

Elements of a Risk-Based Inspection Program

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Introduction

The use of Risk-Based Inspection (RBI) methodologies for inspection planning is not compulsory. The use of RBI is entirely optional, subject to the requirements and limitations of the other inspection codes (such as API 510, API 570, and API 653). This recommended practice (RP) contains the requirements and expectations required to establish and maintain an API 580 compliant RBI program.

RBI is a systematic process that begins with identification of facilities or equipment, continues with a determination of risk (via probability of failure and consequence of failure analysis). The process culminates in the creation of a risk-based management plan based on the credible damage mechanism(s) and the risk of failure. Owner-operators may utilize this output to prioritize the execution of the inspection programs effectively and efficiently. For the purposes of this document, RBI is synonymous with descriptions of other RBI programs used in the industry: risk-prioritized inspection, risk-informed inspection, and inspection planning using risk-based methods.

Elements of a Risk-Based Inspection Program

1 Scope

1.1 Industry Scope

This RP is specifically targeted to the application of RBI in the hydrocarbon and chemical process industries. The principles and concepts herein can be applied in other industries with appropriate documentation.

1.2 Purpose

The purpose of this RP is to provide users with the recommended elements for developing, implementing, and maintaining an RBI program. This RP provides guidelines for establishing an RBI program which when implemented properly, will allow the owner-operator to integrate risk assessment and inspection planning into an existing inspection program. The approach emphasizes safe and reliable operation through risk-prioritized inspection. A spectrum of complementary risk analysis approaches (qualitative through fully quantitative) can be considered as part of the inspection planning process.

This RP contains individual sections that describe the steps in applying concepts and principles of an RBI program which include:

- a) risk-based inspection analysis methods;
- b) planning the RBI program;
- c) roles, responsibilities, training, and qualifications;
- d) data and information collection for a risk assessment;
- e) damage mechanisms review;
- f) assessing probability of failure (POF);
- g) assessing consequence of failure (COF);
- h) risk determination, assessment, and management;
- i) other risk management activities;
- j) evergreening and reassessment of the risk assessment; and
- k) RBI documentation and recordkeeping.

1.3 Flexibility in Application

Because of the broad diversity in organizational size, culture, and regulatory requirements, this RP offers users the flexibility to create and implement an RBI Program within the context of existing corporate risk management practices—including the selection and application of a specific RBI methodology.

Various RBI methodologies exist and are currently being applied throughout industry. This RP is not intended to recommend nor endorse any specific methodology for implementing the assessment steps within an RBI program. However, this document is designed to provide a framework that specifies the minimum requirements and expectations needed for a quality risk assessment without imposing undue constraints on users.

This RP is also intended to promote consistency of the process and quality in the identification, assessment, and management of risks pertaining to material deterioration that could lead to failure. Further, the document provides guidance on the recommended work process for conducting and sustaining a successful RBI program.

1.4 Mechanical Integrity Focused

The RBI process is focused on maintaining the mechanical integrity of pressure equipment and minimizing the risk of loss of containment due to deterioration. RBI is not a substitute for a process hazards analysis (PHA) nor is it a substitute for hazard and operability assessment (HAZOP). Typically, PHA risk assessments focus on the process unit design, operating practices, and the adequacy of the practices, given the unit's current or anticipated operating conditions. RBI complements the PHA by focusing on the mechanical integrity related damage mechanisms and managing risk through inspection and complimentary mitigation and/or monitoring programs.

There are other relevant relationships between RBI and other equipment reliability or risk assessment programs in the industry. For example, RBI is complementary to reliability centered maintenance (RCM) programs in that both programs are focused on understanding failure modes, addressing the modes, and therefore improving the reliability of equipment and process facilities. Relevant relationships between RBI and other equipment reliability or risk assessment programs in industry are discussed in [5.8](#).

1.5 Target Audience

The primary audience for this RP is inspection and engineering personnel who are responsible for the mechanical integrity and operability of equipment covered by this RP. While an organization's inspection or materials engineering group may champion the RBI initiative, RBI is not exclusively an inspection activity. RBI requires the involvement of various segments of the organization such as engineering, maintenance, and operations. Implementation of the resulting RBI product (e.g. inspection plans, replacement/upgrading recommendations, other mitigation activities, etc.) may rest with more than one segment of the organization. RBI requires the commitment and cooperation of the organization. In this context, all stakeholders who are likely to be involved should be familiar with the concepts and principles embodied in the RBI methodology to provide the necessary support for the RBI assessment and in the interpretation and application of the results as it relates to their specific function.

1.6 RBI Assessment Benefits and Limitations

An RBI program can provide the following benefits:

- a) identification of risk drivers;
 - 1) damage mechanisms and damage modes
 - 2) equipment with insufficient or inadequate inspection history
 - 3) consequence driven equipment not impacted by inspection
 - 4) safety, health, environmental and/or economic consequences
- b) development of an inspection plan;
 - 1) techniques and methods to be used for proper detection and quantification
 - 2) establishment of the extent of inspection (e.g. percent of the total area to be examined or specific locations)
 - 3) provision of the inspection interval or next inspection date (timing)
- c) optimization of resources;

- d) identification of mitigation activities which can further reduce risk for the facilities and equipment assessed;
- e) acceptance/understanding of the current risk; and
- f) provision for other applicable risk mitigation activities (including but not limited to):
 - 1) establishing and maintaining Integrity Operating Windows (IOWs);
 - 2) reducing personnel exposure to high-risk areas;
 - 3) upgrading to materials of construction less susceptible to degradation;
 - 4) reducing the consequence of failure (e.g. limiting inventory, detection, and mitigation controls);
 - 5) repair or replacement.

