Living with Defects: Replace/Repair or prove Fitness-For-Service (FFS)?

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13th International Conference on Pressure Vessel & Piping Technology, 20-23 May 2012, London

Keynote Paper – Technical Session: Replacement and Fitness For Service

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Abstract

When oil, gas, petrochemical or power generating plant items are replaced or repaired simply because, for example, the corrosion allowance has been used up or some minor cracking has been detected or material property changes and/or metallurgical degradation are suspected due to active Damage Mechanisms (DMs), the cost implication to the operating companies is enormous. With the availability of established proven Fitness-For-Service (FFS) assessment technologies, for example BS-7910 and API-579, rejection of these items should not be therefore necessarily automatic.

By this principle, an item is considered to be fit for the intended service, if it can be demonstrated (with acceptable safety margin) to BS7910 or API 579 that the conditions to cause failure is not reached within a predetermined time period, giving due regard to its DMs induced risks and the HSE (Health, Safety & Environment) and Business Consequences of Failure.

Application of Fitness-For-Service (FFS) technologies based on knowledge of active & potential DMs and their root causes, along with best-practice Risk Based Inspection technology is changing the way in which such decisions are made to optimize spend, whilst enhancing safety & reliability of affected items of plant. This holistic approach to asset integrity management ensures delivery of the 5 strategic goals aimed for by plant sites:- [1]. Desired operational reliability between inspection turnarounds (TAs); [2]. Desired optimum plant run-length time between TAs; [3]. Maximum cost effective life out of aging equipment; [4]. Optimum inspection interval for each equipment; [5]. Optimum spend on CapEx and RevEx.

The Fitness-For-Service (FFS) assessment can be carried out using either BS-7910 or API-579 or a combination of both, irrespective of the original design code for the equipment (see Section 3.2). The assessor may also have to refer to the equipment design codes, e.g. ASME-VIII and/or British standard BS 5500.. The assessor may also have to refer to the equipment design codes, e.g. ASME-VIII and/or British standard BS 5500. The scope of Fitness-For-Service (FFS) Application includes all types of pressure vessels (reactors, distillation columns, absorbers, strippers, reformers, fired heaters, heat exchangers); storage tanks; utility plant items such as boiler drums, de-aerators, headers; piping and pipelines.

Depending on the reasons for an Fitness-For-Service (FFS) assessment, the Output will include one or more of the following - tolerable corrosion/erosion damage sizes & damage rate; tolerable crack sizes & growth rate; remaining life; integrity operating limits & other risk mitigations; design improvements; suitable intrusive and/or non-intrusive NDT inspection methods. The Output of an Fitness-For-Service (FFS) assessment can also become an input to Risk Based Inspection (RBI) team study to formally decide whether - to run the item as it is and at what optimum inspection interval; to monitor the defect and at what monitoring frequency; to repair / replace item and decide when it should be carried out; to revise operating conditions; and to modify design or upgrade material. These decisions will be influenced by the RBI study output such as the Risk profiles of the applicable DMs and the respective HSE and Business Consequences of Failure.

This paper presents a holistic approach incorporating Fitness-For-Service (FFS), Risk Based Inspection (RBI) and NDT to successfully demonstrate integrity of aging or new plant items, affected by one or more DMs. Examples are given to illustrate the substantial benefits of FFS application in conjunction with RBI and advanced NDT, where this combined technique has saved considerable sums of money for the plant operators, whilst enhancing safety and reliability.

Keywords: Fitness-For-Service; Fitness for Service; FFS; Risk based inspection; RBI; Damage Mechanisms; DMs; BS 7910; API 579;

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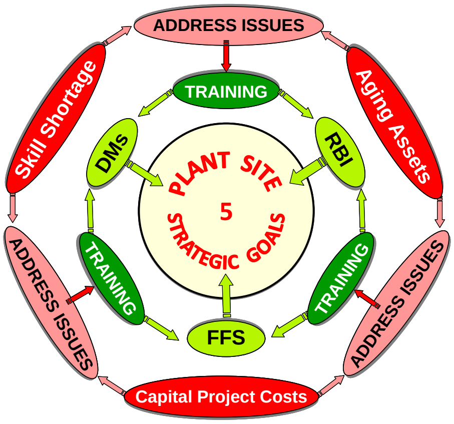
1. Meeting Industry Critical Needs

Effective, economic, safe & reliable management of static equipment asset integrity involves application of best practice Risk Based Inspection and Fitness-For-Service technologies driven by knowledge of both 'active' & 'potential' Damage Mechanisms (DMs) and their root causes, for every equipment & piping in a plant. These 3 core subject areas are closely interlinked and central to effective management of asset integrity.

