shell. The corrosion started at the shoulder of the nozzle and had progressed to the shell. The planned NII did not consider this area at risk of corrosion and had not identified it for inspection. The following lessons can be taken from this example:

- Corrosion risk assessments must be developed with NII in mind and should consider the risk of corrosion at areas that are difficult to inspect (e.g. nozzle corners, under saddle supports, flange faces).
- Inspection of nozzle corners should be considered in NII. In this case future inspections included manual UT inspection for nozzles without doubler plates, and Multiskip for nozzles with doubler plates.
- Where there are no NDT techniques suitable to inspect high risk areas, IVI may be more suitable.

Appendix 13 Frequently Asked Questions

A13.1 Corrosion Risk Assessment

If the CRA has determined that a mechanism is not expected, e.g. preferential weld root corrosion (PWRC), do we have to inspect for it?

An IVI can often find corrosion that has not been anticipated in a CRA, while an NII needs to be designed to ensure the known corrosion mechanisms are covered as well as any "unexpected" mechanisms, e.g. from upset. The CRA should have reviewed potential mechanism under upset conditions for the purposes of NII. Where there is significant confidence that a corrosion mechanism is not active, there could be an argument for not requiring inspection, e.g. PWRC is not expected, so no inspection is required on the welds. However, this would require the following to be confirmed:

- No process upsets have occurred since the last robust inspection.
  - This would require an in-depth review of all process data including temperature and pressure readings, chemical injection readings, corrosion inhibitor levels etc.
  - Where process upsets have occurred, confirmation is required from Process and Corrosion Engineering that any variations are unlikely to have affected the corrosion risks; i.e. confirmation that the mechanism is unlikely to occur even under upset.
- Substantial and reliable previous inspection data is available which confirms that the mechanism in question has not been active, e.g. an IVI coupled with TOFD confirmed no PWRC in different inspections across several years.

Where there is no inspection history, or history where little confidence can be assigned to the integrity knowledge, it is recommended that inspection is still carried out for "unexpected mechanisms" on the basis that a theoretical corrosion assessment by itself, is unlikely to be enough to anticipate potential consequences of upset.

Our CRA has not determined the spatial distribution of the degradation (density and homogeneity). Can we still do NII?

Where CRAs are deficient in any area, it is acceptable for the person undertaking the NII Assessment to do further review/ analysis to fill in gaps. This should be carried out by a person who has been deemed competent by the Operator (or in turn by the contracting company that the asset owner has deemed competent to undertake the Assessment).

How do I know what the homogeneity/density is likely to be?

The homogeneity and density of degradation should be considered in the corrosion risk assessment. This can be based on previous inspection reports where corrosion has been found, or theoretical assumptions based on the type of corrosion expected. Currently there is limited research in the literature about spatial distribution and theoretical modelling. Some broad examples are provided in the table below. Note that these can be taken as a starting point but should be updated with evidence wherever possible.

Table A13-1 Examples of spatial distribution (homogeneity and density) based on available literature for different corrosion types

Situation	Homogeneity	Density
Microbial influenced corrosion	Low	Low
Under deposit corrosion	Low	Low
CO_2 corrosion, carbon steel vessel T < 20°C (non-uniform, fragile $FeCO_3$ surface layer [5])	Medium	Medium
CO_2 corrosion, carbon steel vessel T = 20 to 75°C (insufficiently adherent $FeCO_3$ surface layer [5])	Medium	Low
CO_2 corrosion, carbon steel vessel T = 75 to 120°C (adherent and protective $FeCO_3$ surface layer [5])	Medium	Medium
Chloride pitting in stainless steel	Medium	Medium

Are there any benefits to improving our corrosion risk assessment/ RBA?

Good integrity management, which includes a robust risk assessment or RBA, has its own benefits; the main one being ensuring continued safe operation of equipment. There are two benefits to ensuring a strong, and complete, CRA or RBA is in place for NII purposes. These are:

- More straightforward justification of NII over IVI.
- Inspection costs may be reduced.