The risk assessment can identify equipment that does not require inspection or mitigation because of the acceptable level of risk associated with the equipment's operation. In addition, there can be synergies between the RBI process and process safety management and turnaround activities that may further decrease the amount of inspection related activities. These synergies can lead to a potential decrease in operating expenses, while also reducing the facility risk.

An RBI assessment is limited by and will not compensate for:

- 1) inaccurate or missing information;
- 2) inadequate design, faulty equipment installation, or inadequate testing or commissioning of equipment;
- 3) operating outside the acceptable process limits (e.g. not to exceed limitations, IOWs, etc.);
- 4) not effectively executing the plans;
- 5) lack of qualified personnel or teamwork;
- 6) lack of sound engineering or operational judgment;
- 7) lack of follow-up on inspection findings or recommendations; and
- 8) construction and fabrication errors.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration*

API 570, *Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems*

API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

absolute risk

An ideal and accurate description and quantification of risk.

3.1.2

acceptable risk

A level of risk that is acceptable to the owner-operator.

3.1.3

as low as reasonably practicable

ALARP

A concept of minimization where that attributes (such as risk) can only be reduced to a certain minimum under current technology and with reasonable cost.

3.1.4

components

Parts that make up a piece of equipment or equipment item. For example, a pressure boundary may consist of components (pipe, elbows, nipples, heads, shells, nozzles, stiffening rings, skirts, supports, etc.) that are bolted or welded into assemblies to make up equipment items.

3.1.5

consequence

The outcome of an event.

3.1.6

consequence of failure

COF

The outcome of a failure event such as safety, environmental, financial, damage to reputation or other negative outcomes.

3.1.7

corrosion specialist

A person acceptable to the owner-operator who is knowledgeable and experienced in specific process chemistries, degradation mechanisms, materials selection, corrosion mitigation methods, corrosion monitoring techniques, and impact on equipment.

3.1.8

cost-effective

An activity that is both effective in resolving an issue (e.g. some form of mitigation) and is a financially sound use of resources.

3.1.9

credible

A descriptor where the term being modified has been determined to have a reasonable likelihood of occurrence.

EXAMPLE Credible damage mechanism, credible consequence

3.1.10**credible damage mechanism
deterioration mechanism**

Any type of deterioration encountered in the refining and chemical process industry can result in flaws/defects that can affect the integrity of vessels (e.g. corrosion, cracking, erosion, dents, and other mechanical, physical, or chemical impacts).

NOTE 1 See API 571 for a comprehensive list and description of damage mechanisms affecting the refining industry. Other sources of damage mechanisms and their descriptions exist in ASME PCC-3, WRC 488, WRC 489, WRC 490, ASM Volume 6, ASM Volume 11, and ASM Volume 13 among industry accepted documentation.

NOTE 2 Mechanism assignment is typically completed by a corrosion specialist.

NOTE 3 See [Section 9](#) for further information.

3.1.11**damage mode
deterioration mode**

The physical manifestation of damage (e.g. wall thinning, pitting, cracking, rupture).

3.1.12**damage tolerance**

The amount of deterioration that a component can withstand without failing.

3.1.13**design premise**

Assumptions made during the design (e.g. design life and corrosion allowance needed).

3.1.14**deterioration**

The reduction in the ability of a component to provide its intended purpose of containment of fluids.

NOTE This can be caused by various damage mechanisms (e.g. thinning, cracking, mechanical). Damage or degradation may be used in place of deterioration.

3.1.15**equipment**

An individual item that is part of a system (such as pressure vessels, relief devices, piping, boilers, and heaters) or an assemblage of components.

3.1.16**event**

An incident or situation that occurs in a particular place during a particular interval of time.

3.1.17**event tree**

An analytical tool that organizes and characterizes potential occurrences in a logical and graphical manner and shows the events relationship to each other.

3.1.18**external event**

Events resulting from forces of nature, acts of God, sabotage, or other events usually beyond the direct or indirect control of persons employed at or by the facility.

EXAMPLE Neighboring fires or explosions, terrorism, neighboring hazardous material releases, electrical power interruptions, forces of nature, and intrusions of external transportation vehicles, such as aircraft, ships, trains, trucks, or automobiles.

3.1.19**facility**

Any location containing equipment and/or components to be addressed under this RP.

3.1.20**failure**

The loss of function of a system, structure, asset, or component to perform its required or intended function(s).

NOTE Though there are many definitions for failure of equipment, in this document failure is defined as loss of containment.

3.1.21**failure mode**

The manner of failure. For RBI, the failure of concern is loss of containment of equipment items.

EXAMPLE Small hole, cracks, and ruptures.

3.1.22**Fitness-For-Service Evaluation****FFS**

A methodology whereby damage or flaws/imperfections contained within a component or equipment item are assessed to determine acceptability for continued service.

3.1.23**functional failure**

The inability for a component, equipment, or system to perform its intended function.

3.1.24**hazard**

A physical condition or a release of a unsafe material due to a component failure and which may result in human injury or death, loss or damage, or environmental degradation.

NOTE The hazard is the source of harm. Components that are used to transport, store, or process hazardous material can be a source of the hazard. Human error and external events may also create a hazard.

