

COMPANY STANDARD

RISK-BASED INSPECTIONS

02961.ENG.COR.PRG
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ABSTRACT	The scope of this Company Standard is to describe the approach recommended by Eni for the execution of a Risk-Based Inspection study
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REVISION TRACKING

Rev. 00: Actual revision is of 55 pages.
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Rev. 01: Actual revision is of 31 pages and 5 Appendixes
Complete revision of the document.
Title changed from “Guidelines for Risk Based Inspections” to “Risk Based Inspections”.
This standard is composed by a core document, that describes the general approach of RBI in Eni assets, and 5 Appendixes that describe the approach for Plant, Pipelines, Structures, Naval and Civil Structures.
The Appendix for Subsea is under preparation and will be included in the next revision.
November 2020

INFORMATION REQUEST

Eni personnel can access company standard repository at:
<http://www.eandp.eni.it/TSServices/ITEM/Standards-/Normalizat/Documents-/index.asp>

External user shall refer to the Project Engineer Manager.

For information about the content of this standard, please refer to persons mentioned on the first page or to Company Standard Team (mbxc&st@eni.com).

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1 SCOPE AND GENERAL INFORMATION

1.1 FOREWORD

Oil and Gas (O&G) production facilities, upstream assets, Refineries and Petrochemicals Plants are by their nature, due to the fluid handled and operating conditions, industries where there is a risk of loss of containment with possibly severe consequences on the health and safety of employees, the ecosystem, the integrity of the plant and the reputation of the Company.

To manage this Risk it is necessary to optimize all the efforts of the activities of the inspection carried out during the life of the plants, especially on the items that are most likely to fail and with the highest negative consequence(s) resulting from such failure.

This can be achieved through the adoption of a structured approach that assesses the Risk associated to each equipment, structure and system part of a plant by defining the likelihood of failure and the consequence in case of failure (ex. loss of containment for pressurized equipment, loss of structural integrity for structures, loss of function for instrument and control systems).

The result of the Risk assessment is an inspection plan that may include monitoring and testing activities to enhance the knowledge of the equipment condition and capacity to be operated as intended. The inspection plan (or inspection, monitoring & test plan) based on the calculated Risk defines:

- What to inspect, monitor and test;
- Where to inspect, monitor and test;
- When to inspect, monitor and test;
- How to inspect, monitor and test.

It is important to highlight that the scope of an RBI is not to reduce the costs associated with inspection activities.

Inspection activities do not reduce risk directly. It is a risk management activity that can lead to risk reduction. Inspection, as monitoring and testing, reduces the uncertainty of the risk associated with any equipment, structure or system primarily by improving the knowledge of the respective deterioration state.

1.2 PURPOSE AND SCOPE

The scope of this Company Standard is to describe the approach recommended by Eni for the execution of a Risk-Based Inspection study with the aim to:

- Assess the risk of Eni's assets;
- Plan inspections, monitoring and testing as required, based on risk ranking;
- Identify the scope, effectiveness and techniques to perform inspections, monitoring and testing;
- Evaluate the results of the inspection combined with those from monitoring and testing;
- Reassess the Risk, based on the above results and define mitigation factors and/or activities.

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1.3 REFERENCES DOCUMENTS AND NORMATIVES

The latest edition of each publication shall generally be used, together with any amendments/supplements/revisions thereto, however, new revisions/updates during an activity or project will not be considered unless there are associated safety/environmental impacts.

#	Ref. Code	Title
01	API RP 580	Risk-Based Inspection
02	API RP 581	Risk-Based Inspection Technology
03	API RP 574	Inspection of Piping System Components
04	API RP 571	Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
05	API RP 579	Fitness-for-Service
06	API 584	Integrity Operating Window – IOW
07	API RP 17B	Recommended practice for flexible pipe
08	API RP 2RIM	Integrity Management of Risers from Floating Production Systems
09	API 510	Pressure Vessel Inspection Code; Maintenance Inspection, Rating, Repair, and Alteration
10	API 651	Cathodic Protection of Aboveground Petroleum Storage Tanks
11	API 653	Tank Inspection, Repair, Alteration, and Reconstruction
12	ASME B31G	Manual for Determining the Remaining Strength of Corroded Pipelines
13	ASTM G16	Practice for Applying Statistics to Analysis of Corrosion Data
14	DNVGL-RP-G101	Risk-Based Inspection of Offshore Topsides Static Mechanical Equipment
15	DNVGL-RP-G103	Non-Intrusive Inspection
16	DNVGL-RP-0002	Integrity management of subsea production system
17	DNVGL-RP-F116	Integrity management of submarine pipeline systems
18	DNVGL-RP-F206	Riser integrity management
19	EN 13018	Non-destructive testing. Visual testing. General principles
20	EN 16991	Risk-Based Inspection Framework
21	20602.VAR.COR.SDS	Corrosion Integrity Management

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22	20557.VAR.COR.SDS	Corrosion risk assessment methodology
23	06215.DOC.GEN.SDS	Facility Functional Units
24	02555.VAR.COR.PRG	Design Criteria. Internal Corrosion. Corrosion Parameters and Classification of the Fluid
25	20555.VAR.COR.PRG	Internal Corrosion Monitoring Specification
26	20309.VAR.COR.PRG	Cathodic protection of buried structures in-plant facilities
27	20311.VAR.COR.SDS	Cathodic protection underwater inspection
28	11555.VAR.COR.SDS	Guidelines for planning cathodic protection surveys of on-land Buried pipelines
29	11557.PLI.COR.STD	Cathodic protection measurements and surveys for on-land buried pipelines
30	20415.ENG.INT.PRG	Criteria for the planning of inspections and maintenance on onshore and offshore pipelines
31	28756.ENG.INT.PRG	Risk analysis methodology for pipelines RBI development
32	28755.ENG.INT.PRG	Exposure levels of onshore and offshore pipelines
33	28871.ENG.SSE.REL	SURF inspections
34	20560.ENG.MNU.STD	Maintenance Standards Job plans
35	STAP-P-1_MG-26527	Well Maintenance Procedure
36	BP.SVI.ENG.004	Plant & Structural Integrity for Asset Integrity Management
37	28010.ENG.MME.STD	Inspection Data Management Software Setup & Customization

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1.4 TERMS AND DEFINITIONS**1.4.1 General Definitions**

All acronyms and abbreviations used in the document are summarized in Section 1.4.2.

- i. The Company is **Eni SpA**;
- ii. The word **shall** is used to indicate that a provision is mandatory;
- iii. The word **should** is used to indicate that a provision is not mandatory, but recommended as good practice.