For many deteriorating or aging plant items (equipments and piping), the Risk Based Inspection (RBI) study process is supported by Fitness-For-Service (FFS) assessments to derive reliable remaining life and optimum inspection intervals, based on acceptable level of their DMs driven integrity risks and the HSE and Business consequences of failure. In this process, a comprehensive knowledge of active and potential DMs and their root causes based on reliable operating data for the equipment or piping (or piping corrosion loop), the knowledge of applicable DMs driven integrity operating limits and other risk mitigation measures are crucial to support the correct application of Risk Based Inspection (RBI) and Fitness-For-Service (FFS) technologies.

Only this integrated application knowledge of Risk Based Inspection (RBI), Fitness-For-Service (FFS) and DMs, combined with a holistic approach incorporating other important aspects mentioned above will provide 'Defence in Depth' evidence to asset integrity management at optimum costs, throughout a plant's life cycle. Importantly, it guarantees delivery of the FIVE strategic goals aimed for by plant sites. However, under the current economic climate, the knowledge and skill gap in the plant operating sites with respect to these subject areas are widening and its adverse effects cannot be underestimated.



This diagram highlights the importance of effective training that is required in the 3 critical subject areas for the engineers at plant sites so that the knowledge & skills gap issues are successfully addressed. This is necessary in order for plant sites to effectively achieve their 5 strategic goals.

1. Desired operational reliability & safety between TAs
2. Desired optimum plant run-length time between TAs
3. Maximum cost effective life out of aging equipment
4. Optimum inspection interval for each item
5. Optimum spend on CapEx; Optimum spend on RevEx

2. Equipment and Piping Design Philosophy

For example, ASME-VIII, BS-5500, API-650 & other recognised design codes provide rules for design and fabrication of items of plant, such as pressure vessels, piping, pipeline, storage tanks, boilers and fired heaters.

Acceptance of flaws found during construction is based on "Quality Control levels" set by these codes. Quality Control levels set by design codes are usually both arbitrary and conservative, but are of considerable value as they provide a route to achieve reasonable consistency and confidence in the quality of construction.

2.1. Design Code Issues

The equipment and piping design principles and rules provided in many design codes are to guard against failure, primarily by rupture due to gross plastic deformation, or by brittle fracture, or by buckling, or by time dependent creep or fatigue damage process. The design codes however do not effectively address the fact that these items deteriorate due to many other DMs during operation of a plant & that defects due to deterioration or from original fabrication, which are larger than allowed by the "Quality Control levels" may be found during in-service inspections. Also, these codes do not cater for the fact that the mechanical properties and / or metallurgical status of some materials can change over time, under specific operating conditions. As a result, many operating equipments and piping may not satisfy the original design code requirements after some years in service. Does this necessarily mean rejection of these equipments or piping?

3. Fitness-For-Service (FFS) Concept and Assessment Philosophy

When static equipments or piping operating in the oil, gas, petrochemical manufacturing or power generating plants are replaced or repaired simply because, for example, the corrosion allowance has been used up or some minor cracking has been detected or material property changes and/or metallurgical degradation are suspected, the cost implication to the operating companies is enormous. With the availability of well established and proven Fitness-For-Service (FFS) assessment technologies, for example as provided in BS-7910 and API-579, rejection of these items should not be therefore necessarily automatic, simply because the deterioration is suspected to be more severe than the 'quality control level' set by design codes.

Application of proven state-of-the-art Fitness-For-Service (FFS) technologies based on the knowledge of both 'active' and 'potential' DMs and their root causes, along with best-practice Risk Based Inspection technology is changing the way in which such decisions are made to optimize spend, whilst enhancing safety and reliability of the affected items (equipment and piping) of plant.

The decisions on whether to "run as is / monitor", "repair" or "replace" or "change operating conditions" or "modify design" or "upgrade material" for an equipment or piping is based on the derivation of acceptance levels for defects larger than the "Quality Control levels" and/or the demonstration of suitability of materials for the credible operating conditions. **This is the concept of Fitness-For-Service (FFS) application.**

3.1 Definition of Fitness-For-Service (FFS) Technology

Fitness-For-Service (FFS) technology is a quantitative engineering analysis process incorporating calculations and assessments, which are performed to assess the structural integrity of an in-service item of plant, containing defects or has the potential to develop defects. However, in specific circumstances this technology also can be effectively used, to assess significance of defects found by NDT during construction, which are not acceptable to the design code, usually under 'concession' criteria acceptable to parties involved.