3.1.25**hazard and operability study****HAZOP**

A structured brainstorming process of assessing the existence of dangers and/or risks (i.e. hazard) in equipment and vulnerability of operation.

NOTE The process uses a list of guidewords to focus on process parameters such as flow, level, temperature, and pressure and then branch out to include other concerns, such as human factors and operating outside normal parameters.

3.1.26**inspection**

The external, internal, or on-stream assessment (or any combination of the three) of the condition of an asset conducted by the authorized inspector or his/her designee in accordance with the appropriate code.

NOTE 1 Includes activities performed to verify that materials, fabrication, erection, examinations, testing, repairs, and any other data relevant to the equipment conform to applicable codes, engineering, and the owner-operator's written procedure requirements.

NOTE 2 Inspection also includes the planning, implementation, and evaluation of the results of inspection activities.

3.1.27**inspection plan**

Strategy defining how and when an asset or component will be inspected, repaired, and/or maintained.

NOTE For the purposes of this document, the inspection plan is the product of an RBI analysis that details the scope, extent/locations, methods, and timing of specific inspection/monitoring activities for determining the condition of a specific piece of equipment. It is the essential part of a risk-based management plan.

3.1.28

integrity operating windows

IOWs

Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined amount of time.

3.1.29

ISO-risk

A line of constant risk and method of graphically showing probability of failure (POF) and consequence of failure (COF) values in a two-dimensional plot where risk increases toward the upper right-hand corner.

3.1.30

logic model

A tool used to depict the effectiveness in depicting a combination of events that could result in a loss of containment event.

3.1.31

management of change

MOC

A documented management system for review and approval of changes (both physical and process) to equipment prior to implementation of the change.

NOTE Alteration of inspection plans may occur as a result of the change.

3.1.32

management system

The framework of work processes and procedures is used to provide assurance that an organization can fulfill all tasks required to achieve its objectives.

3.1.33

mechanical integrity

MI

The management systems, work practices, methods, and procedures established to protect and preserve the integrity of operating equipment (i.e. avoid loss of containment due to the effect of equipment damage mechanisms).

NOTE MI is one part of a process safety program.

3.1.34

mitigation

Limitation of any negative consequence or reduction in probability of a particular event.

3.1.35

physical model

A tool used to depict the progression of events and the release of a hazardous material to the environment.

3.1.36

probabilistic

Systematic and comprehensive methodology to evaluate risks associated with a complex engineered entity, which is based on or adapted to a theory of probability; subject to or involving chance variation.

3.1.37 **probability** **likelihood**

Extent to which an event is likely to occur within the timeframe under consideration (i.e. events/year).

NOTE 1 The mathematical definition of probability is “a real number in the scale 0 to 1 attached to a random event.” For a high degree of belief, the probability is near one (1.0).

NOTE 2 Frequency rather than probability may be used in describing risk.

NOTE 3 Degrees of likelihood of probability can be chosen as classes or ranks like “rare/unlikely/moderate/likely/almost certain” or “incredible/improbable/remote/occasional/probable/frequent.”

3.1.38 **probability of failure** **POF**

Likelihood of an equipment or component failure due to a single damage mechanism or multiple damage mechanisms occurring under specific operating conditions.

3.1.39 **process monitoring**

Observing and tracking operating variables such that they are maintained within defined operating limits to minimize damage.

3.1.40 **process unit**

A group of systems arranged in a specific fashion to produce a product or service.

EXAMPLE Power generation, acid production, fuel oil production, and ethylene production.

3.1.41 **qualified person**

A competent person who has met the knowledge and skill requirements and expectations of the owner-operator.

3.1.42 **qualitative risk analysis**

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

3.1.43 **quantitative risk analysis** **QRA**

A risk analysis that uses primarily model-based methods where numerical values are calculated, and more discreet input data used.

3.1.44 **reassessment**

The process of integrating inspection data or other changes into the risk analysis.

3.1.45 **relative risk**

The comparative risk of a facility, process unit, system, equipment item, or component to other facilities, process units, systems, equipment items, or components, respectively.

3.1.46 **residual risk**

The risk remaining after all specified risk management activities have been performed and/or implemented.

3.1.47**risk**

A combination of the POF and COF associated with that failure. In some situations, risk is a deviation from the expected. When probability of failure and consequence of failure are expressed numerically, risk is the product.

3.1.48**risk acceptance**

A level of risk accepted by the owner-operator whether by pre-determined risk threshold or by appropriate approvals to operate with risk above threshold levels.

3.1.49**risk assessment****risk analysis**

Systematic use of information to identify sources to estimate the risk, provide a basis for risk evaluation and develop inspection planning, risk mitigation, and risk acceptance.

NOTE Information can include historical data, theoretical analysis, informed opinions, and concerns of stakeholders.

3.1.50**risk-based inspection****RBI**

A risk assessment and management process that considers both the probability of failure and the consequence of failure due to material deterioration.

3.1.51**risk based management plan**

Prescriptive task(s) used to manage risk for fixed equipment.

NOTE This could include, but is not limited to inspection, examination, replacement, process monitoring, material upgrade, and/or re-rating.

3.1.52**risk criteria**

Terms of reference by which the significance of risk is assessed.

NOTE Includes associated cost and benefits, legal and statutory requirements, socio-economic and environmental aspects, concerns of stakeholders, priorities, and other inputs to the risk assessment.

3.1.53**risk driver**

The primary contributor(s) responsible for a significant share of the equipment's or component's risk value.

