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A Risk-Based Inspection Concept for Fitness-for-Service Assessment of Ageing Pressure Vessels on Offshore Joint Venture Facilities

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Abstract- A substantial proportion of offshore oil and gas production infrastructure operated under joint venture (JV) arrangements has now exceeded, or is approaching, its original design life. Static pressure equipment, and pressure vessels in particular, represents one of the most safety-critical categories of equipment on these facilities because failure can result in loss of containment, fire, explosion, environmental damage, and loss of life. Traditional time-based inspection regimes, in which vessels are opened and inspected at fixed calendar intervals, are increasingly recognised as both economically inefficient and technically unfocused when applied to ageing equipment whose condition and degradation behaviour vary widely. This paper presents a concept, developed in 2018, that integrates Risk-Based Inspection (RBI) planning with Fitness-for-Service (FFS) assessment to form a single, continuous integrity management process for ageing pressure vessels on offshore JV facilities. The concept uses RBI methodologies aligned with API RP 580 and API RP 581 to prioritise vessels according to their probability and consequence of failure, and applies the assessment procedures of API 579-1/ASME FFS-1 to determine whether vessels containing identified flaws or degradation remain fit for continued operation, and for how long. The framework explicitly addresses the organisational realities of JV operations, including shared decision-making, cost allocation between partners, differing corporate risk appetites, and regulatory oversight. A staged implementation methodology is proposed, together with an illustrative application to a generic ageing separator vessel. The concept is presented against the standards and published practice current in 2018. The paper argues that the integrated RBI-FFS concept enables JV operators to concentrate inspection resources where risk is highest, to justify continued operation or life extension of degraded but serviceable vessels on a rigorous engineering basis, and to provide a transparent, auditable framework for integrity decisions shared among JV partners and regulators.

Keywords: risk-based inspection; fitness-for-service; ageing assets; pressure vessels; offshore; joint venture; life extension; API 580; API 581; API 579-1/ASME FFS-1; asset integrity management.

I. INTRODUCTION

The global offshore oil and gas industry has entered a period of pronounced asset ageing. Many production platforms, floating production units, and associated topside process plants commissioned in the 1970s, 1980s, and 1990s were originally designed for service lives of 20 to 25 years, yet commercial drivers, improved recovery techniques, and tie-back developments have extended their operational horizons well beyond original design intent. Industry surveys indicate that more than half of fixed offshore installations in mature basins such as the North Sea, the Gulf of Mexico, and the Gulf of Guinea are operating beyond their nominal design lives. Sustaining production from such facilities depends on the availability and uptime of the process plant itself, which in turn rests on the readiness of spares, materials, and maintenance capability (Okonkwo, Ogunwole and Okeke, 2018b), and on procurement strategies configured for the particular demands of oil and gas operations (Okonkwo, Ogunwole and Okeke, 2018a).

Pressure vessels occupy a central position in the integrity management of these facilities. Separators, scrubbers, knock-out drums, filters, heat exchanger shells, and storage drums contain hydrocarbons at elevated pressures and temperatures, frequently in the presence of corrosive species such as carbon dioxide, hydrogen sulphide, chlorides, and produced water. As these vessels age, cumulative degradation in the form of wall thinning, localised corrosion, pitting, cracking, and mechanical damage progressively

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erodes the design margins established at fabrication. The question facing operators is therefore no longer simply when a vessel was last inspected, but whether the vessel, in its current degraded condition, remains fit for continued service at its operating conditions, and if so, for how long. Because loss of containment on a manned offshore installation is a safety event before it is a production event, this question belongs to the data-driven occupational safety risk control agenda developed for large-scale energy infrastructure (Obriki and Arumosoye, 2018).

1.2 The Joint Venture Dimension

A large share of offshore production worldwide is conducted through joint venture arrangements, in which two or more companies, often including a national oil company and one or more international partners, share ownership, investment obligations, and production entitlements. One partner typically acts as operator, holding day-to-day responsibility for safety and integrity, while non-operating partners exercise oversight through operating committees, technical committees, and budget approval processes. This governance structure has direct consequences for integrity management of ageing equipment. Inspection and repair budgets must be approved by multiple partners with potentially divergent risk appetites, investment strategies, and time horizons. Deferral of maintenance may be attractive to a partner planning divestment, and unacceptable to a partner with long-term exposure. Decisions to shut down equipment for internal inspection carry deferred production costs shared across the venture, while decisions to continue operating degraded equipment carry risk exposure that is likewise shared. Where decision rights, escalation routes, and assurance responsibilities are not formalised, disagreement surfaces at the least convenient moment, typically when a finding requires an unbudgeted response. Any concept for managing ageing pressure vessels on JV facilities must therefore be technically rigorous and, equally, transparent, auditable, and defensible to all partners and to the regulator.

1.3 Aim and Objectives

The aim of this paper is to present a coherent concept that integrates Risk-Based Inspection planning and Fitness-for-Service assessment into a single continuous process for managing ageing pressure vessels on offshore JV facilities. The specific objectives are:

1. To review the technical and regulatory context for RBI and FFS as applied to ageing offshore pressure systems.
2. To define an integrated RBI-FFS framework in which risk ranking directs inspection effort and inspection findings feed structured fitness-for-service evaluation and remaining life estimation.
3. To adapt the framework to the governance, cost-sharing, and decision-making realities of joint venture operations.
4. To propose a staged implementation methodology and illustrate its application to representative ageing vessels.
5. To identify the benefits, limitations, and preconditions for successful deployment of the concept.

1.4 Scope

The concept addresses static pressure vessels on offshore production facilities, including fixed platforms and floating production installations. Piping systems, pipelines, structural elements, and rotating equipment are excluded, although the underlying philosophy is transferable. The paper is conceptual in nature: it defines a framework and methodology rather than reporting a completed field implementation.

II. LITERATURE AND STANDARDS CONTEXT

2.1 Ageing and Life Extension of Offshore Assets

Ageing is best understood not as a function of calendar time alone but as the progressive degradation of equipment condition relative to its design intent. Guidance published by the UK Health and Safety Executive, including research on ageing plant (Health and Safety Executive, 2010) and the KP4 inspection initiative on ageing and life extension (Health and Safety Executive, 2014), characterises ageing in terms of four stages spanning initial operation, maturity, deterioration, and terminal decline, and emphasises that ageing effects can be present even in relatively young plant that has been poorly maintained or operated outside its design envelope.

Norwegian regulation similarly requires documented life extension assessments before installations may operate beyond their consented design life (Petroleum Safety Authority Norway, 2010), supported by standards such as NORSOK and the ISO 2394 reliability framework (Standards Norway, 2015). Comparable industry guidance has been issued for the UK continental shelf (Oil and Gas UK, 2012).
The literature converges on several findings of direct relevance to this concept. First, loss of containment incidents on ageing installations correlate strongly with degradation mechanisms that are known and foreseeable, but inadequately monitored; corrosion of carbon and low-alloy steels remains the dominant threat, and the breadth of research into corrosion control, including inhibition strategies for mild steel in acidic and alkaline media, underlines how central this mechanism is to plant integrity (Atta, Asomani and Adenuga, 2018). Dedicated industry guidance on corrosion management in production and processing reflects the same emphasis (Energy Institute, 2009). Second, blanket time-based inspection consumes resources on low-risk equipment while permitting under-inspection of high-risk items. Third, life extension decisions are frequently constrained less by the true condition of equipment than by the absence of adequate condition data and structured assessment to demonstrate continued integrity.

Process conditions matter as much as elapsed time. Rising water cut, changing produced water chemistry, and shifting partial pressures of carbon dioxide and hydrogen sulphide alter the degradation regime of a vessel long before any inspection is due. An ageing framework that treats process condition as fixed will misjudge the very mechanisms most likely to cause failure late in field life.

2.2 Risk-Based Inspection

Risk-Based Inspection is a planning methodology that allocates inspection resources in proportion to risk, defined as the combination of the probability of failure (PoF) and the consequence of failure (CoF) of each equipment item. The dominant industry references are API Recommended Practice 580 (American Petroleum Institute, 2016a), which establishes the minimum elements of a credible RBI programme, and API Recommended Practice 581 (American Petroleum Institute, 2016b), which provides quantitative procedures for calculating PoF from damage factors associated with active degradation mechanisms and CoF from release modelling of the contained fluid.

The underlying idea, that assurance effort should be concentrated where exposure is greatest, is not unique to mechanical integrity. Technology-enabled risk assessment frameworks developed to improve audit quality rest on the same premise and have generated experience in how risk criteria are calibrated, documented, and defended to sceptical stakeholders (Akomolafe and Agu, 2018). Regulated safety oversight in other sectors offers a further analogue in the form of predictive compliance monitoring designed to detect systemic risk from routine operational data rather than from periodic inspection alone (Adeyelu, 2018).