By this Fitness-For-Service (FFS) principle, an item is considered to be fit for the intended service, if it can be clearly demonstrated (with acceptable safety margin) that the conditions to cause failure is not reached within a predetermined time period, giving due regard to its DMs induced integrity risks and the HSE and Business consequences of failure. The predetermined time period can be, for example, up to the next inspection during a plant inspection/maintenance turnaround.

3.2. Codes and Standards and Scope of Fitness-For-Service (FFS) Application

The popular Codes used in Fitness-For-Service (FFS) assessments are BS-7910 and/or API-579. To avoid any doubts amongst users of these Codes, since the Fitness-For-Service (FFS) technology is based on 'failure criteria principles and safety margins', **either of these documents or their combination can be confidently used in an Fitness-For-Service (FFS) assessment to assess equipment integrity and support the end decisions, irrespective of the original design and construction code** for the equipment. This combination of various methods has been successfully used over the years in many critical applications. The Fitness-For-Service (FFS) assessor may also have to refer to design codes, e.g. ASME-VIII, BS-5500 and other Standards issued by recognised Associations or Government Regulatory Bodies.

Depending on the reason for a Fitness-For-Service (FFS) assessment, the end result, e.g. the calculated remaining life, becomes an input to the Risk Based Inspection study of the concerned equipment or piping. This is important where future inspection requirements and inspection interval have to be assessed from a Fitness-For-Service (FFS) study.

It is important to recognise that, in order to ensure best cost effective decision, the assessment of optimum inspection interval can only be based on the relevant DMs risk profile and the HSE and Business consequence of failure.

The types of Fitness-For-Service (FFS) Applications to address various types of DMs and Operating Conditions may include:-

- Allowable low temperature / pressure envelope to guard against Brittle Fracture
- General metal loss and remaining life
- Localised metal loss and remaining life
- Pitting type corrosion and remaining life
- Shell out-of-roundness, weld misalignment, peaking at weld seams
- Hydrogen blisters and laminations
- Stress Corrosion Cracking
- Planar or crack-like flaws and remaining life
- Fatigue damage and remaining life under cyclic load service (e.g. pressure or thermal cycles)
- Creep damage and remaining life under high temperature service
- Dents/Gouges and remaining life
- Fire Damage or Overheating and remaining life.

The various types of items which are considered in Fitness-For-Service (FFS) Assessment include:-

- Pressure vessels (reactors, distillation columns, absorbers, strippers, heat exchangers, etc)
- Reformers and other fired heaters
- Storage tanks and storage spheres
- Utility plant items such as furnace tubes, boiler drums, de-aerators, superheater headers
- Interconnected Piping between equipments; Pipelines.

3.3. Reasons for Fitness-For-Service (FFS) Assessment

There are a variety of reasons why Fitness-For-Service (FFS) assessments / calculations are carried out to demonstrate structural integrity of an equipment or piping. The most common reasons are listed below:-

- Deterioration or loss of wall thickness by thinning DM
- Presence of a flaw by cracking mechanism or has the potential for initiation of a cracking DM
- Operating conditions conducive to material properties change and / or metallurgical damage
- Concerns on not meeting current design codes or best practices
- Concerns on not meeting the design code during construction
- Concerns on operating conditions which has the potential for initiation of brittle fracture
- Concerns on current operating conditions fault scenarios
- Change in normal operating condition which is more onerous than current

- Operation under high temperature creep environment
- Operation under mechanical or thermal fatigue environment
- Concerns after fire damage
- Concerns due to overheating
- Avoidance of in-situ hydro test after a major weld repair or modification
- Additional justification for operating major hazard equipment, where failure can lead to catastrophic HSE.

Depending on the reasons however, the timing of a Fitness-For-Service (FFS) assessment for equipment or piping may be initiated during equipment design stage, during construction or after plant commissioning.

3.4. The Input considerations for Fitness-For-Service (FFS) Assessment

It is important that all required information for a Fitness-For-Service (FFS) assessment shall be identified, including significance of the problems as well as the various expertises required for supplying of accurate data and carrying out such an assessment.