3.1.54**risk evaluation**

The process is used to compare the estimated risk against a risk criteria to determine the significance of the risk.

3.1.55**risk identification**

Process to find, list, and characterize factors of risk.

NOTE Factors may include source, event, COF, and POF and/or stakeholder concerns.

3.1.56**risk management**

Coordinated activities to direct and control an organization with regard to risk.

NOTE The coordinated activities may include risk evaluation, risk mitigation, risk acceptance, inspection planning, process monitoring and communication.

3.1.57

risk mitigation

Process of selection and implementation of measures to modify risk.

NOTE The term is sometimes used to refer to the measures themselves.

3.1.58

risk reduction

Actions taken to lessen the POF, COF, or both associated with a particular risk.

3.1.59

risk threshold

Criteria which depict acceptable versus unacceptable risk.

3.1.60

semi-quantitative

A risk analysis using aspects of both--a qualitative and quantitative risk analysis. Calculations may be used but can be based on the input of subject matter experts.

NOTE API Recommended Practice 581 is an example of a semi-quantitative risk analysis methodology.

3.1.61

service life

The expected lifetime or the acceptable period during which an asset and/or component can safely and reliably perform within its intended operating envelope.

3.1.62

source

Thing or activity with a potential for consequence. Source in a safety context is a hazard.

3.1.63

stakeholder

Any individual, group or organization that may affect, be affected by, or perceive itself to be affected by the risk.

3.1.64

system

A collection of equipment assembled for a specific function within a process unit.

EXAMPLE Service water system, distillation systems, and separation systems.

3.1.65

toxic chemical

Any chemical that presents a physical or health hazard or an environmental hazard according to the appropriate material safety datasheet.

3.1.66

turnaround

A period of downtime to perform inspection, maintenance, or modifications and prepare process equipment for the next operating cycle.

3.1.67

unmitigated risk

The risk prior to mitigation activities.

3.1.68

user

The individual that is readily applying the principles, recommendations, and requirements herein to establish and maintain an RBI Program.

3.2 Acronyms and Abbreviations

ACC	American Chemistry Council
ALARP	as low as reasonably practicable
BLEVE	boiling liquid expanding vapor explosion
CCPS	Center for Chemical Process Safety
COF	consequence of failure
DMR	damage mechanism review
EPA	environmental protection agency
FMEA	failure modes and effects analysis
HAZOP	hazard and operability assessment
IOW	integrity operating window
LOPA	layers of protection analysis
MOC	management of change
MSD	material selection diagrams
NDE	nondestructive examination
OSHA	occupational safety and health administration
PASCC	polythionic acid stress corrosion cracking
PHA	process hazards analysis
PMI	positive material identification
POF	probability of failure
PSI	process safety information
PSM	process safety management
PVRC	Pressure Vessel Research Council
QA/QC	quality assurance/quality control
QRA	quantitative risk assessment
RBI	risk-based inspection
RCM	reliability centered maintenance
RMP	risk management plan
SIL	safety integrity level
UT	ultrasonic testing

4 Risk Assessment Concepts

4.1 What is Risk?

Risk is the product of the probability of an event occurring during a time period of interest (or POF) and the consequences (generally negative) associated with the event (or COF).

In the context of this document, probability refers to the Probability of Failure (POF) and consequence refers to the Consequence of Failure (COF). In mathematical terms, risk can be calculated by the equation:

$$\text{Risk} = \text{Probability} \cdot \text{Consequence}$$

Risk is assessed by identifying credible damage mechanisms, estimating the POF, assessing the COF, and identifying the risk drivers to enable development of effective risk management strategies.

4.2 Risk Management and Risk Reduction

Once the risk is known and the magnitude of the risk is established, risk evaluation allows for the determination of whether or not risk reduction is needed or desired, and risk management provides methodologies to maintain risks at or below an acceptable level. Risk reduction is typically accomplished using mitigation, the results of inspection activities and/or process control.

Mitigation efforts can reduce risk by changing the variable conditions used to evaluate risk. Examples of effective management strategies may include material upgrades to reduce or eliminate damage and reduce POF or process changes (which reduces COF).

Inspecting an asset for a specific damage mechanism can further quantify the estimated or expected rate of deterioration. Since conservative values are often used during initial risk assessments, inspection typically better quantifies risk as the deterioration rate used for analysis is more representative of the actual rate.

Process control can reduce risk by keeping the operation within the defined operating limits (e.g. IOW). Risk is reduced as compared with operating with upsets or instability.

Modifications to the inspection plan can better ascertain the risk by improving the information used to establish the POF. For example, if the damage mode is localized metal loss, a mitigation plan may require the equipment operate at a reduced inventory to lower risk to an acceptable level until a thorough inspection could validate the equipment condition and allow any repairs to be made. IOWs could be used in the example above to define the operating limits required to maintain the risk of the equipment at an acceptable level.

By using risk management, some risks may be identified as acceptable so that no risk reduction is required within the risk assessment timeframe. Further discussion about risk management can be found in [Sections 12, 13, and 14](#).

4.3 Relative Risk vs Absolute Risk

The complexity of risk assessment and its associated calculations is a function of the number of factors that can affect the risk. Absolute risk, which is an ideal and precise description and quantification of risk, is very time-consuming, and often cannot be done with a high degree of accuracy due to the uncertainty of associated inputs. Additionally, many variables are involved with loss of containment in hydrocarbon and chemical facilities and determining an accurate value for absolute risk is often not possible nor cost-effective.

