BIRO KLASIFIKASI INDONESIA

GUIDANCE FOR SURVEY USING RISK-BASED INSPECTION FOR THE OFFSHORE INDUSTRY

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Section 1

Introduction

A. General

The inspection of process equipment and offshore structural components play a significant role in preventing failures. Inspection and testing programs are established to detect and evaluate deterioration due to in-service operation. The methods, frequency and acceptance criteria used in inspections can affect the likelihood of component failure.

The inspection frequencies for pressure equipment and structures in the marine and offshore industry have traditionally been driven by prescriptive industry practices, usually at time-based or calendar- based intervals. This inspection practice, founded mainly on general industry experience for each type of component, has thus far provided an adequate level of reliability. However such a practice does not explicitly consider the likelihood of failure of a component under its operation and loading conditions, nor the consequences of a failure. Current inspection practices make it difficult to recognize if the same or improved service reliability can be achieved by varying inspection methods, locations or frequencies. Also, current practices do not easily identify if an inspection activity is excessive and provides no measure of increased assurance for the integrity of the component.

Certain sectors of industry have recognized that significant benefits may be gained from more informed inspection methods and have begun evolving into inspection program philosophies that combines factors such as satisfactory operating experience, low deterioration rates, minimal consequences of failure and condition-based inspection interval setting. Most operators have reached their current practice by an evolutionary process based upon experience, regulatory and classification society compliance. However, very few operators have developed their existing programs on the basis of a systematic process that seeks to achieve a balance between risk and the level of inspection effort.

In a facility with substantial production revenues, the cost of downtime can be significant. An effective inspection program is centered on knowing when, where and how to inspect. This enables the operator to not only control the integrity of the assets, but to control it with a focus on the economic value, while maintaining an acceptable service performance. Further, having a documentation trail for the inspection process allows for a focused and confident inspection plan updating should the operator undergo changes in operations, equipment, structures, personnel, contractors, company organization, etc.

Risk-Based Inspection (RBI), which focuses on the optimization of inspection programs for pressure retaining equipment and structures, is the subject of this Guidance. RBI begins with the recognition that the essential goal of inspection is to prevent incidents that impair the safety and reliability of operating facilities. As a risk-based approach, RBI provides an excellent means to evaluate the consequences and likelihood of component failure from specific degradation mechanisms and develop inspection approaches that will effectively reduce the associated risk of failure. RBI is a process that assures inspection resources are focused on the areas of greater concern, and provides a methodology for determining the optimum combination of inspection methods and frequencies. As a result of this there is a continuous improvement aspect to the RBI process that allows for recalculation of risk and subsequent refocusing of the inspections activities.

The recent trend towards RBI practices is being driven by factors such as:

- The increasing awareness and use of risk analysis in all aspects of the asset’s operations
- The location of facilities in remote locations requiring highly effective inspection programs with limited resources
- Asset service life longer than designed and increased reuse of equipment in different services

- Increased emphasis on the justification of inspection frequency and practices required of the asset operators by financial venture partners.

The development and implementation of an RBI program requires the participation and coordination of groups within the operating organization, including process and hardware engineering, maintenance and operations personnel. The whole organization should commit and contribute to the RBI program. Inspections in themselves do not affect the actual failure likelihood of the components being inspected. The inspection process provides a means of gaining confidence in the service reliability of the component being inspected. When an inspection reveals an excessive deterioration, actions are initiated, such as the repair or replacement of the affected component or a change to the operating conditions. By identifying potential problems in a timely manner, RBI increases the chances that mitigating actions will be taken, thereby reducing the frequency of failures. Risk cannot be reduced to zero. There is always a “residual risk” associated with inspection. This is caused by factors such as operational errors, extreme weather, external events, process upsets, limitations of inspection methods and unrevealed deterioration mechanisms.

B. Purpose

The purpose of this document is to provide guidance to BKI Clients on the application of RBI programs to maintain class for an offshore installation. This Guidance describes the fundamentals of RBI, the essential steps in the development of an RBI program and the management systems necessary for maintaining documentation, data requirements and analysis updates. It also describes the interaction between executing the RBI programs and how BKI will audit the plan and execute surveys for maintenance of class within the context of such a program. Specifically, it identifies the minimum elements that BKI requires to be considered in the development and implementation of an RBI program so that it can be considered in lieu of the conventional maintenance of class surveys.

This Guide is intended to clarify the elements involved in the development and implementation of an RBI program, but it does not intend to be a detailed technical reference of RBI methodologies, nor does it intend to single out or endorse any one specific RBI methodology. Appendix A lists some of the most commonly used RBI methodologies.

C. Scope

This Guidance is specifically targeted for structures and production equipment for the offshore oil and gas industry. This Guidance specifically covers:

i) Static pressure retaining equipment, and

ii) Structures for offshore floating and fixed-base platforms

Items specifically excluded from the scope of this Guidance are Instrumentation and Control (I&C) systems, electrical systems and non-static machinery components. For non-static machinery components, the *Guidance for Surveys Based on Reliability-Centered Maintenance* provides guidance on a risk-based approach for such types of equipment.

The application of this Guidance does not cover any statutory survey requirements that may apply to the installation being considered (e.g., MODU code, SOLAS, MARPOL, coastal state regulations, etc.). Although BKI is authorized to perform statutory surveys on behalf of some authorities (Migas), BKI is not in a position to alter or waive them. The cognizant administration or regulatory body is the final determining body for statutory or regulatory requirements under their jurisdiction. The Owner shall ensure that in developing the RBI plan, due consideration is given to Coastal and Flag State requirements.

D. Definitions

Acceptable Risk is the risk that is considered tolerable for a given activity.

Catastrophic failure is a complete functional failure of a component.

Confidence is the analyst's certainty of an estimate.

Consequence is an unwanted event that can negatively affect subjects of interest. It can be expressed as number of people affected (injured or killed), property damage, amount of a spill, area affected, outage time, mission delay, money lost or any other measure of negative impact for the quantification of risk.

Degradation or deterioration is the degradation of materials due to various mechanisms (e.g., corrosion, cracking, embrittlement, fatigue) that causes a detrimental effect on the material's physical properties, eventually resulting in the inability of the component to provide its intended function (i.e., failure).

Event is an occurrence that has an associated outcome. There are typically a number of potential outcomes from any one initial event that may range in severity from trivial to catastrophic, depending upon other conditions and subsequent events.

Failure Mode is defined as the manner of failure, e.g., complete rupture of a pipe, buckling of a side shell.

Frequency is the expected number of occurrences of an event expressed as events per unit time.

Hazards are conditions that can cause harm.

Likelihood is the possibility or frequency of a and event's occurrence.

Qualitative Risk Assessment is a risk assessment that expresses the risk in terms of quality or kind (e.g., low, high, very high).

Quantitative Risk Assessment is a risk assessment that expresses the risk in terms of risk impact per unit time (e.g., $1,000,000 per year).

Residual Risk is the risk remaining after all risk control options are implemented, which is considered acceptable.

Risk is a measure of loss; mathematically, it is the product of frequency with which an event is anticipated to occur and the consequence of the event's outcome.

Risk Analysis is the process of understanding (1) what undesirable things can happen, (2) how likely they are to happen and (3) how severe the effects may be. More precisely, it is an integrated array of analytical techniques, e.g., reliability, availability and maintainability engineering, statistics, decision theory, systems engineering and human behavior that can successfully integrate diverse aspects of design and operation in order to assess risk.

Risk-Based Inspection is a risk assessment and management process that is focused on failure modes initiated by material deterioration, and controlled primarily through equipment and structure inspection.

Risk Controls are the measures taken to prevent hazards from causing consequences. Controls can be physical (safety shutdowns, redundant controls, conservative designs, etc.), procedural (written operating, maintenance, or inspection procedures) or can address human factors (employee selection, training, supervision).

Risk Evaluation is the process used to compare the estimated risk against given risk evaluation criteria to determine the significance of the risk. Risk evaluation may be used to assist in acceptance decisions.

Risk Management is a set of coordinated activities directed to control risks within an organization. These activities usually include risk analysis, risk assessment, risk control, risk acceptance and risk communication.

Scenario is a series of events that result in the occurrence of a potential consequence(s).

Section 2

Fundamentals of RBI

A. Definition of RBI

RBI is a risk assessment and management process that is focused on failure modes initiated by material deterioration, and controlled primarily through equipment and structure inspection. RBI combines risk assessment and risk management techniques with all inspection activities, such as planning, inspecting, documentation and data analysis, to develop inspection plans that direct inspections towards the areas of highest risk. RBI can be applied to all types of material deterioration processes that may cause loss of integrity for pressure retaining equipment and structures.

B. Risk Assessment and Inspection

Risk is defined as the product of the frequency with which an event is anticipated to occur and the consequence of the event’s outcome. In mathematical terms, risk is calculated by:

$$Risk = Frequency \times Consequence$$

Risk assessment is the process of identifying the sources of hazards, estimating the risk and evaluating the results. Appendix A provides a list of reference sources for risk assessment techniques.

The risk assessment process answers the following three questions to determine the risk:

i) What can go wrong?

ii) How likely is it?

iii) What are the consequences?

Risk can be expressed quantitatively as a measure of loss per unit of time, or presented qualitatively.

Presenting risk qualitatively is an effective means of illustrating risk. A qualitative risk matrix as exhibited in Figure 2.1 below illustrates how risk is related to the likelihood and consequence. This matrix is simply a plot with likelihood on one axis and consequence on the other. The matrix shows the basic principles behind all evaluations of risk. A high likelihood combined with a high consequence results in a high risk, located in the upper right hand corner of Figure 2.1. A low likelihood combined with a low consequence results in a low risk, located in the lower left hand corner of Figure 2.1. These two extremes usually do not present any difficult decisions on the persons conducting the risk assessment. If the risk is “High”, then the situation may not be acceptable and changes must be made to lower the risk. If the risk is “Low”, then the situation is tolerable and no changes need to be made. The challenge lies in addressing risks in the central area of the matrix between “Low” and “High”. In this “Medium Risk” range, the question arises as to how much risk is acceptable. An important concept to understand is that high consequence may not mean high risk, and similarly, high likelihood may not mean high risk. The level of risk can only be determined once both of these variables are known or estimated.

As previously defined, RBI is an inspection planning process using risk assessment and risk management. The setting of inspection frequency within RBI is not a rigid process with fixed, predetermined inspection intervals. Inspection intervals for any given component may change throughout the life of the asset as risk increases or decreases. The frequencies that RBI derives are aligned to the needs of the component or situation and the risks associated. There is, nonetheless, a general logic to the inspections and frequency of the inspections, namely:

- Higher risk systems/components generally have the shorter frequencies of inspection and have potentially larger inspection population requirements

- Lower risk systems/components often have extended inspection frequency (or even no inspection) and have reduced inspection population requirements

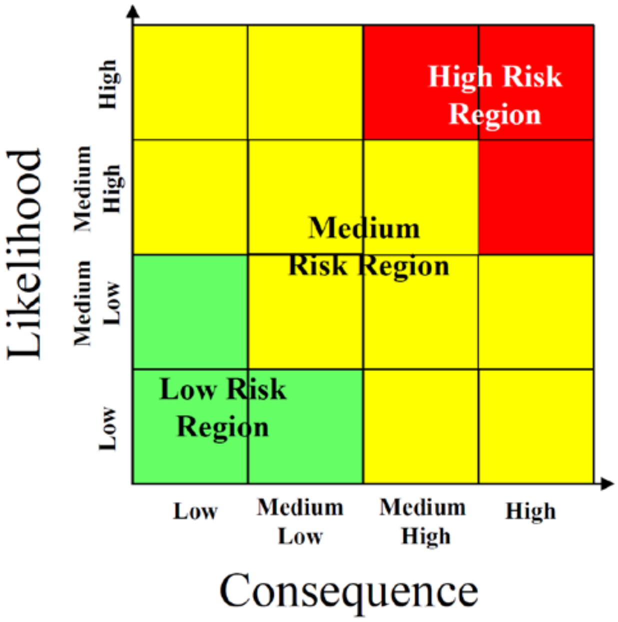


Fig. 2.1 Risk Matrix

Risk for RBI is considered to be the product of the factors of consequence and likelihood:

i) Consequence (i.e., the outcomes that would ensue should a catastrophic failure of the component occur); and

ii) Likelihood (i.e., the probability that a catastrophic failure for the component will occur)

In general, unless there is a major change in the use, service duty or service parameters for a given piece of equipment or structure, the consequence of failure from each type of degradation is likely to remain fixed for its service life. Given this fact, it is correct to assume that the type and frequency of inspection activity will have no impact in modifying the consequence factor values.

In comparison, inspection activities, specifically the actions/results derived from inspections, have a major influence on likelihood and, subsequently, the determined risk value for the component. Rates for degradation of components are the major time based factor that governs likelihood of failure. RBI usually relies on these time-based models of failure frequency, where the expected frequency of failure rises with ongoing degradation. Such time-based models are essential for setting specific inspection intervals that will allow detection of significant degradation before the likelihood of failure (and hence the risk of failure) reaches an unacceptable level. This process allows for enhanced monitoring of degrading components, implementation of mitigation measures to slow down the degradation or corrective actions such as repair or replacement.

C. The RBI Process

Typical standard inspection programs base the inspection techniques and frequencies mainly on manufacturer’s recommendations, industry standards, classification society or regulatory requirements. The general belief is that a decrease in the level of inspection activities would bring an associated increase in failures and hence a risk increase. Conversely, an increase in inspection activities is thought to result in a safer installation, amid an increase in cost. This belief, though accurate in general, has exceptions:

i) If failure of a component does not result in significant risk exposure, then any inspection activity for that component will result in additional costs without any risk reduction and further inspection may not be necessary.

ii) Excessive inspection activities (i.e., too frequent) may not bring any additional risk decrease. The extra inspection could even cause a risk increase due to issues such as human error during inspection and damage to protective coatings.

iii) Inspection activities that do not focus on the detection of the specific degradation mechanisms to which the component is subjected to will result in cost without benefit.