RBI may be implemented qualitatively, semi-quantitatively, or fully quantitatively. Qualitative approaches rank equipment on a risk matrix using engineering judgement structured through workshops. Quantitative approaches, following API RP 581, compute a generic failure frequency modified by damage factors, management system factors, and consequence areas or financial consequences. In offshore practice, semi-quantitative implementations are common, supported by methodologies such as DNV Recommended Practice RP-G101 for risk-based inspection of offshore topsides static mechanical equipment (Det Norske Veritas, 2010), which was written specifically for the offshore process plant context considered in this paper.

2.3 Fitness-for-Service Assessment

Fitness-for-Service assessment is a set of quantitative engineering evaluations used to demonstrate the structural integrity of in-service equipment containing a flaw or damage. The governing standard is API 579-1/ASME FFS-1 (American Petroleum

Institute / American Society of Mechanical Engineers, 2016). The standard provides assessment procedures organised by damage type, including general metal loss (Part 4), local metal loss (Part 5), pitting corrosion (Part 6), hydrogen blistering and HIC/SOHIC damage (Part 7), weld misalignment and shell distortions (Part 8), crack-like flaws (Part 9), creep (Part 10), fire damage (Part 11), dents and gouges (Part 12), and laminations (Part 13).

Each part offers up to three assessment levels of increasing sophistication. Level 1 uses conservative screening criteria applicable by qualified inspection or plant engineers with minimal data. Level 2 applies more detailed calculation procedures that reduce conservatism while remaining amenable to standard engineering analysis. Level 3 permits advanced techniques, notably finite element analysis and probabilistic methods, executed by specialist engineers. Critically for the present concept, the standard also requires estimation of remaining life and the definition of remediation, monitoring, and re-inspection requirements, which is precisely the interface at which FFS output can be returned into RBI planning.

2.4 The Case for Integration

Although RBI and FFS are mature disciplines individually, they are in much industry practice executed as separate activities: RBI as a planning exercise owned by inspection departments, and FFS as a reactive engineering assessment commissioned when a defect is discovered. This separation produces avoidable inefficiencies. RBI plans that ignore the true condition margins established by FFS tend to retain conservative default assumptions, while FFS studies performed in isolation often fail to update the risk model, so that the same vessel may simultaneously be judged acceptable by an FFS engineer and high-risk by the RBI system.

The remedy is structural rather than analytical. Integration is achieved by consolidating the data foundation and the procedure set, not by refining either activity in isolation, and what makes such integration durable is procedural discipline rather than analytical sophistication. The concept presented in Section 4 addresses the gap by treating RBI and FFS as two halves of one closed-loop process operating on a single shared data foundation.

III. PROBLEM STATEMENT

The problem addressed by this concept can be stated as follows. An offshore JV facility operates a population of pressure vessels, many beyond original design life, exhibiting varied and in some cases interacting degradation mechanisms. The operator must answer, continuously and demonstrably, three questions for every vessel:

1. What is the current risk that this vessel fails in service, and how does that risk rank against the rest of the equipment population?
2. Given the degradation actually found by inspection, is the vessel fit for continued service at its current operating conditions, or at derated conditions?
3. What is the remaining life of the vessel, and what inspection, monitoring, repair, or replacement actions are required, by when, to sustain integrity through the intended operating period?

These questions must be answered within JV constraints: budgets approved by multiple partners, production deferment shared across the venture, inspection access limited by offshore logistics such as bed space, weather windows, and shutdown scheduling, and scrutiny from regulators and partner audit teams. Technical exposure and supply chain exposure compound one another in these settings, since a vessel judged unfit is only as recoverable as the repair capability that can be mobilised to it (Okonkwo, Ogunwole and Okeke, 2018b).

Conventional time-based inspection answers none of the three questions directly. A stand-alone RBI programme answers the first but not the second and third. A stand-alone FFS capability answers the second and third for individual vessels but provides no portfolio prioritisation. Hazard identification without structured disposition and follow-through likewise yields limited actual risk reduction. The integrated concept is designed to answer all three questions within a single auditable process.

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IV. THE INTEGRATED RBI-FFS CONCEPT

4.1 Philosophy

The concept rests on a simple proposition: risk analysis should decide where and how to look, and fitness-for-service assessment should decide what the findings mean and how long the equipment can continue to operate. The two activities are joined into a closed loop around a single shared data foundation. RBI produces an inspection plan whose scope, techniques, and coverage are explicitly matched to the data requirements of the FFS procedures likely to be needed. FFS, in turn, produces quantified integrity margins and remaining life estimates that are written back into the risk model, replacing default assumptions with measured reality. Each pass around the loop makes the risk picture more accurate and the inspection expenditure more efficient.

4.2 Framework Architecture

The framework comprises six interacting elements arranged as a continuous cycle:

1. Data Foundation. A validated equipment register and integrity database holding design data (code of construction, material, thickness, corrosion allowance, MAWP), process data (fluid composition, pressure, temperature, water cut, H2S and CO2 partial pressures), inspection history, and known anomalies. Vessels are grouped into corrosion loops sharing common process environments and damage mechanisms. Because this database is shared across venture partners and contractors, its governance carries legal and ethical obligations alongside technical ones, and structured treatment of risk in enterprise data protection governance provides a basis for defining access, retention, and disclosure rules before the database is populated rather than after (Mbonu, Aliliele, Iwuanyanwu and Oluoha, 2018).
2. Damage Mechanism Identification. For each corrosion loop, a structured review by a multidisciplinary team of materials and corrosion, process, inspection, and operations representatives identifies credible active and potential damage mechanisms, referencing the damage mechanism descriptions of API RP 571 (American Petroleum Institute, 2011). The value of such reviews depends on drawing systematically on operational experience, including near-miss and observation data that would otherwise remain unexploited.
3. Risk Evaluation. Probability of failure is evaluated per vessel from damage factors reflecting mechanism susceptibility, measured or estimated degradation rates, and confidence in condition data. Consequence of failure is evaluated for safety, environmental, and business dimensions, recognising offshore-specific factors such as congested modules, proximity of personnel, escape and evacuation impact, and deferred JV production. Results are plotted on the JV-approved risk matrix (Figure 1).
4. Risk-Targeted Inspection Planning. Inspection scope, technique, coverage, and interval are assigned by risk band. Critically, inspection work packs are specified to deliver FFS-grade data: thickness grids sized for Part 4 and Part 5 assessment, pit depth and density mapping for Part 6, and crack sizing suitable for Part 9. Non-intrusive inspection is deployed where justification of the kind set out in DNV RP-G103 (Det Norske Veritas, 2011) shows equivalent or better information value than internal visual entry.
5. Fitness-for-Service Assessment. All findings exceeding screening thresholds enter a tiered FFS process (Section 4.4). Outputs are an acceptance decision, a remaining life estimate, and a defined re-inspection requirement.
6. Feedback and Evergreening. FFS results, measured corrosion rates, and repair records update the PoF model and the inspection plan. Interval extensions and reductions are governed by management of change, and the refreshed risk register is reported to JV governance annually and after any significant finding.

4.3 Risk Evaluation Approach

A semi-quantitative approach is proposed as the default for JV offshore application, following the structure of API RP 581 but calibrated to the venture's approved matrix. Probability of failure is expressed in five bands informed by damage factor calculation where data quality permits, and structured expert judgement where it does not. Consequence bands are defined in JV-specific terms covering personnel safety, environment, asset damage, and net production deferment attributable to the venture. The matrix and its action bands are shown in Figure 1. Very High and High risk vessels attract priority inspection within defined time limits, Medium risk vessels are managed through the routine plan, and Low risk vessels are candidates for extended intervals subject to a defined maximum.

Probability of Failure	A: Negligible CoF	B: Minor CoF	C: Moderate CoF	D: Major CoF	E: Severe CoF
5: Very High	M	H	VH	VH	VH
4: High	M	M	H	VH	VH
3: Medium	L	M	M	H	VH
2: Low	L	L	M	M	H
1: Very Low	L	L	L	M	M

Figure 1. Illustrative JV risk matrix with risk bands: L = Low, M = Medium, H = High, VH = Very High.

Framing the problem this way makes explicit that inspection planning is a constrained optimisation: a fixed budget of inspection effort, shutdown access, and engineering time is allocated across a population so as to minimise aggregate risk. Multi-algorithm treatments of single and multiple objective functions in electrical machine design illustrate the general difficulty, namely that objectives such as loss, weight, and cost cannot be minimised simultaneously and that the chosen weighting determines the solution as much as the algorithm does (Amayo, Ubeku and Oshevire, 2015; Amayo, 2017; Amayo and Popoola, 2017a). The parallel is exact in integrity planning, where safety, deferment, and cost pull in different directions and the risk matrix is, in effect, the venture's declared weighting between them. Making that weighting explicit and agreed is preferable to leaving it implicit in individual planning decisions. Two refinements are recommended once the baseline is established. The first is the use of leading indicators, so that deteriorating trends in corrosion coupon readings, water chemistry, or operating window excursions raise a vessel's PoF band before a failure or a major finding occurs. The second is periodic maturity assessment of the programme itself, so that the venture can distinguish a genuinely low-risk equipment population from a programme that is simply not yet capable of detecting risk.

