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Optimizing Inspection Intervals in Aging Offshore Facilities Using Advanced NDT Evidence within a Risk-Based Governance Framework

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Abstract:*Aging offshore infrastructure—particularly in mature basins such as the North Sea and Gulf of Mexico—faces escalating integrity management challenges as assets operate well beyond their original design lives. While Risk-Based Inspection (RBI) has become the industry standard for prioritizing inspection efforts, a critical gap persists: conventional RBI implementations often lack a formal, auditable mechanism to leverage high-confidence data from advanced non-destructive testing (NDT) methods to dynamically optimize inspection intervals. This paper addresses that gap by proposing a structured governance framework that systematically integrates quantitative evidence from advanced NDT—such as phased array ultrasonic testing (PAUT), robotic corrosion mapping, and drone-based metrology—into the RBI reassessment process. The methodology comprises three core steps: (1) updating the Probability of Failure (PoF) by incorporating measured degradation rates and revising inspection effectiveness factors to reflect the superior Probability of Detection (POD) of advanced NDT; (2) quantifying epistemic and aleatory uncertainties through probabilistic methods such as Monte Carlo simulation to establish confidence bounds on the revised PoF; and (3) subjecting the technical findings to formal review by a cross-functional governance panel against predefined risk acceptance criteria. The framework's efficacy is demonstrated through two real-world case studies: one involving external corrosion under insulation on a topside pressure vessel, and another addressing a fatigue crack indication in a subsea pipeline girth weld. In both cases, high-fidelity NDT data enabled defensible inspection interval adjustments—extending the interval by two years in the first case and transitioning to a targeted monitoring strategy in the second—while ensuring PoF remained within corporate and regulatory risk thresholds. The study delivers a transparent, repeatable, and regulatorily defensible methodology that empowers operators of aging assets to replace rigid, calendar-driven inspection schedules with evidence-based, risk-informed decisions, thereby enhancing safety assurance, operational efficiency, and compliance.*

Keywords: Risk-Based Inspection (RBI), Advanced Non-Destructive Testing (NDT), Inspection Interval Optimization, Probability of Detection (POD), Aging Offshore Assets, Integrity Management, Uncertainty Quantification, Governance Framework, Fitness-for-Service (FFS), Regulatory Compliance

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INTRODUCTION

Over 60% of fixed offshore platforms in the North Sea and more than 50% in the U.S. Gulf of Mexico have surpassed 25 years of operational service, placing a substantial proportion of the global offshore oil and gas infrastructure squarely within the "aging asset" category. These facilities were typically designed for 20–30-year service lives, yet economic, strategic, and energy-transition considerations have compelled operators to extend operations well beyond original design expectations. This trend is not confined to mature basins; similar challenges are emerging in Southeast Asia, Brazil, and West Africa as early-generation developments approach or exceed their intended lifespans.

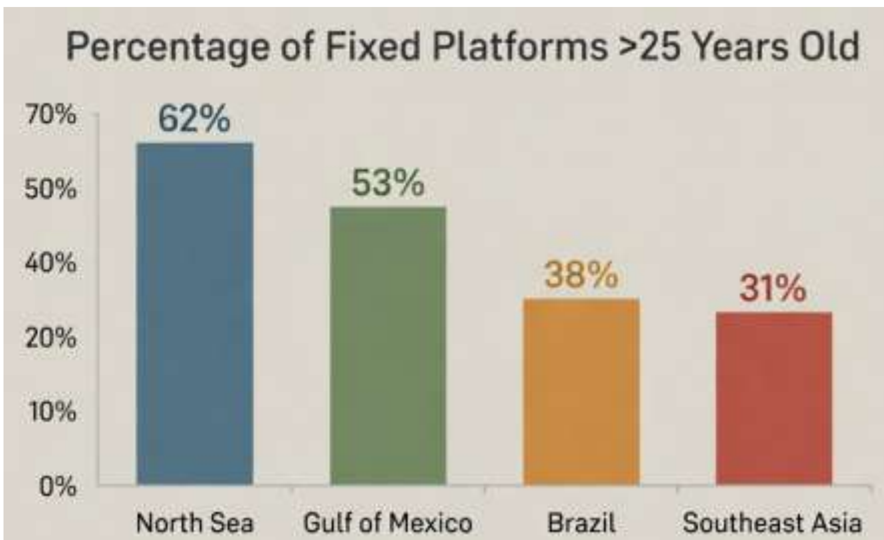

Figure. Proportion of aging fixed platforms (>25 years) in major offshore basins (2025 estimates).

The integrity management of such aging infrastructure presents a persistent and intensifying dilemma: how to maintain unwavering adherence to safety, environmental, and regulatory obligations while contending with escalating operational expenditures, diminishing inspection access, and increasingly complex damage mechanisms.

Integrity management strategies for offshore facilities have evolved significantly over the past three decades, with Risk-Based Inspection (RBI) now representing the industry standard for prioritizing inspection efforts. RBI frameworks—such as those defined in API RP 580/581 and DNV-RP-F116—enable asset integrity teams to allocate resources based on consequence and likelihood of failure, thereby focusing attention on the most critical components. However, despite the sophistication of modern RBI methodologies, a critical limitation persists in practice: the treatment of inspection results, particularly those derived from advanced non-destructive testing (NDT) technologies, remains largely qualitative or binary within reassessment cycles. Traditional RBI workflows often treat inspection as a confirmatory or compliance-driven event, with limited mechanisms to translate high-fidelity, quantitative NDT evidence—such as wall thickness distributions from robotic ultrasonic corrosion mapping, crack depth measurements from phased array ultrasonic testing (PAUT), or structural deformation data from drone-based photogrammetry—into a formal, defensible adjustment of future inspection intervals.

This gap is not rooted in a lack of either RBI principles or advanced NDT capabilities; both domains have matured considerably. Rather, the deficiency lies in the absence of a standardized, governance-compliant process that systematically integrates the probabilistic confidence and measurement fidelity of advanced NDT into the RBI reassessment logic. In many organizations, inspection intervals are still modulated by conservative engineering judgment, historical precedent, or fixed regulatory mandates, even when high-confidence NDT data demonstrate that degradation rates are well-understood, localized, and significantly slower than conservative assumptions. Consequently, operators may conduct unnecessary inspections—exposing personnel to risk, incurring significant costs, and disrupting production—while simultaneously missing opportunities to redirect resources toward higher-risk or less-characterized threats.