The conclusion is that not all inspection programs are equally effective in detecting degradation mechanisms and reducing risks, and they all have different costs. RBI provides the tools and processes to determine the optimum combination of inspection methods and frequencies.

The basic elements in the development of an RBI program are the following:

i) The determination of the risk introduced by the potential failures of each component.

ii) The identification of the degradation mechanisms that can lead to component failures.

iii) The selection of effective inspection techniques that can detect the progression of degradation mechanisms.

iv) The development of an optimized inspection plan using the knowledge gained in the three previous items.

v) The analysis of the data obtained from the inspections and any changes to the installation in order to feed back into the RBI plan.

D. RBI Benefits

RBI programs address risks due to structural or equipment deterioration from a safety, environment and economic perspective. Implementation of RBI plans can provide and document the overall reduction in risk for the facilities assessed. RBI programs may identify risks of such low level that require little or no inspection as a means of mitigation, and consequently, improving management of inspection activities by directing resources to higher risk areas.

RBI ensures that maximum effectiveness and improved efficiency for inspection are gained by:

i) Prioritizing the components based on risk to differentiate criticality.

ii) Ensuring that the correct items within the system are selected for inspection (the “at risk” components).

iii) Ensuring that the optimal inspection frequency is determined and met.

iv) Ensuring that the correct inspection resources are selected for the job (skills set, competence).

v) Selecting the correct inspection methods, since there is a thorough understanding of the potential failure modes.

vi) Planning inspections to minimize business interruptions.

vii) Providing greater focus for future inspection programs as inspection results are used to update the RBI program.

Where RBI is implemented, it is common to observe improvement in both the technical and economic performance of the equipment and installation. This improved performance is delivered through:

i) Reduced installation outages due to unexpected failure of systems or components (reduction in the number of reactive repairs).

ii) Safer operation due to higher level of integrity and reduction in failures.

iii) Greater focus to planned maintenance activities through providing predictive replacement times from derived inspection data for critical components or structures.

iv) Improved budgetary control and forecasting forward inspection planning and inspection survey execution.

v) Reallocated inspection effort and resources to the items that would provide for the biggest impact on risk reduction.

It is important to recognize that seeking ways to relax inspection practices is not the goal of establishing an RBI program. Modifications to inspection plans are not achievable in all circumstances. Only when a relaxation of an inspection plan will not result in an unacceptable increase in risk can such a relaxation be made. This ensures that compromise to the integrity of the asset or component does not occur. The process of developing an RBI plan may uncover the fact that the operator of the asset has actually been operating, maintaining and inspecting some components in a manner which did not provide the most efficient use of inspection resources. RBI is specifically useful at matching the correct inspection frequency and methods to the level of risk posed by the inspectable item.

E. RBI Limitations

As with all inspection programs, RBI is subject to uncertainty in dealing with damage mechanisms, their progression rates and the response of equipment and structures to the damage. Some inspection specifications have developed over time in response to observed damage or failure, and these events tend to govern inspection plans for all such equipment or structures. While it is possible to improve inspection specifications (e.g., using more sophisticated predictive methods for measuring damage rates), it is unwise, without installation-specific or other pertinent data, to assume that inspections are excessive just because failures are rare.

Data used to support the RBI plan must be well characterized and include a clear understanding as to the uncertainties associated with such factors as corrosion rates, fatigue crack growth, material strength and toughness and stresses. Many RBI programs start with a period of data gathering and analyses, allowing the inspection plan to be fine-tuned over a period of time as confidence in the data grows.

It should be recognized that RBI does not eliminate risk. The likelihood and consequence of an event or failure is always present, RBI serves to help manage and control the risk to tolerable and sustainable levels by focusing the resources available towards the components that are recognizable as producing the highest risk to the asset. Within RBI, this consists of (1) ranking the components to be inspected according to risk and (2) devising a plan to proactively inspect these components at an appropriate level and frequency that provides the Owner confidence that such components' integrity remains acceptable. It follows that high-risk contributors deserve stricter management than the low risk contributors. It is this prioritization that allows for an efficient allocation of inspection resources.

Section 3

RBI Program Development

A. Main Steps in the Development of an RBI Program

This section will describe a typical methodology used to develop an RBI program, but a variety of methodologies are accepted by BKI, provided that the steps in the development process as described in this section are included. If any of these steps are missing or they are considered in a substantially different way than common industry practice and standards, a suitable technical explanation on the adequacy of the methodology should be included with the submittal for BKI consideration and approval.

The typical procedural steps for the development on an RBI program are the following (Figure 3.1):

i) *RBI Team Setup.* The first step consists of the setup of an RBI team who will establish (or be given) the goals of the RBI program, and will carry out the RBI methodology to arrive at an inspection plan that achieves those goals.

ii) *Component Grouping and Baselining.* The program development begins with the identification and grouping of the components that are subject to the RBI program, and includes service, design and applicable inspection history data collection for those items. If new construction, then comparable service degradation data or reference material may need to be gathered to establish degradation concerns.

iii) *Risk-Based Prioritization.* Perform a risk-based prioritization screening so that the components most critical to the safety of the installation can be identified. This requires a risk assessment to be initially performed that considers consequences of failure from the anticipated failure modes and degradation mechanisms and frequency based on expected degradation rates. If necessary, additional inspection data is specified if more data is needed to complete the risk assessment. The risk prioritization of the components occurs after the risk assessment is completed.

iv) *Inspection Plan Development.* An inspection plan is developed based on the risk prioritization information so that the risk of failure is at or below acceptable levels.

v) *Inspection Execution and Analysis of Inspection Results.* As the RBI program is executed and each inspection conducted, the results should be analyzed. This analysis should evaluate whether the assumptions made and data used to develop the RBI plan are valid and if the observed state of the component is acceptable for continuing operation until the next inspection.

vi) *RBI Program Updating.* Finally, the observed degradation mechanisms and rates are used to update the RBI inspection plan.

Each step in this process will be described in more detail in the remainder of this Section.

B. RBI Team Setup

An RBI program is best performed by a multi-disciplinary team that synergistically brings together different perspectives and technical strengths. A team approach ensures that all required information that is available within the facility and/or organization is considered in the RBI program, as well as providing a wider perception of the risks of failure.

The specific composition of an RBI team varies depending on the complexity of the facility, scope of the RBI program and any applicable regulatory requirements. Some of the disciplines will be called in as advisors, but a core team is essential for continuity.

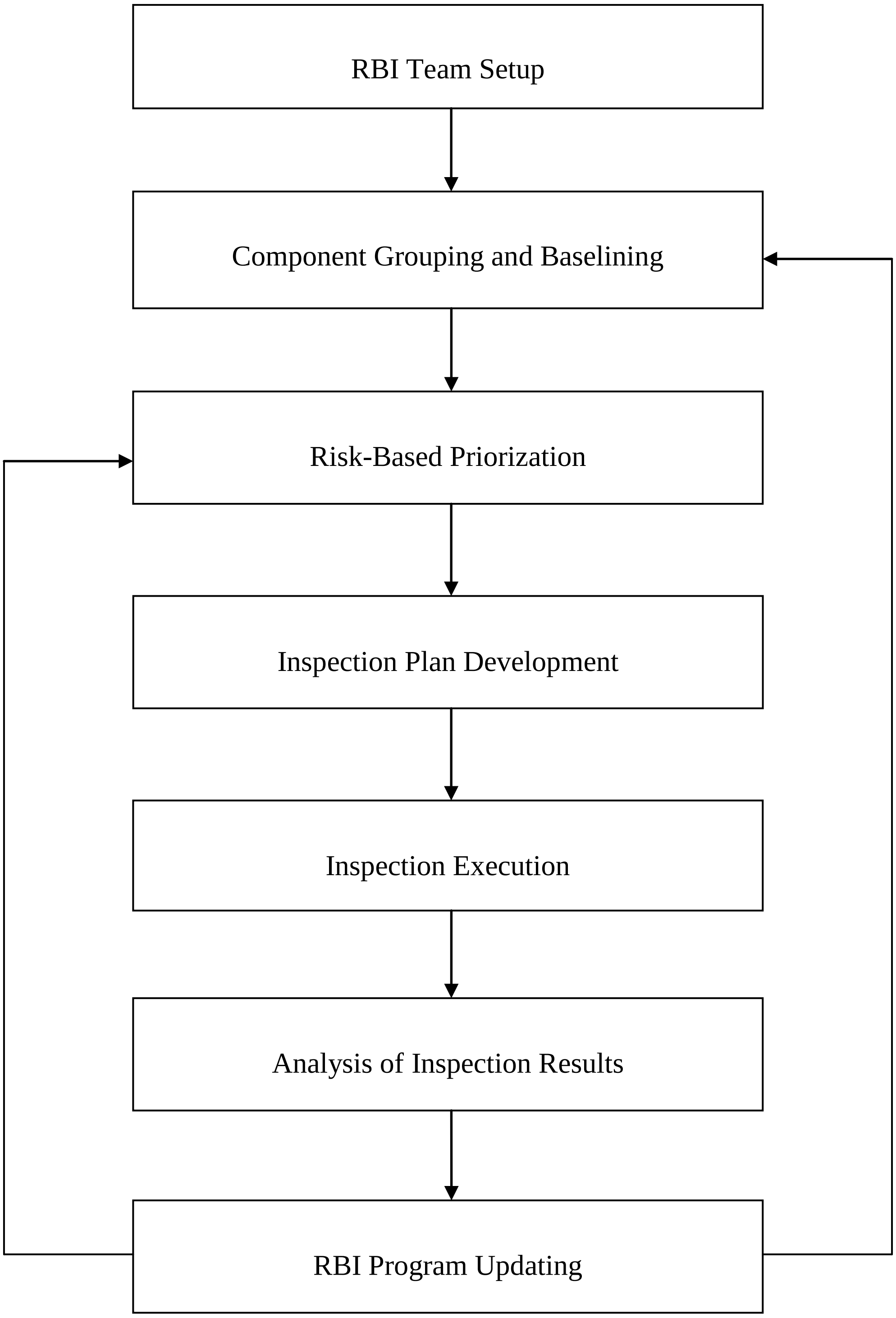


Fig. 3.1. Main Steps in the RBI Program Development

RBI aims to prevent failures that lead to safety, environmental or economic concerns by planning inspections on the basis of information obtained from a risk analysis. The risk analysis for components needs to identify potential causes of failure, likelihood of failure, as well as determine the consequences arising from the failure. The RBI team should contain the expertise to identify and analyze all of the above factors and their implications to personnel safety, environment, property and production. If during the RBI risk prioritization, failure scenarios are inaccurately determined to have low risk, the RBI program could potentially reduce inspection efforts to related components, thus resulting in a hazardous situation. Personnel with technical and risk analysis knowledge are essential for the program to function effectively**.**

The RBI team will typically consist of individuals with experience and technical knowledge in the following disciplines:

i) Maintenance and inspection

ii) Degradation and failure mechanisms

iii) Reliability

iv) Operations

v) Structural integrity

vi) Risk analysis

vii) Production process hazards

viii) Safety and health

ix) Materials of construction

Participation in the team of a representative with knowledge of RBI efforts in other similar facilities will ensure consistency throughout the organization and/or industry, as well as provide wider experience of risks and practices.

Among the duties of the RBI team members are to (a) participate and proactively contribute in all required risk analysis and RBI meetings to ensure their knowledge is easily tapped for the RBI purposes (b) validate the quality and veracity of the information available, and (c) perform their specific RBI tasks, keeping in mind the end goals of the RBI program.

C. Component Grouping and Baselining

1. Asset Hierarchy

All RBI programs require an adequate amount of data be available for the assets in question. Typically, this data is stored in various forms, e.g., original design and constructions data, inspection and maintenance histories, information on repairs and modifications, and operational records and histories. Having this information in hand is essential to develop the RBI program. It should be noted that the lack of data/information and/or the level of accuracy should have bearing on the amount of conservatism and initial assumptions made when developing the RBI program.

Some facilities track and store this information manually. However, in many instances, this information is collected, stored and retrieved in an electronic database that is also used to handle the day-to-day inspection and maintenance tasks. This database will contain unique tag numbers and identifications for all aspects of the process, most often down to the subcomponent level. This classification is sometimes known as the asset hierarchy. A complete asset hierarchy is essential to developing and sustaining a viable RBI program.

2. Breakdown into Inspectable Units

The objective of this step in the RBI program development is to delineate the equipment or components into manageably sized logical groupings, hereby referred to as “inspectable units”. Offshore structures, pressure vessel and piping systems consist of many components and each has a role in the overall integrity of the whole entity. A goal of RBI is to use risk assessment to establish a priority order of components to be inspected from the highest risk to the lowest risk. The selection of the component or system of components to perform the risk assessment is essential for effective RBI inspection planning. The risk for RBI priority setting is usually the risk associated with a failure of a major component or system of components. Therefore, the consequence evaluation has to be performed on a component or sub-system of components that has meaning in context of inspection. It has to be a large enough inspectable unit that has significant consequences when failed, but small enough to have similar load and degradation mechanism exposures.

The inspectable units for topsides equipment to perform consequence evaluations are individual pressure vessels and portions of piping systems with nearly constant fluid conditions (piping circuits). These are easy to define since the equipment is usually discrete, their load conditions are well known and the consequences from the release of the fluids are handled routinely with a variety of commercially available consequence assessment models.

A consequence evaluation for a floating structure or the entire topsides would not be meaningful to an inspection plan since each involves hundreds of disparate components. Also, a consequence evaluation of a single bracket in a highly redundant and complex structural system has little meaningful consequence of failure. The inspectable units for structural components are difficult to identify because of the redundancy of the load paths within the structure. Selection of the components to perform consequence evaluation should be limited to major components with significant function and represent large inspection units. Examples for offshore structures would be:

- Void spaces
- Pump rooms
- Storage/ballast tanks
- Water tight compartments
- Spaces with through hull connections

An inspection plan of complex structural systems such as those found in offshore structures is a series of inspections plans for the inspectable units. Forcing the RBI team to think effectively about inspectable units prior to performing the risk prioritization is beneficial because it:

- Encourages recognition of the relationships that many components have with others
- Seeks common connections between components and failure modes
- Considers degradation processes and rates within the selection of groups
- Helps with the eventual selection of inspection methods
- Establishes groupings with respect to likelihood
- Links components through consequence
- Allows non-safety related issues such as economic risk to be incorporated and managed

This is an essential step since performing an RBI program at too broad a level would be overly vague whereas at the individual component level, it would be very time consuming and difficult to manage. Grouping components together in a consistent manner will ensure that the RBI risk prioritization will be much easier to complete and document.