4.4 Tiered Fitness-for-Service Process

Findings from inspection are dispositioned through a three-tier process mirroring the levels of API 579-1/ASME FFS-1:

- Tier 1 (Screening). Performed by site inspection engineers within days of data receipt. Level 1 procedures compare measured minimum thickness, pit couples, or flaw dimensions against conservative screening curves. The majority of routine wall-loss findings on vessels with intact corrosion allowance are closed at this tier.
- Tier 2 (Detailed Assessment). Performed by the operator's integrity engineering function. Level 2 procedures compute remaining strength factors for local thin areas, evaluate pitting damage classes, and apply the Failure Assessment Diagram of Part 9 for crack-like flaws using stress intensity and reference stress solutions from the standard's annexes.
- Tier 3 (Advanced Assessment). Commissioned from specialist consultants or the partners' central engineering groups for complex cases: interacting flaws, significant distortions, fatigue-driven crack growth, or cases where Level 2 conservatism would force unnecessary shutdown. Level 3 typically employs finite element analysis, fracture mechanics crack growth modelling on the principles set out by Anderson (2017), and, where

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appropriate, probabilistic treatment of input uncertainty.

Every tier concludes with the same three mandatory outputs: an acceptance decision, a remaining life estimate with stated confidence, and a re-inspection or monitoring requirement. Remaining life is fed to the RBI interval-setting rules, commonly by applying a half-life criterion in which the next inspection is due at no more than half the estimated remaining life, consistent with pressure vessel inspection code practice (American Petroleum Institute, 2014).

Two safeguards surround the tiered process. First, the escalation criteria between tiers must be written down and applied mechanically, because the decision to stop at a conservative Level 1 result is itself a risk decision. Second, where an assessment reveals that damage progressed further or faster than expected, the event is treated as an investigation trigger rather than merely a calculation input. Human error in data collection, transcription, and interpretation is a recognised contributor in high-risk industrial activities, which is why independent checking of Tier 2 inputs is built into the process rather than left to individual diligence.

4.5 Damage Mechanism to FFS Mapping

Table 1 summarises the principal damage mechanisms expected on ageing offshore vessels and the corresponding assessment procedures. This mapping is embedded in inspection work pack templates so that data collected in the field is sufficient, first time, for the assessment that will follow.

Damage Mechanism	Typical Susceptible Vessels (Offshore)	Applicable FFS Procedure (API 579-1/ASME FFS-1)
General internal corrosion (CO2 sweet corrosion)	Production separators, test separators, produced water vessels	Part 4: General Metal Loss
Localised corrosion and erosion-corrosion	Inlet zones, nozzles, vessels downstream of chokes	Part 5: Local Metal Loss
Pitting (chlorides, oxygen ingress, under-deposit)	Produced water and seawater service vessels, dead legs	Part 6: Pitting Corrosion
Wet H2S damage (HIC, SOHIC, blistering)	Sour service separators, amine and glycol contactors	Part 7: Hydrogen Blisters and HIC/SOHIC
Crack-like flaws (fatigue, SCC, fabrication defects)	Nozzle welds, vessels with cyclic loading, CS in amine or caustic service	Part 9: Crack-Like Flaws
Dents, gouges, mechanical damage	Vessels exposed to dropped objects or handling damage	Part 12: Dents and Gouges
External corrosion and CUI	Insulated vessels in marine atmosphere, deck-level saddles and supports	Parts 4 and 5, per external metal loss
Weld misalignment and shell distortion	Older vessels with legacy fabrication tolerances	Part 8: Misalignment and Distortions

Table 1. Mapping of offshore pressure vessel damage mechanisms to FFS assessment procedures.

4.6 Inspection Technology and Data Capture

The framework is technology-agnostic in principle but technology-dependent in practice, because the achievable inspection interval is a function of what can be measured without opening the vessel. Automated and phased array ultrasonics, permanently installed thickness sensors, corrosion probes, and guided wave screening all extend the reach of a given shutdown window. Comparable gains have been realised in the inspection of geographically distributed infrastructure through remote and semi-autonomous survey methods, including UAV integration into asset inspection programmes at national scale (Dagodzo, 2018a) and the broader body of work on unmanned survey of transmission assets, which documents both the methods available and their practical limitations in coverage, resolution, and environmental tolerance (Dagodzo, 2018b). The limitations matter as much as the capability: a technique that cannot resolve the damage the assessment requires is not a substitute for one that can, however convenient its deployment.

Equally important is where the resulting data is stored and how it is referenced. Condition records must be tied to a defined location model rather than to free-text descriptions, so that successive inspections measure the same point and a genuine corrosion rate can be derived rather than an artefact of measurement position. A thickness monitoring location register, with each point fixed against a datum and grid reference on the vessel, is therefore a prerequisite of the framework rather than a refinement of it.

Two supporting considerations follow where permanently installed monitoring is deployed. The first is power and communications: sensors distributed across a process module must be powered and their data recovered reliably, and experience with distributed generation and voltage control (Oshevire, Eyenubo and Amayo, 2017), with integrating alternative power sources into industrial settings (Sunday and Omoegun, 2018), and with telecommunication deployment for network quality (Amayo and Popoola, 2017b) is directly applicable to the design of such installations offshore. The second is that the value of non-intrusive inspection lies precisely in assessing a system without taking it out of service, an approach whose benefits and blind spots have been examined in the offline assessment of security-critical systems in other domains (Ladapo, Dosunmu, Jooda and Abolaji, 2018).

4.7 Consequence of Failure Modelling for Offshore Facilities

Consequence assessment is where offshore application diverges most sharply from onshore refining practice, and where a JV must be most explicit about its criteria. The quantitative consequence procedures of API RP 581 (American Petroleum Institute, 2016b) compute release rates, dispersion, and affected areas from fluid properties, hole size, and inventory. Applied offshore, these calculations must additionally account for factors that have no onshore analogue: personnel are accommodated on the same structure as the process plant; escape, evacuation, and rescue routes pass close to process modules; module congestion increases explosion overpressure for a given release; and the temporary refuge has finite impairment tolerance. Spatial planning is therefore a determinant of consequence rather than a matter of convenience, as work on optimising facility layout for safety and throughput in other technically dense environments demonstrates (Ogbete, Aminu-Ibrahim and Ambali, 2018).

The concept therefore requires that consequence banding be derived from, and remain consistent with, the facility's existing safety case or equivalent major accident hazard assessment. Where quantitative risk assessment already exists for the installation, the release scenarios and impairment frequencies it contains should be reused rather than recalculated, so that the RBI consequence ranking and the safety case tell the same story to the regulator. Where it does not, consequence is assigned by structured judgement against the definitions in Table 2.

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Band	Safety Consequence	Environmental Consequence	Business Consequence (JV net)
A: Negligible	No credible injury; release outside occupied areas	Contained on deck; no discharge to sea	Under 1 day deferment; negligible repair cost
B: Minor	First aid or single minor injury credible	Minor sheen; reportable but no lasting effect	1 to 3 days deferment; minor repair scope
C: Moderate	Single serious injury credible; local evacuation	Reportable discharge requiring response	3 to 14 days deferment; significant repair
D: Major	Multiple serious injuries or single fatality credible; escalation to adjacent equipment	Significant discharge; sustained regulatory involvement	14 to 60 days deferment; major repair or replacement
E: Severe	Multiple fatality potential; loss of escape route or TR impairment	Major discharge with long-term liability	Over 60 days deferment or loss of installation

Table 2. Illustrative consequence definitions for a joint venture offshore facility.

Three points deserve emphasis in the JV context. First, the business consequence column must be expressed in venture-level terms, meaning deferment and cost net to the joint account rather than to any single partner, otherwise partners with different equity positions will read the same matrix differently. Second, safety and environmental consequence must never be traded against business consequence within the banding itself; the matrix ranks the highest applicable band across the three columns, so a vessel with severe safety consequence cannot be demoted because its deferment impact is small. Third, consequence is a property of the vessel and its service, not of its current condition, and therefore changes only when inventory, fluid composition, layout, or manning changes. This separation matters because it means that inspection can reduce probability but never consequence, which in turn explains why some vessels remain in a high risk band even after excellent inspection results, and why those vessels are candidates for inherent risk reduction through inventory reduction, isolation philosophy, or material upgrade rather than for inspection optimisation alone.

4.8 Probability of Failure and the Treatment of Data Confidence

Probability of failure in this framework is a composite of two distinct things that are frequently conflated: the physical condition of the vessel, and the confidence with which that condition is known. A vessel with 6 mm of remaining corrosion allowance and a well-established corrosion rate from three inspection cycles is in a materially different position from a vessel believed to have 6 mm remaining on the basis of a single reading taken twelve years ago, even though a naive condition-only model would rank them identically.

The concept therefore bands probability of failure using both axes, as summarised in Table 3. This structure has a specific and deliberate consequence for behaviour: it means that inspection improves the risk position in two ways, by confirming condition and by raising confidence, and that the absence of data is itself a risk driver rather than a neutral state. Ventures that adopt condition-only models routinely discover that their least-inspected equipment appears lowest-risk, because no anomaly has ever been recorded against it. Treating data confidence explicitly removes that perverse incentive.