When the risk calculations and methodology are conducted similarly, the risk values of similar studies can be compared as they relate to similar items. This is considered 'relative risk'. RBI is focused on a systematic determination of relative risk. In this way, RBI will allow facilities, process units, systems, equipment, or components to be comparatively ranked to other facilities, process units, systems, equipment, or components based on relative risk. This type of methodology forces a focus of the risk management efforts on the higher ranked risks and allows decisions to be made on the value of risk management efforts on lower ranked risks.

5 Introduction to Risk-Based Inspection

5.1 The Evolution of Inspection Intervals and Due Dates

In process plants, inspection and testing programs and process monitoring are established to detect and evaluate equipment deterioration due to the effects of in-service operation. The effectiveness of inspection programs varies widely, ranging from reactive programs, which concentrate on known areas of concern, to broad proactive programs covering a variety of equipment. One extreme of this would be the “don’t fix it unless it’s broken” approach. The other extreme is complete inspection of all equipment items on a frequent basis.

Setting the intervals/due dates between inspections has evolved over time. With the need to periodically verify equipment integrity, organizations initially resorted to time-based or “calendar-based” intervals/due dates.

With advances in inspection approaches, and better understanding of the type and rate of deterioration, inspection intervals/due dates became more dependent on the equipment condition (i.e. condition-based inspection), rather than what might have been an arbitrary calendar date. Codes and standards such as API 510, API 570, and API 653 evolved to an inspection philosophy with attributes such as:

- a) inspection intervals/due dates based on some percentage of equipment life (such as half-life calculations);
- b) on-stream inspection in lieu of internal inspection;
- c) internal inspection requirements for damage mechanisms related to process environment induced cracking; and
- d) consequence-based inspection intervals/due dates.

RBI represents a methodology that combines the probability of a loss of containment event and the resulting consequence. This combination represents the risk to a facility due to loss of containment. This risk value is used in setting specific inspection approaches and due dates to help achieve safe and reliable operating facilities. RBI, as a risk-based approach, focuses attention specifically on the equipment and associated damage mechanisms representing the most risk to the facility. In focusing on risk and its mitigation, RBI provides a better linkage between the mechanisms that lead to equipment failure (loss of containment) and the inspection approaches that will effectively reduce the associated risks. There are many industry definitions for failure of pressure equipment, but in this document, failure is defined as loss of containment.

5.2 Consequence of Failure (COF) and Probability of Failure (POF) for RBI

The objective of RBI is to determine what loss of containment incident could occur, and how likely the incident could occur.

In determining the COF, the following are generally true:

- a) There may be one or more consequences from an event.
- b) Consequences are always negative for safety aspects.
- c) Consequences may be expressed qualitatively or quantitatively.

For example, if a pressure vessel subject to a loss of containment event from corrosion under insulation develops a leak, a variety of consequences should be considered. Some of the examples of possible COF events to consider are as follows:

- 1) release of a flammable process fluid that could ignite, causing injury and equipment damage;
- 2) leak of a fluid with release to environment without escalation;

- 3) release of a toxic chemical that could cause injury or long-term health problems;
- 4) release of a chemical that has an adverse economic impact; or,
- 5) release of a chemical as a minor leak of nonflammable or nontoxic fluid that triggers other minimal safety, health, environmental, and/or economic impacts.

When determining the POF, the following are generally true:

- i) The mathematical definition of probability is “a real number in the scale 0 to 1 attached to a random event.”
- ii) Probability can be related to a long-run relative frequency of occurrence or to a degree of belief that an event will occur.
- iii) Degrees of belief about probability can be chosen as classes or ranks such as:
 - rare, unlikely, moderate, likely, almost certain, or
 - incredible, improbable, remote, occasional, probable, frequent.
- iv) Frequency rather than probability may be used in describing risk.
- v) Probabilities may be expressed qualitatively or quantitatively.

Staying with the CUI example from above, some of the possible probabilities of failure (POF) are as follows:

- a) Low, medium, high, etc.;
- b) Occurs once every year in this facility;
- c) Occurs once every 10 years in this facility;
- d) Occurs 10 times every year in this facility.

Loss of containment may occur relatively frequently without significant adverse safety, environmental, or economic impact. Similarly, other failures have potentially serious impact; but if the POF of the incident is low, the risk may not warrant immediate or extensive action. However, if the loss of containment risk is high enough to be unacceptable, then the determination of the appropriate action to reduce the POF (e.g. inspection activities and/or repairs) and/or the COF (e.g. design upgrades) of the event is appropriate.

Understanding the two-dimensional aspect of risk provides insight into the use of risk for inspection prioritization and planning. POF and COF are plotted on an iso-risk plot or risk matrix to demonstrate the risk contribution.

[Figure 1](#) displays an example of the risk associated with the operation of several equipment items in a process plant. In the example, the POF and COF have been determined for 10 equipment items, and the results have been plotted in an iso-risk plot. The numbered points represent the risk associated with each equipment item.

[Figure 1](#) provides a basic visual guidance for a risk plot to demonstrate that:

- 1) Ordering by risk from high POF/high COF to low POF/low COF produces a risk-based ranking of the equipment items to be inspected. From this list, a risk-based management plan can be developed that focuses attention on the areas of highest risk.
- 2) An “ISO-risk” line is also depicted on [Figure 1](#). An ISO-risk line represents a constant risk level, as shown across the iso-risk plot.