For process systems, there are many ways to establish the basis for component grouping. One of the simplest methods is to establish groupings based upon similarity of service. This may be relatively simple to achieve, as operational information and practices such as isolation and lock down philosophy are usually readily available. By using data from the asset hierarchy and related safety management schemes, many of the issues that RBI will seek to establish, such as high/low pressure interfaces, safety relief and process phase interactions (process flow diagrams), will already be available, as will many of the component relationships.

For structural components, the use of structural drawings and analyses that detail the design will aid in the selection of appropriate groupings. In the case of marine and offshore structures, the ability to group structures into like components will also depend on a combination of the function of the structure and its ability to be isolated from other parts of the overall structure during inspection.

3. Baselining and Fitness for Service (FFS) Assessment

In some instances, the asset hierarchy and corresponding database for existing equipment and structures will have no or limited data. In this instance, it is strongly recommended that the initial step towards developing an RBI program include some form of inspection data gathering coupled with a FFS assessment using the data.

Methodologies for conducting gauging surveys and FFS assessments on existing structures such as fixed platforms, as well as ship-shape and non-ship-shape hulls, are available in other BKI Guides and publications as well as industry codes and standards.

The goal of such data gathering and FFS assessment is to review the available information on the facility and identify and execute an inspection scope that can then be used to perform a FFS assessment on the various components that make up the system in question. The FFS assessment should accomplish the following:

i) Identify the type and magnitude and possible cause of deterioration present in each component.

ii) Trend or track deterioration versus the initial as-built condition using tools such as remaining life calculations.

iii) Assess other anomalies and defects (such as crack-like flaws) for suitability for continued operation in terms of the operating environment (e.g., pressure, temperature, cyclic loading, stress field).

iv) Gather information on unknown or unidentified material properties (positive material identification).

Performing a baselining/FFS assessment on the facility will enable information to be gathered on the present condition of the facility, such that the RBI team can then make educated decisions with regard to risk prioritization and in the setting of the RBI plan.

The types of data to be collected and reviewed for the components within the scope of the RBI program in order to facilitate the baselining or FRP assessment may include:

i) *Original Design and As-Built Information.* Covers the initial data point against which all subsequent information can be compared. For example, includes data on original materials of construction, initial thickness, degree of NDT used during fabrication, initially assumed design and operating envelope.

ii) *Operational history.* Covers knowledge of how systems and components were operated from time of construction. Information on loading versus design intent or extent of fatigue related loading can be ascertained from this information.

iii) *Current inspection methods/frequencies.* Enables identification of prevalent damage and trending of that damage versus the initial as-built condition. The effectiveness of prior inspections and confidence in results can also be verified compared with anticipated damage mechanisms.

iv) *Repair and Modifications Records.* Repairs should be investigated in terms of their cause (i.e., was damage greater than anticipated or was a damage mechanism identified which had not been considered in the RBI program?). Modifications should also be noted to ensure that any required upgrade/change is assessed in terms of how this modification affects the original design/operating parameters (management of change).

v) *Mitigation strategies.* Covers strategies such as chemical injection and corrosion inhibition, insulation and coating.

For a new build asset, many of the data sources listed will be available with the exception of historical data. Where the new asset is of similar design to that already managed by an operator, it may be valid to apply the knowledge gained from the existing asset (including degradation rates and repair history) to the new build scenario. In this instance, the parallels drawn between the two assets will require appropriate justification and backup information to support these claims.

D. Risk-Based Prioritization

Prioritization of the components subject to inspection is a critical step in the development of an RBI program. Through prioritization, the most effective and efficient use of resources to execute the inspections is achieved. The prioritization process within RBI is largely governed by the derived risk rankings for systems and components. In the case of a mature RBI program, prioritization may also be influenced by additional factors such as anomalies, repairs or scheduled shutdown programs.

In general, the RBI prioritization is performed using risk as the ranking parameter, which gives an equal weight to the likelihood and consequence components in the risk equation. Using consequence or likelihood alone for prioritization purposes can prove problematic and may not accurately reflect the worst potential scenario, resulting in dissimilarities for priority of inspection. Using overall risk rank assures that the most critical components (higher consequence, higher likelihood) are easily distinguishable and, as such, are prioritized accordingly. For high and medium consequence scenarios, special attention should be paid when assigning the likelihood values so as not to inaccurately underestimate the overall risk. The use of conservative likelihood values is recommended so as not to screen out potentially high-risk scenarios.

The risk assessment for the prioritization step in the development of an RBI program is limited in scope to the accident scenarios resulting from deterioration mechanisms of the components within the scope of the analysis, and which can potentially be detected by inspection.

There are many types of risk assessment methodologies that might be applied to evaluating risk for RBI component prioritization. It is important to re-emphasize that the primary objective of RBI is to determine what undesirable incidents could result from degradation of components, the severity in terms of consequence that may ensue and how likely those events would be. For RBI to have a positive impact on these factors, these events must be detectable by one or more inspection techniques.

Risk assessments for RBI may be conducted at various levels ranging from fairly simple to highly complex, but essentially they seek to answer the same basic question set. Table 3.1 outlines the elements that the risk assessment process of an RBI program typically seeks to answer.

Table. 3.1. Basic Elements for an RBI Risk Prioritization

Basic Elements	*Questions to Answer*
Identification of potential modes of failure for the components within the scope	How can an event be initiated? What can go wrong?
Development of accident scenarios	How the accident evolves?
Assessment of likelihood of accident scenarios	How likely is it?
Assessment of consequences of accident scenarios	What are the consequences?
Assessment of risk and prioritization	Which components contribute the most to risk?

The risk prioritization of the inspectable units within an RBI program is performed by the results of the component identification and grouping discussed in Section 3.C. As much as possible, the components identified through that process should be followed when determining appropriate likelihood and consequences of failure. If, when working through the prioritization process, it is found that the system identification is too broad or too narrow to accurately describe the risks, the system identification and grouping should be revisited and, where appropriate, refined sets of components identified. This will ensure that the risk assignments developed match the components inspected under the RBI program.

The first element in the Risk Prioritization step is to identify the initiating events. Each inspectable unit, as identified in the Component Grouping step, is analyzed in terms of which ways or failure modes that unit can catastrophically fail and initiate an accident sequence. At this point in the program development, it is not necessary to analyze in detail the causes of such potential failures, i.e., the degradation mechanisms that could generate the unit failures.

Many common failure modes are easily recognizable, predicted and well understood by engineers in the field of materials, design and inspection. With such ’traditional’ failure modes, one can make an attempt to either eradicate or at least mitigate within the concept design basis. If this is not achievable within the design, it is possible to rely on inspection to provide for a fall back reactive integrity assurance method. However, design of facilities regularly advances adapting or selecting technology and materials, which offer performance advantage over existing designs. In such a changing design world, use of such exotic materials may often produce potential for unusual modes of failure. In many cases of use of new materials, it is observed that although the mode of failure may be well recognized by engineers, the parameters of the newer materials (e.g., thinness, density) may stretch the capabilities of available inspection technology beyond their existing boundary.

Once the failure modes for an inspectable unit are listed, the progression of the accident sequence that each failure mode can initiate is analyzed. Any existing mitigation system or measure that could prevent the progression of the accident is identified. Likelihood and consequence of each accident sequence are estimated. It should be noted that the likelihood factor includes both the frequency of the initiating event (inspectable unit failure) and the probability of failure of any identified mitigation system/measure. The frequency of failure of the inspectable unit depends on the specific degradation mechanism that could cause the failure.

An in-depth analysis of degradation mechanisms and frequencies for all the units within the scope of an RBI program can be very labor-intensive. Therefore, depending on the scope of components within the RBI program, at this stage, it is acceptable to use conservative values for the frequency of failure of each inspectable unit for screening purposes. A more detailed analysis can be performed more efficiently later during the Inspection Plan Development step, once high priority items have been identified using screening estimates.

Once all inspectable units are analyzed and risk estimates for each failure mode are assigned, a prioritized list of the inspectable units can be obtained, which will constitute the input to the next step in the RBI program development.

1. The Risk Assessment Methodology

The choice of risk assessment methodology is highly dependent on several factors such as:

- Whether the installation is a new build or existing asset
- Number of facilities/components/structure items to study
- Available resources
- Complexity of facilities and processes
- Nature and quality of available data
- Purpose of analysis (e.g., to support company policy, to satisfy a regulatory, legal or stakeholder requirement)

Once the above items have been evaluated, the method best suited to the particular scenario may be selected and applied. There are three basic groups of methodologies:

i) Fully qualitative

ii) Fully quantitative

iii) Semi-quantitative

In the fully qualitative approach, competent personnel may make expert judgments or subjective review within a formal evaluation process for assessment of the severity and likelihood of failure of each component under review. This process is usually facilitated by an individual experienced in risk assessment evaluation, thus focusing the study outcomes. Both factors of likelihood and consequence are assessed. A final value for risk is derived through placing the components’ derived likelihood and consequence assessments within a risk matrix, thus delivering a final component risk score or rank. Qualitative analyses normally use descriptive ranges for inputs and outputs that are intended to be broad enough to cover the ranges of uncertainty involved. The most typical use of this technique is for the purpose of “screening” out low risk items for which the time and cost of a quantitative study cannot be justified. As an aid to solicitation of input, it is common to establish pre-defined categories or ranges for likelihood and consequences.

This process has one unique advantage in that all of the strategic personnel who are involved with the daily management of the installation are directly involved in the evaluation process. In fact, best practice is to ensure that such individuals drive the outcome of the risk evaluation, as their knowledge of the installation and potential scenarios that may occur is crucial.

In the fully quantitative method, rather than making use of experience or subjective decision to enumerate risk, quantitative methods use formulas, algorithms, engineering analysis or event modeling to provide a direct numerical value for each factor of consequence and likelihood. While this method has a greater substance (i.e., mathematically calculating risk rather than subjectively evaluating it), it often overlooks the value that is gained from the input offered by experienced operations personnel.

In practice, it is doubtful that any RBI approach could be termed wholly qualitative (without use of any analytical tools) or wholly quantitative (without use of judgment). Almost all approaches are “semi-quantitative”, although some are at the qualitative end of the spectrum while others are at the analytical side. Thus the qualitative and quantitative approaches do not compete with each other, but complement each other. Figure 3.2 illustrates this concept. When utilizing this method, the objective is to get the best of the qualitative and quantitative methods. This combined methodology can often provide for the most favorable and practical results for risk ranking and optimize the time expended on the assessment.

There are certain limitations with quantitative and qualitative methods. For qualitative methods of RBI, the main issue that may undermine the results of the RBI analysis is that this method is largely an expert scoring process. As a result, the outcomes of such a study could be considered to be overly judgmental and wholly reliant on the expertise of the individuals who evaluate the risks. Qualitative analysis can be fairly labor-intensive, but simpler to complete. Qualitative RBI in certain cases may not be fully adequate to accurately evaluate the worst-case as certain key factors, e.g., failure degradation/propagation rates, may have critical importance. By comparison, quantitative analysis in support of RBI programs requires considerable quantities of detailed data and as such can be exceptionally labor- and technologically-intensive. As a result of these factors, choices or compromises are often made, given the realistic economics within which the RBI must be achieved. For this reason, it is usual to perform a first pass qualitative analysis in advance of the quantitative to pre-screen for components where use of quantitative methods would neither be technically appropriate nor cost-effective due to low risk. Table 3.2 outlines various pros and cons associated with the two approaches.

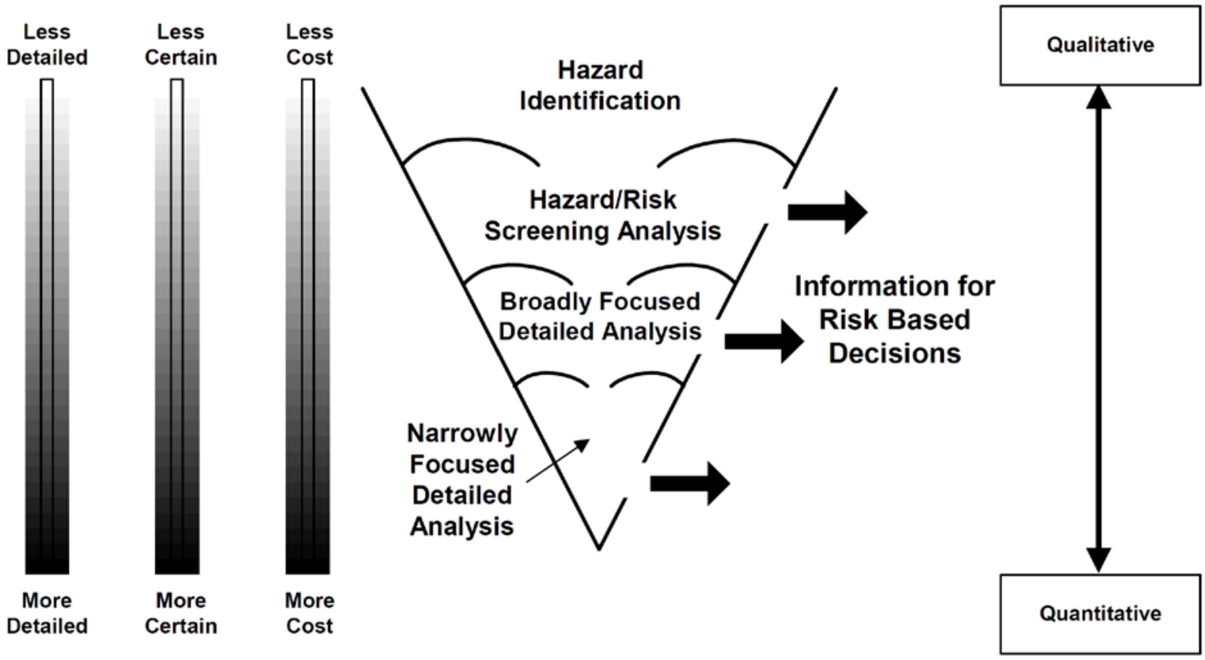


Fig. 3.2. Levels of RBI Analysis

More detailed descriptions of specific risk assessment methodologies to use in the RBI program development can be found in the literature. Appendix 1 gives some references. Appendix 2 provides an overview of some issues related to the likelihood and consequence assessment process.