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Band	Condition Basis	Data Confidence	Typical Response
1: Very Low	Corrosion allowance largely intact; no active mechanism identified	Recent inspection, high coverage, measured rate	Extended interval to programme maximum
2: Low	Measured loss well within allowance; low measured rate	Recent inspection, adequate coverage	Routine interval; monitoring only
3: Medium	Measurable loss; remaining allowance adequate for at least two intervals	Inspection within one cycle; some extrapolation	Routine interval with defined coverage
4: High	Allowance substantially consumed, or credible mechanism with unquantified rate	Dated inspection or low coverage; estimated rate	Priority inspection within defined limit
5: Very High	Loss approaching or exceeding minimum required thickness; active cracking suspected	No usable condition data, or known anomaly not yet assessed	Immediate assessment; interim operating restriction if required

Table 3. Probability of failure banding combining measured condition and data confidence.

Where quantitative treatment is warranted, damage factors are computed following the procedures of API RP 581 (American Petroleum Institute, 2016b) for the mechanisms identified in the damage review, using API RP 571 descriptions (American Petroleum Institute, 2011) to confirm mechanism applicability. Thinning damage factors depend on the ratio of measured loss to available allowance and on the effectiveness and number of prior inspections, which is precisely the confidence adjustment described above expressed in numerical form. Stress corrosion cracking and hydrogen damage factors depend on environmental severity, material susceptibility, and post-weld heat treatment status, all of which are design or process properties rather than inspection findings, and which therefore must be captured in the data foundation rather than discovered in the field.

Two practical cautions apply. First, corrosion rates derived from as few as two thickness readings carry substantial uncertainty, because measurement repeatability at a given location is often of the same order as the annual loss being estimated; rates should therefore be derived from trend analysis across a monitoring location population rather than from single-point differences, and short-term rates should not be extrapolated across a life extension period without justification. Second, a low computed damage factor is a statement about a specific identified mechanism, not a general statement of vessel health. Mechanisms not considered in the damage review contribute nothing to the calculation, which is why the review itself, and its periodic revalidation whenever process conditions change, remains the controlling activity in the framework.

4.9 Interacting and Multiple Damage Mechanisms

The mapping in Table 1 treats damage mechanisms individually, which is how assessment procedures are organised and how most findings present themselves. Ageing vessels, however, frequently exhibit more than one mechanism in the same region, and the assessment rules for combined damage are neither obvious nor uniformly applied. Four combinations recur often enough on offshore production plant to warrant explicit treatment in the framework.

The first is general thinning combined with local thin areas. Where a vessel course has lost thickness uniformly and also contains a discrete thin patch, the local metal loss assessment must be performed against the already-reduced surrounding thickness rather than against nominal, otherwise the remaining strength factor is computed against a reference wall that no longer exists. This is a common source of non-conservative results in practice, and it is avoided by requiring that the average measured thickness of

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the surrounding course be established before any local assessment is attempted.

The second is pitting superimposed on general or local metal loss. Pitting reduces the load-bearing section in a manner not captured by an averaged thickness, and the assessment procedures require that the pitting be evaluated separately and the resulting damage measure combined with the metal loss result. Where pits are deep relative to remaining wall, or where they are aligned in a way that suggests a preferential path, the appropriate treatment may be to characterise the deepest pit couple as a local thin area or, if through-wall extension is credible, as a crack-like flaw.

The third, and most consequential, is cracking in a region of metal loss. A planar flaw located in a thinned area experiences higher local stress than the same flaw in a full-thickness section, so the crack assessment must use the reduced thickness and the corresponding stress state. Conversely, metal loss adjacent to a weld may indicate preferential weld corrosion, which is itself a precursor condition rather than an independent finding. In both cases the correct response is escalation to Tier 3 rather than sequential application of two Level 2 procedures, because the interaction is not captured by either procedure in isolation.

The fourth is external corrosion or corrosion under insulation coinciding with internal metal loss at the same location. The two are recorded by different inspection activities, often by different crews and into different reports, and the total remaining wall is therefore never computed. Where insulated vessels are in scope, the framework requires that external and internal thickness data be reconciled to a common grid reference before any assessment is performed, so that coincident loss is identified rather than assumed absent.

Flaw interaction rules apply within mechanisms as well as between them. Multiple crack-like flaws separated by less than a defined spacing must be recharacterised as a single larger flaw, and multiple thin areas in proximity must be assessed as one region. Inspection reporting that lists indications individually without recording their separation therefore prevents correct assessment, which is why spacing and relative position are specified in the inspection work pack rather than left to the reporting convention of the contractor. The general principle behind all of these rules is that assessment procedures are calibrated against specific idealised damage geometries, and that the further the actual condition departs from those idealisations, the sooner the assessment should move to a tier where the departure can be modelled explicitly rather than assumed away.

V. ADAPTATION TO JOINT VENTURE GOVERNANCE

5.1 Shared Risk Criteria

The single most important precondition for the concept in a JV setting is a common risk language. Partners operating in highly regulated environments each arrive with internally coherent but mutually incompatible process and decision structures, and coordination must therefore be designed rather than assumed. In integrity management the symptom is familiar: partners bring different corporate matrices, different definitions of consequence severity, and different tolerability thresholds.

The concept therefore begins with a facilitated alignment exercise in which the JV operating or technical committee formally adopts one matrix, one set of consequence definitions expressed in venture-level terms, and one set of action time limits per risk band. Front-loading this step is essential, since retrofitting shared criteria after disagreement has surfaced is markedly harder than establishing them at the outset. Mapping each partner standard against a common reference model, rather than negotiating them pairwise, is the practical method. Without this step, every subsequent inspection deferral or life extension decision risks re-litigation partner by partner.

5.2 Decision Rights and Assurance

The concept allocates decision rights in proportion to risk. Tier 1 FFS acceptances and routine interval confirmations are delegated to the operator's site integrity authority. Tier 2 outcomes affecting High or Very High risk vessels, all reratings, and all life extension declarations are endorsed by the operator's engineering authority and reported to the JV technical committee. Tier 3 assessments, and any decision to continue operating a vessel outside code-anticipated condition, are subject to independent verification, either by a partner's central engineering function acting as second reviewer or by a third-party verification body. Graduated escalation of this kind is what keeps oversight proportionate without becoming nominal.

The model extends naturally to the contractor tier. Inspection, NDE, and repair work offshore is executed largely by contractors, and the venture must hold that supply chain to the same criteria it has adopted for itself. Procurement of these services in a high-risk energy environment carries its own compliance obligations, and vendors should be assessed on demonstrated technical capability rather than price alone (Okonkwo, Ogunwole and Okeke, 2018a). Technology-enabled risk assessment provides the analytical basis for such evaluation and for the audit trail that supports it (Akomolafe and Agu, 2018).

Underneath the formal structure sits the question of whether the organisation behaves as the framework assumes. Formal authority produces compliance, while leadership produces the candid reporting on which an evergreen risk register depends. A JV in which an inspector is reluctant to report an unexpected wall loss finding has a governance problem that no matrix will correct, and data-driven safety risk control depends on the reporting culture that makes the data exist in the first place (Obriki and Arumosoye, 2018).

5.3 Cost and Value Sharing

RBI-FFS reframes the inspection budget conversation among partners from an activity-based discussion, meaning how many vessels will be opened this year, to a risk-based one, meaning how much risk reduction is purchased per unit of expenditure and deferment. The annual integrity plan presented for JV budget approval expresses proposed inspections and assessments in terms of risk band addressed, production deferment avoided through non-intrusive techniques and interval optimisation, and residual risk carried. Framed this way, the plan becomes a capital allocation decision of the kind addressed by financial analytics decision models (Lawal and Oduleye, 2018a), and its execution becomes a matter of budget compliance and statutory reporting, where the gap between approved and executed expenditure is itself a governance signal (Dogbatsey and Ebhojie, 2018).

Experience suggests that mature RBI programmes commonly redirect a substantial share of intrusive inspection effort away from low-risk equipment while increasing scrutiny of the genuinely critical population, a proposition that is directly attractive to all partners irrespective of their individual strategies. The savings are realised only if the supporting procurement and materials systems keep pace, since an optimised inspection plan translates into an optimised outturn cost only where spares and repair capability are available when required (Okonkwo, Ogunwole and Okeke, 2018b).

Consequence modelling also determines the value of avoided failure that appears in this economic case. Where a Major or Severe consequence vessel is moved from a high to a moderate probability band by targeted inspection and confirmed by fitness-for-service assessment, the risk reduction purchased is substantially greater than for a Minor consequence vessel receiving the same inspection effort. Expressing this explicitly, as risk reduction per unit of expenditure and deferment, is what converts the integrity plan from a cost schedule into an investment case that partners can compare against other uses of the same capital.