- i) All items that fall on or very near the ISO-risk line illustrates that all of the different combinations of POF and COF on that line are roughly equivalent in risk, even though the level of POF and COF can vary widely.
 - ii) A user-defined acceptable risk level could be plotted as an ISO-risk line. In this way the acceptable risk line would separate the unacceptable from the acceptable risk items.
- 3) Due to the nature of the magnitude differences along each axis, a risk plot is often drawn using log-log scales for a better understanding of the relative risks of the items assessed.

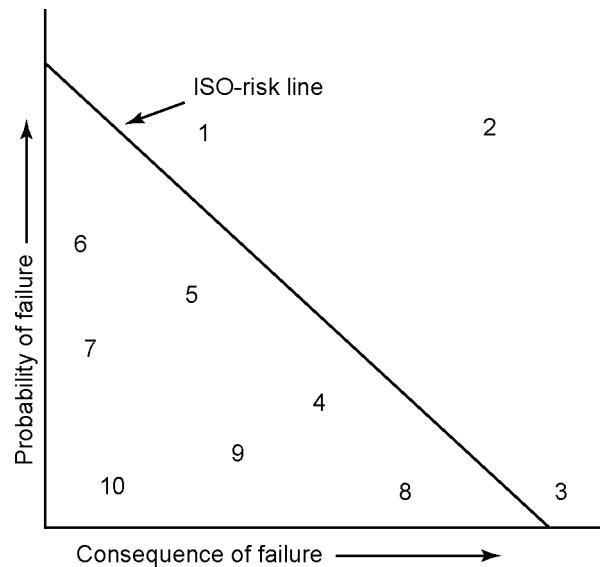


Figure 1—Risk Plot

5.3 Precision vs Accuracy

An RBI assessment involves collecting data that is used to monitor changes in a company's processes, so it is essential that the systems used for collecting and reporting measurements are valid and reliable. If the measurement system cannot be trusted, then the data that it produces cannot be trusted. RBI relies on data that can be trusted. To that end, the user needs to understand the difference between precision and accuracy when it comes to risk analysis.

- a) **Accuracy**—how close data measurements are to the “true” value (“the state of being correct”, a description of systematic errors, a measure of statistical bias). In RBI, accuracy is a function of the analysis methodology, the quality of the data, and consistency of application.
- b) **Precision**—how close measurements are to each other (“the state of being exact”, a description of random errors, a measure of statistical variability). In RBI, precision is a function of the selected metrics and computational methods.

In other words, accuracy describes the difference between the measurement and the actual value, while precision describes the variation between repeated measurements using the same method or technique. The accuracy of any type of RBI analysis depends on using a sound methodology, quality data, and qualified personnel.

Precision can be broken down further into two components:

- 1) **Repeatability**—the variation observed when the same operator measures the same part repeatedly with the same device.
- 2) **Reproducibility**—the variation observed when different operators measure the same part using the same device.

Concerning precision in RBI data, the basis for predicted damage and rates, the level of confidence in inspection data, the technique used to perform the inspection are all factors that should be considered.

For example, API Recommended Practice 581 is an example of a semi-quantitative RBI method that is highly reproduceable due to rigorous calculations. Conversely, a qualitative RBI method is less reproduceable due to the subjectivity introduced by expert opinion.

Note Quantitative analysis uses logic models to calculate probabilities and consequences of failure. These logic models, which are used to characterize materials damage of equipment and to determine the COF, can have significant variability and therefore can introduce error and inaccuracy that impacts the quality of the risk assessment.

Measurement systems can suffer from both accuracy and precision problems. The dart boards in [Figure 2](#) help us visualize the difference between the two concepts:

			
a) Accurate and Precise	b) Precise, but not Accurate	c) Accurate but not Precise	d) Neither Accurate nor Precise
Examples of Data/Program Control			
High quality data Detailed procedures Rigorous, reproduceable, and repeatable calculations	Detailed procedures Repeatable calculations Good calibration, but to wrong value	Quality data Reproduceable calculations Calibration required	Subjective Opinions Vague procedures Little or no calculations
The mean of the data sample is about the true value and there is low standard deviation in the sample.	The mean of the sample is not close to the true value, but the standard deviation for the sample is low.	The mean of the sample is close to the true value, but there is a high standard deviation.	The mean of the sample is not close to the true value and there is a high standard deviation.
The result would be free from errors.	The result is in disagreement with the expected one.	There are meaningful variations in the measurements.	The result would lack correctness and exactness at the same time.

Figure 2—Accuracy vs Precision

NOTE Risk presented as a precise numeric value (as in a quantitative analysis) implies a greater level of accuracy when compared with a risk matrix (as in a qualitative analysis).

The procedure used to execute the RBI methodology can have significant impact on both accuracy and precision. If no procedure exists, the likely output for both semi-quantitative and qualitative RBI processes would be neither accurate nor precise. A detailed and complete procedure for a qualitative program will likely give an output that is accurate, but not precise. This is due to the amount of subject matter expert input into the program that could cause variance based upon the individual's experience. A detailed and complete semi-quantitative procedure (e.g. API Recommended Practice 581 methodology) that does not check the data inputs into the program would give consistent results that are precise but may not be accurate.

Examples of RBI inputs that can affect accuracy and precision are shown in [Table 1](#).