1.4.2 Specific Terms, Definitions, Acronyms and Abbreviations

Asset	Natural resources and all tangible and intangible investments to exploit and to process them (including crude oil extraction facilities, storage and import/export facilities, hydrocarbon refining facilities, conversion and treatment facilities, power plants and environmental treatment facilities). In this document "Assets" means the physical portion of the assets.
Consequence of failure	The consequence of failure through the unintentional release of hazardous fluids, including effects on Health and Safety, of employees, as well as of the public, to the environment, to the operability of the asset and the company reputation.
Corrosion allowance	The thickness of material which can safely be allowed to corrode having regard for the operating environment and applied stresses
CMMS	A computerized maintenance management system is a software that helps manage assets, schedule maintenance and track work orders.
Critical Thickness Profile	Profile of the penetration if a defect through the wall thickness of a vessel shell or pipe, assessed through inspection measurements, for instance by spot UT readings. It shall be determined in the longitudinal and circumferential direction.
Damage (type)	The observed effect on a component of the action of a degradation mechanism. The damage type gives rise to the failure mechanism of a component. Examples of damage include cracking, uniform wall thinning, and pitting.
Damage model	A mathematical and/or heuristic representation of the results of degradation. This may express the accumulation of damage over time as functions of physical or chemical parameters, and normally includes the estimation of the conditions that give rise to failure.
Damage rate	The development of damage over time.
Defect	A defect is a non-compliance with project specifications or without the acceptance criteria defined.
Design life	That period during which an item or component is intended to remain fit for service under the specified design and operating process conditions.
Failure	Termination of the ability of a system, structure, or component to perform its required function of containment of fluid (i.e. loss of containment). Failure may be unannounced and undetectable until the next inspection (unannounced failure) or may be announced and detected by any number of methods at the instance of occurrence (announced failure). The point at which a component ceases to fulfil its function and the limits placed on it. The failure condition must be clearly defined in its relationship to the component. Failure can be expressed, for example, in terms of non-compliance with design codes, or exceedance of a set risk limit, neither of which necessarily imply leakage.

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Flaw	The physical manifestation of a degradation mechanism, in terms of cracking, pitting or wall loss etc.
HAZOP (Hazard and Operability Analysis)	Analysis carried out by a multidisciplinary team which uses a systematic approach to identify hazards and operability problems occurring as a result of deviations from the intended range of process conditions.
IDMS	Inspection Data Management System. An Inspection Data Management System (IDMS) is a software program utilized to organize data related to a facility's fixed equipment inspection regime.
Inspection	An activity carried out periodically and used to assess the progression of damage in a component. Inspection can be through technical instruments (NDT) or as a visual examination.
Inspection effectiveness	A description of the ability of the inspection method to detect the damage type inspected.
Inspection level	The Inspection Level is an attribute given to an item in the inspection planning phase which reflects the risk class, or criticality, attributed to the item itself, or a part of it. It is used to define the extent of the inspection, for instance as spacing of spot measurements or size and number of sample areas to be inspected.
Inspection methods	How inspection can be carried out such as visual, ultrasonic, radiographic.
Inspection program / plan	A summary of inspection activities mainly used as an overview of inspection activity for several years into the future.
Internal Visual Inspection (VI)	This is considered as an intrusive close visual examination of all internally accessible plate material and, where applicable, conventional magnetic particle (MPI) or dye penetrant (DPI) inspection of welds.
Monitoring	An activity carried out over time whereby the amount of damage is not directly measured but is inferred by the measurement of factors that affect that damage. An example would be the monitoring of CO ₂ content in a process stream concerning CO ₂ corrosion.
NDT	Non-destructive testing. Inspection of components using equipment to reveal the defects, such as magnetic particles or ultrasonic methods.
Non-Intrusive Inspection (NII)	This refers to any inspection performed from the outside of the vessel without having to break containment and/or not requiring vessel entry. It may be performed on-stream or off-stream. The terms "non-invasive" and "non-intrusive" are often used interchangeably.
Remnant life	That period during which it is judged that an item or component will remain safe to operate, allowing for the elapsed service life.
Risk	The combination of the probability that a certain event may occur in a certain period or in specific circumstances and the consequences that can arise.
Risk-Based Inspection (RBI)	A decision-making technique for inspection, monitoring and test planning based on risk – comprising the probability of failure and consequence of failure.
Subsea Distribution System	Dynamic umbilical, static umbilical, integrated pipeline umbilical, Subsea Distribution Unit (SDU)
Subsea Processing	Multiphase pump, Electrical Submersible Pump (ESP), subsea separator, subsea compressor, subsea pump module
Subsea Safety System	High Integrity Pressure Protection System (HIPPS), Subsea Safety Isolation Valve (SSIV) module

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Subsea Structures	Midwater arch, subsea template, crossing support, crossing structure, protective structure
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Symbol or abbreviation	Unit	Definition
AE	(-)	Acoustic Emission
ALARP	(-)	As Low As Reasonably Practicable
BLI	(-)	Baseline Inspection
CHIME	(-)	Creeping Head Inspection
CMMS	(-)	Computerized Maintenance Management System
COF	(-)	Consequence of Failure
CR	(mm/y)	Corrosion rate
CRA	(-)	Corrosion Resistant Alloy
CS	(-)	Carbon Steel
CSCC	(-)	Chloride Stress Corrosion Cracking
CTP	(-)	Critical Thickness Profile
CUI	(-)	Corrosion Under Insulation
D	(-)	Diameter (vessel or piping)
DFI	(-)	Design Fabrication Installations
DL	(years)	Design life
DMS	(-)	Development Management System
PT	(-)	Liquid Penetrant Inspection
ECT	(-)	Eddy Current Testing
EL	(-)	Exposure Level
EMATs	(-)	Electromagnetic Acoustic Transmission
FIV	(-)	Flow-Induced Vibrations
HAZID	(-)	Hazard Identification Study
HAZOP	(-)	Hazard and Operability Study
HSE	(-)	Health, Safety, Environment
IDMS	(-)	Inspection Data Management System
II	(-)	Inspection Interval
IMP	(-)	Inspection and Maintenance Plan
IR	(-)	Base Inspection Interval
LAS	(-)	Low Alloy Steel
LC	(-)	Location Class
LCI	(-)	Life Cycle Information
LRUT	(-)	Long Range Ultrasonic
MFL	(-)	Magnetic Flux Leakage
MP	(-)	Magnetic Particle Inspection
N/A	(-)	Not Applicable
NDT	(-)	Non Destructive Testing
OPDS	(-)	Opportunity and Project Development System
OPOS	(-)	Opportunity and Production Operation System