The expertise requirements may be multi-disciplinary depending on the complexity of the equipment and problems. Based on this, who should carryout the assessment, the scope of work, output and final decision process shall be clearly defined. The most important aspects are listed below:-

- Understanding the problem and effects (HSE and Business consequences of failure)
- Defining what is required from the Fitness-For-Service (FFS) assessment and final decision options
- Defining scope of Fitness-For-Service (FFS) assessment based on plant operational loads and process conditions (e.g., normal operation, fault scenarios, start-up/shutdown, chemical cleaning, etc)
- Defining expertise & data requirements
- Gathering reliable data, Completing the assessment, Analysing results, Feeding to RBI study if required
- Identifying ‘active’ and ‘potential’ Damage Mechanisms (DMs) applicable to the item
- Defining scope of any root cause investigations of the DMs
- Choosing the appropriate Fitness-For-Service (FFS) assessment method(s)
- Making informed decisions and delivering solutions
- Documentation and Report contents
- Addressing future updates based on operational changes or inspection findings.

3.5. The scope of Fitness-For-Service (FFS) Assessment study

Initially it will be generally necessary to complete the following tasks, so that the scope and methods of necessary assessments, calculations, investigations and testing as well as the data and expertise requirements can be clearly defined:-

- Identify all damage causing chemicals in the process fluid streams, fluid phase, applied loads, etc
- Identify all DMs and any interdependency in relation to the defects being assessed.

Depending on the complexity of the item and the identified DMs & problems, the Fitness-For-Service (FFS) assessment may involve and include one, more or all of the following:-

- Root Cause Analysis and Metallurgical Investigations

- Stress analysis (can range from use of design code calculations, Finite Element Analysis to the application of Strain Gauging methods or a combination of these methods)
- Fracture Mechanics assessments to assess tolerable crack sizes
- Remaining life calculations (e.g. Thinning, Creep, Fatigue, certain types of Metallurgical damage, etc)
- Calculation of pressure vs. temperature operating envelope (e.g. assessment against brittle fracture)
- RBI team study to evaluate DMs risk profiles
- Identification of Integrity Operating Limits and Critical Maintenance Activities
- Identification of other risk mitigation measures based on DMs risks and consequences of failure
- Assessment of optimum Inspection Interval & Methods based on DMs risks and consequence of failure
- Acceptance criteria safety factors are based on acceptable risk profile for the DMs and HSE & Business consequences of failure.

3.6. The Expertise requirements for Fitness-For-Service (FFS) Assessment study

Depending on the scope of the defined study, the required expertise may involve and include one, more or all of the following specialist areas of subject disciplines:-

- Vessel / Piping Design Engineer or Inspection Engineer (with design experience); Experienced in using Fitness-For-Service (FFS) assessment techniques.
- Inspection Engineer; Experienced in inspection & knowledge of inspection history relevant to item & knowledge of traditional and advanced NDT methods.
- Metallurgist or Corrosion Engineer; Experienced in root cause failure analysis and damage mechanisms and their causes.
- Risk Based Inspection (RBI) Engineer; Experienced in facilitating Risk Based Inspection team studies & having a good knowledge of subject areas and various expertise involved.
- Process Engineer and Plant Operations Engineer; Experienced in operating conditions and historical operational changes relevant to the item.

A team based approach may be necessary depending on the equipment complexity and its DMs and the subject disciplines which need to be involved.

3.7. The Output from Fitness-For-Service (FFS) Assessment

Depending on the reasons for the Fitness-For-Service (FFS) assessment and the HSE and Business consequences of failure, the Output may include one or more of the following:-

- Tolerable thinning (e.g. corrosion, erosion) damage sizes and damage rates
- Tolerable crack sizes and crack growth rates
- Tolerable pressure vs. temperature operating envelope
- Tolerable material toughness and/or other mechanical properties
- Remaining life
- Fatigue Life
- Creep life
- Integrity Operating Limits / Windows
- Critical Maintenance Activities
- Other risk mitigating measures (e.g. design improvements, material upgrade, changes to current operating conditions, etc)
- Suitable intrusive and/or non-intrusive NDT inspection methods
- NDT method effectiveness and capability.

3.8. The Role of NDT Inspection in RBI & Fitness-For-Service (FFS) Assessments

When RBI study or Fitness-For-Service (FFS) Assessment is used to justify extended inspection intervals, in particular for high consequence items, or extended plant run-length times between turnarounds, or size/monitor significant defects, the role of NDT inspection and the accuracy required of the inspection results cannot be underestimated. The important aspects are highlighted below.

- Define purpose of NDT – [to detect DM or to assess DM rates or both]

- NDT inspection plan needs to match the Damage Mechanism (DM)

- When selecting NDT method, optimise balance between risk, effectiveness and cost, which depends on consequence and complexity. Define which components of the item, what methods, what coverage and required accuracy of results.