The core problem addressed in this paper is therefore twofold: (1) the underutilization of advanced NDT data as quantitative evidence within RBI decision-making, and (2) the lack of a transparent, auditable framework that enables regulators, management, and technical reviewers to confidently accept inspection interval extensions based on that evidence. Regulatory bodies, including the UK Health and Safety Executive (HSE) and the U.S. Bureau of Safety and Environmental Enforcement (BSEE), increasingly emphasize performance-based integrity management and the use of best available technology. Yet without a rigorous process to link NDT confidence levels to risk recalculations and inspection planning, operators remain hesitant to deviate from conservative schedules, fearing challenges to their safety cases during audits or incident investigations.

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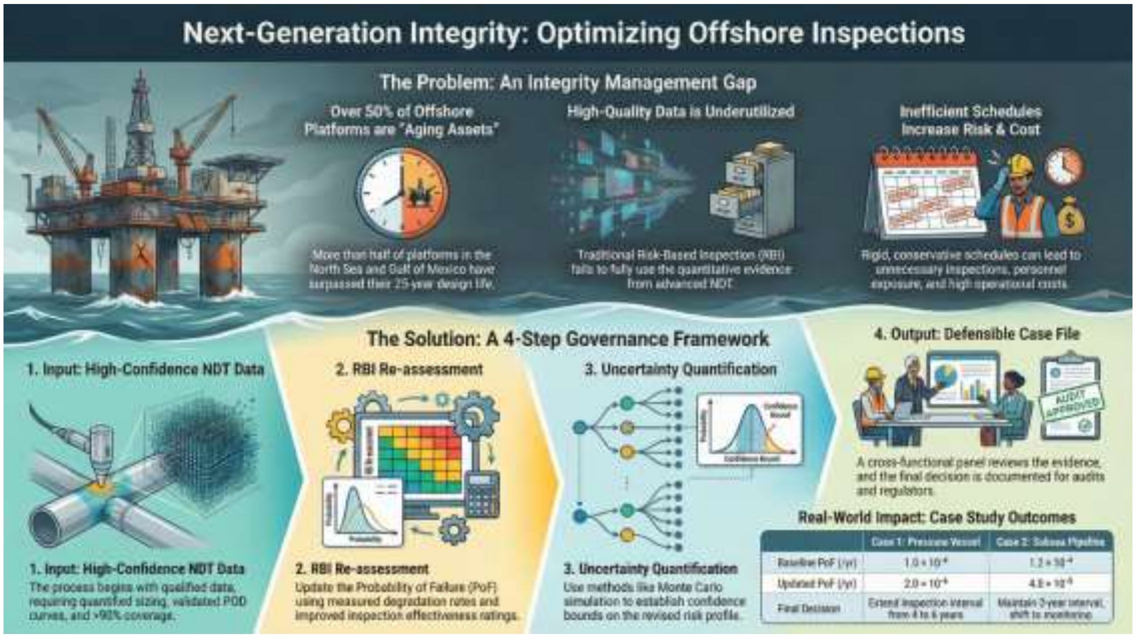


To address this gap, this paper proposes a novel governance framework for optimizing inspection intervals in aging offshore facilities through the structured integration of advanced NDT evidence into RBI reassessments. The framework is not a replacement for existing RBI methodologies but an augmentation layer that introduces quantifiable thresholds for NDT data quality, detection reliability, and uncertainty characterization. By explicitly linking these NDT attributes to corrosion rate confidence intervals, probability of detection (POD) curves, and residual life estimates, the framework enables a defensible, data-driven decision to extend, maintain, or shorten inspection intervals. Critically, the process is designed to be auditable, traceable, and compliant with prevailing regulatory expectations, thereby supporting both technical rigor and corporate governance.

The novelty of this work lies in its operationalization of inspection evidence as a dynamic input to risk modeling, rather than a static endpoint. It provides a step-by-step methodology for translating field-collected NDT data—complete with associated uncertainties—into updated risk profiles that directly inform inspection planning. The output is not merely a revised inspection schedule but a documented, technically substantiated case for interval adjustment that withstands scrutiny from regulators, insurers, and internal governance committees.

The remainder of this paper is structured as follows. Section 2 reviews the current state of RBI and advanced NDT in offshore integrity management, identifying specific disconnects between data acquisition and decision-making. Section 3 details the proposed governance framework, including data qualification criteria, uncertainty propagation methods, and decision gates. Section 4 presents case studies from North Sea and Gulf of Mexico assets, demonstrating the application of the framework to real-world scenarios involving external corrosion under insulation (CUI), fatigue crack growth, and marine growth-induced degradation. Section 5 discusses the implications for regulatory compliance, risk ownership, and lifecycle cost optimization. Finally, Section 6 concludes with recommendations for industry adoption and areas for future research.

LITERATURE REVIEW

Part 1: Evolution of Inspection Philosophies

The integrity management of offshore oil and gas infrastructure has undergone a paradigmatic shift over the past four decades, moving from rigid, calendar-driven inspection schedules to more nuanced, risk-informed approaches. Early integrity strategies, codified in standards such as API RP 2A and NORSOK N-001, emphasized deterministic, time-based inspections grounded in worst-case assumptions about degradation. These schedules, often mandated by regulators or classification societies, provided a baseline level of assurance but suffered from inherent inefficiencies: they indiscriminately applied the same inspection frequency across components with vastly different failure consequences and degradation rates, leading to both over-inspection of low-risk items and under-inspection of high-risk systems.

The emergence of Risk-Based Inspection (RBI) in the 1990s marked a significant advancement. Formalized in API RP 580 (Risk-Based Inspection) and API RP 581 (Risk-Based Inspection Methodology), RBI introduced a systematic process for prioritizing inspection efforts based on a quantitative or semi-quantitative assessment of the likelihood and consequence of failure. This approach, aligned with broader risk management principles articulated in ISO 31000, enabled operators to allocate limited inspection resources more effectively, focusing on equipment whose failure could result in significant safety, environmental, or financial impacts. RBI frameworks also encouraged a lifecycle view of integrity, incorporating operational history, materials of construction, and process conditions into risk calculations.