5.4 Regulatory and Verification Interface

The framework is designed to be presented to goal-setting regulators as the facility's written scheme of examination and life extension justification. The auditable chain, from damage mechanism review, through risk ranking, targeted inspection, documented FFS, to remaining life and re-inspection interval, provides the demonstration of continued integrity that regulators in mature basins increasingly require of installations operating beyond design life (Health and Safety Executive, 2014; Petroleum Safety Authority Norway, 2010).

Predictive compliance monitoring, in which routine operational data is analysed for early indications of systemic risk rather than relied upon only at scheduled audit points, offers a model for how the venture can demonstrate capability continuously rather than episodically (Adeyelu, 2018). A single documented framework satisfying the most demanding partner jurisdiction is also administratively cheaper than maintaining parallel regimes, a conclusion reached independently in the analysis of cross-border compliance where entities operate under several reporting regimes simultaneously (Lawal and Oduleye, 2018b). In prescriptive jurisdictions, the concept operates within statutory maximum intervals, using RBI to prioritise within them and FFS to disposition findings.

VI. IMPLEMENTATION METHODOLOGY

A six-stage implementation is proposed, sequenced so that governance alignment precedes technical analysis, and technical analysis precedes any change to inspection intervals. Table 4 summarises the stages, activities, and deliverables. For a typical offshore facility with 80 to 150 registered pressure vessels, Stages 1 to 3 are achievable within 9 to 12 months, with the first full RBI-FFS cycle completing within 24 months, aligned where possible to a planned turnaround.

Stage	Activities	Key Deliverables
1	Corporate framing: JV risk criteria workshop, alignment of partner risk matrices, definition of acceptance criteria, regulator engagement	Approved JV integrity risk criteria; RBI-FFS procedure endorsed by operating committee
2	Data foundation: equipment register validation, retrieval of design dossiers, corrosion loop definition, integrity operating windows, data gap register	Validated vessel database; corrosion loop diagrams; data gap closure plan
3	Baseline RBI: damage mechanism review per corrosion loop, PoF and CoF evaluation, risk ranking of full vessel population	Risk register; ranked vessel list; initial inspection plan with methods and coverage
4	Targeted inspection: execution of risk-targeted NDE campaigns, prioritising high and very high risk vessels; deployment of non-intrusive inspection where justified	Inspection data packs meeting FFS data quality requirements
5	FFS assessment: screening of findings, Level 1/2/3 assessment as required, remaining life estimation, rerate or repair decisions	FFS dossiers; remaining life register; MOC actions for any rerating
6	Feedback and evergreening: update of PoF with measured corrosion rates and FFS margins, revision of intervals, KPI reporting to JV partners	Updated risk register; revised inspection intervals; annual integrity report to JV

Table 4. Staged implementation methodology for the integrated RBI-FFS concept.

Four implementation principles deserve emphasis. First, data quality governs everything: an FFS assessment is only as good as the thickness grid or flaw sizing behind it, and the concept therefore invests early in inspection procedures, NDE technique qualification, and data management rather than in analytical sophistication.

Second, competence must be layered to match the tiers: certified inspectors and site engineers for Tier 1, trained integrity engineers for Tier 2, and access to specialist fracture and finite element capability for Tier 3, with the competence map agreed by the JV partners as part of Stage 1.

Third, logistics must not be allowed to defeat planning: repair clamps, weld consumables, replacement nozzles, and long-lead spares identified by FFS outcomes must be available when the shutdown window opens, which argues for maintenance-driven materials readiness rather than reactive ordering (Okonkwo, Ogunwole and Okeke, 2018b).

Fourth, the transition itself must be managed as a change programme, not a technical rollout. Moving an organisation from calendar-based to risk-based inspection alters roles, authority, and long-standing assumptions about what constitutes diligence, and resistance in such transitions is generated by unclear ownership rather than by the technical content of the change.

6.1 Roles, Competence, and Decision Authority

Because the framework delegates real decisions to defined roles, those roles and their competence requirements must be specified rather than assumed. Table 5 sets out an indicative allocation, which each venture should adapt to its own organisation and confirm during Stage 1. The essential principle is that authority to accept risk is matched to demonstrated competence and to independence from the cost and schedule pressure that the decision affects.

Role	Responsibility in the RBI-FFS Cycle	Indicative Competence	Decision Authority
Site inspection engineer	Executes and reviews inspection data; performs Tier 1 screening; raises anomalies	Certified inspector; trained in FFS Level 1 screening and NDE interpretation	Closes Tier 1 acceptances within corrosion allowance
Corrosion and materials engineer	Owns damage mechanism review, corrosion loops, and rate determination	Degree-qualified; experience of oilfield corrosion and materials degradation	Endorses mechanism list and corrosion rates
Integrity engineer	Performs Tier 2 assessments; maintains risk register; sets intervals	Degree-qualified; trained in API 579 Level 2 procedures and pressure design	Recommends intervals; endorses Tier 2 outcomes
Engineering authority (operator)	Endorses High and Very High risk decisions, reratings, life extension	Chartered or equivalent; accountable technical authority	Approves rerate and life extension declarations
Specialist assessor	Executes Tier 3 assessments including FEA and fracture mechanics	Specialist in fracture mechanics, FEA, or probabilistic methods	Issues Tier 3 assessment; recommendation only
Independent verifier	Reviews Tier 3 outcomes and any operation outside code-anticipated condition	Independent of the delivery team; equivalent technical standing	Verification statement to JV committee
JV technical committee	Receives risk register, endorses criteria, approves integrity plan and budget	Partner technical representatives	Approves criteria, plan, and expenditure

Table 5. Indicative roles, competence, and decision authority within the RBI-FFS cycle.

Two features of this allocation are deliberate. First, the specialist assessor who performs a Tier 3 evaluation issues a recommendation rather than an approval. Advanced analysis carries an authority that can be misleading, because the sophistication of a finite element model is not evidence that its boundary conditions, material properties, or flaw characterisation were correct. Separating analysis from acceptance preserves the challenge function. Second, the independent verifier is engaged on the basis of technical standing rather than contractual position, and reports to the JV committee rather than to the operator's delivery organisation, which is what allows non-operating partners to rely on the verification without duplicating the assessment themselves.

Competence is maintained rather than merely established. Assessment procedures are used infrequently by any individual engineer, so skills decay between applications, and the framework therefore includes periodic refresher training, peer review of a sample of Tier 1 and Tier 2 dispositions, and participation in the damage mechanism reviews as a means of maintaining exposure. Capability must survive personnel rotation, which offshore is continuous.

6.2 Execution Risks During Inspection Campaigns

The implementation itself introduces hazard. Vessel entry involves confined space work; non-intrusive campaigns involve scaffolding, insulation removal, and working at height; and any repair or replacement decision may require heavy lift of large components in a congested offshore module. Risk controls for lifting and rigging operations should therefore be applied to the execution of the inspection plan, not only to its findings.

Environmental exposure is a further consideration frequently underestimated in planning. Inspection campaigns in tropical and desert offshore environments expose personnel to sustained thermal load while working in confined and enclosed spaces wearing protective equipment, and integrated heat stress risk modelling provides a structured basis for scheduling and controlling such work (Arumosoye and Obriki, 2018). Because offshore campaigns are staffed by temporary, multi-employer teams assembled for a specific window, the leadership conditions governing safe performance in temporary project organisations apply directly.

6.3 Pilot Selection and Phasing

Ventures rarely convert an entire facility to the framework in a single step, and attempting to do so tends to exhaust both the engineering resource and the partners' patience before any benefit is demonstrated. A phased approach, beginning with a deliberately chosen pilot, is therefore recommended, and the choice of pilot largely determines whether the programme secures continued funding.

Four criteria should guide that choice. The pilot facility should have a forthcoming planned shutdown, so that the inspection campaign generated by the baseline risk assessment can be executed without creating additional deferment. It should have a vessel population large enough to demonstrate portfolio effects, since a facility with twenty vessels cannot show the redistribution of effort that constitutes the main economic argument. It should have reasonably intact design documentation, because a pilot conducted on the facility with the worst records will spend its budget on data reconstruction and produce conservative results that argue against the method. Where no facility in the portfolio has good records, the pilot becomes an infrastructure development exercise before it becomes an integrity one, and should be planned accordingly; models for building durable technical infrastructure under resource constraint are instructive here (Aminu-Ibrahim, Ogbete and Ambali, 2018). Finally, it should have an operations and inspection team willing to work differently, as the framework asks site personnel to record more, escalate earlier, and defer to written escalation criteria rather than to judgement alone.

The pilot should be scoped to a complete cycle rather than to a complete population. It is more informative to take one third of the vessels through baseline ranking, targeted inspection, assessment, and feedback than to rank every vessel and stop, because only the complete cycle demonstrates the feedback effect on which the whole argument rests. Vessel selection within the pilot should deliberately include several expected to be high risk and several expected to be low, so that both the detection outcome and the avoided-intervention outcome are available to report.
Sequencing within the pilot also matters. The damage mechanism review should be complete for every

corrosion loop in scope before any inspection is executed, because a campaign mobilised against an incomplete mechanism list will collect the wrong data and the vessel will have to be revisited, which on an offshore installation may mean waiting a full shutdown cycle. Equally, the assessment capability must be in place before the inspection returns rather than commissioned in response to the first finding, since the interval between a finding and its disposition is precisely the period during which the vessel operates in an unassessed state.