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P&ID	(-)	Process Instrumentation Diagram
P _{DEFECT}	(-)	Penetration of a defect
PEC	(-)	Pulsed Eddy Current
PFD	(-)	Process Flow Diagram
PIM	(-)	Pipeline Integrity Management
PLEM	(-)	Pipeline End Manifold
PMI	(-)	Positive Material Identification
POD	(-)	Probability of detection
POF	(-)	Probability of Failure
QC	(-)	Quality Control
QRA	(-)	Quantitative Risk Assessment
RT	(-)	Radiography
RTR	(-)	Real Time Radiography
RVI	(-)	Remote Visual Inspection
SECE	(-)	Safety and Environmental Critical Element
SLOFEC	(-)	Saturated Low-Frequency Eddy Current
SSC	(-)	Sulphide Stress Corrosion Cracking
S/I	(-)	Stability/Instability
T	(mm)	Nominal wall thickness (referred to a pipe or a vessel)
t _{CA}	(mm)	Corrosion allowance
t _{CD}	(mm)	Declared design corrosion allowance.
T _{MIN}	(mm)	Minimum required thickness
TOFD	(-)	Time of Flight Diffraction
TT	(-)	Thermography
UT	(-)	Conventional Ultrasonic Testing
VIV	(-)	Vortex-Induced vibrations
VT	(-)	Visual Inspection
XT	(-)	Christmas Tree

1.5 ORDER OF PRECEDENCE

In conjunction with this specification, the codes, standards and regulations listed in Section 1.3 shall be applicable. Reference to any Standard or Code shall mean the latest edition of that Standard or Code including addenda, supplements or revisions unless otherwise stated in this document.

The order of precedence shall be as follows: (descending order)

- i. Local Regulations of the Country where the equipment is installed;
- ii. Project Specifications and Data Sheets;
- iii. Company General Specifications;
- iv. International Codes & Standards.

International Standards are at the lower level of the hierarchy, their contents, assumed as a reference, is developed and detailed within the Company Specifications considering the specific application and the area of business in which Eni SpA is operating. On top of those, there are the Local Regulations, the Project Specifications than the Company Specifications. Any applicable local mandatory rule prevails on this specification. Should there be a perceived conflict between

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this standard and other referenced standards, or lack of clear definition as to the applicability of any specification or standard, the Facilities Technical Units owner of the Standard, shall seek guidance to the Standard Team.

2 DOCUMENT FORMAT

This standard is composed of a core document that describes the methodology with the main damage mechanisms to be considered and several appendixes that deal with different areas of application of the RBI approach in Eni's Assets.

The basic concepts of an RBI analysis apply to every Eni facility (refining, petrochemical, chemical process plants and oil and gas production facilities). There are however some aspects specifics of the different types of Assets, that are described in details in the following separated Appendixes.

Appendix:

A) Plant

- a. Oil & Gas Upstream
- b. Refinery
- c. Petrochemical

B) Pipeline

- d. Onshore
- e. Offshore
 - i. Rigid steel risers connected to a fixed platform
 - ii. Rigid steel pipelines
 - iii. Subsea rigid jumpers and subsea rigid spools

C) Fixed Steel Platform

- f. Jacket/Deck
- g. Crane

D) Naval

E) Onshore Civil and Coastal Marine Structures

- h. Buildings
- i. Piperacks
- j. Concrete works
- k. Retaining walls
- l. Underground elements
- m. Steel structures
- n. Equipment foundations
- o. Jetty and port structures
- p. Sea protection works
- q. Water intakes and outfalls

F) Subsea (under preparation)

- r. Rigid steel, hybrid and flexible risers connected to a floating production system
- s. Flexible flowlines and flexible jumpers

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- t. Subsea structures
- u. Subsea XT
- v. Subsea distribution system
- w. Subsea manifold and PLEM
- x. Subsea safety system
- y. Subsea processing.

3 INTRODUCTION

RBI provides an alternative and more efficient approach vs time-based or calendar-based inspection planning by focusing the efforts on the areas of the plant or facilities with the highest risk.

The main aim of an RBI study is to optimize the inspection plan accordingly to the acceptable risk level defined by the plant owner.

RBI is focused on any threats (degradation mechanisms, corrosion forms, material deterioration, and environmental events) that can be discovered and managed primarily through inspections and monitoring activities.

Although inspection does not reduce risk directly, it is a risk management activity (provider of new information) that may lead to risk reduction.

Inspection influences the uncertainty of the risk associated with assets by improving knowledge of the deterioration state and predictability of the POF.

It has to be noted that Risk is never reduced to zero through an RBI since there will always be a residual risk due to factors like operational errors, process upsets, external events or limitations of inspection methods available.

3.1 RBI AT DIFFERENT PROJECT PHASES

The RBI analysis shall be performed:

- During the design phase, before the start-up, as part of the handover from Engineering to Operations;
- During operations, if not done during the design phase;
- In operations, it shall be kept updated throughout the service life of the asset.

3.1.1 Engineering Phase

For new assets in the development phase, the RBI analysis shall be performed during the Engineering phase to define inspection, monitoring and testing requirements and to accommodate such requirements into the design. Based on that, Engineering produces the initial inspection, monitoring and test plan to be implemented during the Operation phase.

In the Engineering phase, the P&IDs issued as “As-Built” are not usually available and the RBI analysis is based on P&IDs resulting from the HAZOP analysis.

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A baseline inspection shall be performed before the start-up to provide base-line data for future inspections and to confirm that the equipment/structure/system is free from construction defects and compliant with the design.

3.1.1.1 Handover from Engineering to Operations

The RBI analysis shall be reviewed taking into account the results of the baseline inspection and also any new threats or relevant aspects detected during installation, pre-commissioning and commissioning.

The initial inspection, monitoring and test plan are reviewed based on the RBI re-assessment, respective frequency and requirements are adjusted accordingly.

The results of the RBI analysis shall be uploaded in a dedicated IDMS to be handed over to Operations.

3.1.2 Operation Phase

Inspection, monitoring and test activities shall be executed as per plan and respective results shall be used to update the RBI analysis as soon as possible.

The inspection, monitoring and test plan shall be revisited following each RBI analysis update to accommodate any change of risk criticality. For instance, the risk level of an item may increase following an external event as a dropped object or because excessive degradation was detected. In that case, besides the root cause investigation, it shall be considered to apply a more rigorous inspection interval and to introduce new monitoring techniques and tests whenever applicable. In the other hand, it should be considered to extend the inspection intervals as long as more knowledge of an item is gained and no degradation is recorded over time.

Furthermore, considering existing facilities already operating, the RBI methodology can be performed as¹ a:

- First implementation to replace a time-based approach;
- Evaluation after asset acquisition;
- Asset re-qualification;
- Update existing RBI to perform a more detailed analysis (quantitative vs qualitative or semi-quantitative);
- Update existing RBI to align with relevant standards;
- Rerun of existing RBI after new inspections and/or significant process changes.

¹ Rational: There could be the case of a plant already operating for which an RBI analysis has been already performed with a different approach (e.g. fully-qualitative) and/or based on an old revision of the API standard. The scope of the RBI analysis in this case is to update the analysis using a more detailed approach and/or to align with the new revision of the standard.