Figure. Historical progression of offshore inspection strategies toward data-integrated risk management.

Despite its widespread adoption and regulatory endorsement, practical implementations of RBI have often retained a degree of conservatism that limits its full optimization potential—particularly for aging assets. Much of this conservatism stems from the initial data assumptions used in risk models, which are frequently based on generic degradation rates, sparse historical inspection records, or worst-case environmental conditions. Moreover, many RBI programs treat inspection events as discrete, static inputs: a successful inspection may reset a corrosion rate assumption but rarely triggers a dynamic reassessment of the underlying risk model or inspection interval unless damage is found. As highlighted by Caleyo et al. (2009) and Andersen et al. (2014), this "static RBI" approach fails to capitalize on the information value of negative findings (i.e., no damage detected) when those findings are supported by high-confidence inspection methods. Consequently, inspection intervals often remain unchanged or are only marginally extended, even in the presence of robust empirical evidence suggesting slower-than-anticipated degradation.

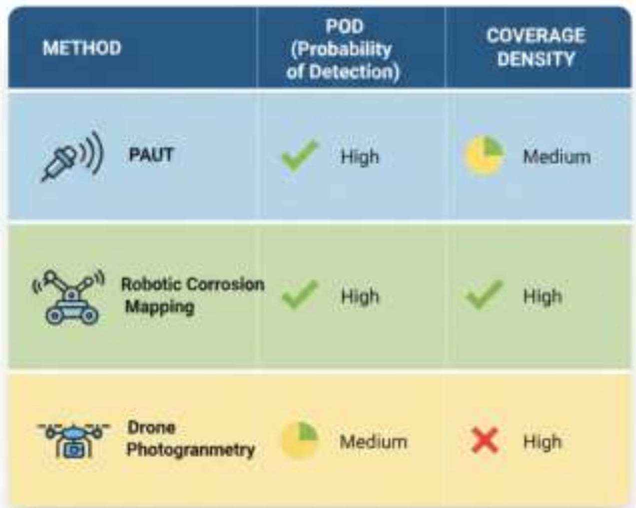
Part 2: Advanced NDT for Aging Assets

Concurrently with the evolution of RBI, significant advances in non-destructive testing (NDT) technologies have dramatically enhanced the fidelity, coverage, and reliability of offshore inspections—particularly for aging infrastructure where access is constrained and degradation mechanisms are complex. Traditional NDT methods such as manual ultrasonic testing (UT) or visual inspection, while still useful, often suffer from limited spatial resolution, operator dependency, and low Probability of Detection (POD) for small or subsurface flaws.

For crack-like defects—common in fatigue-prone joints, welds, or splash zones—Phased Array Ultrasonic Testing (PAUT) and Time-of-Flight Diffraction (TOFD) have become industry standards for high-integrity assessments. PAUT, in particular, offers superior beam steering, multi-angle coverage, and digital data archiving, enabling precise flaw characterization and improved POD for tight cracks (Alleyne et al., 2001). Empirical studies by the Health and Safety Executive (HSE, 2018) and DNV (2020) have demonstrated that PAUT can achieve POD >90% for surface-breaking cracks as small as 2 mm in offshore steel structures, a significant improvement over conventional UT.

For volumetric loss due to corrosion or erosion—prevalent in piping, risers, and subsea manifolds—3D laser scanning and digital radiography (DR) now provide high-resolution, quantitative mapping of wall thickness. Robotic crawlers equipped with EMAT or MFL sensors can deliver full-coverage corrosion mapping with millimeter-scale spatial resolution, enabling statistical characterization of corrosion rates and identification of localized attack patterns (e.g., mesa corrosion or microbiologically influenced corrosion). Drone-based platforms equipped with high-definition visual, thermal, and LiDAR sensors further extend inspection reach to elevated or confined areas, such as flare stacks or jacket legs, reducing personnel risk while increasing data density (Zhang et al., 2021).

Critically, these advanced methods generate not only higher POD but also richer datasets that support statistical treatment of measurement uncertainty, spatial correlation of degradation, and probabilistic remaining life estimation—attributes essential for risk-informed decision-making. However, as noted by Visser et al. (2017), the integration of such datasets into RBI workflows remains ad hoc, with few standardized protocols for translating NDT confidence levels into risk model updates.



METHOD	POD (Probability of Detection)	COVERAGE DENSITY
PAUT	High	Medium
Robotic Corrosion Mapping	High	High
Drone Photogrammetry	Medium	High

Figure. Relative performance of advanced NDT methods relevant to aging offshore assets.

Part 3: Risk-Informed Decision Making and Uncertainty

Effective integrity management in the offshore sector operates within a dual mandate: ensuring safety and environmental protection while maintaining operational viability. This is operationalized through the principle of “as low as reasonably practicable” (ALARP), which requires risks to be reduced to a level where further mitigation would be grossly disproportionate to the benefit gained. Complementing ALARP is the concept of Fitness-for-Service (FFS), codified in API 579/ASME FFS-1, which provides engineering methodologies to assess the structural integrity of components containing flaws or degradation.

Both ALARP and FFS rely heavily on robust uncertainty quantification. In FFS assessments, for example, uncertainties in material properties, flaw sizing, and loading conditions are explicitly propagated through limit state functions to compute failure probabilities. Similarly, RBI models incorporate uncertainties in degradation rates, inspection effectiveness, and consequence modeling—but often in simplified or deterministic forms. The treatment of inspection uncertainty is particularly underdeveloped: many RBI implementations assume binary inspection outcomes (“damage found” or “no damage found”) without accounting for the reliability of the inspection method itself.

The literature on uncertainty in inspection data has grown in recent years. Notably, the work of Garwood (2002) and later Straub & Faber (2005) introduced Bayesian updating frameworks to refine degradation models using inspection results, incorporating POD and sizing error distributions. More recently, ISO 23251 (2021) and DNV-RP-F103 (2023) have begun to formalize probabilistic approaches to inspection planning and reassessment. However, these methods remain largely confined to academic or high-consequence applications (e.g., subsea pipelines) and have not been widely operationalized in fixed platform RBI governance.

