

RISK BASED INSPECTION METHODOLOGY OVERVIEW

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The paper presents general methodology of Risk Based Inspection. The method concerns the estimation of frequency and scope of inspection of static equipment, which operates in oil & gas industry. About 80% of risk of equipment's failure is associated with only 20% of equipment quantity so it becomes very important to establish a prioritised list of carried out inspections. In RBI method this priority is established as function of risk of equipment failure and consequences of such failure. In the paper the definition of risk in RBI aspect and way of its assessment are given.

Keywords: inspection, risk, inspection program

INSPEKCJA W OPARCIU O RYZYKO – PRZEGLĄD METODY**Streszczenie**

W artykule przedstawiono ogólne założenia metody RBI ustalania częstotliwości i zakresu przeprowadzania inspekcji urządzeń eksploatowanych w przemyśle naftowym. Literatura podaje, że około 80% ryzyka związanego z uszkodzeniami tych urządzeń związane jest z około 20% ich liczby, ważne jest zatem ustalenie priorytetu wykonywanych inspekcji. W metodzie RBI priorytet ten ustala się w zależności od ryzyka wystąpienia uszkodzenia jak i jego skutków. W artykule podano określenie ryzyka w ujęciu metody RBI jak również sposób jego szacowania.

Słowa kluczowe: inspekcja, ryzyko, program inspekcji

1. INTRODUCTION

In the nineteen's, the American Petroleum Institute (API) initiated a RBI project with a sponsor group composed of petroleum industries, dedicated to refineries. The aim of project was to elaborate the method to direct inspection resources to the areas of a plant where there is the greatest risk-reduction and cost savings potential. Other facility types could be covered by a RBI methodology. The main principles remain unchanged, only the detailed methodology has to be customised according to the activities under consideration.

2. WHAT RBI IS

RBI is a method for using risk as a basis for prioritising and managing the effort of an inspection program to rationally allocate inspection resources. The term of "inspection" is understood as a systematic procedure used to assess equipment technical conditions. It is usually performed on a fixed periodical basis. In a operating plant or installation, a relatively large percentage of risk is associated with a small percentage of the equipment items. Typically, about 80% of risk of equipment's

failure is associated with only 20% of equipment (fig. 1). RBI allows shifting inspection and maintenance resources to provide a higher level of coverage on the high-risk items and an appropriate effort on lower risk equipment.

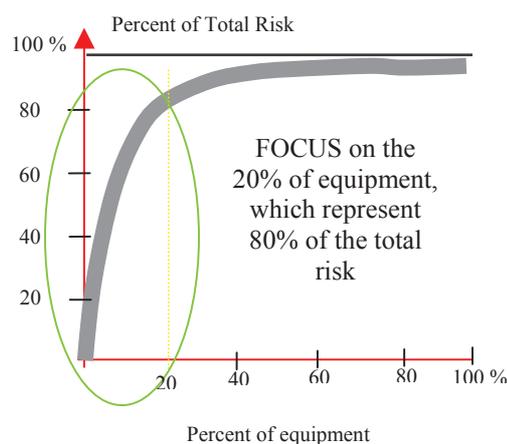


Fig. 1. Typical risk plot "total risk vs. quantity of equipment"

The RBI method defines the risk of operating equipment as the combination of two separate terms: the likelihood of an undetected failure and the consequence of such a failure. It is worth to notice, that such approach of term "risk" is also

used in safety standards as well as in other disciplines [3].

The assessment of failure consequences follows these steps:

- Scenarios definition in which failure (i.e.: leak) progress into undesirable events
- Estimation of the physical effect of each scenario
- adverse effect on people, equipment, environment, productivity as a result of the outcome.

The likelihood of failure assessment takes into consideration such criteria as :

- the damage mechanisms applicable to the item analysed
- the inspection history of the item
- the effectiveness of the previous inspection

The detailed method to assess consequence and likelihood depends directly upon the facility type. Furthermore, the level of detail of the method is fitted to the future use of the result, the available data for the analysis, the need of accuracy of the result: a range of probability/consequences or a formal probability/consequences.

In general, main steps of RBI study are as follow:

- preliminary analysis,
- failure probability assessment,
- consequence evaluation,
- risk ranking,
- inspection program

3. RISK ASSESSMENT - QUALITATIVE AND QUANTITATIVE APPROACH

Talking about the risk assessment as part of an RBI study, basically two approaches are possible:

- Qualitative
- Quantitative.

Qualitative approach is effective mainly for preliminary screening and to justify a hierarchy within the equipment criticality (=prioritisation). Qualitative method is based on factor ranking from expert judgement. Such prioritisation allows a rational allocation of inspection resource. However, it is usually difficult to assess precisely the impact of an inspection strategy on the risk with a qualitative approach.