3.1.3 RBI and local regulation

Before starting an RBI analysis, it shall be verified that the local regulation where the plant is located allows planning inspection using an approach based on Risk vs a time-based or calendar-based approach.

It shall be verified if the local regulation gives requirements for the definition of the inspection intervals in the inspection plan and how these relates to the results of the RBI analysis².

3.1.4 RBI and Asset Integrity Management

RBI is one of the Tasks of Asset Integrity Management and it contributes to the prevention of major accidents and to maintain the safe operability of production facilities.

The Integrity Management System (BP.SVI.ENG.004) has been established to adequately handle the Integrity Threats in the engineering phase (OPDS - Opportunity and Project Development System) and during production (OPOS - Opportunity and Production Operation System) through several well-defined and organized activities, or TASKS.

3.1.5 Benefits of RBI

RBI is intended to provide beneficial effects that may lead to:

- Increased operability through an increase in asset availability and reduction of shutdowns;
- Reduced risks of loss of containment and associated consequences, including safety and environmental impact;
- Inspection effort optimization, through optimization of the number of items and positions to be monitored and frequency of inspection;
- Monitoring optimization, through the identification of most critical positions and parameters, to be monitored.

The reasons for selecting a *risk-based* approach to inspection planning are:

- To focus inspection efforts on items where the safety, economic or environmental risks are identified as being high, whilst similarly reducing the effort applied to low-risk systems;
- To ensure that the overall installation risk does not exceed the risk acceptance limits, set by the operator;
- To identify the appropriate inspection or monitoring methods according to the identified degradation mechanisms.

It is important to highlight that the RBI approach can lead to a reduction of the inspection costs, however, **cost reduction is neither the target nor the motivation of an RBI.**

² Rational: In some countries the local regulation foresees that at fixed interval there must be an internal inspection irrespective of the results of the RBI analysis while in other countries it is possible to delay the internal inspections if supported by the results of an RBI. In some countries there are no local regulations that give recommendations or instruction on the timing and extent of the inspections and reference is made to API or other international recognized standards.

4 **RBI PROCESS**

RBI is a process consisting of independent and correlated steps or tasks:

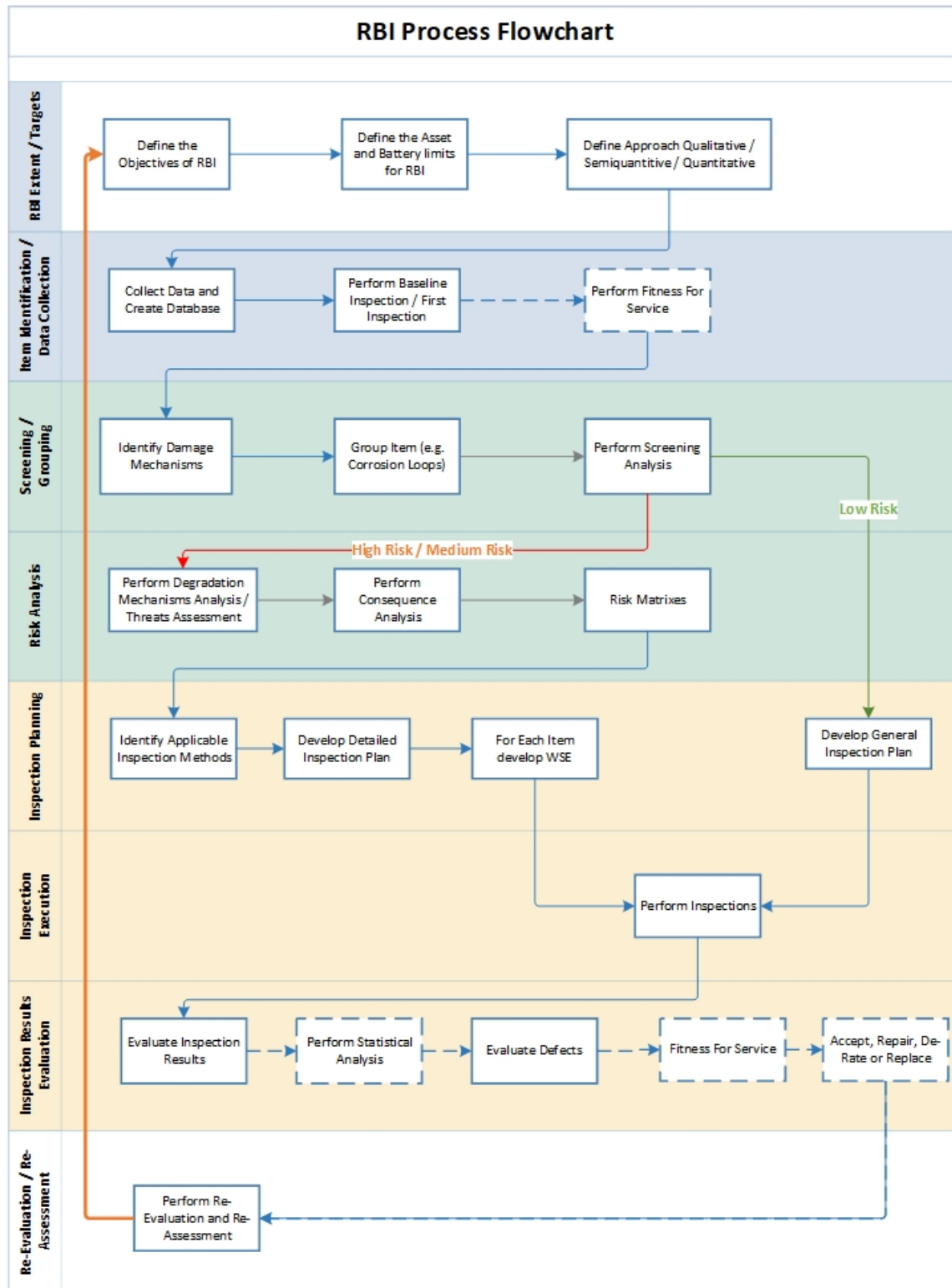


Figure 1 – Example of RBI process flowchart consisting of both quantitative approach and qualitative screening approach.

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5 RBI OBJECTIVES AND EXTENT

The first step is the definition of objectives and extent.

5.1 RBI OBJECTIVES

Definition of the objectives of an RBI represents the first step of the RBI process.

RBI objectives shall be identified and agreed amongst the Parties involved and Risk-based inspection shall address one or more of the following objectives:

- meeting the requirements of health, safety and environmental regulations;
- improving the safety and reliability of the plant;
- optimizing inspection and maintenance (possibly also production and quality) activities;
- extending the useful service life of the plant, e.g. beyond its design life, and implementing an appropriate end of life strategy.