The RP takes a common-sense approach to coverage: where confidence in knowledge about a vessel is low, higher coverages for inspection are required. This can increase inspection costs overall. Figure A13-1 shows an example of how increasing the confidence for a large vessel can reduce the coverage requirements; the improvements are most noticeable for a Type B vessel.

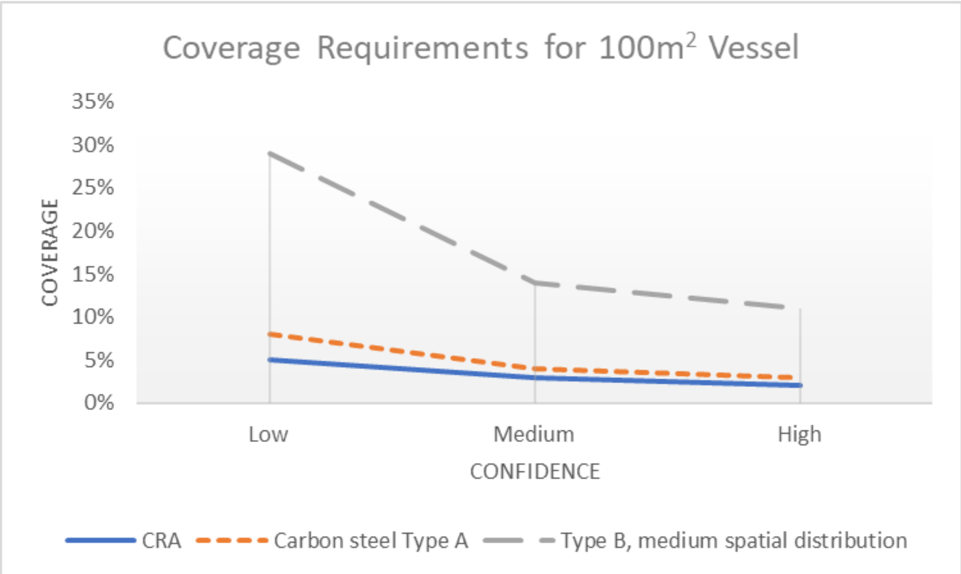

Figure A13-1 Coverage requirements for a 100 m² vessel with high COF and medium density

A13.2 Confidence in Ability to Predict Type and Locations of Degradation

What constitutes a Low/ Medium/ High confidence in ability to predict type and locations of degradation?

The Recommended Practice provides definitions for this quantity (Section 3.3 in [1]) but does not give explicit advice if your CRA and history do not match the definitions exactly. For example, a ***medium*** confidence requires a Type 1 CRA and four inspections, but a vessel may have a Type 2 CRA and 2 inspections, or the inspection may have been of low effectiveness. A common-sense approach is required with the confidence reviewed by an appropriately competent person. Where a stronger CRA is in place, less inspection history is required compared to the guidance in Section 3.3 in [1]. In practice, a ***high*** confidence is rarely seen in industry based on the CRA alone, and most RBAs and inspection histories meet the requirements for a ***medium*** confidence.

A13.3 Previous Inspection Effectiveness

What constitutes High effectiveness for previous inspections?

There is not a rigid definition of what constitutes High effectiveness. Since Medium effectiveness is “calibrated” against a good IVI, it should be more quantitative and robust than that. The following table provides some practical examples of effectiveness categorisations.

Table A13-2 Examples of effectiveness categorisations

Situation	Appropriate decision
Manual UT only	Low
Recorded as NII but no evidence of an evaluation of the inspection data and locations inspected do not meet the recommendations in [1]	Low
IVI carried out. Records do not give details, but state that corrosion was found. No information given on location or depths.	Low
IVI carried out. Records do not give details but that state no corrosion was found.	Medium
IVI carried out. Records provide details of the depths and locations of degradation and include photographs.	Medium
Recorded as NII but no evidence of an evaluation of the inspection data. On review of the available inspection report, the areas inspected. and the inspection techniques chosen appear to broadly meet the recommendations in [1].	Medium
IVI carried out. Records provide details of inspection and include photographs. MPI carried out on internal welds. UT carried out on sample areas across strakes and on nozzles. Data reviewed against expected mechanisms and RBA updated based on inspection.	High
NII carried out according to [1]. Evaluation shows inspection had high conformance to the planned inspection (i.e. nothing less than a Level 2 conformance). Robust analysis of the data was carried out such that there is a high confidence in the results (whether there was corrosion or not). Data reviewed against expected mechanisms and RBA updated based on inspection.	High