- Define how to inspect – Invasive or Non-Invasive Inspection (NII)?
  - Consider feasibility and benefits.

- Implementing Non-invasive Inspection [NII]
  - Decide in accordance with industry best practices.
  - Need a structured decision process to have confidence in NII technique and results.
  - Capability and Effectiveness of the technique must be demonstrated as reliability of results is key, particularly for high consequence equipment.
  - The selected NDT technique may need validation to improve confidence in results.
  - Who will do it? – need proven record of experience on degradation types / locations

- More responsibility is placed on the NDT Engineers
  - Expected to be more proactive when defects are detected.
  - Qualification and experience relevant to DMs.
  - Accuracy of results – need to check calibration and question the findings at the time of inspection. If in doubt ASK. (*It is too late when plant is back on line after a TA)*.
  - Better reporting format of inspection results to help update Fitness-For-Service (FFS) Assessment, RBI study output and future inspection plans.
  - Need clear procedures & inspection briefing to narrow reliability gap between NDT engineers' performance, so that confidence in results and repeatability is improved.

3.9. The Outcome of the Fitness-For-Service (FFS) Assessment and Final Decision Making

Based on the requirements, the output from the Fitness-For-Service (FFS) assessment becomes an input to the Risk Based Inspection team study to formally determine whether to, for example:-

- Run the item as it is and at what optimum inspection interval
- Monitor the defect(s) and at what monitoring frequency
- Repair / replace item and when should be carried out
- Revise operating conditions
- Modify design and/or upgrade material
- Implement identified Integrity Operating Limits, and other risk mitigating measures.

The final decision based on a combination of these actions will be influenced by the Risk Based Inspection study output such as the risk profiles of the applicable DMs and the respective HSE and Business Consequences of Failure.

4. Integrating Risk Based Inspection (RBI) and Fitness-For-Service (FFS) Assessments

In order to get the best out of Fitness-For-Service (FFS) assessment and help the final decision process, it will be prudent to effectively use the results in the Risk Based Inspection (RBI) study for the affected equipment or piping.

This is important, as without this process, it will be difficult to make evidence based defendable and cost effective judgment, simply because the risk profiles of the applicable DMs and the HSE and Business consequences of failure have not been formally taken into consideration in the final decision process.

The following sections outline a proven process which can be effectively used to incorporate Fitness-For-Service (FFS) assessment results into the Risk Based Inspection (RBI) study.

Upon identification of the applicable DMs for the equipment or piping, the main part of the Risk Based Inspection study involves the following to assess the risk profile of each of the identified DMs:-

- Assigning failure mode for each of the identified DMs
- Assessing HSE and Business Consequence of Failure (CoF) for each the DMs against its failure mode
- Assessing Probability of Failure (PoF) for each of the DMs
- Assessing the HSE and Business risk profile for each of the DMs.

Using this information, the final decisions and actions as outlined in Section 3.9 above can be invoked as considered appropriate.

Clearly therefore, any resulting spend is correctly optimised and is supported by evidence based justification.

4.1. Assigning Failure Mode

Part of the assessment of risk profile for a DM is the evaluation of its Failure Mode.

This is important in order to correctly determine the HSE and Business Consequence of Failure, which in turn will have an effect on the DM risk profile and hence on the latest inspection date for the DM and the optimum inspection interval for an equipment or piping.

The Failure Mode is based on most likely damage process applicable to each DM under consideration. This should be related to, for example, the metallurgy, construction quality, operating conditions, the type of defects found or expected and the extent of likely damage prior to failure.

The various Failure Modes that can be considered are outlined below:-

- Minor Leak
- Small Hole
- Large Hole
- Local Rupture
- Gross Rupture
- Brittle Fracture
- Buckling
- Plastic Collapse
- Operational Problem.

4.2. Assigning HSE and Business consequence of failure (CoF)

HSE and Business consequences of failure need to be assessed separately for each of the identified DMs for an item.

The following factors are generally considered in assessing the HSE Consequence severity for each DM, taking into account the Failure Mode:-

- Stored energy release
- Rate & temperature of fluid release
- Fluid flammability and detection / mitigation of release
- Fluid toxicity and detection / mitigation of release
- hazard related to other fluids – e.g. steam, acids
- Location of equipment in plant – occupancy at the point of release
- Threat to site personnel (onsite injury)
- Threat to community (offsite injury).