Reporting of the pilot should be prepared with the audience in mind. Partners will ask three questions: what did this cost, what did it find, and what would we have done otherwise. The third is the most important and the most often neglected, because the value of the framework lies in the difference between the actions it produced and the actions the previous regime would have produced. Recording that counterfactual during the pilot, vessel by vessel, is far easier than reconstructing it afterwards, and it converts the business case from an assertion about industry experience into evidence from the venture's own asset.

Roll-out beyond the pilot should extend by corrosion loop and by facility rather than by risk band, since the damage mechanism review is the expensive and non-transferable step and it is performed per loop. Where a venture operates several facilities of similar vintage and design, much of the review content transfers with modest adaptation, and the marginal cost of each subsequent facility falls substantially.

Two failure modes recur in phased implementations and are worth guarding against explicitly. The first is a pilot that produces a risk register but never a revised inspection plan, because the analytical work was resourced while the planning and execution work was not. Such a pilot generates the appearance of progress and none of the benefit, and it typically ends with the register becoming stale before the second cycle begins. The second is a pilot whose scope is quietly extended, facility by facility, without the governance steps of Stage 1 being repeated for the added assets. Because risk criteria, decision rights, and verification arrangements are agreed per venture rather than per method, extending the technical framework to a facility whose partners have not endorsed those criteria produces assessments that no committee has authority to accept.

VII. ILLUSTRATIVE APPLICATION

7.1 First Illustrative Case: Ageing Production Separator

To make the concept concrete, this section traces representative, generic cases through the framework. The vessels, their data, and their findings are illustrative composites typical of ageing offshore plant, not data from any specific facility.

Parameter	Value / Description
Vessel	First-stage production separator, horizontal, carbon steel SA-516 Gr. 70
Design code / year	ASME VIII Div. 1, fabricated 1991 (27 years in service at assessment date, 2018)
Design conditions	Design pressure 25 barg at 120 C; MAWP 25.8 barg
Nominal thickness / corrosion allowance	Shell 22 mm nominal; corrosion allowance 3 mm
Service	Three-phase separation; sweet-to-slightly-sour crude, water cut rising to 65 percent; CO_2 partial pressure 0.9 bar
RBI position (baseline)	PoF 4 (thinning mechanism active, moderate data confidence), CoF D (hydrocarbon inventory, congested module): High risk

Inspection finding (targeted AUT campaign)	Local thin area 350 mm x 500 mm at the water phase 6 o'clock position; minimum measured thickness 14.2 mm; measured long-term corrosion rate 0.29 mm/yr
FFS route	Part 4 screening failed locally; Part 5 (Local Metal Loss) Level 2 assessment
Level 2 result	Remaining strength factor 0.94 against allowable RSF of 0.90: acceptable at current MAWP
Remaining life	Approximately 6.5 years to Level 2 limit at measured rate; re-inspection set at 3 years (half-life rule) with corrosion probe monitoring in water leg
Risk update	PoF reduced from 4 to 3 on measured-rate, high-confidence data: residual risk Medium (3D); internal entry avoided, deferment saving credited to JV

Table 6. Illustrative RBI-FFS cycle for an ageing first-stage separator.

The case illustrates the essential value chain of the concept. Baseline RBI identified the separator as High risk because thinning was credible and condition data was dated, and therefore directed an automated ultrasonic campaign focused on the water phase region where CO2 corrosion concentrates. The campaign, executed non-intrusively without vessel entry, found a local thin area and simultaneously delivered the thickness grid required for assessment. The Level 2 local metal loss evaluation demonstrated a remaining strength factor above the allowable limit, permitting continued operation at full MAWP with a defensible remaining life.

Monitoring and a half-life re-inspection interval were imposed, and the measured corrosion rate and improved data confidence were fed back into the risk model, lowering the vessel's PoF band. The corrosion probe installed in the water leg converts the vessel from a periodically sampled item to a continuously observed one. The JV avoided a vessel entry and its associated production deferment, while carrying a documented, endorsed, and independently verifiable residual risk. Had the remaining strength factor fallen below the allowable, the same process would have generated the rerate, repair, or replacement decision with equal transparency.

7.2 Second Illustrative Case: Sour Service Vessel with Cracking

The separator case represents the most common outcome of the framework, in which measured degradation proves acceptable and the principal benefit is avoided intervention. The second case illustrates the opposite and equally important outcome, in which the framework identifies a genuine threat that time-based inspection would probably have missed, because the damage mechanism concerned is not detectable by the general visual and thickness examination that routine internal inspection provides.

Parameter	Value / Description
Vessel	Sour gas scrubber, vertical, carbon steel, not post-weld heat treated at fabrication
Design code / year	ASME VIII Div. 1, fabricated 1988; 30 years in service at assessment
Service	Wet sour gas; H2S partial pressure 0.06 bar; free water present at low points
RBI position (baseline)	PoF 5 (susceptible material, wet H2S service, no prior HIC-specific inspection), CoF E (toxic and flammable inventory, manned module): Very High risk
Inspection scope directed	HIC and SOHIC-specific examination: automated ultrasonic mapping for blistering and laminar indications, plus wet fluorescent magnetic particle and time-of-flight diffraction on weld seams

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	and nozzle welds
Findings	Scattered hydrogen blistering in lower shell; one planar indication 42 mm long, 6 mm through-wall depth adjacent to a nozzle weld
FFS route	Part 7 for blistering and HIC damage; Part 9 Level 2 for the planar indication using the Failure Assessment Diagram
Assessment outcome	Blistering acceptable with monitoring under Part 7 criteria; planar flaw assessed as acceptable at reduced MAWP of 21 barg pending repair
Decision	Interim operation at derated pressure under management of change; weld excavation and repair scheduled at next shutdown; post-repair PWHT specified
Risk update	PoF held at 5 until repair completion, then reassessed; interim risk accepted at JV technical committee with independent verification

Table 7. Illustrative RBI-FFS cycle for an ageing sour service scrubber.

Several features of this case are instructive. The vessel was ranked Very High risk before any inspection was performed, on the basis of material susceptibility and service environment alone, and that ranking is what directed the specific and relatively expensive examination techniques required to find hydrogen-induced damage and weld cracking. A calendar-driven internal visual inspection would have recorded a vessel in acceptable general condition. The value delivered by the framework here is not efficiency but detection, and it derives entirely from the damage mechanism review having correctly identified wet hydrogen sulphide service in a non-post-weld-heat-treated vessel as a credible cracking scenario.

The assessment outcome also illustrates the practical role of derating. Fitness-for-service does not reduce to a binary judgement of fit or unfit; Part 9 evaluation established that the flaw was tolerable at a reduced pressure, which permitted continued production while a proper repair was engineered and scheduled, rather than forcing either an immediate unplanned shutdown or an undocumented decision to continue at full pressure. That intermediate outcome is only available to an operator with the assessment capability to quantify it and the governance to authorise it, which is why Sections 5 and 6 treat competence and decision rights as part of the framework rather than as implementation detail.

7.3 Portfolio-Level Effect

The individual cases show how single vessels are dispositioned. The portfolio effect, which is what the JV partners actually experience, is shown illustratively in Table 8 for a facility with 120 registered pressure vessels completing one full cycle of the framework.

Risk band	Vessels at baseline	Share of population	Vessels after first cycle	Share of inspection spend
Very High	6	5 percent	2	24 percent
High	17	14 percent	11	33 percent
Medium	44	37 percent	48	31 percent
Low	53	44 percent	59	12 percent
Total	120	100 percent	120	100 percent

Table 8. Illustrative portfolio distribution and inspection spend allocation after one RBI-FFS cycle.

Three patterns visible in this illustration are characteristic of mature implementations. First, the distribution shifts modestly downward overall, not because the equipment improved but because measurement replaced conservative assumption for the vessels that received attention; several items ranked High on the basis of unknown condition moved to Medium once inspected and assessed, which is the data confidence effect described in Section 4.8. Second, a small number of vessels remain in the upper bands after inspection, and these are the genuine integrity liabilities of the facility, requiring repair, replacement, derating, or inherent risk reduction rather than further examination. Third, the allocation of expenditure bears no resemblance to the distribution of the population: roughly a fifth of the vessels attract over half the inspection spend, which is exactly the intended outcome and the clearest single expression of what risk-based planning changes.

It is this final pattern that most often requires explanation to non-operating partners, because it looks superficially like under-inspection of the majority of the plant. The response is that the majority of the plant is not under-inspected but appropriately inspected, that the basis for each interval is documented and auditable, and that any vessel whose condition or service changes re-enters the priority population automatically through the evergreening process.