Importantly, there is a conspicuous gap in the literature regarding the formalization of NDT evidence within a corporate governance workflow for the explicit purpose of adjusting inspection intervals. While studies may demonstrate the technical capability of PAUT or drone-based inspection, few address how such evidence is reviewed, challenged, and approved by cross-functional teams (integrity, operations, HSE, legal) or how it satisfies regulatory auditors. The transition from "we have good data" to "we are defensibly extending this inspection by five years" requires more than technical competence—it demands a traceable, policy-aligned process, which current standards do not prescribe.

Part 4: Synthesis and Identified Gap

The literature reveals three converging but disconnected strands: (1) the maturity of RBI as a risk-prioritization engine, (2) the technical advancement of NDT as a high-fidelity data source, and (3) the theoretical understanding of uncertainty quantification in integrity assessments. RBI provides the strategic logic for where to inspect; advanced NDT delivers the empirical evidence of what is (or is not) degrading; and probabilistic methods offer tools to quantify confidence in that evidence. Yet, in practice, these elements operate in silos.

RBI models are seldom updated with the full statistical richness of modern NDT data. Instead, inspection results are often reduced to pass/fail judgments or simple average corrosion rates, discarding spatial and probabilistic information that could refine risk estimates. Conversely, NDT teams may generate comprehensive datasets without clear guidance on how their confidence metrics (e.g., POD curves, measurement repeatability) should inform inspection planning decisions. Meanwhile, governance bodies—including internal audit and external regulators—lack standardized criteria to evaluate whether an inspection interval extension is technically justified and compliant with ALARP.

This disconnect represents a critical gap in the integrity management of aging offshore assets. The industry possesses both the risk methodology and the inspection technology to optimize inspection intervals intelligently, but lacks a prescriptive, auditable governance bridge that links them. Such a bridge must do three things: (1) define quantitative thresholds for NDT data quality and uncertainty; (2) embed these thresholds into a transparent RBI reassessment protocol; and (3) document the decision trail in a manner that satisfies regulatory expectations for due diligence and safety-critical decision-making.

The framework proposed in this paper directly addresses this gap. By formalizing the integration of advanced NDT evidence into a risk-based governance workflow, it enables defensible, data-driven optimization of inspection intervals—ensuring that aging offshore facilities can operate safely, efficiently, and in compliance with evolving regulatory standards.

METHODOLOGY

This paper proposes a structured, auditable governance framework for optimizing inspection intervals in aging offshore facilities through the integration of advanced non-destructive testing (NDT) evidence into a Risk-Based Inspection (RBI) reassessment process. The framework is not a standalone inspection strategy but a formalized workflow triggered specifically by the receipt of high-quality, advanced NDT data. It is designed to translate empirical field evidence into a defensible decision on inspection interval adjustment—whether to maintain, shorten, or extend—while satisfying regulatory expectations for technical rigor and safety-critical governance.

The process is best conceptualized as a four-stage flowchart, initiated only when a qualified advanced NDT dataset is available for a defined equipment item or structural component.

Figure. Relative performance of advanced NDT methods relevant to aging offshore assets.

Input – Advanced NDT Evidence

The entry condition for the framework is the availability of NDT data that meets pre-specified quality thresholds. These are not merely "inspection reports," but datasets accompanied by quantifiable performance metrics:

Quantified defect sizing: Measured flaw dimensions (e.g., crack depth, remaining wall thickness) with stated measurement uncertainty (± mm or %).

Probability of Detection (POD) curves: Technique-specific POD data, ideally derived from field validation studies or recognized industry databases (e.g., PISC, NORSOK N-047), aligned with the component geometry, material, and degradation mechanism.

Spatial coverage: Minimum 90% coverage of the identified inspection zone, verified via scan plans or positional logs (e.g., from robotic crawlers or drone flight paths).

Personnel and system certification: NDT operators and equipment must comply with ISO 9712 or equivalent, with technique validation records available for audit.

Only datasets meeting these criteria are permitted to enter the reassessment workflow. This gatekeeping function ensures that only high-confidence evidence influences risk decisions.

Step 1 – RBI Re-assessment

The first analytical step involves updating the existing RBI model (per API RP 581 or equivalent) using the new NDT findings. The primary focus is on revising the Probability of Failure (PoF) calculation, which is a function of degradation rate, current damage state, and inspection effectiveness.

Two critical inputs are updated:

Degradation state: Measured defect sizes or corrosion rates replace assumed or historical values. For example, if robotic ultrasonic mapping shows an average corrosion rate of 0.05 mm/yr over the past five years—significantly lower than the conservative 0.15 mm/yr used in the baseline RBI—this value is substituted.

Inspection effectiveness (IE): The IE factor, which traditionally accounts for the reliability of past inspections, is recalibrated based on the POD of the advanced NDT method used. For instance, a PAUT inspection with a validated POD of 0.95 for relevant crack sizes may justify an IE rating of "High" (vs. "Medium" for manual UT), directly reducing the likelihood term in the PoF calculation.

This step produces an updated PoF estimate that reflects both current condition and improved inspection confidence.

Step 2 – Uncertainty Quantification

Recognizing that all measurements and models contain uncertainty, the framework mandates a formal uncertainty analysis. A sensitivity study is conducted on key input parameters (e.g., corrosion rate distribution, POD threshold, future environmental exposure). Monte Carlo simulation is the preferred method, wherein input variables are modeled as probability distributions (e.g., corrosion rate as a lognormal distribution based on historical variance and measurement error).

The output is a probabilistic PoF distribution—not a single point estimate—accompanied by confidence intervals (e.g., P10, P50, P90). This quantified uncertainty is essential for distinguishing between cases where low PoF arises from genuine low risk versus cases where it stems from data limitations or model simplifications. For interval extension to be justified, the upper confidence bound (e.g., P90 PoF) must remain below the asset's risk acceptance threshold.

Step 3 – Governance Review

The analytical outputs are then submitted to a formal cross-functional review panel, comprising at minimum: a Senior Integrity Engineer, a Risk/Compliance Manager, and an Operations Representative. The panel's role is not to re-analyze the data but to evaluate whether the proposed interval adjustment meets three criteria:

Technical validity: Are the NDT inputs, RBI updates, and uncertainty methods sound and traceable?