Table. 3.2. Advantages and Disadvantages of Qualitative and Quantitative Risk Analysis Approaches

Qualitative		*Quantitative*	
Pros	*Cons*	*Pros*	*Cons*
Captures expertise of persons most familiar with facility	Need time commitment from qualified persons	Can generate results based on existing data	Need to determine which models to use and how they will be integrated with each other
Can quickly screen out equipment or structures with no damage mechanisms or with low consequence of failure	May fail to consider all failure mechanisms in all modes of operation, especially combination of failures	Requires less time on part of experts during the analysis	Expensive to build and maintain, may require software support
Can be less costly than quantitative analysis	Results may be difficult to defend to third party	Becomes less costly with experience in use of models	May be high cost on initial studies
Can be faster than quantitative study	Inconsistent results, care must be taken to provide audit trail	Consistent results, auditable, perception of accuracy	Accuracy depends on data availability and accuracy

2. Assessment of Likelihood of Failure

Within RBI, the frequency of a failure or occurrence of an undesirable event is called its likelihood. With respect to the RBI program, likelihood is considered to be the most important factor in the risk equation since it most directly affects the selection of inspection frequency.

Degradation mechanisms and likelihood are intrinsically linked, thus determining mechanisms and degradation rates are essential requirements for RBI. Personnel performing failure mode assessments must be knowledgeable of the potential modes of failure, degradation mechanisms that can cause them and deterioration rates that may be prevalent for each component type or service duty.

Analysis data are available and are utilized in a failure analysis study. Specific analysis of the data using industry-recognized methods, formulas or algorithms must be applied to provide an accurate threat value for each given degradation mechanism. Generic or specific degradation models may also be adopted to predict the remaining safe working life for given components.

As mentioned before, if the scope of components within the RBI program is too large, a detailed analysis of degradation mechanisms could be deferred to a later step. In this case, likelihood estimates at this stage are qualitatively assigned based on expert judgment for screening purposes. The more detailed analysis on degradation mechanisms and frequencies is performed after the screening based on risk prioritization is made, on that subset of components of relatively high-risk.

3. Assessment of Consequence of Failure

Within RBI, consequence is the outcome of the failure of an inspectable unit. This activity is geared towards assessing and differentiating the relative ranking of components in relationship to each other and to their relative consequence were failure to occur. The consequence of failure can be assessed qualitatively or quantitatively. Qualitatively, consequences can be assessed by performing hazard analysis activities such as HAZIDs (Hazard Identification), FMEAs (Failure Mode and Effects Analysis) and functional failure analysis. Within quantitative assessment methods, calculation of consequence estimates are possible utilizing tools such as fire, blast and dispersion modeling or any other accident-modeling tool.

The consequence factor may be scored using several parameters as metrics. The parameters commonly used are the following:

- Safety

- Environment
- Economic

Safety consequences include immediate harm to asset personnel or immediate surrounding public.

Environmental consequences can be defined as damage to immediate ecosystem or landfall. The extent of environmental impact and ultimate rectification costs is directly associated with the consequence of the release or failure of a major system or component. The combination of cleanup costs, regulatory fines and loss of public relations should be evaluated as a factor within the RBI consequence evaluation, as well as the long-term impact on the environment for each release scenario. Relevant information that is needed to determine consequence includes fluid type, phase, release rate, inventory release, toxicity and flammability.

Economic consequences include property protection, damage to or loss of critical capital equipment, production outage or reduced availability of asset system. Equipment availability has a very high influence over the economic factor of the consequence determination. Business interruption is usually the costs that are associated with failures of equipment on an offshore facility. The amounts of downtime and equipment repair are costs that all offshore facilities are trying to reduce. If businesses have an effective inspection plan that helps them reduce shutdown frequency and reduce costly repairs or replacements, this will save the facility large amounts of money.

Consequences may vary significantly, ranging from almost inconsequential to totally catastrophic. It is important to highlight that the evaluation of the consequences for the asset should consider all of its potential modes of operation or states, thus ensuring that the worst consequence scenario has been identified and accounted for.

Through consequence assessment, the lowest ranked items can be partially or fully screened out from the inspection program. This is an acceptable practice, as those items that have negligible consequence, irrespective of their likelihood of failure, do not have a significant impact on the assets' integrity.

It is of value to note that once consequences have been determined for a component or system, these remain relatively static. Only where a major change in the use, service, process parameters or location of the equipment is enacted would the consequence factor change. If and when such change events occur, a reassessment of this factor is required.

An important consideration when identifying the consequences of failures is setting reasonable limits on the extent of the failures assessed. If cascading events are followed, even relatively minor structural failures (e.g., a cracked weld) can lead to significant and even catastrophic consequences. It is more useful to a practical RBI program development to identify realistic failure consequences, as described in the Section 3.D.4 "Potential for Escalation". Some of these limits will be dictated by the failure mode assessed. Corrosion effects are more likely to impact a broad range of components, so it may be appropriate to considering the consequences of combinations of component failures at the same time. Other failure mechanisms, such as mechanical damage, may be more localized, so combinations of a much smaller set of components would be appropriate.

The use or function of the component will also dictate what constitutes failure. A pipe rack serves only to support a set of pipes and resist vertical and lateral loads. Failure of this component would be loss of load carrying capacity. But for a storage tank on a floating system, there is both a load-resistant function and a liquid containment function. Loss of containment may occur long before loss of load-carrying capacity, so the failure of this component is driven by non-structural considerations.

4. Potential for Escalation

Most significant failures that occur in any system or facility are the result of a series of events that build upon each other rather than a single failure point. However, defining the frequency and consequences of these escalations can be difficult. For the purposes of establishing a risk prioritization, it is most useful to consider escalation potential as a modifier once the initial ranking has been determined.

In other words, the definition of likelihood and consequence should be performed for each component and failure mechanism to establish a baseline prioritization. At that point, the results should be reviewed and potential escalation scenarios considered. If serious escalation scenarios exist, modifications may be made to the risk levels. But keep in mind that the likelihood will decrease with each successive event added to the chain (since they all must occur). Ultimately, these escalations may not dramatically change the prioritization since the reduction in likelihood may offset the increased consequences.

Some considerations to make when defining escalation scenarios:

- Are there potential explosion or fire sources that could be triggered by failure of a component?
- Are there proximity issues that would cause one system to fail into a separate one creating a cascading effect?
- Are there dependent systems that would be compromised by the failure of this system or component?

E. Inspection Plan Development

Once a risk-prioritized list of inspectable items is generated as discussed in Section 3.D, those items with higher associated risk should be assessed for potential risk reduction by an appropriately selected inspection strategy. This is the objective of the "Inspection Plan Development" step of the RBI program. The setting of the inspection strategy involves the establishment of the most appropriate inspection methods, scope and frequency. This strategy is aimed to deliver timely inspections that bring valuable information in the form of inspection results. The reduction in component condition uncertainty and increase in predictability of deterioration rates translate directly into a reduction in the likelihood of failure. The inspection strategy must address the following areas:

- Which items are susceptible and where are they located?
- What inspection methods or tools must be adopted in order to deliver the required inspection result?
- How effective are the selected inspection methods at detecting the perceived degradation mechanisms?
- How much inspection is required in order to assure the target inspection effectiveness.
- What frequency of inspection is required for each inspectable unit or component?

When available, the RBI plan should consider and build upon the knowledge gained during baselining and assessment, as discussed in Sections 3.C and 3.D.

1. Degradation Mechanisms and Inspection Methods

Potential failure modes should be estimated before inspection methods are selected. For each failure mode, the potential degradation mechanisms that can cause those failures are identified. The evaluation of such mechanisms should consider the type and rate (time dependency) of degradation that may be likely. Typical degradation mechanisms for offshore structures and process systems include:

- Uniform corrosion
- Localized corrosion
- Galvanic corrosion
- Pitting corrosion
- Crevice corrosion
- Erosion
- Fatigue cracking

- Environmentally induced cracking
- Creep
- High temperature oxidation and metallurgical changes
- Brittle fracture
- Mechanical damage

A preliminary evaluation of the applicable degradation mechanisms and deterioration rates may have been performed during the likelihood estimation in the risk prioritization step. During this step, those evaluations should be reconsidered for the higher risk items, and perhaps a more detailed assessment may be necessary. Once the degradation mechanisms have been accurately assessed, the selection of an inspection method can be successfully achieved.

It is important to consider that there are many inspection techniques and testing methods available to accurately assess component integrity. Table 3.3 provides a listing of inspection methods available to assess common degradation mechanisms. Some methods available do have inherent limitations that may impair at least the accuracy of reported results. Many inspection methods are subjective and as such provide an assessment tool rather than a quantification tool (e.g., visual inspection can only provide a qualitative assessment of the condition of the component), whereas NDT methods provide values in the form of thickness values or crack dimensions (length/depth). Even with NDT methods, an error band on the measured values exists and must be recognized and accounted for. The level of error for some NDT methods is often directly associated with the level of cleaning and preparation performed prior to the recording of the resultant value for degradation. This may be a problem if not managed by procedures, and could lead to an under -or over- prediction of the integrity, which in turn may impact inspection intervals.

RBI uses the same types of inspection techniques as traditional inspection planning methods, the main difference being the prioritizations applied and the feedback of results into future plans. As with all inspection plans, RBI requires the use of appropriate inspection technology performed by competent practitioners. Each type of inspection has its limitations and these should be accounted for within the RBI program. Typical types of inspections for either offshore structural components or pressure system components include:

- External Visual
- Internal Visual
- External Gauging
- Internal Gauging
- Flaw Detection
- Material Characterization

The level of confidence gained from the results of an inspection is an important factor for RBI and all steps available to improve the effectiveness of an inspection should be taken. This would include preparation of the component and provision of a safe working environment for the inspector.

Table 3.4 describes inspection conditions that may affect confidence of inspection results for typical inspection methods.

1.1. Visual Inspections

Visual inspections are useful for determining the basic overall condition of a component and whether surface deterioration of a component is present. Close visual inspections require the inspector to be within touching distance of the component under investigation. For a general visual inspection, the operator may require to be only within the vicinity of the item. Close visual inspection will provide for more accurate assessment of a component’s condition than would a general visual assessment. Where visual results indicate a potential problem, it is common to confirm the visual finding with additional inspection methods.

1.2. Thickness Gauging

Thickness gauging of components is a useful method for determining the remaining thickness of plate or pipe components. This can be used to either confirm the results of external corrosion events or to assess internal/opposite side corrosion. When thickness gauging is performed from the opposite side of the surface of interest, this can provide less confidence than gauging from the side that has the corrosion evident, as interpretation of the result by the UT operator is required rather than physically witnessing the corroded area.

Where accessible or where eventual repair of a component is carried out (those inspected by NDT methods), it is good practice to physically measure and document the extent of the defects observable via direct measurement. This method will not only allow a 'calibration' of the effectiveness and accuracy of the NDT methods utilized for inspection, but will also provide data that may be used to calculate confidence factors for the inspections.

1.3. Flaw Detection

In many instances, flaw detection methods are often used as a secondary check inspection for anomalies identified using visual or gauging methods. Flaw detection methods are also applicable as a primary method that may be used in preference over VT or UT, specifically where cracking failure may be the issue. Eddy current techniques provide a rapid tool for the detection of even small cracks and prove useful for in-situ inspections, as no removal of coating systems is required to perform the inspection. Where the results of such eddy current inspections identify potential cracks, flaw detection methods such as MPI are often used to confirm the finding of a crack. See Section 4.E.2 for specific guidance on usage of Eddy current techniques.

1.4. Confirmation and Confidence

In general, it is particularly valuable to reconfirm the results of one inspection method by application of a second test method (use of alternative NDT method as a check). This is especially important where anomalous conditions are observed and reported. By applying this secondary check, increased levels of confidence that the inspection program and methods selected are proving successful will be established.

2. Scope of Inspection (Sample Population Size, Location and Extent of Inspection)

This topic in the inspection plan development addresses the questions of where to inspect and how much to inspect. These elements together are largely driven by the likelihood assessment.

It must be recognized that the likelihood of loss of integrity increases as the number of components affected by the same degradation mechanism increases. Risk is observed to increase as inspectable units degrade. As likelihood is time-dependant, older and more frequently used systems generally are more likely to fail.

2.1. Sample Population Size and its Relationship to Degradation Mechanisms

The target for the setting of inspection scope is to measure the levels of activity for the degradation processes. The sample population size (number of test locations) that is selected should reflect the nature and type of degradation under investigation. An example of this may be where overall uniform corrosion is identified as the likely cause of failure of a system. In this scenario, the factors that govern where and how much to inspect are less complicated than with other degradation scenarios where isolated failure would be the main feature. For a uniform corrosion example, failure of any given part of the inspectable unit should (in theory) be as likely as any of the other locations. Uniformity of degradation may allow the inspection engineer to be less specific and focused when considering where and how much of the system requires inspection. This method would provide an answer to the basic question "is the degradation present"? Where a measurement of degradation rate is required, the sample population (number of test points) must be large enough to be collectively representative. Although one or two test point and results may well answer the questions as to whether uniform corrosion is present, this sample population size would be too small to accurately define a corrosion rate. Ideally, the sample inspection must be of a sufficient size and population spread to accurately reflect the system make-up as a whole, both geometrically (i.e., for piping systems, this would cover all of the different types of piping geometric features such as ‘tees’, ‘bends’, ‘reducers’ as well as straight line pipe) and as representative of the size of the system (i.e., a more extensive piping system requires a larger number of tests than a smaller system). Consideration must be given to the possibility that no other deterioration mechanism, such as erosion, may be influencing the outcome of the inspections. Were such a case encountered, then the inspection plan should be modified in recognition of this influence and the scope be modified to investigate a combined failure scenario.