Table 1—Example of RBI Inputs

Example	Impact on Accuracy	Impact on Precision
NDE use of radiography vs. straight beam ultrasonics	Straight beam ultrasonics, from a qualified technician, provides more accurate thickness results than radiography.	The precision of radiography largely depends on the procedure being used and the reproducibility of the inspection results executed by the same NDE technician.
NDE use of radiography vs angle beam ultrasonics	Depending on the type of flaw being detected the accuracy between these two NDE techniques will differ e.g. radiography is better at detecting porosity vs. UT angle beam is better at detecting lack of side wall fusion.	Individual technician variance in executing and interpreting the NDE results.
Use of NDE screening techniques	Screening techniques for wall thickness that detect volumetric corrosion wall losses, infer a wall loss based upon estimated defect dimensions e.g. guided wave or PEC. Thus, screening techniques are not as accurate as direct measurement techniques.	Usage of GUL at interval inspection vs. GUL fixed mounted sensor will impact the precision of NDE results. Five % vs 1 % making the fixed mounted sensor more precise.
NDE technician to technician differences and qualification test	Qualification tests will determine how accurate a technician is at detecting flaws and anomalies as the test have sizing limits a technician needs to remain within to obtain credit for finding the flaw.	From a qualification test it can be determined if the technician consistently over or under sizing flaws. This data could be offset by a constant to make the measurements more accurate.
Pressure and temperature sensors/ gauges	Having redundant sensors providing two readings for pressure and temperature. Calibration and maintenance of sensors maintains sensor/gauge accuracy.	A pressure or temperature sensor sending real time data provides more accurate real time data for analysis than operator rounds taking readings from gauges. Pressure and temperature sensors can drift over time providing either consistently higher or lower readings; thus, being highly precise, but not accurate.
Process composition (e.g. weight/mole percents	Accuracy largely will depend upon the type of device being used to measure process contaminants e.g. Draegor tubes vs. gas chromatograph for measuring H ₂ S. Calibration of measurement devices also impacts accuracy.	Type of device being used to measure process contaminants can have variation when measuring the same sample e.g. Draegor tubes vs gas chromatograph for measuring H ₂ S.

Examples of variables impacting accuracy of RBI assessment:

- 1) Competency of personnel supplying and validating the inputs causing poor data that will likely lead to inaccurate RBI results.
- 2) Process excursions potentially missing credible damage mechanisms as part of the RBI assessment.
- 3) Equipment Information:
 - a) Materials of construction—improper identification of materials of construction (either through improper management of documents or documentation of repairs) can impact the selection of credible damage mechanisms.

- b) Correct damage mechanism assignment—poor process or competency of individuals executing damage mechanism assessment can impact the identification of credible damage mechanisms and thus, impact the accuracy of the overall RBI process.

Flawed Logic—where accuracy and/or precision problems are encountered with RBI data, focus on improving the measurement system before relying on the data and moving forward with the RBI assessment. The accuracy and precision of data are increasingly critical to ensure repeatable and reproduceable results of the selected RBI methodology.

Further, within RBI the implied linkage of precision and accuracy may not exist because of the element of uncertainty that is inherent with probabilities and consequences. In practice, there are often many extraneous factors that will affect the estimate of deterioration (POF) as well as the magnitude of a failure (COF) that cannot be fully considered with a fixed model. Therefore, it may be beneficial to use quantitative and qualitative methods in a complementary fashion to produce the most effective and efficient risk assessment, as well as one that maximizes accuracy and precision of both data and results.

5.4 Types of RBI Assessment

5.4.1 Risk-Based Inspection Analysis in General

RBI is a methodology that uses relative risk as a basis for prioritizing and managing the efforts of an inspection program. The overall RBI process also incorporates the efforts of monitoring and mitigation activities to help manage risk. It provides focus for the inspection activity to specifically address threats to the integrity of the equipment. The POF and COF are assessed and then combined to determine the risk of failure. Risk is compared and prioritized for inspection planning and risk mitigation.

Some quantitative RBI programs also identify and measure the relative uncertainties associated with ascertaining the condition of the equipment. Such a program uses risk to identify and prioritize when those uncertainties must be reduced, typically by improved knowledge through additional data gathering. This may be achieved by verification of actual degradation rates or actual condition of equipment via inspection and monitoring methods. As an illustration, implementation of IOWs, use of permanently mounted monitoring probes, or complete equipment scanning are all examples of methodology and technology that may be used to reduce uncertainty.

An RBI assessment should include the following:

- a) Systems or processes within an operation prioritized by risk.
- b) Determined risk value or category associated with an equipment item within a system or process based on a consistent methodology.
- c) Equipment ranking based on risk.

5.4.2 Risk-Based Inspection Analysis Methods

An RBI program is based on relative risk and it is imperative that the RBI assessment be performed consistently. RBI assessment methods can be:

- 1) qualitative,
- 2) quantitative, or
- 3) semi-quantitative.

The choice of RBI assessment method is dependent on multiple variables such as, but not limited to:

- i) objective of the assessment;

- ii) number of facilities and equipment items in the assessment;
- iii) available resources;
- iv) length of time that the assessment is valid;
- v) complexity of facilities and processes;
- vi) nature and quality of available data;
- vii) risk differentiation between equipment; and
- viii) degree of precision desired.

Each method provides a systematic way to screen for risk, identify areas of potential concern, and develop a prioritized list for more in-depth inspection or analysis. Also, each method develops a risk ranking measure to be used for separately evaluating the POF and the credible COF. These two values are then combined to estimate the risk of failure.