Quantitative approach allows an accurate appraisal of the impact of an inspection strategy on the risk. A detailed quantitative approach is used for the most critical equipment resulting from the screening stage. Risk assessment uses statistical data and damage mechanism modelling.

The choice of the analysis level depends on the knowledge of risk level associated to the installation. However, the detailed specification of the method has to be fully designed to:

- The final need of its user,

- The required accuracy in the result,
- The availability of the data,
- The actual practices.

3.1. Qualitative approach

In the qualitative approach, which could concern units, systems or items, different likelihood and consequence factors are assessed. Each factor is rated within a pre-defined scale or framework. Weight of each factor and their combination to obtain the global likelihood/consequence factor have to be defined. Ranking is based on expert judgement.

Likelihood assessment - factors

- The equipment factor is related to the number of components in the unit that have the potential to fail.
- The damage factor is a measure of the risk associated with known damage mechanisms in the unit. These mechanisms include levels of general corrosion, fatigue cracking, low temperature exposure, high temperature exposure
- The process factor is a measure of the potential for abnormal operations or upset conditions to initiate a sequence leading to a loss of containment. It is a function of the number of shutdowns or process interruptions (planned or unplanned), the stability of the process and the potential for failure of protective devices because of plugging or other causes.
- The mechanical design factor measures the safety factor within the design of the unit: whether it is designed to current standards, and how unique, complex or innovative the unit design is.
- The inspection factor provides a measure of effectiveness of the current inspection program and its ability to identify the active or anticipated damage mechanisms in the unit. It examines the types of inspections, their thoroughness and the management of the program
- The condition factor accounts for the physical condition of the equipment from a maintenance and housekeeping perspective. A simple evaluation is performed on the apparent condition and upkeep of the equipment from a visual examination.

The likelihood factor is a combination of these factors. A likelihood category will correspond to the likelihood factor. The likelihood category gives the vertical position of the item in the risk matrix.

Consequence assessment - factors

The consequence factor is the highest factor between the damage factor and the health factor.

- The damage factor

The damage factor is derived from a combination of five sub-factors that determine the magnitude of a fire or explosion hazard:

- the chemical and quantity factor represents a chemical's inherent tendency to ignite (this is derived as a combination of the material's Flash factor and its reactivity factor) and the largest amount of material that could reasonably be expected to be released from a unit in a single event

- the state factor is a measure of how readily a material will flash to a vapor when it is released to the atmosphere. It is determined from a ratio of the average process temperature to the boiling temperature at atmospheric pressure

- the pressure factor is a measure of how quickly the fluid can escape.

- the credit factor is determined to account for the safety features engineered into the unit. These safety features can play a significant role in reducing the consequences of a potentially catastrophic release

- the degree of exposure is represented by the damage potential factor. This is accomplished by a rough estimate of the value of equipment near large inventories of flammable or explosive materials.

- The health factor

The health factor is a combination of four sub-factors :

- the toxic quantity factor is a measure of both the quantity and the toxicity of a material. (the toxicity is found using NFPA toxicity factor

- the dispersibility factor is a measure of the ability of a material to disperse. It is determined directly from the normal boiling point of material. The higher the boiling point, the less likely a material is to disperse

- the credit factor is determined to account for the safety features engineered into the unit

- the population factor is a measure of the number of people that can potentially be affected by a toxic release event.

A consequence category will correspond to a consequence actor. The highest one is plotted in the horizontal axis of the risk matrix.

3.2. The quantitative approach

The RBI programme is not a full risk analysis, but a hybrid technique between risk analysis and mechanical integrity. In its elemental form, a risk analysis is comprised of five tasks:

- System definition
- Hazard identification
- Consequence assessment
- Probability assessment
- Risk results.

Depending on the nature of the process and the detail of the study, a risk analysis may include thousands of different scenarios. The risk analysis would evaluate both the likelihood and the consequence of the set of events in each scenario.

For RBI, likelihood and consequence are also evaluated, but for a carefully defined and limited number of scenarios.

3.2.1. Preliminary analysis

In the system definition phase of the analysis, the ground rules are established and all pertinent information is collected. In fact, to be able to assess the likelihood and the consequences required for the risk assessment, some preparatory work has to be carried out more or less accurately according to the level chosen for the analysis :

- the design analysis
- the process and flow analysis
- the identification of damage mechanisms and evaluation of their kinetics

3.2.2. Consequence of failure

The failure of pressure –containing equipment and subsequent release of hazardous materials can lead to many undesirable effects. The RBI programme has condensed these effects into four basic risk categories:

Flammable events can cause damage in two ways : thermal radiation and blast overpressure

Toxic releases, in the RBI approach are only addressed when they affect personnel. These release can cause effects at greater distances than flammable events. And unlike flammable releases, toxic releases do not require an additional event (ex. : ignition) to cause an undesirable event.