Localized isolated or dispersed (non-uniform) degradation mechanisms, as exemplified by pitting events or cracking, are more complicated to assess and would more likely require a much greater sampling population, increased spread and density of test locations across the system in order to effectively assess for them.

Table. 3.3. Degradation Mechanisms, Causes and Inspection Methods

Degradation Mechanism	*Causes*	*Inspection Methods*
Uniform and localized corrosion	Exposure to corrosive material such as mineral or carbonic acids or aqueous environments, seawater and humid or condensing environments. Damage can be localized over an area and is accelerated by exposure to alternating wet/dry conditions, increases in corrosive specie concentration, temperature, oxygen content of the fluid and the large cathodic/anodic surface area ratios in contact with the fluid.	Visual Inspection (VT), direct measurement (DM) and Ultrasonic Testing (UT)
Pitting	Exposure to corrosive material such as mineral or carbonic acids or aqueous environments, seawater and humid or condensing environments. Damage can be localized over an area or uniform distributed surface in contact with the aqueous phase. Corrosion rates can be much higher than uniform or localized corrosion.	VT, DM
Crevice corrosion	Electrochemical concentration cell set up associated in crevice areas with stagnant aqueous phase fluids, such as under sludge, sand, biological materials or corrosion products, failed coatings, gasket surfaces, bolt heads and riveted lap joints. Damage is usually found within the crevice area.	VT and DM
Erosion	High fluid velocity in piping or impingement on a surface, accelerated by solids in the stream	VT, UT and Radiography Testing (RT)
Fatigue cracking	Cyclic loading coupled with an initiating location caused by a stress riser, weld defect, arc strike, mechanical, corrosion damage or environmentally-induced cracking	Surface flaw detection, UT flaw methods, RT
Environmentally induced cracking	Exposure to specific agents that cause environmentally-induced cracking such as caustic and aqueous phases with hydrogen sulfide	Surface flaw detection, UT flaw methods, RT
Creep	Temperature exposure coupled with appropriate stress damage is exposure time dependent, for most steels short term exposure generally above 1200°F is of concern	VT and DM
High temperature oxidation and Metallurgical Changes	Prolonged temperature exposure generally above 1000°F, damage is exposure time dependent, or rapid cooling from above 1300°F in a fire situation.	VT, DM and metallographically, PMI
Brittle Fracture	Low temperature exposure and appropriate stress condition, either applied or from thermal stresses. Enhanced by internal or external defect.	None, inherent property of material, enhanced by external and internal defects
Mechanical damage	Impact or abrasive loading	VT, RT

Table. 3.4. Inspection Types, Techniques and Factors Affecting Confidence

Type of Inspection	*Inspection Method*	*Inspection Conditions Affecting Confidence of the Results*
External Visual	Visual Technique (VT)	VT: Surface condition, lighting and close access to surface
Internal Visual	Visual Technique (VT)	VT: Surface condition, lighting and close access surface
External Gauging	Visual Technique (VT) Ultrasonic Technique (UT) Radiographic Technique (RT)	VT: Thickness of reference surface for pit gauging UT: Surface preparation and surface condition relative to transducer diameter. Component temperature and metal composition. RT: Access to both sides and relative position of source and film
Internal Gauging	Visual Technique (VT) Ultrasonic Technique (UT)	VT: Thickness of reference surface for pit gauging UT: Surface preparation and surface condition relative to transducer diameter. Component temperature and metal composition
Flaw Detection	Ultrasonic Technique (UT) Radiographic Technique (RT) Surface Flaw Detection: Liquid Penetrant Magnetic Particle Eddy Current	UT: Surface preparation and surface condition relative to transducer diameter. Access to location relative to beam path. Component temperature and metal composition RT: Access to both sides and relative position of source and film. Material thickness and film resolution. Surface Indication Techniques: correct surface preparation for method
Material Characterization	Positive Material Identification (PMI) In-Place Metallography	Access to surface

2.2. Test Point Location Selection

The degradation mechanism will dictate the locations to inspect. However, sampling of common features within the inspectable unit is a proven consideration for inspection location selection.

All of the major surfaces of the component may be targeted for inspection, as are other features. These may include:

- Weld seams and heat-affected zones
- Connections to piping or adjacent structural members
- Process internals, phase boundaries
- Vapor spaces
- Internal structural members
- Heat-affected zones from weldments attached to the component surface (e.g., welded pipe supports)
- Stagnant and low flow areas
- Areas subject to impingement

When available, knowledge gained from baselining and fitness for service assessment (Sections 3.C. and 3.D.) will allow the inspection plan to focus on the areas known historically or through analysis to be prone to failure or degradation.

2.3. Extent of the Inspection

The extent of the inspection identifies how much, in terms of surface area, is required to be inspected for each given component. For smaller components, this may involve inspecting the whole component. For larger components such as pressure vessels or large structural components, this may be restricted to smaller representative areas often known as ‘grids’ or to localized areas that are at risk from degradation (e.g., the upper area of a web frame uniquely exposed to atmospheric interaction).

Often complex or multiple degradation effects may be observed. In such cases, the areas to be inspected for these larger components must be wholly representative of the service duty seen by the whole component (e.g., for a process separator, there may be three distinct process phases: a wet gas phase, and oil phase and a produced water phase, all within the one pressure vessel). With this example, risk from failure for each of these phases may be very different in value, but all three potential risks should be addressed within the inspection program. Degradation to a point of failure and loss of containment within any of the phase areas of the pressure vessel will likely produce an unacceptable consequence.

3. Frequency of Inspection

Inspection frequency is the time interval between planned inspections. The inspection frequency to be selected, in general, is directly related to the identified degradation rate and the determined condition of components following each inspection.

Inspection frequencies set by the initial RBI plan must have a realistic time period that ensures adequate inspections are performed to assess the ongoing integrity of the components and produce reliable measurements for degradation rates. The initial inspection frequency set by the RBI plan is likely to be more conservative than those that may ultimately be achieved. In general, and specifically for high-risk items, these initial frequencies should reflect the typical intervals that are presently established within existing industry codes and standards commonly in use. These frequencies are likely to remain a feature of the RBI until the factors predicted by the RBI such as trends for degradation and rates are recognizable. Once validated, the RBI plan may provide for optimization of frequencies, as discussed in Section 3.G, “Analysis of Inspection Results” and Section 3.H, “RBI Program Updating”.

The inspection interval, in terms of an RBI, is the time span for estimating the likelihood of an undesirable consequence or condition occurring based on the component’s current condition and degradation rate. The inspection interval should be planned for the component reaching a damage condition, rather than failure, which permits development of mitigation options in which the timeliness and scope can be evaluated with risk assessment tools.

Several methods or concerns are listed below that may establish inspection plan interval or change a planned inspection interval:

- Default maximum intervals in industry-accepted inspection codes.
- Corrosion rate or condition-based to an appropriate technical evaluation condition.
- Probabilistic methods based on variations in degradation rates and in loads to an appropriate technical evaluation condition.
- Fixed time schedule for condition, to meet jurisdictional requirements, or to meet a sequential inspection sampling plan (a different component every inspection so all components are inspected over the life of the asset).
- Run to failure (no interval).
- In response to an extreme event or the presence of an overt condition below the technical evaluation condition.

Changes in process conditions or load-state, such as increased temperature and or the advent of persist cyclic loading

4. Compiling the Inspection Plan

Compilation of the overall RBI plan itself is the final step/deliverable task within the development of the RBI Plan Development step. With all of the elements now established and quantified, this task is achieved by distilling them into a format or framework that constitutes a recognizable plan. This plan should clearly set out where, when, what and how the asset will be inspected.

The plan should be organized in a logical fashion based on identified inspectable units so that it is easily understandable and easily applied, and must clearly identify the associated risk analysis.

F. Inspection Execution

RBI not only attempts to ensure that systems are inspected in a risk-prioritized manner, but also seeks to ensure that the data gathered during inspections may be utilized to the maximum benefit, thus assuring the highest level of ongoing integrity for the asset. The effective and efficient execution of the inspection plan is a prerequisite for a successful RBI. The inspections themselves are one of the primary data gathering sources of an RBI program and the results of each inspection has a significant impact on both the perceived integrity of the asset and the accuracy of the RBI program updating. If the execution of the inspection fails to deliver quality results, then a resultant negative impact on the RBI will ensue. This alone will cause the RBI process to fail, regardless of the quality of the RBI assessments and inspection planning processes employed. The success or failure of the whole RBI program largely hinges on this particular activity. If inaccurate, spurious or incomplete results are the outcome of inspections, it follows that subsequent analysis, assessment of integrity and the updating of the RBI program will be flawed and may place the asset, its personnel and the environment in jeopardy. Measures to ensure that the inspection execution occurs in a controlled manner must be devised as part of the RBI program development. These measures must be introduced prior to implementation of the inspections. Furthermore, a method of ‘change management’ must be evident to ensure that if deviations to the initial plan are required, they will not detract from the overall objective of the RBI program.

1. Controlling the Inspection Execution

There are many areas where application of simple control mechanisms can ensure a successful outcome of inspections and collection of accurate and comparable inspection data. These may include:

- Forward preparation of clear and concise inspection work scope
- Clear inspection control procedures that should be followed
- Standardization of reporting formats
- Use of qualified and competent personnel
- Use of quality inspection equipment with controlled calibration
- Clear anomaly acceptance criteria and reporting mechanisms
- Clear change management processes that allows flexibility to respond to findings on a real time basis
- Responsibilities matrix with appointed roles
- Clear safety guidelines and policies

One commonly employed method of exerting improved control over the inspection program is to compile and issue the planned inspection work scope as a formal inspection workbook. This workbook is then issued to the inspection technicians who will enact the inspections. The workbook format should be designed in a way that is easy to understand and follow, and should be self- contained. Included within should be copies of all of the necessary information such as drawings, procedures, test locations, inspection methods, reporting sheets, calibration logs and required anomaly reporting forms. This workbook acts as the inspection instruction, specifying the goals set for the inspection program and how to affect the program in the safest, controlled manner.

This workbook should fully reflect the inspections as dictated by the plan and it is essential that this program should be followed in full.

There may be instances that require deviation from the initial planned work scope, i.e., where results of inspection dictate a change in emphasis, such as severe anomalies or unexpected findings. In such a case, the developed inspection execution workbook should have sufficient flexibility and provide instructions as to allow for further inspection to assess the condition of such defective components. However, where such deviations occur, the method specified must be to the same standard of quality and control as those applied to the initial work scope. If such anomaly-driven events occur, these additional activities should not be at the expense of cutting short the original inspection plan. It is essential that once these unplanned anomaly assessment inspections are completed, the inspection plan should return to the original RBI inspection scope. Any additional inspections performed in support of anomalies must be captured and documented after they are completed and fed back into the RBI update process. This activity will ensure that 'lessons learned' are utilized.

G. Analysis of Inspection Results

Once inspection activities for a given set of components is complete, a review must take place to determine whether any action is required to address anomalies, revisit assumptions on degradations and modify future inspection frequencies, methods or scope.

1. Anomalies

Anomalous data are of immediate concern since they may represent a deficient condition outside of the normal operating boundaries or the acceptable integrity level. Assessments must be made to determine what action may be appropriate. Actions may include:

- Re-inspection to resolve data capture, measurement or input errors
- Additional inspections including broader coverage and possibly more invasive techniques to refine the scope of the anomalous condition
- Technical analysis of the system or component to determine its suitability for continued service
- Design of repairs to restore the system or component to safe operation
- Modification of the RBI plan to include increased inspection intensity (scope and frequency) of the component

Once the anomalous condition has been resolved, the the RBI plan should be updated. Similar components should be reviewed for susceptibility to the same anomaly, inspection frequencies may need to be modified, and operational changes may be appropriate to reduce the likelihood of future occurrences.

Sometimes, more sophisticated analysis methods are required to evaluate severe anomalies. The selection of which method to apply will vary on a case by case basis. The analysis method to be applied will usually be specific to the type and nature of the defect under evaluation. Software and engineering tools such as fracture mechanics (FM), finite element modeling (FE), corrosion modeling/prediction (CM), fitness for service assessments (FFS), spectral fatigue (SF) and dynamic loading assessment (DLA) are all acceptable methods that may be applied. The above range of analysis tools, although not comprehensive, would likely cover most deterioration mechanisms encountered within offshore oil and gas production.

2. Trending of Results

One important function of a sustaining RBI program is to identify and make use of observed trends. This is particularly useful for degradation mechanisms such as corrosion and fatigue. The following considerations should be made when analyzing the trending information:

- How do these trends compare to previous inspections of the same components?
- How do these trends compare to like systems or components?
- Are degradation mechanisms proceeding more quickly or more slowly than anticipated?
- Are damage mechanisms occurring that were not part of the original RBI program development?

Opportunities to review this trending information should be identified in the RBI program and should occur at regular intervals. This should occur after each inspection is completed.

The methods by which data may be processed prior to investigation of trends should be considered. In many cases, pre-processing data such as averaging of values may be detrimental and may effectively mask otherwise observable trends. Caution should be applied when other than raw values are analyzed or trended.

H. RBI Program Updating

In order to be an effective risk management program, the RBI program must be dynamic. A continuous feedback to improve the program will increase the confidence levels in the condition of the installation and the RBI effectiveness.

Because the data around which the RBI is based changes over time, the RBI program should be updated periodically and at relevant stages in the life of the installation. The updating may include the risk assessment, risk ranking and inspection plan. Consideration of increased inspection history, observed industry advances/knowledge and experienced trends for degradation will add value to the updating process.