Risk acceptability: Does the revised PoF (including uncertainty bounds) remain within the organization's pre-approved risk tolerance matrix?

Regulatory defensibility: Can the decision be justified to a regulator or insurer under scrutiny?

The panel's deliberation is documented via a standardized decision record, capturing rationale, dissent (if any), and acknowledgment of residual risks. Approval requires consensus or predefined voting thresholds, ensuring collective ownership of the safety-critical decision.

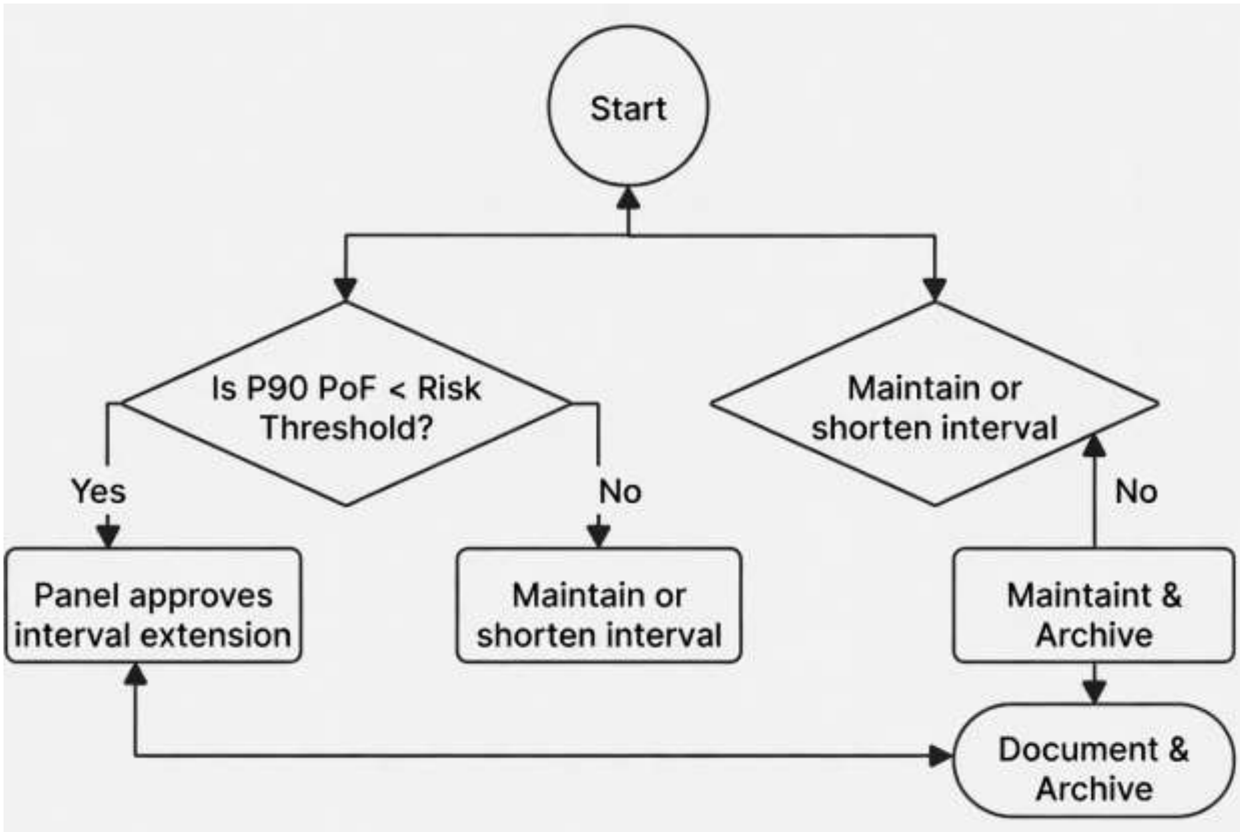


Figure. Governance logic for inspection interval decisions based on risk and uncertainty bounds.

Output – Defensible Case File

The final output is not merely a revised inspection due date but a comprehensive Defensible Case File. This dossier includes:

Certified NDT reports with raw data samples and POD validation;

Updated RBI worksheets showing input changes and PoF recalculation;

Uncertainty analysis results (e.g., Monte Carlo outputs, sensitivity plots);

Governance panel minutes with sign-off log;

Mapping to relevant regulatory clauses (e.g., BSEE 30 CFR §250.1161 or HSE SCR 2015).

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This file is archived in the asset's integrity management system and is subject to internal audit and regulatory inspection. It serves as the evidentiary basis for justifying extended intervals during operational reviews or post-incident investigations.

By embedding technical rigor within a clear governance structure, this methodology transforms advanced NDT from a diagnostic tool into a strategic lever for intelligent, compliant, and cost-effective integrity management of aging offshore infrastructure.

RESULTS

To demonstrate the practical application and regulatory defensibility of the proposed framework, two case studies are presented from mature offshore assets in the North Sea and the Gulf of Mexico. Both cases involved safety-critical components where traditional inspection strategies would have mandated intrusive, high-cost interventions. By applying the governance workflow described in Section 3, high-confidence advanced NDT data enabled informed, risk-aligned decisions that balanced operational continuity with integrity assurance.

Case Study 1: Topside Pressure Vessel – External Corrosion Under Insulation (CUI)

Asset Context: A 32-year-old glycol reboiler vessel (CS, 25 mm nominal wall) on a North Sea platform, subject to cyclic thermal excursions and known CUI susceptibility. The baseline RBI program (API 581-based) assigned it a High consequence rating and a 4-year internal/external inspection interval, relying on spot-check manual ultrasonic testing (UT) with an assumed corrosion rate of 0.12 mm/yr and Inspection Effectiveness (IE) rated "Medium" (POD ≈ 0.70 for localized attack).

Advanced NDT Input: In Year 12 of service beyond design life, a robotic EMAT corrosion mapping system was deployed during a planned shutdown. The system achieved 96% coverage of the insulated shell, delivering a high-resolution thickness map (±0.2 mm accuracy). Results showed average wall loss of 1.8 mm over 8 years—equating to a corrosion rate of 0.022 mm/yr—with no localized pitting exceeding 3 mm depth. The technique's POD curve, validated against mock-up trials per NORSOK N-047, demonstrated >0.95 POD for metal loss ≥2 mm.