Environmental risks are an important component to any consideration of overall risk in a processing plant. Environmental damage can occur with the release of many materials: the predominant risk comes from the release of large amounts of liquid hydrocarbons outside the bounds of the plant.

Business interruption can often exceed the costs of equipment and environmental damage and, therefore, should be accounted for in the RBI programme. Equipment replacement costs can be trivial compared to the business loss of a critical unit for an extended period of time.

Various scenarios are then developed to show how leaks may occur and how they can progress into undesirable events. They are four defining factors in a leak scenario :

- the size of the hole in the equipment
- the fluid properties : in equipment and at ambient conditions
- the total mass available for release
- the mitigation systems

The risk calculation is performed for each scenario (hole size), for all four risk categories, if desired. The risk for each equipment is then found by summing the individual risk components from each scenario calculation.

In a practical manner, a discrete set of hole sizes must be used. It would be impractical to perform risk for a continuous spectrum of hole sizes. Experience has shown that limiting the number of hole sizes allows for an analysis that is manageable yet still reflects the range of possible outcomes. The RBI method uses a predefined set of hole sizes representing small, medium, large and rupture case, with associated probability of occurrence. This approach provides reproducibility and consistency between studies; and it increases the ease with which the process can be automated with software. Finally, the three main steps of the consequence analysis are by order :

- The scenarios definition in which leaks may progress into undesirable events (a set of hole size)
- The estimation of the physical effect of each scenarios
- The adverse effects on people and equipment as a result of the outcome

But as the consequence analysis aims at aiding in establishing a relative ranking of equipment items on the basis of risk, the consequence measures usually presented are intended as simplified methods for establishing relative priorities for inspection programs. If more accurate consequence estimates are needed, the analyst could refer to more rigorous analysis techniques, such as those used in Quantitative Risk Analysis, and after could re-inject his result in the consequence analysis.

3.2.3. Likelihood of failure

The likelihood analysis begins with a database of generic failure frequencies for the specific equipment types. Examples of so called generic failure frequencies are presented in table below. For the sake of simplicity it is assumed that, in any case, the final failure mode is a breach of conventional size (1/4", 1", 4", 16" or rupture).

	1/4"	1"	4"	rupture
Column	$8 \cdot 10^{-5}$	$2 \cdot 10^{-4}$	$2 \cdot 10^{-5}$	$6 \cdot 10^{-6}$
Filter	$9 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
pipng.(8")	$3 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$8 \cdot 10^{-8}$	$2 \cdot 10^{-8}$
vessel	$4 \cdot 10^{-5}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-5}$	$2 \cdot 10^{-5}$

These generic frequencies are then modified by two terms, the Equipment Modification Factor (F_E) and the Management System Evaluation Factor (F_M):

$$\text{Frequency}_{\text{adjusted}} = \text{Frequency}_{\text{generic}} * F_E * F_M \quad (1)$$

The database of generic failure frequencies is based on a compilation of available records of equipment failure histories. The records can come from a variety of sources. Generic failure

frequencies have been developed for each equipment and each diameter of piping. If enough data were available for given equipment item, true failure probabilities could be calculated from actual observed failures.

The generic failure frequencies are built using records from all plants within a company or from various plants within an industry, from literature sources, past reports, and commercial databases. Therefore, the generic values represent an industry in general and do not reflect the true failure frequencies for a specific plant or unit.

The RBI method requires that the analyst use a generic failure frequency to "jump start" the probability analysis.

Equipment Modification Factor

The Equipment modification factor reflects the specific operating conditions of each item. It evaluates two categories of information linked to the equipment item:

- damage rate of the equipment item's material of construction, resulting from its operating environment.
- effectiveness of the facility's inspection program to identify and monitor the operative damage mechanisms prior to failure.

The RBI approach considers by definition that items are monitored and if an inspection points out a critical state for an item, preventive measures are systematically taken (repaired, changed...). So we don't consider only the failure likelihood but the likelihood that an undetected damage state becomes critical.

In fact, the equipment modification factor takes into account both the failure likelihood of the item, P_f , and the likelihood to detect the real damage state, P_{dp} . This second factor varies according to the inspection results in accordance to the Bayes principle.

As a consequence, the non detected failure probability is symbolically written as:

$$P_f * P_{dp} = F_{\text{Generic}} * F_E \quad (2)$$

The failure likelihood for each equipment item is calculated from structural integrity method where the damage mechanism kinetics is taken into account.