A13.4 Severity and Rate of Degradation

What constitutes a Low/ Medium/ High rate of degradation?
The Recommended Practice provides definitions for this quantity based on risk to the vessel within the plant lifetime (Section 3.3 in [1]). It is often useful to consider whether the expected rate will cause risk to the vessel within two inspection intervals. Selection should be conservative, considering uncertainty in the degradation rate estimates. Some practical examples are provided in the table below.

Table A13-3 Examples of degradation rate categorisations

Situation	Appropriate decision
Vessel composed of, or lined with, corrosion resistant material and no history of corrosion.	Low
Vessel composed of, or lined with, corrosion resistant material and history of corrosion (e.g. microbial). Calculated corrosion rate suggests remaining life >2x inspection interval.	Medium
Vessel composed of, or lined with, corrosion resistant material and history of corrosion (e.g. microbial). Calculated corrosion rate suggests remaining life <2x inspection interval.	High[1]
Vessel composed of carbon steel and sees dry gas. No history of corrosion.	Low
Vessel is carbon steel and see process fluids. No history of corrosion. CRA determines vessel at low risk of corrosion if mitigation (inhibitor) in place.	Low only if strong evidence of good inhibitor control otherwise: Medium
Vessel is carbon steel and see process fluids. History of corrosion. Calculated corrosion rate suggests remaining life >2x inspection interval.	Medium
Vessel is carbon steel and see process fluids. History of corrosion. Calculated corrosion rate suggests remaining life <2x inspection interval.	High[1]

A13.5 Strategy Selection

A Type C inspection will make NII economically infeasible. Can less than 100% be inspected?
A Type C is only applied where the risk of missing corrosion by not undertaking 100% coverage is either too high, or too severe, i.e. either the degradation cannot be predicted in location, or the rate of corrosion is so high that the integrity of the vessel is likely to be threatened if corrosion is missed. It is very difficult to justify reducing the coverage of a Type C pressure vessel with high consequence of failure while maintaining the inspection interval (see Appendices A12.3 and A12.4 for examples of failed NIIs). However, the following are examples of where the reviewer may be able to justify deviating from the recommended practice:

- A shorter inspection interval is to be applied, i.e. a deferral (see Section 8.5 of [1] for calculation of coverage).
- A fully glass flake lined vessel where it has been zoned such that some areas have no risk of corrosion, e.g. wetted areas are the only areas at risk. This would require a strong CRA (Type 3 or above) which clearly shows a negligible probability of corrosion of unprotected steel in the zones where reduced coverage is planned.
- A fully glass flake lined vessel where there are limited corrosion risks, e.g. a dry air receiver. This is a rare but real occurrence where a lining has been applied to a vessel with no significant risk of corrosion but there is limited information about why the lining was applied. This dichotomy would need to be addressed explicitly in the CRA.

[1] Where this is the case, the inspection interval is questionable, and the RBA should be reviewed.

- A glass flake lined tank operating at very low or atmospheric pressure where the consequences of a leak are not high (e.g. water tanks, small lube oil tanks). The risk of failure by leakage would have to be reviewed and accepted by the Asset Operator.

Any reductions in coverage in a Type C case should be very carefully considered. There is growing industry experience of integrity threatening degradation being missed in internally lined vessels where coverage was scaled back in order to reduce the cost of the inspection.

A13.6 Vessel Area

How do I calculate the surface area of a vessel?
An approximation is considered sufficient for the purposes of NII (i.e. there is not a requirement to account for area lost to nozzle openings etc). For most pressure vessels, consider the vessel to consist of a cylinder (excluding ends) and two half sphere domed ends.

Cylinder:

$$A_{shell} = \pi DL$$

Where *D= external diameter* and *L = length*

Half a sphere:

$$A_{dome} = 2\pi r^2$$

Where *r = radius of vessel* (based on external diameter).