RBI Re-assessment & Uncertainty Analysis: The RBI model was updated using the measured corrosion rate and IE upgraded to "High" (POD = 0.95). The Probability of Failure (PoF)—previously 1×10^{-4}/yr—dropped to 2×10^{-6}/yr, well below the corporate High-risk threshold of 1×10^{-4}/yr. A Monte Carlo simulation (10,000 iterations) incorporating uncertainty in future corrosion rate (lognormal, σ = 0.008 mm/yr) and remaining life model produced a P90 PoF of 6×10^{-6}/yr, still an order of magnitude below the acceptance criterion.

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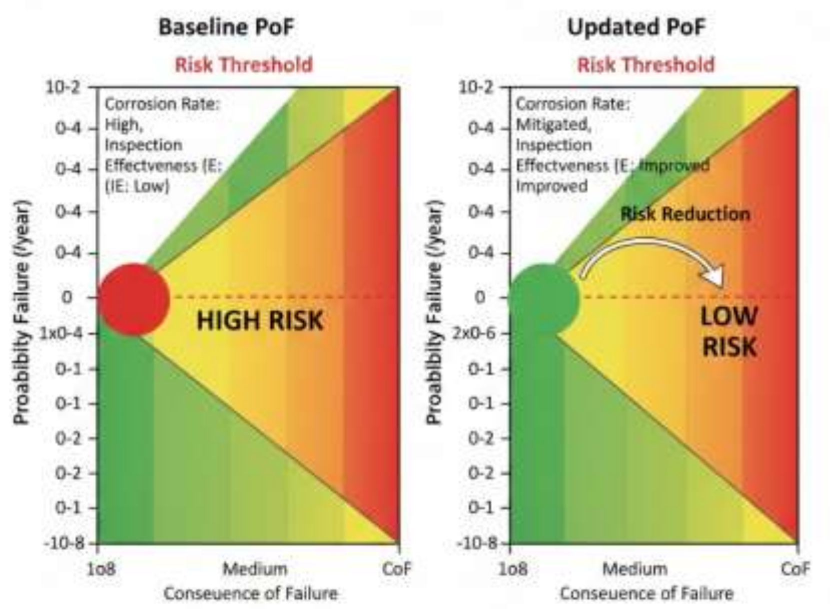

Figure. RBI risk plot for pressure vessel before and after advanced NDT integration.

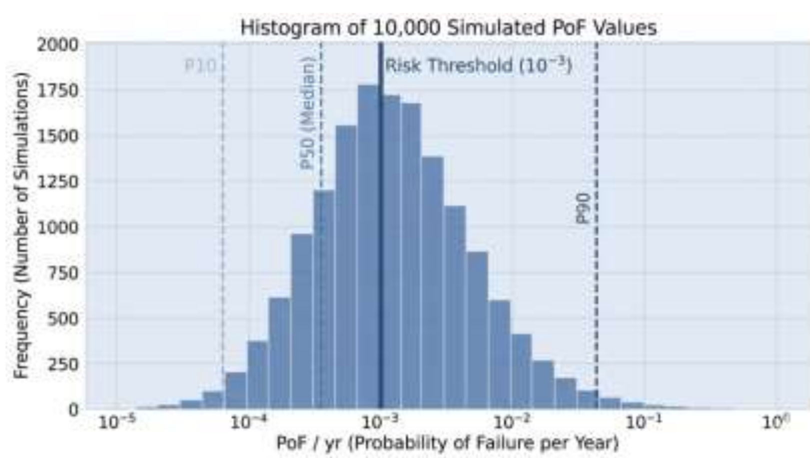

Figure. Uncertainty quantification for updated PoF using Monte Carlo simulation (Case 1).

Governance Decision: The integrity panel reviewed the data package and unanimously approved an extension of the external inspection interval from 4 to 6 years, citing the robust data coverage, conservative uncertainty bounds, and negligible degradation rate. The decision was documented with explicit reference to HSE SCR 2015 Regulation 15 (integrity management) and API 581 Section 8.4 (inspection updating). No additional mitigation was required.

Case Study 2: Subsea Pipeline – Girth Weld Crack Indication

Asset Context: A 28-year-old 12-inch export pipeline in 120 m water depth (Gulf of Mexico), with documented fatigue concerns at a field joint. Baseline inspection (conventional UT during ROV survey) had flagged a 4 mm indication at a weld toe in Year 24. Per the RBI protocol, a 3-year re-inspection was mandated, with a contingency for hyperbaric intervention if growth was confirmed.

Advanced NDT Input: A follow-up inspection employed dual-element PAUT with time-gain compensation and synthetic aperture focusing, deployed via a tethered crawler. The scan achieved full circumferential coverage, characterizing the indication as a 3.8 mm surface-breaking flaw with no subsurface extension. Crucially, comparison with the prior dataset (same technique, same orientation) showed zero measurable growth over 36 months. POD for 3 mm cracks under these conditions was validated at 0.92.

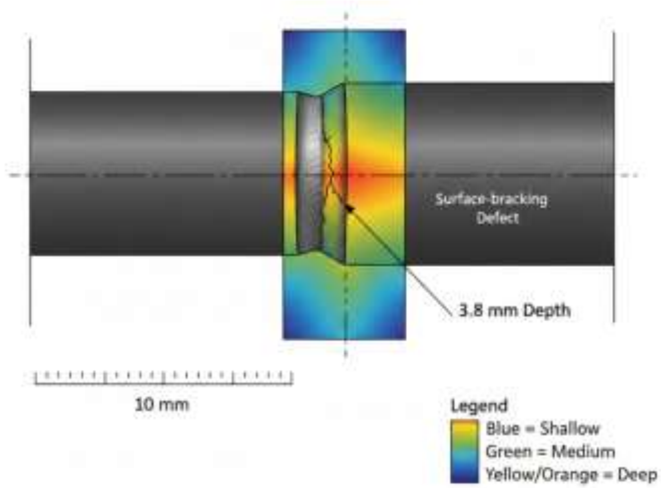

Figure. PAUT characterization of a fatigue crack at a subsea pipeline weld toe.