The RBI objective shall take into account:

- the phase of the asset within the project life:
 - design;
 - installation, pre-commissioning and commissioning;
 - operation;
 - re-qualification;
 - new asset operated by Eni;
- requirements from the legislation of the country where the asset is located;
- time available to perform the RBI study;
- timing for the RBI:
 - after inspection (routine periodical or extraordinary);
 - following a failure;
 - following a change in operating or process conditions and/or fluid composition;
 - significant environmental events;
- cost-related aspects: e.g. budget available to perform the RBI study, budget for the inspection activities;
- technologies available for the inspections.

5.1.1 The RBI Team

The RBI is a complex process which involves several, including:

- specialists covering the various type of assets (equipment, structures and systems) being assessed;
- specialists with corrosion and materials background;
- Inspection and monitoring techniques specialist;
- Engineering manager or representative;
- HSE manager or representative;
- Asset Integrity manager or representative;
- Maintenance manager or representative;
- Operation manager or representative;
- Contractors when done during the design phase;
- Independent Third Parties.

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5.1.2 RBI Deliverables

The main typical deliverables of an RBI study are:

- RBI Report;
- Inspection Plan and/or Inspection, Monitoring and Test Plan as applicable to the asset;
- WSE (Written Scheme of Examination) identified on construction/mechanical drawings for equipment/structures and isometrics for piping;
- (Plant Facilities) Corrosion Loops identified on PFDs and P&IDs;
- (Plant Facilities) Corrosion Loops Masters: List of all the corrosion loops with identification of the damage mechanisms and main data (e.g. operating conditions, materials of construction, etc.);
- Eventual improvement activities documentation suggested by the study.

When the RBI study is completed all the main deliverables shall be uploaded in the IDMS.

5.2 RBI EXTENT

The asset object of the RBI process shall be defined, and battery limits established. Once identified the asset and the battery limits, an Asset Register shall be created to list all items to be included in the RBI analysis.

Grouping of items is recommended to simplify the analysis; the main criteria used to group items are the potential damage mechanisms, which are based on:

- Material;
- Sizes/thickness;
- Exposure conditions (present and past);
- Operating parameters;
- Fluid composition;
- Presence of coating and insulation;
- Environment:
 - Buried;
 - Underwater;
 - Atmospheric.

5.3 RBI APPROACH

An RBI analysis can be performed with different level of details:

- Qualitative;
- Quantitative;
- Semi-Quantitative.

The main differences between the approaches are in the level of details and data necessary to perform the study.

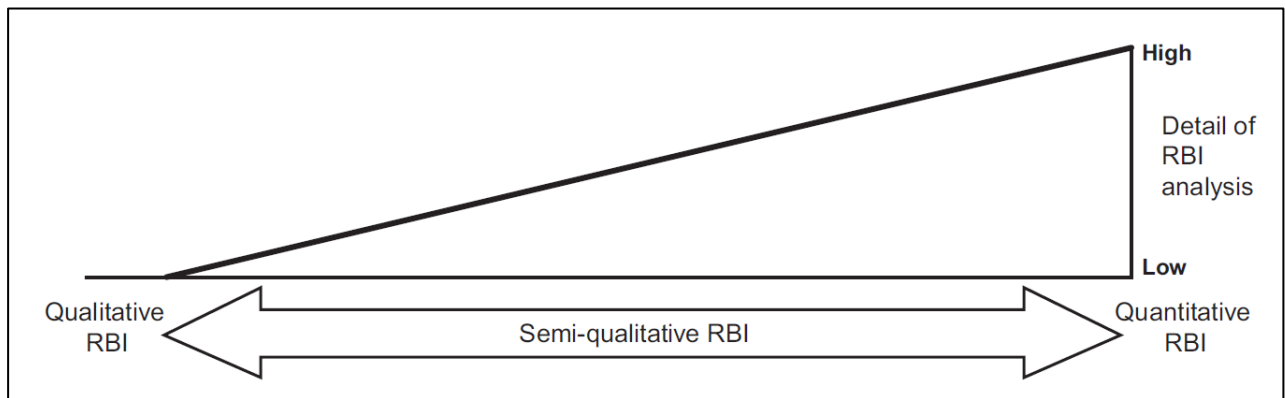


Figure 2 - Continuum of RBI Approaches (Ref. API 580)

Qualitative: A risk analysis using primarily subject matter expertise and experience to assign broad categorizations for POF and COF.

This approach requires data inputs based on descriptive information using engineering judgment, subject matter expertise, and experience as the basis for the analysis of probability and COF.

Inputs are often given in data ranges instead of discrete values. Results are typically given in qualitative terms such as high, medium, and low, although numerical values may also be associated with these categories.

Pros:

- Enables completion of a risk assessment in the absence of detailed quantitative data;
- Effective in screening out units and equipment with low risk;
- Requires less time and efforts;
- The qualitative approach can be used as a screening methodology in case the study covers a lot of items to be analyzed.

Cons:

- The accuracy of results from a qualitative analysis is dependent on the background and expertise of the risk analysts and team members;
- Less precise than more quantitative approaches;
- Qualitative assessments generally are not as repeatable as quantitative assessments;
- Generally, more conservative associated with the more qualitative approach should be considered when making final mitigation and inspection plan decisions.
- A qualitative approach alone is not able to give a valuable ranking between those items.

Quantitative: A risk analysis that uses primarily model-based approaches where numerical values are calculated, and more discrete input data used.

Quantitative programs are model-based approaches where numerical values are calculated, and more discrete input data used.

Pros:

- Calculates, with some precision, when the risk acceptance limit is reached or exceeded;
- Discrimination between equipment risk allowing prioritization of mitigation;
- Trending and monitoring risk exposure over time as well as other metrics;

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- Benchmarking of reliability management such as POF trending and comparisons;
- More systematic, consistent, and documented, and they can be updated with inspection results than qualitative approaches;
- A software program is used to calculate risk and develop inspection program recommendations;
- The models are initially data-intensive, but the use of models removes repetitive, detailed work from the traditional inspection planning process.

Cons:

- Requires more data than a qualitative or semi-quantitative;
- Requires more time for the analysis;
- Cost is higher than a qualitative or semi-quantitative;
- Requires a dedicated software;
- Requires a more rigorous approach in terms of update after inspection, monitoring and testing activities.

Semi-Quantitative: A risk analysis that includes aspects of both qualitative and quantitative analyses.

It is geared to obtain the major benefits of the previous two approaches (e.g. speed of the qualitative and rigor of the quantitative). Typically, most of the data used in a quantitative approach are needed for this approach, but in less detail. The models may not be as rigorous as those used for the quantitative approach. The results are usually given in consequence and probability categories or as risk numbers, but numerical values may be associated with each category to permit the calculation of risk and the application of appropriate risk acceptance criteria.