Examples of changes to be considered to the RBI program are:

- Revised prioritization of the risk-based on frequency changes or additional failure mechanisms
- Revised or different inspection techniques to increase confidence in results
- Revised inspection frequency and/or scope

The RBI program must include a structured and documented process to incorporate new experience and improved knowledge into their risk assessment, risk prioritization and inspection plan. Such a process should state conditions where a revision and update of parts of the RBI program are warranted. Changes or events that should explicitly be indicated as triggers for a revision of the RBI program may include:

- Operational events such as excursions above maximum parameters
- Improved inspection and integrity knowledge
- Unanticipated degradation rates or increased failures

1. Operational Events

Events or changes in the operation of the installation (even very small ones) can have significant consequences in the integrity of an RBI covered item. One example may be where previously unused equipment such as chemical injection is brought into service without consideration of the impact on the RBI program. In this case, possible localized failure threat may be introduced without identifying this new potential failure within the RBI. Significant events or changes to the operation of an installation that would likely warrant a review of the risk assessment and/or RBI program may include:

- Significant process or operational upsets
- Movement of phase boundaries for process systems (e.g., loss of dew point control)
- Failure of a component within an equipment or system
- Changes in parameters of operations and type of fluids
- Changes in process chemistry
- Changes in the level of experience and knowledge of operators

If the installation does not have a formal program for managing change (i.e., review and approval of the change, as well as communication of the change to all parties that may be impacted), the RBI team should introduce measures to ensure that change processes are managed within the RBI program.

2. Improved Inspection and Integrity Knowledge

All acquired knowledge with respect to the integrity of the components (i.e., degradation mechanisms, results of inspection, repairs, new technology) should be incorporated in the RBI Program in order to review and revalidate the assumptions. This may be acquired from inspections, repairs and through published industry sources. Events that may justify re-assessment of the RBI program include:

- Unanticipated degradation or failure mechanisms
- Results from anomaly assessment and data trending
- Increased or decreased degradation rates for anticipated failure mechanisms
- Repairs/modifications/replacements or other mitigation actions taken as a result of inspection
- New inspection technology
- Updated information gathered from industry databases

Decisions to change inspection frequencies will be highly dependent on several aspects of the degradation mechanisms. These include:

- Specific characteristics of the deterioration mechanism
- Inspection methods employed
- Time dependency of failure

In many cases, the justification to elongate the interval between inspections may be easy to justify, but for some degradation mechanisms, caution must be used prior to resetting.

In the case where corrosion of a component is the dominant factor in the likelihood of failure, positive evidence that the corrosion observed is not as severe as that initially perceived may be easy to gather and substantiate. In this case, actual correlation and trending may be established and modified frequencies can be calculated and implemented.

For other mechanisms of failure, evidence of the deterioration may not be detectable or verifiable until some critical point within the deterioration process' profile has been reached. Such scenarios are exemplified by fatigue and 'work/service hardening' deterioration mechanisms. In these cases, crack propagation within a component may be occurring without obvious indication. Only where the surface-breaking phase of the crack is reached will the crack be recognizable. This is especially relevant where the inspection methods selected (such as visual or MPI) rely on this feature. In such a case, changing the inspection frequency would be unwise until the predicted time to failure is confidently established.

In all cases, the setting of inspection frequencies must be performed in a responsible manner and ensure that systems assessed as having undesirable consequences will not face imminent potential failure. All changes to the RBI frequencies (other than minor changes for low risk systems) would require being processed within a change management procedure and may ultimately require validation.

3. Unanticipated failures

Upon occurrence of unanticipated failures, an investigation should be undertaken to ensure any lessons that may be learned can be gathered. Even where the failure does not impact on safety, business or the environment, it should be investigated. The root causes of many major accidents that have occurred in the offshore industry usually were preceded by smaller or indicative incidents. Significant damage could be prevented if these smaller incidents are investigated and lessons learned implemented.

Section 4

RBI Program Approval and Classification Activities

A. General

RBI plans are subject to the BKI approval upon a demonstration that the overall criteria for safety and strength standards of the Rules and Guides are maintained. While various techniques/methods may be applied, the suitability and appropriateness of any selected method will be determined by the BKI. If the methodology used deviates from common industry practice and standards, a suitable technical explanation on the adequacy of the methodology should be included with the submittal for BKI consideration and approval.

The following are procedures and conditions under which a properly conducted RBI program may be initially approved and subsequently credited as satisfying the requirements of a Continuous Class Renewal Survey program.

B. Program Requirements

For an RBI plan in lieu of a conventional Continuous Class Renewal Survey to be accepted for implementation, the following conditions must be met:

1. Approach

The RBI program must address all deterioration mechanisms present in the structure or system to be covered by the RBI plan. Both the likelihood and the consequence of the damage are to be considered under all applicable operating conditions. The extent of damage must be anticipated under all operating conditions, including operational transients, severe weather conditions or other extreme loading.

2. Implementation for Existing Units

There is no limit on the age of an installation when entered into the program. However, an existing installation applying for entrance into the program will be subject to a review of the installation’s records to ascertain the historical performance of the equipment and structure that could affect the RBI plan. Provided there are no historical problems related to the inspection and performance of the equipment and structures, and further provided that there is a baseline condition report of all items verified by the Surveyor, the installation will be considered eligible. This baseline condition and any trends derived thereof shall be utilized in the setting up of the RBI Plan.

3. Site Specific Information

Where RBI is to be adopted on a Floating Installation, the risk assessment upon which the inspection and maintenance plan is based is to be site-specific and shall incorporate all potential hazards associated with that particular location. If for any installation, the installation is to be relocated, the risk assessment is to be reviewed and updated as deemed necessary by the Owner and resubmitted to BKI for approval. Data used for corrosion rates due to process fluids, severity of fatigue loads and other types of damage are to be gathered from the same installation for which the RBI plan is being developed. Consideration will be given to data from similar installations producing from the same field, provided the applicability of the data can be demonstrated.

4. Survey Status

Surveys related to the installation are to be up-to-date, without outstanding recommendations that would affect the RBI plan. For equipment or structure for which an outstanding recommendation exists, confirmation is to be made that repairs have been performed.

Only equipment and structures subject to Continuous Class Renewal Survey are to be included in the program (unless consideration of non-essential equipment and structures is specifically requested by the Owner). Any equipment and structure items not covered by the RBI plan are to be surveyed and credited in accordance with Surveys after construction contained in pertinent the Rule/Guide for that equipment or structure.

5. Inspection Scope and Frequency

This Guidance considers inspections to be carried out on the basis of intervals recommended by manufacturers, documented operator's experience or an inspection and testing plan developed in accordance with this Guidance. In general, the scope and intervals for the RBI plan need not exceed those specified for Continuous Class Renewal Survey. However, if an approved program of installation specific testing, monitoring and measuring damage and damage rates is in effect and has been validated through observation, the survey scope and intervals based on the Continuous Class Renewal Survey cycle period may be modified.

6. Computerized System

A computerized system for performing calculations (e.g., remaining life, inspection intervals) and maintaining records related to the RBI plan and inspections is recommended, but not required. However, the ability to perform trending and calculations as new data is collected and to apply this to RBI plan updates is required. If the software utilized is not widely used in the industry, BKI may require submitting more detailed information about the software package.

7. Implementation Survey

The implementation survey is to be carried out by the attending Surveyor within one year from the date of the letter approving the RBI plan, as issued by the responsible BKI Head Office. The Surveyor is to verify the following:

i) The RBI plan is implemented according to the approval documentation.

ii) The RBI plan is producing the documentation required for the Annual Confirmation Survey and the requirements of surveys and testing for retention of class in accordance with the approved plan are complied with.

iii) The onboard personnel responsible for inspection, maintenance and repairs (IMR) are familiar with the RBI plan.

When this survey is carried out and the implementation found to be in order, a report confirming the implementation of the RBI plan is to be submitted by the attending Surveyor to BKI, and the plan may be put into service.

8. Cancellation of Program

The survey arrangement for equipment and structures under the RBI plan may be cancelled by the Bureau if it has been deemed by the Surveyor in attendance for the Annual Confirmation Survey that the program is not being satisfactorily carried out. Evidence of such deficiencies can be gathered either from the maintenance records or the general condition of the equipment and structures, or when the approved intervals between inspections per the RBI plan are exceeded. Sale or change of management of vessel or transfer of class is to be cause for reconsideration of the approval.

The Owner may at any time cancel the arrangement for equipment and structures maintained under the RBI plan by informing the BKI in writing. In this case, items which have been inspected under the program since the last Annual Confirmatory Survey may be credited for class at the discretion of the Surveyor.

9. Coastal and Flag States Requirements

The application of this Guidance does not cover any statutory survey requirements that may apply to the installation being considered (e.g., MODU code, SOLAS, MARPOL, coastal state regulations, etc.)

Although BKI is authorized to perform statutory surveys on behalf of some authorities (MIGAS), BKI is not in a position to alter or waive them. The cognizant administration or regulatory body is the final determining body for statutory or regulatory requirements under their jurisdiction. The Owner shall ensure that in developing the RBI plan, due consideration is given to Coastal and Flag State requirements.

10. Damage, Failures and Repairs

All damage to components is to be reported to the BKI. Repairs of such damaged components under the RBI Plan are to be carried out to the satisfaction of the Surveyor in accordance with D.1 dan D.2

Any repair and corrective action regarding components under the RBI Plan is to be recorded and the repair verified by the attending Surveyor at the Annual Confirmation Survey.

C. Submission Requirements

Documentation outlined in Section 4.C.1 and 4.C.2 below shall be submitted to the BKI Head Office for approval.

1. Program Description Submittal

A description of the approach and methodology to be used for development and implementation of the RBI program is to be submitted for review prior to detailed work being carried out. The following to be included:

i) A brief description of the overall RBI methodology to be used and components to be covered.

ii) The RBI team make-up by areas of expertise.

iii) The basis and methodology employed in the grouping and risk-based prioritization of inspectable units.

iv) The means to establish the baseline condition for existing units, including how existing inspection data (if any) would be assessed and validated as meaningful for the RBI plan.

v) Rationale to be used in order to establish inspection plans, including consideration of specific degradation mechanism.

vi) The technique to be used to update and modify inspection plans.

2. Program Results Submittal

For RBI Programs developed with distinct phases, it is recommended, though not required, that submittals be made for each completed phase. This will allow for BKI feedback during the development phase. The minimum information to be submitted includes the following:

i) A list and description of the components covered by the Program.

ii) Results of risk-based prioritization with supporting analysis justification.

iii) Degradation models applied

iv) Scheme for the development and updating of the inspection plan, including method, scope and frequency of inspection.

v) Organization chart identifying areas of responsibility for inspections and scheme for validation of qualifications of those responsible.

vi) The schedule of inspections, i.e., RBI plan, clearly identifying those components and tasks that will be carried out by the Owner, and those which require attendance by the Surveyor as per 4.E, Special Conditions.

vii) Description of the work to be performed at each inspection for all components covered by the program, including the procedure for corrective actions following identified deficiencies.

viii) Plan update and record keeping procedures (or database software description).

D. In Service Maintenance and Updating of RBI Plan

1. Annual Confirmation Survey of RBI Program

Simultaneously with each Annual Survey required by Surveys After Construction contained in the pertinent Rule/Guide for the equipment or structure, an Annual RBI Confirmation Survey is to be performed by the attending Surveyor. The purpose of this survey is to perform random spot-checking of the plan execution and to verify that the program is being correctly operated and that equipment and structures covered by the RBI plan have been functioning satisfactorily since the previous survey.

The survey is to include the following:

i) A general examination of the items covered by the RBI Plan is to be carried out.

ii) The Surveyor is to review the RBI plan documentation and records, including:

- Verification of inspector qualification scheme
- The complete description of inspections completed since the last Confirmation Survey, including inspection sheet(s)/record(s), and exceptions, notes and comments noted during inspection
- Modifications to the RBI plan, if any, with justification of the change as supported by inspection data and the RBI methodology subject to the approval of the appropriate BKI Head Office and verification by attending the Surveyor (see Section 4.D.2 below)

iii) The records are to be examined to verify that the equipment and structures have functioned satisfactorily since the previous survey or action has been taken to correct deficiencies.

iv) Written details of breakdown or malfunction are to be made available.

v) Description of repairs carried out is to be examined. Any component which has been replaced due to damage is to be retained onboard, where possible, until examined by a Surveyor.

vi) At the discretion of the Surveyor, function tests, confirmatory surveys and random check readings, such as gauging, are to be carried out as far as practicable and reasonable.

Upon satisfactory completion of the above requirements, the Bureau will accept the RBI program for its continued use.

2. Review of Plan Updates

In most instances, as data is collected during the plan execution, initial assumptions and estimations regarding damage rates will either be validated or changed. This information must feed back into the plan. The updating of information may result in changes to the scope and frequency of the original approved plan. BKI will require the plan update to undergo a review (see Section 4.C.2). Data to be submitted covering the plan update should include the following:

i) New updated data for corrosion rates, fatigue severity and other applicable degradation mechanisms.

ii) The procedures and calculations used to update and modify inspection plans.

iii) Revised schedule of inspections, if necessary.

iv) Revised description of the work to be performed at each inspection for all components covered by the program, if necessary.

E. Special Conditions

1. BKI Surveyor Attendance

The Surveyor is required to attend for examinations of underwater items and internal examination, gauging and non-destructive testing for the hull structure and mooring systems.

In addition, the Surveyor is to attend representative inspections of high risk ranked components.

2. Usage of Eddy Current and ACFM techniques

Eddy-Current and Alternating Current Field Measurement (ACFM) technique for nondestructive examination of welds may be employed, provided it is conducted in association with the following comments:

i) The equipment to be used when conducting eddy-current examination is to be of the cross- coil type.

ii) The written inspection procedure is to be presented to the attending Surveyor prior to commencing the inspection.

iii) All equipment and calibration standards are to be supplied with appropriate serial numbers (for traceability and reproducibility). The calibration standards should be constructed from material similar to the material to be tested.

iv) The eddy-current technician is to demonstrate to the attending Surveyor proper calibration and operation of the equipment as stated in the above noted written procedure.

v) 10% of the areas subjected to eddy-current or ACFM examination are to be backed-up by magnetic particle inspection.

For areas found to have defects or suspect readings, the Surveyor may consider that these areas are backed-up by magnetic particle inspection.