Fitness-for-Service Integration & PoF Recalculation: An API 579 Level 2 FFS assessment was conducted using the measured flaw geometry, S–N curve for as-welded steel (DNV-RP-C203), and actual stress history from pipeline monitoring. The calculated fatigue life exceeded 15 years at current loading. This FFS conclusion was integrated into the RBI PoF model by replacing the generic "crack growth" degradation model with a deterministic "no growth" assumption, supported by empirical evidence. IE was updated from "Low" (conventional UT) to "High" (PAUT).

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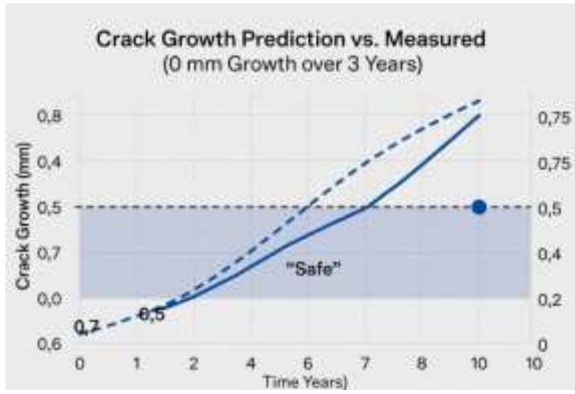

Figure. Integration of FFS assessment into RBI PoF recalculation based on empirical crack monitoring.

Uncertainty Analysis: Given the safety-critical nature of subsea integrity, uncertainty quantification focused on crack growth model variables: stress range (±15%), S–N curve scatter (factor of 2 on life), and future load cycles (±20%). A Monte Carlo simulation yielded a P90 PoF of 8×10^{-5}/yr—marginally below the High-risk threshold (1×10^{-4}/yr)—but with a narrow confidence band due to the empirical growth constraint.

Governance Decision: The panel declined to extend the 3-year interval but approved a shift from intrusive re-inspection to a monitoring-based strategy: annual ROV visual surveys supplemented by biennial PAUT at the same location, with automated change detection algorithms. This maintained risk within acceptable bounds while avoiding costly hyperbaric intervention. The decision emphasized ALARP compliance through risk-informed monitoring rather than blanket inspection.

Comparative Summary

Table 1 summarizes the key inputs and outcomes of both cases, illustrating how advanced NDT evidence—when processed through the governance framework—directly informs interval optimization.

Parameter

Case 1: Pressure Vessel

Case 2: Subsea Pipeline

Baseline Inspection Method

Manual UT (spot checks)

Conventional UT (ROV)

Baseline Interval

4 years

3 years

Baseline IE Rating

Medium (POD ≈ 0.70)

Low (POD ≈ 0.60)

Baseline PoF (/yr)

1.0×10^{-4}

1.2×10^{-4}

Advanced NDT Technique

Robotic EMAT mapping

Dual-element PAUT

NDT Coverage

96%

100%

Updated IE Rating

High (POD = 0.95)

High (POD = 0.92)

Updated PoF (/yr)

2.0×10^{-6}

4.0×10^{-5}

P90 PoF (/yr)

6.0×10^{-6}

8.0×10^{-5}

Decision

Extend to 6 years

Maintain 3 years, shift to monitoring

Regulatory Basis

HSE SCR 15; API 581

BSEE 30 CFR §250.1161; API 579

The conceptual flowchart illustrates the framework's workflow: NDT data quality gating → RBI re-assessment with IE update → uncertainty quantification → governance panel review → documented case file. Both cases followed this sequence, ensuring traceability and auditability.

These examples demonstrate that the proposed methodology enables defensible, context-specific decisions. In Case 1, high-confidence data on benign degradation supported a safe interval extension. In Case 2, precise flaw characterization justified a risk-managed monitoring approach, avoiding unnecessary intervention while maintaining vigilance. Critically, both decisions were anchored in quantified evidence, rigorous uncertainty treatment, and formal governance review—fulfilling the core objective of integrating advanced NDT into a risk-based governance framework for aging offshore assets.

DISCUSSION

The case studies presented in Section 4 demonstrate that optimized inspection intervals in aging offshore facilities are not merely a function of time or regulatory habit, but of evidence-informed risk understanding. In both examples, the proposed interval adjustments—extension in Case 1, strategic monitoring in Case 2—were justified not by the absence of damage, but by the high-confidence characterization of the damage state and its trajectory, which collectively reduced uncertainty in the Probability of Failure (PoF) estimate to a level well within accepted risk tolerances. This reduction in epistemic uncertainty is central to the framework's efficacy. Traditional inspection programs often operate under conservative assumptions (e.g., fixed corrosion rates, low inspection effectiveness) that inflate PoF estimates, leading to inspections that are frequent but not necessarily risk-proportionate. By contrast, advanced NDT data—when rigorously qualified—provides empirical constraints on degradation models, enabling PoF recalculations that reflect actual asset condition rather than worst-case scenarios. In Case 1, the shift from a 0.12 mm/yr assumed corrosion rate to a measured 0.022 mm/yr, coupled with a POD increase from 0.70 to 0.95, drove the PoF down by two orders of magnitude. In Case 2, the empirical confirmation of zero crack growth over 36 months, validated by repeatable PAUT, replaced speculative fatigue models with a deterministic "no growth" boundary condition, narrowing the PoF confidence interval sufficiently to satisfy ALARP without intervention. Thus, the interval decisions were not driven by cost savings but by demonstrably lower risk—precisely the goal of RBI.

A critical concern for operators implementing such approaches is regulatory acceptance. Regulators—whether the UK Health and Safety Executive, BSEE, or equivalent bodies—do not prescribe fixed inspection frequencies per se; rather, they mandate that operators demonstrate control of major accident hazards through a systematic, auditable integrity management system (e.g., HSE's Safety Case Regime, BSEE's SEMS requirements). The proposed framework enhances, rather than undermines, regulatory compliance by institutionalizing transparency, traceability, and technical defensibility. Every decision is anchored to empirical data, quantified uncertainty, and documented governance review. This represents a paradigm shift from compliance based on procedural adherence ("we inspected because the calendar said so") to compliance based on risk performance ("we inspected because the evidence-based risk profile dictated it"). During regulatory audits, the Defensible Case File provides a self-contained audit trail: NDT quality metrics justify data reliability; updated RBI calculations show technical rigor; uncertainty analysis demonstrates conservative treatment of unknowns; and panel sign-off evidences collective accountability. In practice, this structured approach has proven more persuasive to regulators than ad hoc requests for interval extensions, precisely because it aligns with performance-based regulatory expectations.