Total area:

$$A_{total} = \pi DL + 2(2\pi r^2)$$

Alternatively, a 2:1 semi-elliptical dome would be as follows with $\varepsilon = 0.866$:

$$A_{dome} = \frac{\pi D^2}{8}\left(2 + \frac{1}{4\varepsilon} ln\left(\frac{2\varepsilon + 2}{2 - \sqrt{3}}\right)\right)$$

The area of a cuboidal tank can be calculated using:

$$A_{total} = 2LW + 2LH + HW$$

Where *L = length, W = width,* and *H = height*

A13.7 Locations

How do I select the areas for inspection?
This is governed by the inspection strategy type and the CRA; however, all inspection should aim to cover the different process regions (e.g. water, oil, and gas regions) with a focus on the most likely areas to experience corrosion.

In a Type A inspection, the aim is to sample enough of the vessel to confirm degradation is not active. Thus, the areas should be widely spaced along the length and round the circumference of the vessel. The emphasis should be on many small areas providing wide coverage across the vessel.

In a Type B inspection, the aim is to gather sufficient information to be able to make predictions (using statistics) about the condition of the uninspected areas. The areas can be larger and more focused on where corrosion is expected. Where there is history of corrosion, these areas should be inspected to examine for further growth, in addition to other areas to look for new corrosion.

As a general rule, the bottom of a vessel is often the most at risk of corrosion as liquids and debris tend to gather there.

Do I have to inspect all nozzles and flange faces?
Due to their different functions and geometries, nozzles often see significantly different corrosion conditions and it is more difficult to consider one nozzle representative of many compared to an area on strake. It is recommended that if a sampling approach is taken, a significant number of the process nozzles should be inspected. Other nozzles that should be inspected include any deadlegs, those that have a history of corrosion, and those that have a history of blockages.

Where there is an identified risk of flange face corrosion or damage, the flanges at risk should be inspected. A sampling approach may be sufficient depending on the level of risk identified. Similarly, if there is an identified risk to the nozzle corner (shell to nozzle weld), this should also be inspected for on nozzles where the risk is deemed credible.

Access to the bottom domed end is in a skirt and therefore challenging, do I have to inspect it?
This will depend on the CRA. If the highest risk is at the bottom of the vessel, it will be hard to justify not inspecting it if the NII is to be used as a replacement for IVI. Consider whether you can inspect the domed end without entry to the skirt (e.g. specialist tools, and/or robotic solutions), or whether you can use less effective methods but increase coverage (e.g. manual UT instead of automated corrosion mapping but over 100% of the area). If access is not possible for any methods, NII is unlikely to be suitable.

A13.8 Inspection Enactment

Do we need verification of NDT procedures (i.e. third-party approval) in order to ensure compliance with the proposed work scope?
The RP does not state what level of verification or competency is required from an inspection body for NII. Inspection bodies should be able to provide evidence that they can achieve the inspection scope and required POD, accuracies etc. This may be in the form of examples of past inspections, internal and/or external validations, or results of trials if the techniques are new. It is up to the asset owner to determine the level of assurance they require.

What is required to prove the inspection met the accuracy requirements?
Appendix D.3 of [1] provides some information on potential factors that can affect the accuracy, and ways to measure relative changes in these. It does not, however, provide advice on precise ways to measure the achieved accuracy. The HOIS Recommended Practice for precision thickness measurements for corrosion monitoring [6] sets out recommendations on probe selection, calibration, and wave form analysis (amongst other factors) which, when fully adopted have been demonstrated to deliver accuracy of ±0.1 to 0.2 mm, i.e. better than the highest accuracy requirements set out in [1]. Therefore, the best way to ensure the inspection meets the accuracy requirements is to follow in full the recommendations set out in [6] and perform a semi-quantitative review on the waveforms post inspection as suggested in [1]. Where there are significant variations in signal quality (e.g. significant differences in A-scan peak width across a file with no clear reason), this should be taken into account in the evaluation if the data is used for estimations for uninspected area, corrosion rate estimates, remaining life estimates, or fitness for service assessments.

Some areas which should be inspected are not accessible. What should we do?