Appendix A

References

1 Risk Assessment Techniques

1. *Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries*.
2. Government Institutes/ABS Consulting. *Marine Safety Tools for Risk-Based Decision Making*. 2002. Rockville, MD.
3. Center for Chemical Process Safety. *Guidelines for Chemical Process Quantitative Risk Analysis, Second Edition.*2000. New York, NY
4. Center for Chemical Process Safety. *Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples.* 1992. New York, NY
5. Center for Chemical Process Safety. *Guidelines for Process Equipment Reliability Data.*1989. New York, NY
6. Center for Chemical Process Safety. *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs.* 1994. New York, NY

2 Risk-Based Inspection

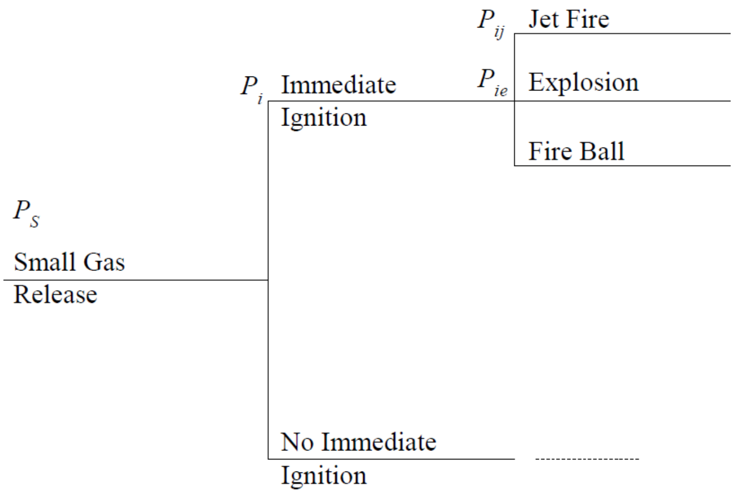
1. American Petroleum Institute. *Risk-Based Inspection*, API Recommended Practice 580. January 2001.
2. American Petroleum Institute. *Risk-Based Inspection Base Resource Document,* API Publication 581. May 2000.
3. UK Health & Safety Executive. *Best Practice for Risk-Based Inspection as a Part of Plant Integrity Management*. Contract Research Report 363/2001.
4. The American Society of Mechanical Engineers. *Risk-Based Inspection – Development of Guidelines*, Vol. 1, General Document, CRTD, Vol. 20-1, 1991.
5. The American Society of Mechanical Engineers. *Risk-Based Methods for Equipment Life Management: A Step-by-Step Instruction Manual with Sample Applications*, 2003.

Appendix B

Risk Assessment for Process Systems

1. Assessing Process Accident Scenarios

In RBI, the objective is to control risks associated with some type of deterioration, such as metal loss due to corrosion. But before consequences and risk can be evaluated, a specific *event* must be described. Risk is the measure of expected loss at some frequency. The event is how the loss occurs. It is common in risk assessment to describe the consequences of a leak as initiating with the leak itself, which produces a chain of events that may or may not lead to fire or explosion, along with the "ultimate" consequences of injuries, equipment or structural damage and business loss. Figure B.1 and B.2 are examples of *event trees* that are used to show the chain of events starting with the initiating event and ending in a final event, usually called the *end state*.

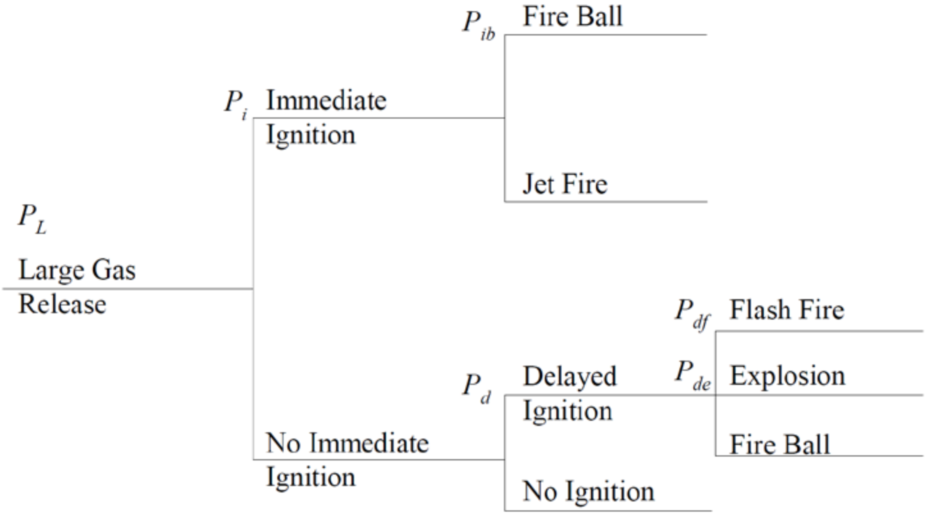


P_S – Probability of a small hole (small leak)	P_i – Probability of immediate ignition
P_{ie} – Probability of an explosion	P_{ij} – Probability of a jet fire

Fig. B.1. Example Event Tree for a Small Gas Release

Note that there are many possible end states than can result from an initiating event. Each end state has a unique likelihood of occurrence that depends on the frequency of each of the initiating events and the probability of *intermediate events* that lead to that particular end state. The above event trees are much simplified from a "real world" case where other intermediate events can occur. For example, there is the early detection of the leak, the activation of water sprays, the activation of an emergency isolation and blowdown system, each with its own probability of occurring or failing to occur. The event tree could also be extended to other end states resulting from escalation and evacuation.

The entire set of events beginning at the initiating event and ending at a specific end state is called a *scenario*. For special applications such as RBI, it is common to refer to the risk of a collection of scenarios. For example, if the risk of a corrosion-induced leak is to be determined, then all of the scenarios that can occur from all leak sizes are needed to fully describe the risk. The risk of the individual scenarios can be summed to determine the total risk. It is common practice in RBI to speak of the risk of a pipe or the risk of a structural member as a short hand expression, but the scenarios that compose that risk should be kept in mind and understood. One by-product of the use of RBI is the identification of intermediate events that offer potential for risk reduction by reducing the likelihood or consequence of one or more end states, such as gas detectors that automatically trip the emergency shutdown system and close all isolation valves.



P_L – Probability of a large hole (large leak)	P_i – Probability of immediate ignition
P_{ib} – Probability of a fire ball	
P_d – Probability of delayed ignition	P_{df} – Probability of a flash fire
P_{de} – Probability of an explosion	

Fig. B.2. Example Event tree for a Large Gas Release

2. Consequence Assessment for Process Systems

Every production installation has its own unique characteristics, and when developing an RBI program, these characteristics must be considered. As can be seen in Figure B.1 and B.2, the event trees terminate at the point of a fire or explosion occurring. In order to assess the consequences of each end state, the severity or impact must be determined for each case. An important first step in the analysis is to identify what consequences are to be evaluated and measured, either qualitatively or quantitatively. These might be harm to people, property loss, environmental damage, business interruption or all of these.

If the study is being done for a number of similar installations, or if the purpose of the study is to simply “screen” the equipment or structures by risk category, then it may be sufficiently accurate to group production areas together with respect to consequence of an equipment or structural failure (e.g., leak). The following is an example of what such a categorization might look like:

- High pressure gas or any toxic stream – High Consequence
- Low pressure gas or a high pressure liquid stream – Medium Consequence
- Low pressure liquid stream – Low Consequence
- Non-flammable, non-toxic stream – Insignificant Consequence

Depending on the scope and purpose of the study, such terms as “high pressure” can be more clearly defined. There may be a need for more categories so that any one category is not too broad to be useful. This approach is known as a qualitative consequence assessment.

If a more detailed consequence analysis is needed, then quantitative models can be used. For the example case of fire and explosion, the impact of these can be quantified using sophisticated modeling software to determine, for example:

- The rate and velocity of release of a given gas or liquid through a given hole size at a particular pressure and temperature
- The dispersion of gas in the atmosphere depending on the properties of the gas and a given set of weather conditions
- The spread and evaporation rate of liquids that leak, and also the effects of a gas condensing in the air and raining out as fluid
- The tendency of the leaking fluid to ignite upon encountering an ignition source
- Whether a fire or explosion or both result from ignition and the type of fire or explosion
- The heat produced by a fire as a function of distance from the fire, or the overpressure from an explosion given as a function of distance from the explosion source.

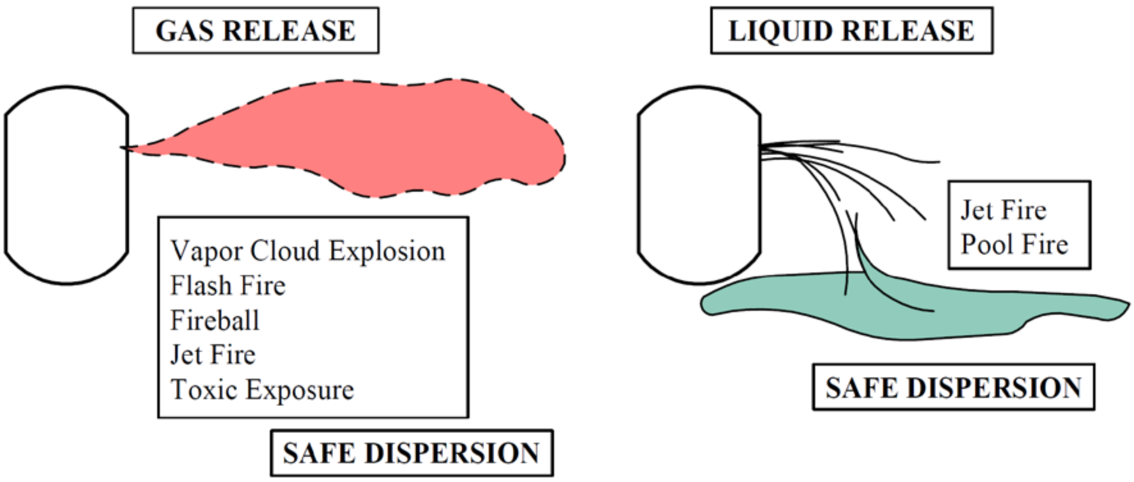


Fig. B.3. Result of a Process Leak of Flammable or Toxic Fluid

Once these calculations have been made, the “real” impact of the leak can be expressed in terms of the consequences that are to be studied. Some examples are:

- Safety: using the heat flux that is known to cause serious injury, the area of fire safety hazard can be determined. Alternately, using the blast overpressure that is known to cause serious injury, the area of explosion safety hazard can be determined.
- Equipment or structural damage: similar to the safety calculations, but the area affected will be smaller since it takes more heat or overpressure to damage equipment or structures than to injure people.
- Environmental damage: based on the amount of liquid released, the amount that enters the environment can be determined.
- Business interruption: from the area of equipment or structural damage, the cost and time of repair or replacement can be determined.

Figure B.4 illustrates the calculation of the overpressure area affected by an explosion. Note that some of the overpressure area is beyond the boundaries of the FPSO, therefore, no damage to personnel, equipment or structures can occur in this area. This is one of many possible pitfalls that the analyst must face in the use of complex models.

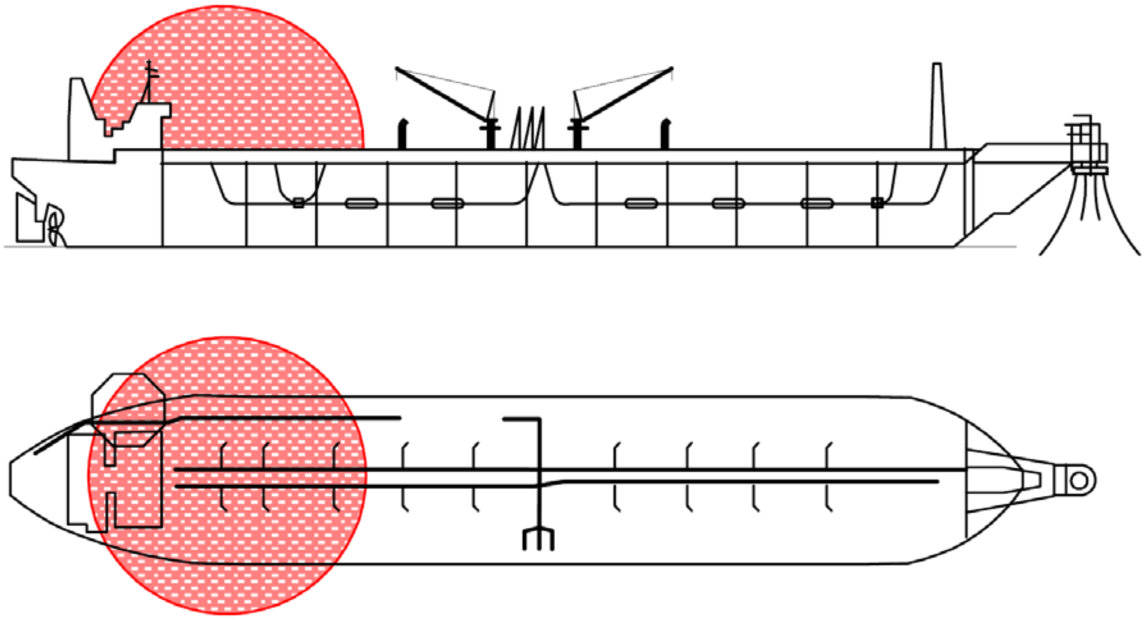


Fig. B.4. Modeling of Explosion Overpressure Area on an FPSO

Examining all of the above calculations, the analysis appears to be very quantitative, but clearly a great deal of judgment (qualitative) must be used in every step along the way. To recap some of these judgments, consider some of the inputs that cannot be known with great certainty:

- The size and shape of the hole
- The likelihood of each size of hole
- The likelihood of ignition
- The effectiveness of detection, isolation and mitigation measures
- The conditions of weather affecting dispersion
- The number of persons within an affected area
- The potential for escalation from equipment/structures in the damaged area
- The impact of escalation on evacuation

It is this mixture of analytical tools with human judgment that results in an analysis that can never be said to be fully quantitative. As mentioned before, most studies can be considered to be "semi-quantitative". Given the uncertainties listed above, it can easily be seen why a qualitative study to screen out low risk items from further analysis is justifiable.