The selection of the type of approach to be used depends on factors like:

- Time available to perform the study;
- Number of the item to be analysed;
- Local regulations;
- Available data;
- Available expertise.

A possible approach is to perform at first a screening / qualitative analysis to define the items or group of items with a low level of risk, for which a general inspection plan will be developed. More details are given in the relevant appendixes.

The items with a medium-high level of Risk will be then analysed with a quantitative methodology and a detailed inspection plan (i.e. WSE) will be prepared.

An example of this approach is reported below.

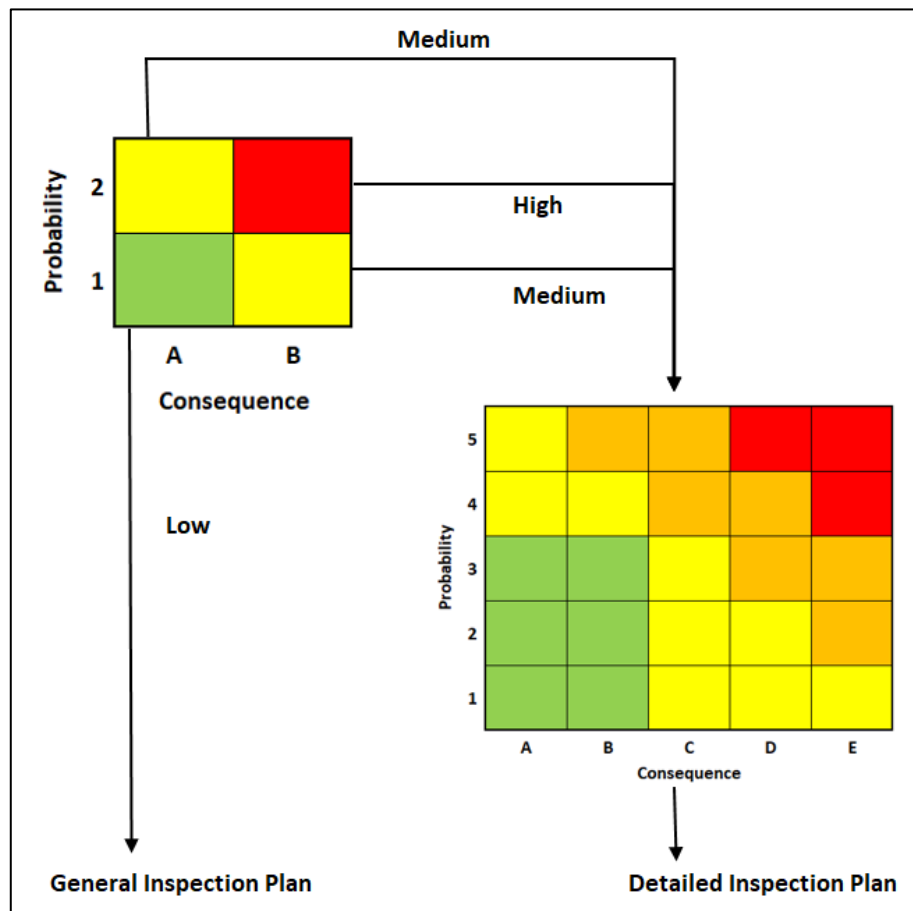


Figure 3 - Example of a screening process

6 DATABASE

6.1 DATA COLLECTION AND REVIEW

The source of data available shall be identified and it is usually found in the following documentation:

- Design premises and design codes;
- Geohazard Report;
- Seismic Hazard Report;
- Design life;
- Layout drawings;
- P&IDs;
- PFDs;
- Piping class specifications;
- Heat and material balances;
- Corrosion prevention philosophy studies;
- Corrosion monitoring data;
- Materials selection reports;
- Material selection diagram (MSD);
- Mechanical data-sheets;
- Flow rate data, past and forecast;

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- Operating data, past and actual;
- Fluid composition, past and actual;
- Failure track records and failure analysis reports;
- Inspection history and reports;
- Monitoring reports;
- Test history and reports;
- Repair interventions history and reports;
- Painting, coating and insulation specifications;
- Cathodic protection specification;
- Cathodic protection inspection reports;
- Previous risk assessments, including HAZOP, HAZID and FMEA;
- Construction drawings / general arrangement drawings;
- Legislation and standard codes.

The quantity and quality of data shall be tailored to the expected level of detail of the RBI analysis.

Where no data exists (e.g. inspection data in case of RBI performed in the design phase) a conservative risk approach should be applied.

Each selected item shall be univocally identified by a code or tag.

6.2 DATABASE SETUP AND MANAGEMENT

The documents listed in the previous paragraph, together with all useful sources, shall be reviewed, validated and uploaded into a dedicated IDMS (Ref. /37/).

As a minimum, the database shall contain the following categories of data (for each item):

- Codes and extent (from/to for pipework only);
- Dimensional data;
- Materials and grades;
- Design and operating parameters (actual and past);
- Fluid chemical analysis and physical parameters (actual and past);
- Bacterial analysis (water only);
- Fluid treatments with chemicals: types; injection points; injection mode; dosages (actual and past);
- Process treatments;
- Cathodic protection data (actual and past);
- Coating and painting;
- Monitoring data;
- Inspection and failures data;
- Risk matrixes.

7 INSPECTIONS

7.1 BASELINE INSPECTION

To increase the data quality in case of new facilities, or new items to be incorporated in an existing facility before the respective start-up a “baseline inspection” should be performed to:

- measure the actual thickness of the item to be used as a reference for RBI analysis;

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- assess any non-compliance with the original design (e.g. pipe installed with a schedule different from the piping class);
- verify that the thickness is within the fabrication tolerance ³;
- perform other NDT to be used as a reference for RBI analysis.

In the case of subsea assets, baseline inspections usually coincide with the as-built surveys and shall be used to capture any new threats or damages and/or anomalies from installation and pre-commissioning activities.

The available results from the baseline inspections shall be evaluated and taken into account during the updating of the RBI analysis for re-assessing the active damage mechanisms and damage (e.g. corrosion) rates.

Further details are defined in each Appendix.

7.2 FIRST INSPECTION

The scope of the First Inspection is to:

- Verify the assumptions of the RBI analysis (e.g. Active damage mechanisms);
- Verify critical areas where damage is most likely to occur;
- Compare obtained results with those from the baseline inspection for damage evaluation (e.g. Corrosion rate) and for detecting any change of condition or any new threat to the asset;
- Ensure that the asset can be safely operated until the next inspection;
- Gather input data for RBI update.

7.3 FITNESS FOR SERVICE

In case of non-compliance with the original design or if flaws/damage are discovered during inspections and are not possible to intervene on the defect/non-conformity, a Fitness for Service (FFS) analysis shall be performed to evaluate the structural integrity of the components and their suitability for continuous service.