Similarly, the following factors are considered in assessing the Business Consequence severity for each DM, taking into account the Failure Mode:-

- Equipment or Plant shutdown impact (downtime)
- Consequential damage, Repair and replacement costs
- Bad Publicity effects
- Total cost impact of failure.

Both the HSE and Business consequences of failure can be grouped into 5 categories to support the typical 5 x 5 risk matrix (see section 4.4):-

- Major
- Severe
- Significant
- Minor
- Low.

Note however, that the above categorisation is generally based on the existing definitions at the plant site. Typically these definitions would have been already used in their Process Hazard Analysis (PHA) or Hazard and Operability (HAZOP) studies or Risk Based Inspection team studies.

4.3. Assigning probability of failure (PoF)

The probability of failure (PoF) for the DM against a time frame can be based on the safety margins available for the actual defect sizes against what is tolerable at the respective Fitness-For-Service (FFS) assessment locations relevant to the equipment or piping (for example, this may be based on tolerable defect sizes, remaining life due to thinning, fatigue or creep, etc).

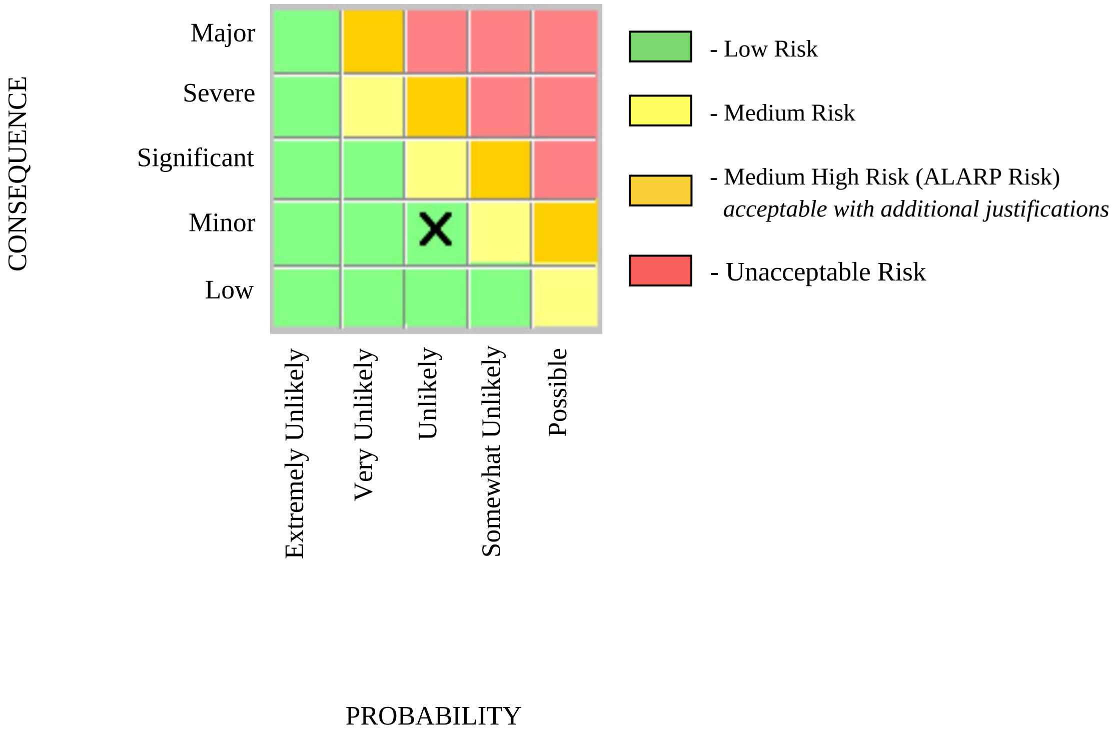
It may also be necessary to incorporate additional safety factors, for example, to cater for any uncertainties in data or assessment techniques used.

The required overall safety margin also needs to be assigned for each of the 5 consequence of failure categories.

Clearly it makes sense that the assigned safety factor will be relatively smaller for ‘Low’ consequence category and relatively higher for ‘Major’ consequence category.

4.4. Assessing the HSE and Business risk profile for each of the DMs

The typical 5 x 5 risk matrix is shown below for the assessment of risk profile of a DM. However its colour coding can be adjusted to suit the assessor’s / end user’s preference.



It should be noted that, depending on the complexity of the equipment and applicable DMs, the integrity risk assessment of the DMs (Risk Based Inspection (RBI) study) may require a study team having multi-discipline expertise.