3. Likelihood Assessment for Process Systems

In most risk assessments, the initiating event is some form of failure (e.g., structures, equipment, instruments, or even human error). In RBI, normally the initiating event is some form of structural failure due to progressive damage (degradation mechanism). This might result in leakage from some part of the "envelope" that contains the fluids – oil and gas - that are produced.

To estimate the likelihood of component failures, historical data can be used, if available. There are databases of equipment failures for many industries: nuclear, aerospace, petrochemical processing and offshore operations. Data from such sources is referred to as "generic" failure data, and is often used in risk assessments to describe the failure rate of a "typical" component. For a particular installation, there may be reason to believe the failure rates may be higher or lower than those reported in databases. In such cases, these "generic" data are sometimes adjusted to reflect the expected performance at the particular location being studied. When using data from databases, it is recommended that a person familiar with risk assessment and statistics be consulted on the proper applications of the failure rates.

A characteristic of “generic” data is the assumption that all components in the population on the average will fail at the generic failure frequency. There is no way to determine directly from the failure data what the performance of any particular member of the population will be. The goal of RBI is to identify not just the “generic” failure frequency, but which components have the higher probability of failure due to specific inspectable damage mechanisms.

As described above, the “generic” failure frequencies are averages of the failure frequencies of all members of a population, and the data do not provide information regarding any individual component. In addition, such databases rarely record the cause of failure. A model of the damage mechanism can be created for each type of failure that can help identify which components are more subject to one or more mechanisms. What is desired is to split the entire population of components into groups according to their probability of failure due to the mechanism under study.

This can be done using informal methods. Many engineered structures such as pipes, tanks and pressure vessels all have a maximum allowable amount of corrosion, called a “corrosion allowance” or “wastage allowance”. These allowances can be considered to be the dividing points between acceptable probability of failure and unacceptable probability of failure, as described in more detail below.

The time anticipated for the wastage allowance to be consumed (or a crack to grow to a critical size) is often referred to as the “remaining life”. This merely indicates that at some time the equipment or structures will no longer conform to the design requirements, and not that they will fail at the end of the “life” determined by this method. The concept of remaining life is useful, however, in that equipment or structures with a longer remaining life are less likely to fail due to errors or uncertainties associated with the determination of the remaining life. This provides a way to effectively, qualitatively and quickly “screen” equipment or structures to identify those that need a more detailed analysis. An example is given here that shows the relationship between remaining life and the “confidence” or expected accuracy of determining that life.

Based on these simple criteria, which may be developed using expert judgment, the equipment or structures under consideration will be given a score from two to six, thus subdividing the group into five categories for further analysis based on priority. Items with a score of six will be highest priority, five will be next, and so on. This is a qualitative approach for assessing likelihood.

As has been previously discussed, almost all RBI programs are to some extent both qualitative (judgmental) and quantitative (analytical).

It should be noted that as was done in the examples above, confidence in the values used for analysis should always be included. In highly quantitative analyses to be discussed next, this “confidence” may be quantified as a standard deviation or some form of scatter in the distribution of values used. Accounting for possible errors in evaluations is one of the keystones of RBI.

Appendix C

Reliability Analysis Approach for Marine Structures

1. General

The aim of this appendix is to present an outline and framework of the reliability analysis approach for marine structures using probabilistic theory

Structural reliability is commonly defined as the probability of safety, or proper performance, of a structure over a given period of time under specified operating conditions. The complement of the reliability is failure probability, which is generally defined as the small probability that a structure does not perform the intended functions.

The structural reliability approach more properly takes into account the various uncertainties associated with structural degradation, environment and loads, strength and fatigue, material performance, inspections and maintenance, etc. Compared to traditional deterministic approaches, the reliability approach measures more rationally the safety of marine structures.

2. Documentation

Analysis methods, basic assumptions and knowledge information should be properly documented. The predicted reliability is a nominal measure of safety, and is dependent on the methods and information. The state-of-the-art technology is to be applied and the probabilistic models are to be based on experience that is well established and reflects as close as possible the actual conditions of the structures.

3. Main Components of a Structural Reliability Analysis

Major components of a structural reliability analysis include:

i) Identification of failure modes of structure or operation

ii) Formulation of limit state functions for each failure mode

iii) Selection of stochastic variables and defining associated distribution types and parameters

iv) Modeling of degradation mechanisms (e.g., corrosion, crack)

v) Consideration of the influences of inspection and maintenance

vi) Reliability analysis

vii) Determination of acceptance criteria (target reliability)

viii) Assessment of the estimated reliability and/or study of the sensitivities

4. Typical Failure Modes

Typical failure modes of marine structures include (but are not limited to):

- Yielding
- Buckling or collapse
- Fatigue crack, fracture (including brittle fracture)
- Severe deflection
- Leakage or loss of containment
- Vibration

- Loss of stability

All failures that will have significant consequences are to be identified. These include failures of individual components, assemblies or sub-systems and the entire system. Consequences include those to

- Personnel
- Operation
- Property
- Environment

5. Limit states

The safety of the structure against the failure modes is often termed as limit states. The following four types of limit states are generally considered:

- Serviceability limit state (SLS)
- Ultimate limit state (ULS)
- Fatigue limit state (FLS)
- Accidental limit state (ALS)

SLS conventionally represents failures under normal operations due to deterioration of less vital functions. ULS (also called ultimate strength) represents the collapse of the structure due to loss of structural stiffness and strength. FLS represents fatigue crack occurrence in structural details due to stress concentration and crack propagation under the action of cyclic loading. ALS represents excessive structural damage as consequences of accidents, e.g., collisions, grounding, explosion and fire, which affect the safety of the structure and the environment.

These various types of limit states may be required to have different safety levels. The actual safety level to be attained for a particular type of limit state is a function of its perceived consequences and ease of recovery to be incorporated in design and operation.

6. Limit State Functions

The limit state functions define the safety/failure of structural components or structural system. A limit state function that is often used is resistance (e.g., structural capacity) minus loads, with associated model uncertainty factors applied to them.

The limit state function for a particular failure mode is formulated in accordance with state-of-the-art knowledge. Well-established engineering approaches such as design can be referenced in developing the limit state functions. Background describing the rationales of the limit state function is to be properly documented.

Parameters defining resistance can be:

- Geometrical properties
- Strength (buckling strength, ultimate strength, fatigue strength)
- Structural stiffness

They are dependent on structural scantlings, material properties and manufacture tolerance. Loads to be considered include:

- Static loads
- Dynamic loads
- Impact and accidental loads in some cases

These loads can be global or local, and can be dead weight, live loads due to environments (wave, current, wind, earthquake), operational loads and deformation loads.

When more than one load component acts upon the structure simultaneously, the correlation of these load components should be properly taken into account.

7. Uncertainties and Probabilistic Models

Identification of all uncertainties for complex marine structures is often difficult. Usually, the uncertainties associated with an engineering analysis can be broken down into:

- Phenomenological uncertainty, which usually arises in novel designs
- Decision uncertainty, which arises in connection with the decision as to whether a particular phenomenon occurs
- Modeling uncertainty, which is associated with idealizing a physical behavior with analytical models
- Prediction uncertainty, which is associated with the state of knowledge available at the time of the analysis
- Physical uncertainty, which is associated with the inherent random nature of basic variables
- Statistical uncertainty, which arises due to limited information
- Uncertainty due to human factors, which results from human errors or human intervention

In the reliability analysis, these uncertainties are represented using probabilistic models for variables.

The aforementioned uncertainties should be modeled as far as possible in the reliability analysis. However, it is usually not possible to include all of them.

The probability distribution functions and the associated statistical estimators (such as mean value and standard deviation) are to be based on available experiences (field measurements from previous similar structures) that are recognized by the industry. When experience data is statistically limited, the probabilistic models and the associated statistical estimators may be based on experts' opinions.

8. Degradation Mechanisms

Marine structures suffer various types of degradation:

- Corrosion: general or uniform corrosion, pitting, grooving/necking
- Cracking: fatigue cracks, brittle fracture
- Mechanical damage: local dents, contact damage, collision damage

Corrosion and fatigue cracks are related to ship service time while mechanical damage is often caused in operation or by accidents.

Knowledge databases, for example, those of manufacture tolerance and corrosion wastage, are usually based on collective studies of previous experience. Information can be obtained from well-recognized sources or based on experts' opinions in case there is only limited experience, or a combination of both.

A marine structure is frequently maintained and inspected. Additional information of current conditions of the marine structure, such as gauging reports, shall be used as much as possible to refine or update the probabilistic models for the variables involved in the reliability analysis.

9. Reliability analysis

The reliability analysis can be categorized as either component analysis or system analysis. The component analysis refers to cases where only one limit state function is involved (e.g., stiffener tripping failure in a stiffened panel). The system analysis refers to cases where more than one limit state function is involved. For example, in a stiffened panel analysis when the gross panel buckling and stiffener buckling failure modes are considered simultaneously, it constitutes a system reliability problem. Another example can be when the fatigue inspection results are used to update the fatigue reliability of a connection. This type of problem is also generally formulated as a system reliability problem.

The component reliability problems can be solved using:

- Analytical methods, such as FORM (first-order) and SORM (second-order)
- Monte Carlo simulation techniques
- Other methods

In general, the much more efficient FORM/SORM type of method is preferred. The Monte Carlo method is typically used to validate the FORM/SORM results.

The system reliability problems can be solved using:

- Approximate bounding method
- Monte Carlo simulation techniques

The reliability calculation should be performed by way of commercially available software that incorporates the reliability method, as mentioned above.

10. Acceptance Criteria (Target Reliability)

Acceptance criteria (target reliability) are used to judge if the estimated reliability is sufficient for the intended functions.

The target reliability is a nominal measure of the acceptable reliability of the marine structure for a considered failure mode. It is dependent on the failure mode, analysis methods, level of information available, uncertainties taken into account, among others.

The target reliability may be based on well-established standards, or recommendations and results of state-of-the-art research. It can also be determined through calibrating against successful and unsuccessful experience of existing similar designs. In the case of novel designs where there is no similar preceding design, special techniques may have to be introduced.

11. Influence of Inspection

During operation and construction, a marine structure is frequently inspected and monitored. Additional information gained in inspection and maintenance helps to reduce the uncertainties of the analytical models. As a result, probabilistic models for the variables can be updated and refined so that they reflect as close as possible the actual conditions of the marine structure.

Appendix D

Contribution of Inspection Plan Elements

The RBI planning process is the means to manage the risk associated with in-service inspection. The two variables of risk, the likelihood of reaching an undesirable condition prior to the next inspection and the consequences of realization of the undesirable condition, are reflected in the elements of a component's inspection plan. The six elements of an inspection plan are the means to understand and manage the risk associated with in-service inspection activities. The six elements of an inspection plan are:

i) Component Identification

ii) Inspection Methods

iii) Scope: Sample Rate, Inspection Location and Extent of Inspection

iv) Inspection Data Documentation

v) Frequency of Inspection

vi) Update Inspection Plan

The intent of any in-service inspection activity is to match the level of inspection effort to the benefit of the results obtained. Inspection of components with insignificant consequences resulting from the realization of an undesirable condition at any time during its service life does not meet this intent, nor does inspecting for degradation conditions that have been shown through prior experience not to be active or aggressive. RBI is a planning tool to identify these types of opportunities. Additionally, RBI can be used to assess the risk associated with the inspection of an individual component, its risk contribution within a system of components and the overall risk of the system. An RBI plan uses risk to justify the intensity (frequency and scope) of inspection for a component or system of components. The inspection plan becomes the risk management plan for the component or system.

Table D.1, "Summary of Contribution of Inspection Plan Elements in an RBI Plan," lists each element in an inspection plan and its contribution in the likelihood and consequence assessments required for the risk assessment.

Table. D.1. Summary of Contribution of Inspection Plan Elements in an RBI Program

Inspection Element	*Likelihood Assessment*	*Consequence Assessment*
Component Identification	May identify inspectable units that have common degradation potentials and likelihood.	Establishes types of potential loss scenarios to be considered based on function of the component. The ultimate consequence of the component's failure establishes minimum technical evaluation condition, such as allowable stress or area of minimum thickness
Inspection Methods	Type of inspection and detection limits of inspection method contributes to confidence that representative condition of the component is identified	Identifies the degradation mechanisms to be included in the plan.
Scope: Sample Rate, Location and Extent of Component Inspection	Contributes to the confidence the degradation rates used in the plan are representative of the current condition. Likelihood of loss scenario increases with the number and the extent of components affected by the degradation mechanism	Contributes to the confidence that the correct degradation mechanisms were identified in the plan by inspection of multiple locations and potential areas for unsuspected degradation mechanisms or damage locations
Inspection Data Documentation	Accurate and comparable inspection data establishes confidence the initial conditions and degradation rates premised in the plan from current, historical or industry data are representative.	Accurate historical record contributes confidence that transient and continuous degradation mechanisms have been addressed in plan
Inspection Frequency	The inspection interval should be set in cognizance of the time span estimated for likelihood of failure of that component. This frequency must be realistically prudent so that condition assessment of the component and actual degradation rates occurring can be estimated without threat of imminent failure. In other words, the date of the next inspection must be significantly less than the projected failure date.	Inspection frequency does not impact consequence
Next Inspection Plan	Evaluates the results of an inspection to estimate the likelihood of an undesirable consequence or condition based on confidence in the inspection activities or generic industry frequency data	Consequence assessment generally remains unchanged, except for changes in function or additions to the facilities or structure.
	Risk of an undesirable condition or consequence determined qualitatively or quantitatively from the likelihood and consequence assessments. Risk may be used in prioritizing components for inspection, or used to optimize inspection plan intervals for finding the lowest risk that creates the largest functional benefit. Inspection risk is managed by adjusting the elements of the inspection plan, such as by changing the inspection intensity, or the changing the inspection methods to improve detection. The inspection intensity is a combination of an inspection plan's frequency, sample rate, extent and location of inspection methods.	