Table 5-1 in the RP [1] provides guidance on what actions can be taken on-site if areas are not accessible for inspection. For Type A and Type B strategies, an inaccessible area can be substituted for another area provided the two areas experience similar conditions. For Type C's all efforts should be made to overcome the obstacle preventing inspection; this can include substituting the inspection technique for one with lower POD or reproducibility, e.g. manual over small areas where corrosion mapping is not possible. It is important for the inspection team and onshore team to be in agreement with changes to the work scope.

What other factors must be considered to enable inspection?
In order to ensure an NII is successful, it is important that the work scope is reviewed for practicality. This includes access requirements to the vessel, and any cleaning that may be required. In addition to the cost of the inspection, Operators need to consider peripheral costs such as scaffolding, grit blasting, insulation removal and reinstatement, etc. This can make NII more costly than IVI when comparing the inspection phase alone; savings mainly come from reduced shutdown and increased vessel availability.

A13.9 Conformance Levels

What conformance level equates to percentage work scope complete?
The Recommended Practice [1] provides an explanation of what constitutes a non-conformance for each Type of inspection (Section 6) and has tables for quick reference. Further guidance on the overall conformance of an inspection is provided in the following question.

Some areas were substituted due to access restrictions. Does this affect the conformance?
The location of the substituted area should be reviewed in terms of degradation risks and overall coverage and locations on the vessel. For example, on a Type A inspection, where the risk of corrosion is low, moving an area for inspection above bottom dead centre (BDC) compared to that planned is unlikely to be of concern. In a Type B inspection, however, the BDC may be the area at most risk and a shift could mean less useful information is gathered. If, however, several areas along BDC were collected and only one area was moved, the conformance could be viewed as minor (Level 2).

What affect does a reduced inspection accuracy have on the conformance of the inspection?
The RP takes account of reduced inspection accuracy by including a factor in the coverage calculation for Type B vessels. Reduced inspection accuracy requires coverage to be increased. If there is evidence that the inspection accuracy may not have been achieved in a Type B inspection, e.g. all data is saturated and waveform analysis is affected as a result, the data should be reviewed during the evaluation phase. Where no evidence of degradation has been found during an inspection, increased coverage may not be necessary but only a review of the data can confirm this. Where degradation has been found, it may be prudent to reinspect the same area using a more accurate technique (especially in cases where degradation may be significant in depth) or to increase the coverage as per the calculation in [1].

Some planned nozzles/ areas were not inspected, and substitutions were not made (for Type A/B). The Recommended Practice states that this is a Level 4 conformance, does this mean my NII has failed?

Using the worst-case conformance level for an individual component to determine the success of an NII provides a very conservative outcome. A common-sense approach is required in these circumstances, with a suitably competent reviewer considering the risks associated with missing the areas. The following table provides some examples for the different strategies.

Table A13-4 Example strategies for risk assessment of conformance decisions for incomplete inspections

Strategy	Actions	Low Risk?	Outcome
Type A	If high confidence[2] that no corrosion has been found in all other areas, consider risk that the missed areas may be different.	Yes	Overall conformance of NII is acceptable. Full inspection interval may be applied. Recommend next inspection must capture missed areas.
		No	Overall conformance of NII is not acceptable. Consider reducing inspection interval of entire vessel or requiring intermediate inspection for the missed areas.
Type B	If no corrosion has been found in all other areas, consider risk that the missed areas may be different.	Yes	Overall conformance of NII is acceptable. Full inspection interval may be applied, or reduced interval based on remaining life estimates. Recommend next inspection must capture missed areas.
		No	Overall conformance of NII is not acceptable. Consider reducing inspection interval of entire vessel or requiring intermediate inspection for the missed areas.
Type B	If corrosion has been found, consider what might be the remaining life if corrosion is active at similar, or worse, rate in the missed areas. Look at previous inspection reports for last known wall thickness. Consider risks associated with this.	Yes	Overall conformance of NII is acceptable. Full inspection interval may be applied, or reduced interval based on remaining life estimates. Recommend next inspection must capture missed areas.
		No	Overall conformance of NII is not acceptable. Consider reducing inspection interval of entire vessel or requiring intermediate inspection for the missed areas.
Type C	No corrosion has been found.	N/A	Reduce the inspection interval as per §8.5 of [1]. Or plan to inspect the missed areas ASAP.
Type C	If corrosion has been found, consider what might be the remaining life if corrosion is active at similar, or worse, rate in the missed areas. Look at previous inspection reports for last known wall thickness.	N/A	Reduce the inspection interval as per §8.5 of [1] or as per the remaining life calculations dictate. Or plan to inspect the missed areas ASAP.