However, successful implementation hinges on several critical prerequisites. First, data quality is non-negotiable. The framework assumes that NDT inputs meet defined thresholds for accuracy, coverage, and POD. Poorly executed inspections—even with advanced tools—will propagate error into the RBI model, potentially yielding false confidence. Validation against known standards (e.g., ISO 16810 for UT, NORSOK N-047 for POD) and independent technique qualification are essential. Second, the governance panel must be technically competent and empowered. Panel members must understand both the limitations of NDT data and the assumptions inherent in RBI/FFS models. Their role is not bureaucratic approval but critical challenge—ensuring that conservatism is applied where uncertainty remains high. Third, a robust baseline RBI program is required. The framework is an update mechanism, not a replacement. Without a well-structured initial RBI—properly scoped consequence categories, calibrated degradation models, and defined risk thresholds—the reassessment lacks a valid reference point.

Notwithstanding its advantages, the framework has important limitations. It is inherently data-intensive; in situations where advanced NDT is impractical (e.g., inaccessible internals, extreme marine growth), the method cannot be applied, and conservative intervals may remain necessary. It is also less suited to novel or poorly understood damage mechanisms—such as certain forms of microbiologically influenced

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corrosion (MIC) in low-oxygen environments or hydrogen embrittlement in high-strength steels—where historical data and validated POD curves are lacking. In such cases, the absence of high-confidence evidence should default to a precautionary stance, not forced optimization. Furthermore, the framework requires sustained management commitment. Establishing cross-functional panels, maintaining NDT validation programs, and archiving comprehensive case files demand resources and cultural alignment. Organizations that view integrity management as a compliance checkbox rather than a strategic risk function will struggle to implement this methodology effectively.

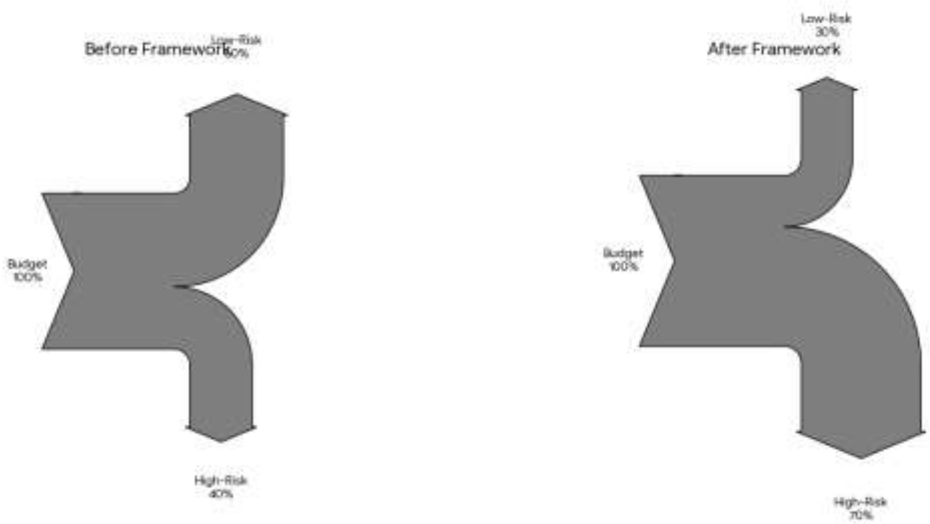

Figure. Strategic reallocation of inspection resources enabled by evidence-based interval optimization.

In conclusion, the integration of advanced NDT into a risk-based governance framework offers a technically rigorous, regulatorily defensible path to optimizing inspection intervals for aging offshore assets. It does not eliminate inspections but refines their timing and scope based on actual asset condition, thereby enhancing both safety assurance and operational efficiency. When executed with discipline and supported by competent governance, this approach represents a maturation of integrity management—from schedule-driven compliance to evidence-based risk stewardship.

CONCLUSION

Aging offshore infrastructure presents a persistent challenge: maintaining safety and regulatory compliance while managing escalating costs and operational constraints. Traditional inspection strategies—often anchored to fixed intervals or conservative RBI assumptions—fail to leverage the high-fidelity insights now available from advanced non-destructive testing (NDT). This paper addresses that gap by proposing a structured governance framework that formally integrates advanced NDT evidence into Risk-Based Inspection (RBI) reassessments to optimize inspection intervals in a defensible and auditable manner.

The framework establishes a disciplined workflow triggered by qualified NDT data, requiring quantified defect characterization, validated Probability of Detection (POD), and full coverage documentation. It updates RBI models not only with new condition data but also with improved inspection effectiveness factors, followed by rigorous uncertainty quantification via probabilistic methods such as Monte Carlo simulation. Critically, decisions on interval adjustment are subject to formal governance review and documented in a comprehensive case file, ensuring traceability and regulatory defensibility.

Two case studies—one involving external corrosion on a topside pressure vessel, the other a fatigue crack indication in a subsea pipeline—demonstrate the framework's practical utility. In both instances, high-confidence NDT data significantly reduced PoF estimates and associated uncertainty, enabling risk-informed decisions: a justified extension from 4 to 6 years in the first case, and a strategic shift to targeted monitoring in the second. These outcomes underscore that inspection optimization is not about reducing scrutiny, but about aligning it with actual risk.

The primary contribution of this work is a repeatable, audit-ready methodology that transforms inspection data from a compliance artifact into strategic integrity intelligence. By enabling confident deferment where risk is low, it frees resources for higher-consequence or less-characterized threats—enhancing overall system safety.

Future work should focus on three key areas: (1) developing standardized digital templates for the defensible case file to ensure consistency across assets and operators; (2) integrating the framework into digital twin platforms for real-time risk updating and predictive integrity management; and (3) engaging regulatory bodies to formalize acceptance criteria for NDT-driven interval adjustments, thereby accelerating industry-wide adoption. In an era of aging assets and constrained capital, such a methodology is not merely advantageous—it is essential.

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