The FFS is not part of the RBI process, but its output can impact RBI input data and results. Due to this reason, FFS studies have always to be taken into account during the database creation phase.

8 DAMAGE MECHANISMS

The damage mechanisms are defined as how a component degrades thus reducing its ability to carry out its function (Ref. /4/).

Several damage mechanisms can affect the integrity of production facilities and structural components. Some of the main categories are:

- Mechanical and Metallurgical Failure Mechanisms;
- Uniform or Localized Loss of Thickness;
- High-temperature corrosion;

³ Mismatched materials during construction.

- Environmental – Assisted Cracking;
- Environmental events.

Amongst the degradation mechanisms, a distinction can be made between *time-dependent* and *non-time dependent* mechanisms.

Non-time dependent degradation mechanisms occur as sudden rupture, for instance by fracture, and inspection criteria based on inspection intervals cannot be applied.

RBI, in its most appropriate and complete interpretation, applies to time-dependent degradation mechanisms where risk prediction can be performed. However, the RBI approach can be extended and adapted to all expected degradation mechanisms.

8.1 IDENTIFICATION OF APPLICABLE DAMAGE MECHANISMS

The scope of the first step in an RBI analysis is to identify all the reasonable damage mechanisms that can be active in the asset under evaluation based on:

- Fluid composition (for process equipment);
- Operating conditions;
- Environment (Offshore, Onshore, Subsea);
- Material of Construction;
- Inspection/maintenance history.

In the next table are reported the most common damage mechanisms expected based on API 571 and DNVGL-F116, along with the indication of the industries where they are commonly active if they are internal (Int) or external (Ext) and the most commonly affected materials.

It shall be noted that the next table may not cover all damage or degradation mechanisms of all types of equipment, structures and systems presently installed in the various Eni facilities/assets.

Therefore, applicable damage mechanisms may vary and shall be customized on a case by case basis depending on the type of facility/asset being analyzed.

Table 1 - List of Damage mechanisms

	Material Affected	Int Ext	Plant	Sub	Pip.	Naval	Civil	Struc
Damage mechanisms that are common to a variety of industries								
Mechanical and Metallurgical Failure Mechanisms								
Graphitization	CS/LAS	I	X					
Softening (Spheroidization)	CS/LAS	I	X					
Temper Embrittlement	LAS	I	X					
Strain Aging	CS/LAS	I	X					
885°F (475oC) Embrittlement	CRA	I	X					
Sigma Phase Embrittlement	CRA	I	X					
Brittle Fracture	CS/LAS/CRA	I	X	X	X	X	X	X
Creep and Stress Rupture	ALL	I	X	X				
Thermal Fatigue	ALL	I	X					
Short Term Overheating – Stress Rupture	ALL	I	X					
Steam Blanketing	CS/LAS	I	X					
Dissimilar Metal Weld (DMW) Cracking	CS/LAS	I	X	X	X			
Thermal Shock	ALL	I	X					
Erosion/Erosion – Corrosion	ALL	I	X	X	X			
Cavitation	ALL	I	X	X	X			
Mechanical Fatigue	ALL	I	X	X	X	X	X	X
Vibration-Induced Fatigue	ALL	I	X	X		X	X	X
Refractory Degradation	REF	I	X					
Reheat Cracking	LAS/CRA	I	X					
Gaseous Oxygen-Enhanced Ignition and Combustion	CS/CRA	I	X					
Uniform or Localized Loss of Thickness								
Galvanic Corrosion	ALL	I/E	X	X		X	X	X
Atmospheric Corrosion	CS/LAS	E	X		X	X	X	X
Corrosion Under Insulation (CUI)	CS/LAS/CRA	E	X		X	X	X	X
Cooling Water Corrosion	ALL	I	X					
Boiler Water Condensate Corrosion	ALL	I	X					
CO2 Corrosion	CS/LAS	I	X	X	X			
Flue-Gas Dew-Point Corrosion	CS/LAS/CRA	I	X					
Microbiologically Induced Corrosion (MIC)	ALL	I/E	X	X	X	X	X	X
Soil Corrosion	CS/LAS	E	X	X	X		X	X
Caustic Corrosion	CS/LAS/CRA	I	X					
Dealloying	CU/CI	I	X					
Graphitic Corrosion	CI	I	X					
Seawater Corrosion	ALL	I/E	X	X	X	X	X	X
High Temperature Corrosion [>400°F (204°C)]								
Oxidation	ALL	I	X					
Sulfidation	ALL	I	X					
Carburization	CS/CRA	I	X					
Decarburization	CS/CRA	I	X					
Metal Dusting	CS/CRA	I	X					
Fuel Ash Corrosion	ALL	I	X					
Nitriding	CS	I	X					
Environment – Assisted Cracking								
Chloride Stress Corrosion Cracking (Cl-SCC)	CRA	I/E	X	X	X	X	X	
Corrosion Fatigue	ALL	I	X	X				
Caustic Stress Corrosion Cracking (Caustic Embrittlement)	CS	I	X					
Ammonia Stress Corrosion Cracking	CS	I	X					
Liquid Metal Embrittlement (LME)	CS/CRA	I/E	X					
Hydrogen Embrittlement (HE)	CS/CRA	I/E	X	X	X			X
Ethanol Stress Corrosion Cracking (SCC)	CS	I	X					
Sulfate Stress Corrosion Cracking	CS/CRA	I	X					
Other Mechanisms								
Materials Ageing	NON METAL	I	X	X	X	X	X	X

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Damage mechanisms that are specific to the refining and petrochemical industries								
	Material Affected	Int Ext	Plant	Sub	Pip.	Naval	Civil	Struc
Uniform or Localized Loss in Thickness Phenomena								
Amine Corrosion	CS	I	X					
Ammonium Bisulfide Corrosion (Alkaline Sour Water)	CS	I	X					
Ammonium Chloride Corrosion	CS	I	X					
Hydrochloric Acid (HCl) Corrosion	ALL	I	X					
High Temp H ₂ /H ₂ S Corrosion	CS	I	X					
Hydrofluoric (HF) Acid Corrosion	ALL	I	X					
Naphthenic Acid Corrosion (NAC)	CS/CRA	I	X					
Phenol (Carbolic Acid) Corrosion	CS/CRA	I	X					
Phosphoric Acid Corrosion	ALL	I	X					
Sour Water Corrosion (Acidic)	CS	I	X					
Sulfuric Acid Corrosion	ALL	I	X					
Aqueous Organic Acid Corrosion	CS	I	X					
Environment-Assisted Cracking								
Polythionic Acid Stress Corrosion Cracking (PASCC)	CS/CRA	I	X					
Amine Stress Corrosion Cracking	ALL	I	X					
Wet H ₂ S Damage (Blistering/HIC/SOHIC/SSC)	ALL	I/E	X	X	X			
Hydrogen Stress Cracking - HF	CS	I	X					
Carbonate Stress Corrosion Cracking (ACSCC)	CS	E	X					
Other Mechanisms								
High Temperature Hydrogen Attack (HTHA)	ALL	I	X					
Titanium Hydriding	Titanium	I	X					
Environmental and External Threats								
Free Span	ALL	E		X	X			
Landslide	ALL	E			X	X	X	X
Ice Loads	ALL	E			X		X	
Trawling	ALL	E		X	X			
Vessel Impact	ALL	E			X	X	X	X
Vandalism	ALL	E			X			
Earthquake	ALL	E	X	X	X		X	X
Storm	ALL	E	X	X	X	X	X	X
Dropped Object	ALL	E		X	X			X
Landslide	ALL	E	X	X			X	X
Marine Growth	ALL	E		X	X	X	X	X
Anchor	ALL	E		X				
Temperature Variations	ALL	E					X	
Freeze/Thaw Cycle	Concrete	E					X	
Structural Threats								
Global Buckling	ALL	I/E		X	X		X	
End Expansion	ALL	I/E			X			
Static Overload	ALL	I/E		X	X		X	
On-bottom Stability	ALL	I/E		X	X			
Pipe Walking	ALL	E			X			
Cracking	Concrete	E					X	
Fatigue	ALL	I/E		X	X		X	