A13.10 Data Analysis

What are the typical data analysis steps for Type A zones?

For Type A zones the data analysis should focus on (i) assessing and demonstrating that the performance achieved meets the requirements and (ii) checking that there is no evidence of degradation, even at a low level.

[2] If a high confidence is not achieved in a Type A, then the NII is considered unsuccessful anyway.

The first point is addressed by review and analysis of the data quality, specifically addressing questions around whether there are any factors that would cause a reduction in performance compared to what is expected from the procedures applied under conditions in which the performance requirements are reliably met. For plate material where 0° corrosion mapping is used the POD achieved can be determined by use of the HOIS corrosion mapping POD model. This uses actual data collected as input.

The second point above is addressed by detailed review of the data and, where applicable, additional analysis steps. For example, for plate material where 0°corrosion mapping is used the following additional analysis is useful.

- Removal of spurious data, e.g. associated with locally poor surface conditions.
- View the corrosion maps on a fine colour scale. This helps discriminate small changes in thickness and local variations.
- Plot and review the wall thickness distributions, looking for evidence of variations in tail behaviour, see [3].

What are the typical data analysis steps for Type B zones?

For Type B zones the aim is to use the data collected to make estimates of the condition in the areas not inspected. As such a sampling approach is used. The basis of the approach is to use the data collected to determine distributions which are used for extrapolation to estimate the minimum thickness. It is recommended [3] is consulted for details on how to carry out the analysis, however the key steps are summarised here as follows.

- Data clean up. Remove spurious data.
- Define analysis approach. There are two options typically, i.e. extreme value analysis or use of the full wall thickness distributions.
- Collate data into groups for each zone under consideration.
- Derive the wall thickness distributions.
- Check applicability of candidate distributions and carry out the distribution fitting.
- Make estimates for minimum thickness and probabilities for exceeding limiting conditions. Where applicable this should also include a review of sensitivity to sample selection.
- Report on findings in the evaluation report.

Note that the analysis for Type B inspections should also include consideration of inspection performance as achieved, i.e. measurement accuracy and POD.

What are the typical data analysis steps for Type C zones?

For Type C zones the emphasis is on (i) demonstrating that the POD achieved meets the performance requirement and (ii) reliable identification of any localised wall loss in the steel and finding the worst degradation in the zone.

The first point is addressed by review and analysis of the data quality, specifically addressing questions around whether there are any factors that would cause a reduction in performance compared to what is expected from the procedures applied under conditions in which the performance requirements are reliably met. For plate material where 0° corrosion mapping is used the POD achieved can be determined by use of the HOIS corrosion mapping POD model. This uses actual data collected as input.

The second point is addressed by detailed review of the data. The approach varies according to the technique used. In the case of internally lined vessels, wall loss can be very small diameter following a localised breakdown of the coating. The analysis approach should be tailored to meet this objective and recognise that one is effectively looking for mild to severe corrosion in random locations in these cases. A combination of automated analysis and manual review is recommended to give the highest reliability. Statistical methods can be helpful but should not be relied on in isolation, e.g. wall thickness distributions can identify very localised degradation in corrosion mapping data but should be used in conjunction with review of the corrosion maps and waveform data.

Appendix 14 Case for Use of NII

A14.1 Introduction

This section provides a brief summary of the requirements and benefits of NII. It is aimed at a non-technical audience and can be used to support the business and safety case for replacing IVI with NII.

A14.2 What is NII?