On completion of the assessment of HSE and Business risk profiles (Risk Based Inspection (RBI) study) for each of the relevant DMs using the output from the Fitness-For-Service (FFS) assessments, the final decision and the required actions as outlined in Section 3.9 can be based on the risk profiles of the applicable DMs and the respective HSE and Business Consequences of Failure of the relevant equipment or piping.

5. Examples

Three examples are given below to illustrate the substantial benefits of Fitness-For-Service (FFS) assessment in conjunction with Risk Based Inspection (RBI) study. In all three cases the latter was conducted by a multi-discipline study team.

5.1. Assessment of several redundant Distillation Columns for re-use on a new duty

Background: Under the previous operating duty, the columns had suffered various levels of localised corrosion damage (below design corrosion allowance) and cracking at some weld seams. New duty involved higher working pressures and temperatures and a low temperature pressurised start-up.

The adopted approach included and was not limited to:-

After identification of active (past) and potential DMs (under new operating duty), the Fitness-For-Service (FFS) assessment was supported by stress analysis, fracture mechanics calculations, remaining life assessment, material damage studies including toughness testing, supported by specific NDT inspections to assess condition of the columns, followed by Risk Based Inspection (RBI) team study using the output from Fitness-For-Service (FFS) assessments.

Outcome:-

- Mechanical integrity of the Columns on new duty was established proving that the previous damage, apart from 2 defects, did not require any repairs and the respective DMs confirmed inactive under new duty.
- Risk Based Inspection plan incorporating optimum inspection interval was implemented, with additional NDT to match newly identified potential DMs under new operating conditions.
- Several $ million savings on capital expenditure.

5.2. Fitness-For-Service (FFS) of several Pressure Swing Absorbers

Background: The Pressure Swing Absorbers (approximately 20 years old), which were approaching their allowable design pressure cycles.

The requirement was to establish the remaining life based on actual cyclic operating pressures; future optimum inspection interval; scope of future inspections; matching NDT methods for reliable detection of active DMs and propagation of any significant defects; vessels replacement strategy.

The adopted approach included and was not limited to:-

After identification of all the active and potential DMs, the Fitness-For-Service (FFS) assessment was supported by stress analysis, initial fatigue analysis using BS-5500 method to assess remaining life (cycles) and a refined remaining life assessment based on fracture mechanics approach (BS-7910) to establish crack growth rates and allowable crack sizes. The latter assessment was based on postulation of a surface crack size that can be reliably detected by established NDT inspection methods. This was followed by Risk Based Inspection (RBI) team study using the output from the Fitness-For-Service (FFS) assessments.

Outcome:-

- Mechanical integrity of the Absorbers was proven for a minimum of further 12 years.
- Optimum inspection interval from RBI study output set at 6 years (alternative turnarounds) incorporating two reliable Intrusive and Non-Intrusive NDT methods with extensive inspection scope covering vulnerable areas of the vessels where fatigue cracking can initiate.
- Deferred substantial capital expenditure for replacement absorbers/piping.

5.3. Fitness-For-Service (FFS) Assessment of a 15,000 Tonne refrigerated Ammonia Storage Tank

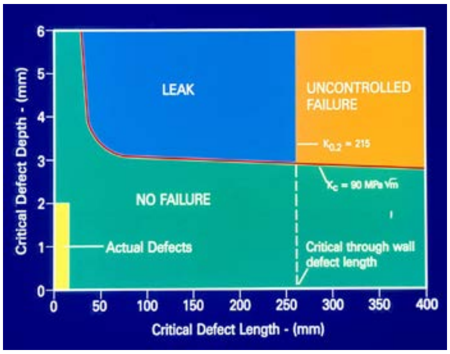
Background: This is a 15,000 Tonne fully refrigerated Ammonia Storage Tank (double wall construction) operating at 50 mbarg and at -33°C. Its last internal inspection was in 1994, with its next inspection due in 2006 (after 12 years).

The MPI inspections required for the Inner tank to detect Stress Corrosion Cracking (SCC) at internal welds are prohibitively expensive, due to size of tank and preparatory requirements. The key DM which drives internal inspection is SCC, which is caused by presence of O_2 in the liquid ammonia.

There is also interest industry-wide to minimise the number of Intrusive inspections by supporting it with Non-Intrusive inspections for SCC, because the potential for damage is most likely as oxygen can get into the tank during re-commissioning. For these reasons, the project scope was to assess the possibility of deferment of internal inspection to 2012.