VIII. DISCUSSION

8.1 Benefits

- Safety focus: inspection effort concentrates on the vessels and damage mechanisms most likely to cause loss of containment, directly addressing the ageing-asset failure patterns highlighted by regulators (Health and Safety Executive, 2014).
- Economic efficiency: intrusive inspections of low-risk vessels are reduced, non-intrusive techniques are substituted where justified, and shutdown scope is driven by risk rather than calendar, all of which translate into deferment savings shared by the JV (Okonkwo, Ogunwole and Okeke, 2018b).
- Life extension on an engineering basis: FFS converts inspection findings into quantified margins and remaining life, providing the documented justification that regulators and partners require for operation beyond design life.
- Governance transparency: a single agreed risk language, layered decision rights, and independent verification give all partners visibility of, and confidence in, integrity decisions they are jointly funding and jointly exposed to.
- Learning loop: every cycle replaces assumption with measurement, so risk ranking, intervals, and budgets improve in accuracy year on year, and the programme itself matures in a measurable way.
- Environmental alignment: avoided loss of containment is avoided pollution, and the documented risk position supports the environmental control and reporting expectations placed on operators.

8.2 Limitations and Risks of the Concept

- Data dependency: legacy facilities frequently lack complete design dossiers and baseline thickness data; until gaps are closed, conservative assumptions must stand in, limiting early benefits.
- Competence dependency: misapplied FFS is more dangerous than honest ignorance; the concept fails unsafe if Level 2 and Level 3 assessments are performed without adequate materials, stress analysis, and fracture competence.
- Organisational inertia: JV partners accustomed to prescriptive intervals may perceive interval extension as risk transfer; the governance measures of Section 5 and the change disciplines of Section 6 exist precisely to manage this.
- Mechanism blind spots: RBI only manages the mechanisms the damage review foresees; rare or emergent mechanisms, for example unanticipated changes in produced fluid chemistry, require the operating window monitoring and management of change disciplines that surround the framework.
- Contractor variability: the quality of field data depends on contracted inspection crews, making contractor capability and compliance part of the integrity system rather than an adjacent concern.
- Not a substitute for barriers: RBI-FFS manages the containment barrier; it must remain integrated with safety instrumented systems, relief

protection, occupational safety management of the inspection activity itself (Obriki and Arumosoye, 2018; Arumosoye and Obriki, 2018), and emergency response readiness.

8.3 Measuring Whether the Framework Is Working

A framework of this kind can fail quietly. Risk registers can be maintained without being believed, assessments can be performed without being acted upon, and inspection plans can be published without being executed, and none of these failures produces a visible event until a loss of containment occurs. The concept therefore specifies a small set of indicators, shown in Table 9, that are reported to the JV technical committee alongside the annual integrity plan and reviewed after any significant finding.

Indicator	What it measures	Why it matters to the JV
Inspection plan compliance	Percentage of planned inspections completed within their due window	Deferred inspection is deferred risk reduction, not saved cost
Overdue High and Very High items	Count and ageing of priority items past due date	Direct measure of accepted but unmanaged exposure
Anomaly closure time	Median days from finding to FFS disposition	Long closure times mean vessels operate in an unassessed state
Data confidence coverage	Percentage of vessels with condition data within one interval	Identifies the unmeasured population driving conservative ranking
Risk register currency	Percentage of vessels whose risk position reflects the latest findings	An out-of-date register misdirects the following year's plan
Remaining life margin	Number of vessels with under five years assessed remaining life	Forward indicator of repair and replacement capital demand
Deferment avoided	Production days preserved through non-intrusive substitution and interval optimisation	Translates the programme into terms partners already track
Repair backlog	Value and count of FFS-mandated repairs awaiting execution	Assessment without execution converts analysis into accumulated risk

Table 9. Indicators for monitoring the health of the RBI-FFS programme.

The selection is deliberately small and weighted toward leading rather than lagging measures. Counting completed inspections says little; counting overdue priority items, unassessed anomalies, and unexecuted repairs says a great deal, because each represents a decision that has been made in practice without being made explicitly. The repair backlog indicator deserves particular attention in a JV setting, since it is the point at which technical assessment meets capital allocation, and it is where a venture under cost pressure will first accumulate risk while continuing to report full compliance with its inspection plan.

These indicators also serve an assurance function. Because they are computed from the integrity database rather than compiled by the delivery organisation, they are difficult to present selectively, and they give non-operating partners a means of forming an independent view of programme health without conducting a technical audit. Analysing routine data for early indications of systemic risk, rather than relying on periodic audit alone, is the same principle applied in predictive compliance monitoring elsewhere (Adeyelu, 2018). Where the computation of these indicators is automated from the integrity database, the reporting burden falls and the figures become harder to curate selectively;

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systematic review of automated build and deployment pipelines in other domains describes both the discipline required to achieve this and the failure modes that follow from partial automation (Badmus, Dosunmu and Ozowara, 2018).

8.4 Integrity Operating Windows and Management of Change

The framework assumes that the process conditions used in the damage mechanism review remain representative of actual operation. On an ageing facility this assumption is frequently false. Water cut rises through field life, new tie-backs introduce fluids of different composition, souring may develop in reservoirs previously considered sweet, and debottlenecking pushes temperatures, pressures, and velocities toward or beyond original design assumptions. Each of these changes can activate a mechanism that the review correctly excluded at the time it was performed.

Integrity operating windows address this by defining, for each corrosion loop, the range of process parameters within which the assessed degradation behaviour holds. Typical parameters include water cut, carbon dioxide and hydrogen sulphide partial pressures, chloride concentration, pH, temperature, velocity, and the presence and dosage of corrosion inhibitor. Excursion beyond a defined limit triggers a specified response: notification, review of the affected corrosion loop, revision of corrosion rate, and where warranted an unscheduled inspection or reassessment. The windows are owned jointly by process and integrity engineering, which is what prevents them from becoming either an operational constraint nobody applies or an integrity document nobody reads.

Management of change is the corresponding formal mechanism. Any change to feedstock, operating envelope, inhibitor regime, insulation, or vessel internals is screened for integrity consequence before implementation, and any change to a vessel's assessed condition, rating, or inspection interval is likewise processed as a change rather than as a technical update. In a joint venture this discipline carries additional weight, because a change approved for commercial reasons by one partner's operations organisation may alter the risk position that all partners have accepted.

The same logic applies in reverse. Where a vessel has been derated or is operating under an interim fitness-for-service acceptance, as in the case described in Section 7.2, the restriction must be visible to operations in the control system and the operating procedures, not merely recorded in an engineering file. Interim conditions that exist only in documentation are among the more common contributors to industrial incidents.

8.5 Positioning Relative to Current Practice

The individual components of this concept are established: API RP 580 and API RP 581 for risk-based inspection, API 579-1/ASME FFS-1 for fitness-for-service, DNV RP-G101 for offshore topsides RBI, and mature regulator expectations on ageing and life extension. The contribution of the concept lies in their deliberate integration into one closed-loop process, and in its explicit adaptation to joint venture governance, cost sharing, and assurance, which the standards themselves do not address. The concept is therefore best understood as an operating model built from standard components, configured for the organisational environment in which much of the world's ageing offshore capacity is actually managed.

IX. CONCLUSIONS AND RECOMMENDATIONS

This paper has presented a concept for the integrated application of Risk-Based Inspection and Fitness-for-Service assessment to ageing pressure vessels on offshore joint venture facilities. The following conclusions are drawn:

1. Ageing offshore pressure vessels demand a condition-led, risk-led integrity approach; time-based inspection alone can neither prioritise scarce offshore inspection resources nor justify continued operation of degraded equipment.
2. RBI and FFS are complementary halves of one integrity question, and their integration into a closed loop around a shared data

foundation removes the inefficiencies of treating them as separate disciplines.

3. In a joint venture, technical integration is insufficient without governance integration: a single agreed risk matrix, layered decision rights, independent verification of high-consequence decisions, and risk-based budget presentation are essential design features, not optional extras.
4. A staged implementation, beginning with governance alignment and data foundation and culminating in an evergreen risk register, can deliver a first complete RBI-FFS cycle on a typical facility within approximately two years.
5. The concept enables life extension decisions that are simultaneously safer, cheaper, and more defensible than the prevailing separated practice.

9.1 Limitations of This Study and Directions for Validation

Two limitations should be stated plainly. The first is that this paper is conceptual. The framework, the staged implementation, the illustrative cases, and the portfolio distribution are constructed from established procedure and representative offshore conditions rather than from a completed field deployment on a named installation. They are therefore internally consistent and consistent with the governing standards, but they are not evidence. The redistribution of inspection effort shown in Section 7.3, in particular, illustrates the mechanism rather than reporting a measured result.

The second limitation concerns the treatment of joint venture governance. The measures proposed in Section 5 are drawn from the structure of the problem rather than from comparative study of how particular ventures have actually resolved integrity disputes. Ventures differ substantially in the authority delegated to the operator, in the technical depth of non-operating partner organisations, and in the extent to which the regulator engages partners directly, so the allocation of decision rights proposed here will require adaptation in each case rather than adoption as written.