Non-intrusive inspection (NII) of pressure vessels and tanks provides an alternative to internal visual inspection (IVI) that avoids risky man-entry and costly shutdown. It consists of a detailed planning process, targeted application of externally applied, appropriate, non-destructive testing (NDT) techniques, and an evaluation phase to provide assurance that the inspection has provided sufficient confidence in the integrity knowledge for the vessel. It is not a random, or unplanned inspection using NDT techniques. The Recommended Practice (RP): HOIS-RP-103 provides extensive guidance on how to apply NII robustly. In order to provide sufficient assurance that risk levels are not adversely affected by replacing IVI with NII, either the guidance in HOIS-RP-103 should be followed, or alternatively, company specific procedure should be developed that meet the aims of the Recommend Practice.

A14.3 What are the benefits of NII?

OGTC have estimated that adopting NII could deliver increased production and lower maintenance costs worth up to £242 million per year to the UKCS. The benefits of good NII include:

Safety

- Remove requirement for vessel isolation and breaking of flanges.
- Remove requirement to put personnel in confined spaces.
- Remove requirement to decontaminate vessel.
- Reduce risk of incorrect sealing following completion of inspection.

Cost

- Reduce shutdown duration.
- Increase uptime (increased production).
- Reduce costs for vessel cleaning.
- Reduce manpower requirements for rescue teams, cleaning teams etc.
- Reduce bed space requirements during shutdown.

Knowledge

- Improved reproducibility of inspection results.
- Improved accuracy of corrosion rate estimates leading to:
    - Improved estimates of remaining life.
    - Improved inspection intervals.

Examples of actual savings include:

- NII on LP Separator reduced a planned 21 day shutdown by 10 days adding 3% to the annual availability of the platform.
- NII on 33 vessels on a gas plant saved 12 days of shutdown with £4 million saved.

Note that the total cost of an NII may be greater than an IVI (where scaffolding/ cleaning requirements are high, or coverage is high). Additional costs of NII need to be considered holistically with savings from reduced shutdown and increase availability of the vessel.

A14.4 What are the risks of NII?

As with all forms of inspection, a poorly planned and executed NII may lead to increased risks of vessel failure. IVI has the advantage that usually the entire internal surface of the vessel can be seen; NII often uses more targeted inspection areas. Poor application of NII includes:

- Using NII where there is insufficient confidence in corrosion risks.
- Using NII where there is a risk of failure of the internal furniture.
- Using inappropriate levels of coverage for inspection (e.g. low coverage when corrosion is unpredictable).
- Using inappropriate inspection techniques for the types of corrosion expected.
- Inspecting the wrong areas of the vessel (where sampling inspection is carried out).
- Applying the inspection techniques poorly.
- Failure to evaluate the inspection results for compliance with the planned inspection.
- Failure to review and analyse the inspection results to determine current integrity status of the vessel and likely future status.

One of the objectives of the Recommended Practice is to reduce this risk. NII will not be suitable for all vessels and should not be applied without due regard for the risks involved. From industry experience, a high proportion may be technically feasible across an asset for NII but only a proportion of these would also be strategically suitable for NII.

A14.5 What support is needed to implement NII in my organisation?

NII planning can be carried out in-house or an external supplier can be appointed. In order to implement NII successfully, the process requires significant input from several disciplines including:

- Process
- Corrosion
- Integrity
- Inspection
- Data science

It is important that all stakeholders understand the basic principles of NII and their role in the process which will require training, or time to allow familiarisation with the RP.

One of the key requirements for NII is an understanding of the history of the vessel, and the corrosion risks. The RP uses a common-sense approach to coverage: where there is less confidence in the risks, coverage should be increased. In order to allow NII to take place, and to reduce inspection costs, this may require improvement and/or update of any risk-based inspection (RBI) processes and/or corrosion risk assessments (CRA).

A14.6 What do I need to look for in an NII provider?

An NII provider should be able to demonstrate knowledge and understanding of the RP and be able to confirm that they can work to the RP requirements. They may not offer the entire process; for example, a company may offer inspection, but no NII planning. In these instances, the provider should be able to demonstrate how they can work with other service providers, or with in-house integrity staff, to ensure the entire NII process is implemented robustly, e.g. an inspection company should be able to show how their inspection reports can provide sufficient information for the evaluation phase.