The chosen method should be selected at the beginning of the analysis process and carried through to completion. However, the method may be changed (i.e. the analysis may increase or decrease the quantitative degree) as the analysis progresses due to the quality and quantity of data being obtained. Overall, the consistency of the method will be vital to comparing results from one risk assessment to the next.

The spectrum of risk analysis should be visualized as a continuum with qualitative and quantitative methods being the two extremes of the continuum and everything in between being a semi-quantitative method ([Figure 3](#)). Use of expert opinion shall be included in a risk assessment regardless of type or level.

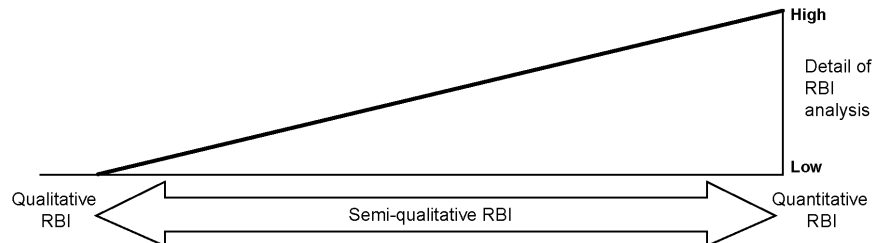


Figure 3—Continuum of RBI Methods

5.4.3 RBI Method Descriptions

5.4.3.1 Continuum of Methods

In practice, an RBI program typically uses aspects of qualitative, semi-quantitative and quantitative methods (see [Figure 3](#)). For a continuum approach these methods are considered as complementary rather than competing. For example, a high-level qualitative method could be used at a unit level to select the unit within a facility that provides the highest risk equipment for further analysis. Higher risk systems and equipment within the unit may then be screened using a quantitative method. Another example could be to use a qualitative COF combined with a semi-quantitative POF.

When performing risk analysis across different equipment, a single site or multiple sites, the user is cautioned about comparing specific results unless the same or very similar RBI methodologies and assumptions were applied. The user is also cautioned against drawing conclusions about different results when different methodologies are used to evaluate the same piece of equipment. Most risk results are relative in nature therefore the results of any one methodology should be viewed as a relative risk ranking as determined by the specific methodology selected.

5.4.3.2 Qualitative Method

The qualitative method requires data inputs based on descriptive information using engineering judgment, subject matter expertise, and experience as the basis for the POF and COF. Inputs are often provided in data ranges instead of discrete values. Results are typically given in qualitative terms such as high, medium, and low, although numerical values may also be associated with these categories. The value of this type of analysis is that it enables completion of a risk assessment in the absence of detailed data. The accuracy of results from a qualitative analysis is more dependent upon the background and expertise of the risk analysts and team members and whether a detailed procedure is being used consistently. Qualitative methods are less precise than quantitative methods, but not necessarily less accurate. Qualitative methods can be effective for initial screening of units/equipment and may prove beneficial when attempting to prioritize where to begin a quantitative methodology. If used as the sole methodology, it should be known that qualitative methods are generally more conservative than quantitative methods and will typically generate more conservative mitigation and inspection plan recommendations. Qualitative methods are generally more difficult to reproduce than quantitative risk assessments.

5.4.3.3 Semi-Quantitative Method

Semi-quantitative is a term that describes any method that has aspects derived from both a qualitative and more data intensive, albeit theoretical, fully quantitative method. A semi-quantitative method is geared to obtain the major benefits of both the qualitative and quantitative methods (e.g. speed of the qualitative and rigor of the quantitative). The majority of RBI assessments performed fall into the semi-quantitative realm due to the enormity of the extent of data and calculations required for the quantitative risk assessments. Often even qualitative approaches will have some quantitative elements for asset COF and/or POF. With that being said, most RBI methodologies are categorized as semi-quantitative risk assessments. The results are usually given in COF and POF categories or as risk numbers, but numerical values may be associated with each category to permit the calculation of risk and the application of appropriate risk acceptance criteria.

With most semi-quantitative approaches, model-based methods are used where numerical values are calculated, and more discreet input data are used. The advantages are:

- a) calculates with standardized precision, i.e. typically produces more repeatable risk results;
- b) discrimination between equipment risk allowing prioritization of mitigation;
- c) trending and monitoring risk exposure over time as well as other metrics;
- d) benchmarking of results to allow for POF and COF trending and comparisons.

Many of the semi-quantitative methods require a software program to calculate risk and will generate standardized inspection program recommendations. The standardized software models used are initially data-intensive, but the use of models can remove repetitive, detailed work from the traditional inspection planning process.

These methods provide for a means of prioritizing equipment risk in a risk matrix or ISO-risk plot. Additionally, they can provide for calculations of discrete risk values for prioritization from higher to lower risk. Equipment items are ranked based on risk with POF, COF, and risk calculated and reported separately to aid identification of major contributors to risk, or risk drivers.

NOTE There are differences in the RBI methodologies that are available, using widely varying degrees of quantitative and qualitative approaches, analytical methodologies, level/complexity of analysis, etc. relative to the individual risk assessments of POF and COF. The owner-operator should review the program (in-use or as a potential for utilization) to understand the premise for the analysis and its limitations.

5.4.3.4 Quantitative Methods

Quantitative RBI programs should be viewed as theoretical due to the lack of fully quantitative data sets and corresponding modeling that captures all aspects of a risk scenario. RBI for the petrochemical industry produces