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8.2 ITEM GROUPING

The scope of this activity is to reduce the time required to perform the Risk Analysis and also to develop an inspection, monitoring and test plan for a group of items instead of a specific plan for each item.

Grouping is based on items that are exposed to the same operating conditions, external environment, made of the same material, thus having the same potential degradation mechanisms.

9 RISK ANALYSIS

Risk analysis is the task within the RBI process whose outputs allow to rank the items analyzed based on their level of risk to optimize the inspection activities.

The calculation of risk (R) involves the determination of a probability of failure (POF) combined with the consequence of failure (COF):

$$R(t) = Pf(t) \times Cf$$

- Pf, **POF** is a function of time since it increases as the damage in the component accumulates with time.
- Cf, **COF** is assumed to be invariant as a function of time. However, significant process changes, items modifications and installation of active/passive protection systems can result in COF changes.

9.1 RISK MATRIX

The POF and COF are plotted on a risk matrix to show the Risk level.

It is possible to use different Risk Matrixes to show the level of risk of a single item or a group of items (e.g. corrosion loops, process units) depending on the standard used for the Risk assessment.

The same risk matrix shall be used in all the phases of the entire life of the asset from the development to the operation.

Recommended Risk matrix are defined in each Appendix.

9.2 ACCEPTABLE RISK LEVEL

At the beginning of each RBI, it is required to define the Risk Target or Acceptable Risk Level in compliance with Company HSE requirements and Local ones.

The Risk Target is defined as the maximum level acceptable for continued operation without requiring a mitigating action. Once the target has been met or exceeded, an activity such as inspection shall be performed.

9.3 RISK ANALYSIS RESULTS

The risk analysis allows, for each evaluated item, to position the item in the risk matrix through the relevant coordinates of failure likelihood and consequence, and then to assign a risk level.

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As a result of the risk analysis the following information is provided:

- Expected degradation mechanisms;
- Expected damage morphologies;
- Localization of the attacks (e.g. Bottom-of-line for CO₂ corrosion; elbows for erosion-corrosion, etc.);
- Risk level with relative POF and COF;
- Ranking by risk classes for homogeneous items (e.g. Vessels and pipework for homogeneous process units).

The above information is used in the inspection planning step of the RBI process.

10 INSPECTION, MONITORING AND TEST PLANNING EXECUTION

10.1 INSPECTION PLAN

Planning is the key task of RBI process, aimed to establish the requirements for inspection, monitoring and testing execution.

The following minimum information shall be included in the Plan:

- Ranking of items based on risk class;
- Selection, for each type of item (vessels, pipework, etc.), of the methods and technologies to be applied;
- Extent and coverage;
- General requirements for execution;
- Schedule;
- WSE (written scheme of examination) for critical equipment (e.g. Equipment analysed with a quantitative approach in the RBI analysis);
- Reporting requirements.

In every appendix of this standard the applicable and recommended inspection, monitoring and testing methods are described.

11 RESULTS EVALUATION

11.1 INSPECTION RESULTS ANALYSIS

Results of inspection, monitoring and testing shall be adequately validated and compliance with inspection plans. In case of deviations, for instance, due to impossibility to perform inspections in some areas (e.g. presence of obstacles; inaccessibility; etc.), this shall be recorded.

The results shall be available in a convenient format, depending on the type of NDT methods that can be easily uploaded into an IDMS.

Complete and univocal indications shall be reported of:

- Item tag number;

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- Inspection positions;
- Time of inspection;
- Instrumentation employed;
- NDT operator;
- Any other useful information.

Results shall be analyzed and compared with RBI analysis. In particular, for each item, the predicted damage mechanisms forms and their severity shall be confirmed through inspection, monitoring and testing results.

11.2 DEFECTS EVALUATION: ACCEPTANCE, REPAIR OR REPLACEMENT

Defect analysis shall be carried out using applicable standard, for instance, API-RP-579 (Ref. /5/) which provides guidance for conducting Fitness-for-Service assessment for in-service pressurized items containing a flaw or damage.

The scope of the analysis is to define if:

- A defect is acceptable at design conditions;
- A defect is acceptable after de-rating of the item;
- A defect is not acceptable and shall be repaired;
- A defect is not acceptable, and the item shall be abandoned and replaced.

11.3 RE-EVALUATION

Inspection, monitoring and testing results represent feed information for the next RBI assessment.

In the case of criticality resulting from the inspection activities that have an impact on the calculated Risk, it is necessary to assess the proper actions to be implemented to remain below the Risk Target.

The possible actions could be:

- Item replacement;
- Item repair;
- Change of material;
- Change of operating conditions;
- Implementing a system to reduce the consequence of failure.

Accordingly, the database of the asset under evaluation shall be updated with the results.

Re-assessment have an impact on:

- Attribution of risk class, or criticality;
- Inspection, monitoring and test intervals.

12 IDMS

The inspection plan, RBI results and WSE shall be uploaded into an IDMS (Ref. /37/) before the handover to Operation.

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An Inspection Data Management System (IDMS) is a software program utilized to organize data related to a facility's fixed equipment inspection regime.

IDMS software focuses on two primary tasks. The first is creating and keeping track of inspection schedules for various equipment. The second is to record the results of each inspection for later review and analysis.

The IDMS should also incorporate a Risk-Based Inspection (RBI) tools to perform analysis using the results of the inspections activities.

The IDMS should also be connected to the Computerized Maintenance Management System (CMMS) used by the operator to manage the work orders for the Inspection activities.