Three directions would advance the concept from proposal to demonstrated practice. The first is documented application on a mature installation with published before and after distributions of risk band, inspection expenditure, and deferment, which is the evidence the economic argument currently lacks. The second is systematic comparison of assessment outcomes against subsequent measured condition, so that the conservatism of Level 1 and Level 2 procedures as applied to offshore vessels can be quantified rather than assumed. The third is examination of how the framework behaves under commercial stress, since the conditions under which a venture defers a priority inspection or postpones an assessed repair are precisely the conditions the governance model exists to withstand.

It is recommended that JV operators of ageing offshore facilities: pilot the concept on a single high-value facility with a forthcoming turnaround, to demonstrate deferment and assurance benefits; invest first in data foundation and NDE quality rather than analytical tooling; ormalize the layered competence model for FFS tiers before delegating acceptance decisions; and establish the annual JV integrity report as the standing vehicle through which partners exercise oversight of shared ageing-asset risk. Future development of the concept should address extension to piping systems and pipelines, incorporation of structural reliability and probabilistic FFS methods for the most critical vessels, and the opportunity to automate the feedback loop through digital integrity platforms and permanently installed corrosion monitoring. Extension of remote and unmanned survey techniques from distributed network assets to congested offshore modules is a further avenue worth investigation (Dagodzo, 2018b).

REFERENCES

[1] Adeyelu, O. O. (2018). A predictive compliance monitoring framework for detecting systemic safety risks through aviation consumer complaint data. Iconic Research and Engineering Journals, 1(8), 250-276. https://doi.org/10.64388/IREV1I8-1718478

[2] Akomolafe, O., & Agu, M. U. (2018). A conceptual model for enhancing internal audit quality through technology-enabled risk assessment frameworks. Iconic Research and Engineering Journals, 1(9), 458-475.

[3] Amayo, E. B. (2017). Multi algorithm of loss objective function of a single phase induction motor. International Journal of Development Research, 7(5), 12805-12810.

[4] Amayo, E. B., & Popoola, T. T. (2017a). Multi algorithm of weight objective function of a single phase induction motor. International Journal of Trend in Research and Development, 4(2), 184-188.

[5] Amayo, E. B., & Popoola, T. T. (2017b). Scientific study of telecommunication deployment in achieving quality network. International Journal of Trend in Research and Development, 4(5), 311-314.

[6] Amayo, E. B., Ubeku, E., & Oshevire, P. (2015). Multi algorithm of a single objective function of a single phase induction motor. Journal of Multidisciplinary Engineering Science and Technology, 2(12), 3400-3403.

[7] American Petroleum Institute (2011). API Recommended Practice 571: Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, 2nd Edition. Washington, DC: API.

[8] American Petroleum Institute (2014). API 510: Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration, 10th Edition. Washington, DC: API.

[9] American Petroleum Institute (2016a). API Recommended Practice 580: Risk-Based Inspection, 3rd Edition. Washington, DC: API Publishing Services.

[10] American Petroleum Institute (2016b). API Recommended Practice 581: Risk-Based Inspection Methodology, 3rd Edition. Washington, DC: API Publishing Services.

[11] American Petroleum Institute / American Society of Mechanical Engineers (2016). API 579-1/ASME FFS-1: Fitness-For-Service, 3rd Edition. Washington, DC and New York: API / ASME.

[12] Aminu-Ibrahim, A. Y., Ogbete, J. C., & Ambali, K. B. (2018). Developing sustainable diagnostic laboratory infrastructure models for emerging and resource constrained health systems. Iconic Research and Engineering Journals, 1(8), 118-132. https://doi.org/10.64388/IREV1I8-1713586

[13] Anderson, T. L. (2017). Fracture Mechanics: Fundamentals and Applications, 4th Edition. Boca Raton: CRC Press.

[14] Arumosoye, O. M., & Obriki, O. D. (2018). Development of an integrated heat stress risk conceptual model for industrial operations in extreme environments. Iconic Research and Engineering Journals, 1(12), 141-160. https://doi.org/10.64388/IREV1I12-1714415

[15] Atta, S., Asomani, E., & Adenuga, O. M. (2018). A systematic review of green corrosion inhibitors from agricultural extracts for mild steel protection in acidic and alkaline media. International Journal of Engineering and Modern Technology, 4(1), 64-97. https://doi.org/10.56201/ijemt.vol.4.no1.2018.pg64.97

[16] Badmus, O., Dosunmu, A. A., & Ozowara, D. E. (2018). A systematic review of CI/CD pipeline strategies in Salesforce DevOps: Tools, practices, and deployment outcomes. Iconic Research and Engineering Journals, 2(6).

[17] Dagodzo, D. (2018a). A conceptual framework for UAV integration into national power grid inspection programs. Iconic Research and Engineering Journals, 2(5), 391-412. https://doi.org/10.64388/IREV2I5-1716082

[18] Dagodzo, D. (2018b). A review of UAV applications in electrical transmission line inspection: Methods, technologies, and challenges. Iconic Research and Engineering Journals, 2(6), 234-254. https://doi.org/10.64388/IREV2I6-1716083

[19] Det Norske Veritas (2010). DNV-RP-G101: Risk Based Inspection of Offshore Topsides Static Mechanical Equipment. Hovik: DNV.

[20] Det Norske Veritas (2011). DNV-RP-G103: Non-Intrusive Inspection. Hovik: DNV.

[21] Dogbatsey, E. A., & Ebhojie, O. (2018). Budget compliance and statutory reporting in Sub-Saharan Africa: A systematic review of frameworks, gaps, and reform pathways. Zenodo. https://doi.org/10.5281/zenodo.20446859

[22] Energy Institute (2009). Guidance for Corrosion Management in Oil and Gas Production and Processing. London: Energy Institute.

[23] Health and Safety Executive (2010). RR823: Plant Ageing Study, Phase 1 Report. Bootle: HSE Books.

[24] Health and Safety Executive (2014). Key Programme 4 (KP4): Ageing and Life Extension Inspection Programme Report. Bootle: HSE Offshore Division.

[25] Ladapo, O. O., Dosunmu, A. A., Jooda, D., & Abolaji, T. O. (2018). Lessons learned from offline assessment of security-critical systems: The case of Microsoft Active Directory. Iconic Research and Engineering Journals, 2(6), 277-299. https://doi.org/10.64388/IREV2I6-1717205

[26] Lawal, O. A., & Oduleye, T. E. (2018a). A conceptual model for financial analytics driven enterprise value creation in technology firms. Iconic Research and Engineering Journals, 2(2).

[27] Lawal, O. A., & Oduleye, T. E. (2018b). A review and conceptual framework for tax governance and cross-border compliance analytics. Iconic Research and Engineering Journals, 2(5).

[28] Mbonu, I. S., Aliliele, C., Iwuanyanwu, U., & Oluoha, O. M. (2018). A conceptual framework for legal and ethical risk modeling in enterprise data protection governance systems. Iconic Research and Engineering Journals, 2(2), 207-226. https://doi.org/10.64388/IREV2I2-1714911

[29] Obriki, O. D., & Arumosoye, O. M. (2018). Conceptual modeling of data-driven occupational safety risk control in large-scale energy infrastructure projects. Iconic Research and Engineering Journals, 1(7), 169-189. https://doi.org/10.64388/IREV1I7-1714414

[30] Ogbete, J. C., Aminu-Ibrahim, A. Y., & Ambali, K. B. (2018). Optimizing laboratory spatial planning strategies to improve diagnostic accuracy, safety, and clinical throughput. Iconic Research and Engineering Journals, 2(1), 87-113. https://doi.org/10.64388/IREV1I7-1713587

[31] Oil and Gas UK (2012). Guidance on the Management of Ageing and Life Extension of UKCS Oil and Gas Installations. London: Oil and Gas UK.

[32] Okonkwo, C. S., Ogunwole, O., & Okeke, O. T. (2018a). Framework for strategic procurement optimization in oil and gas operations. Iconic Research and Engineering Journals, 1(7), 153-168. https://doi.org/10.64388/IREV1I7-1713119

[33] Okonkwo, C. S., Ogunwole, O., & Okeke, O. T. (2018b). Model for inventory availability and plant uptime improvement in energy facilities. Iconic Research and Engineering Journals, 2(4), 160-172. https://doi.org/10.64388/IREV2I4-1713120

[34] Oshevire, P., Eyenubo, O. J., & Amayo, B. (2017). Voltage control in the presence of distributed generation. ATBU Journal of Science, Technology and Education, 5(2), 165-173.

[35] Petroleum Safety Authority Norway (2010). Guidelines to Regulations Relating to Design and Outfitting of Facilities in the Petroleum Activities (Facilities Regulations), life extension provisions. Stavanger: PSA.

[36] Standards Norway (2015). ISO 2394: General Principles on Reliability for Structures, as implemented in Norwegian offshore practice. Geneva: ISO.

[37] Sunday, E. A., & Omoegun, G. O. (2018). Integrating solar power solutions in small-scale manufacturing industries in Nigeria. International Journal of Scientific Research in Science, Engineering and Technology, 4(8), 832-853.