The adopted approach included and was not limited to:-

After identification of all the active and potential DMs, the Fitness-For-Service (FFS) assessment was supported by Risk Based Inspection (RBI) team study. Extensive work was initiated following the RBI team study which involved comparing the RBI outcome with the EFMA (Ref.4) RBI process; fracture mechanics work to establish critical SCC defect sizes (Ref.5); setting-up a minimum sub-critical defect size having an acceptable safety margin (against critical size) and developing a new on-line ultrasonic procedure to detect this minimum size defect on a manufactured test piece and qualifying NDT technicians; development of an on-line entry regime into tank annular space & risk assessment; carrying out the on-line ultrasonic inspection; and installing an oxygen monitoring system.



Outcome:

- Inspection interval was safely extended to 2012.
- Non-Intrusive ultrasonic inspection was implemented to inspect most vulnerable welds on a sample basis.
- Procedure was implemented to ensure no ingress of O_2.
- The local Regulatory Body approved the work carried out.
- This outcome deferred inspection costs of ~£1m to 2012, whilst reducing the potential for SCC initiation.

6. Conclusion

This paper has covered the key aspects which are considered to be important for a Fitness-For-Service (FFS) assessment to be meaningful and reliable. The paper has also outlined a proven process, together with three examples, for incorporating Fitness-For-Service (FFS) assessment results into a Risk Based Inspection study so that the final decisions and required actions by the plant site can be based on the risk profiles of the applicable DMs and the respective HSE and Business Consequences of Failure of the relevant equipment or piping. Clearly therefore, any resulting spend is correctly optimised and is supported by evidence based justification.

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ICPVT-13 KEY NOTE SPEAKERS

STUART CAMERON
CONSULTANT, DOOSAN BABCOCK ENERGY

Stuart Cameron is a Consultant for Doosan Babcock Energy. He has worked with the company, formerly Babcock & Wilcox, for over 40 years and held the position of Chief Engineer until 2011 with specific responsibility for technical risk management and investigations throughout all parts of the Company including compliance with existing and new legislation regarding pressure equipment. He is also a Visiting Professor at the University of Strathclyde, Vice President of the Institution of Mechanical Engineers and Chairman of the BSI Boiler Committee and the ISO Working group for procedures on international compliance of boiler and pressure vessel standards.

RON SELVA
ENGINEERING DIRECTOR, PP SIMTECH

Ron Selva has more than 35 years of experience in static equipment integrity managing technologies relating to the oil, gas, petrochemical and fertilizer manufacturing plants operating worldwide. As Engineering Director at PP SIMTECH, he has spent the last 20 years championing the development and implementation of best practice Risk Based Inspection (RBI), Fitness-For-Service (FFS) assessment and Total Integrity Management of Assets (TIMA) technologies.

PROFESSOR JIM BOYLE
TRADES HOUSE CHAIR IN MECHANICS OF MATERIALS, UNIVERSITY OF STRATHCLYDE

Jim Boyle is Trades House Professor of Mechanics of Materials in the Department of Mechanical & Aerospace Engineering at the University of Strathclyde. His main areas of research lie in nonlinear continuum mechanics and computational mechanics with special reference to high temperature design problems. Major practical applications continue to lie in the field of pressure vessel and piping design and design by analysis. Jim has been involved in Design by Analysis for over thirty years and was a co-writer of the Design by Analysis Manual for the DBA direct route in CEN's unfired pressure vessel standard prEN 13445-3.

NIGEL KNEE
HEAD OF NUCLEAR POLICY, NUCLEAR NEW BUILD, EDF ENERGY

Nigel Knee has over 25 years' experience in the electricity industry, starting out in engineering where he carried out failure investigations and research into the defect tolerance of reactor pressure vessel steels. He has also worked on safety assessment, research programme management and diverse commercial issues including electricity trading strategy, business planning and market regulation. He is currently responsible for nuclear policy issues within EDF Energy's nuclear new build team. Previously he was part of British Energy's strategy and business development team, focusing on the opportunity for new nuclear build.

CLAUDE FAIDY
SENIOR CONSULTANT ENGINEER, EDF-SEPTEN

Claude Faidy joined EDF in 1976 and SEPTEN Engineering Division in 1978. After working on Fracture Mechanic analysis, he moved to the major failure modes and degradation mechanisms analysis for PWR and FBR. Claude currently employs this experience to support the design and operation of French and International Codes and Standards. He is closely involved to the French Ageing Management program for the 58 PWRS and is a member of code organisations in Europe and the USA.