Management System Evaluation

Management Systems Evaluation Factor is derived from the results of an evaluation of a facility or operating unit's management systems that affect plant risk to adjust generic failure frequencies for differences in Process Safety Management systems. The factor is applied equally to all equipment items within the study and as a result, it does not change the order of the risk-based ranking of the equipment items. As an information, the management systems evaluation covers a wide range of topics like leadership and administration, process safety information, process hazard analysis, management of change, operating procedures, safe work practices, training, mechanical integrity, pre-startup safety review, emergency response, incident investigation, contractors, audit.

4. CRITICALITY ASSESSMENT AND ACCEPTANCE CRITERIA

The risk assessment produces, as result, item per item, a likelihood of failure and a consequence of failure, which are reported on a matrix representing a risk level (fig. 2). Each item is located on such a matrix to have a global representation of the risk.

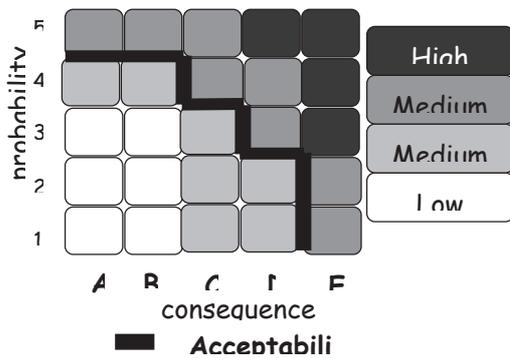


Fig. 2. Example of risk matrix

The definition of the matrix (usually 5X5 or 3X3), definition of each level and definition of acceptance criteria are set up case by case and depend on standard practices and industry practices.

As for example, in the matrix on figure 2, the black line figures a possible acceptability limit to be adjusted case by case:

High: it is likely that the failure occur more than once before next inspection - so criticality has imperatively to be reduced

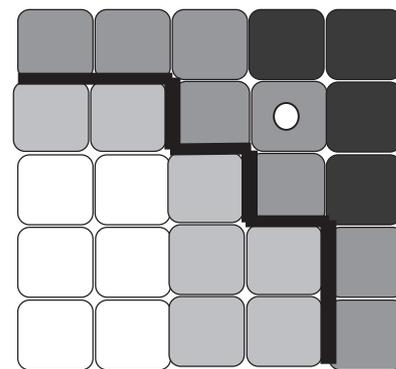
Medium-high: it is likely that the failure occurs once - it needs corrective actions

Medium: it is unlikely that the failure occurs - it is an acceptable risk

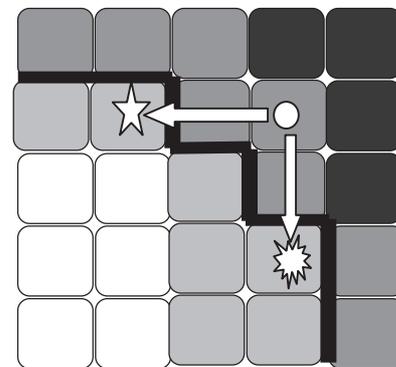
Low : it is very unlikely that the failure occurs - does not need specific actions.

Then it is essential to define where is the acceptability limit.

For an item in the unacceptable part of the matrix, the risk has to be reduced. Given that the risk of an accident has two components, likelihood and consequence, to limit risk, one must reduce one or both of the risk components (fig. 3). In fact inspection only affects the likelihood factor. In order to reduce consequence, the design have to be reviewed (adding mitigation systems, distancing equipment...), and this is not within the RBI scope. The objective of RBI is to issue an inspection programme. So, the mitigation measures will consist in defining an inspection strategy to get more information on the condition of the equipment to better control it.



Definition of mitigation measures in order to achieve an acceptable risk



- Unacceptable risk D4
- ☆ Acceptable risk B4
- ★ Acceptable risk D2

Fig. 3. Reducing risk components

For acceptable risk, one should not avoid to define mitigation actions as far as it won't cost: benefit planned inspection to extend the scope at quasi zero cost.

If no inspection strategy is able to make the risk acceptable a “run, repair, replace” decision has to

be defined. This action “RRR” is usually not considered are being included in an RBI process.

5. INSPECTION PROGRAMMING

This step contains two major points :

- development of inspection programmes addressing the types of damage that inspection should detect, and the appropriate inspection techniques to detect the damage
- reducing risk through inspection discusses the application of RBI tools to reduce risk and optimise inspection programmes.

Inspection influences risk, primarily by reducing the probability of failure. Many conditions (design errors, fabrication flaws, malfunction of control devices) can lead to equipment failure but in-service inspection is primarily concerned with the detection of progressive damage. The probability of failure due to such damage is a function of four factor.

- damage mechanism and resulting type of damage,
- rate of damage progression,
- probability of detecting damage with inspection techniques and predicting future damage states,
- tolerance of the equipment to the type of damage.

The purpose of an inspection programme is to define and perform those activities necessary to detect in-service deterioration of equipment before failures occur. An inspection programme is developed by systematically identifying:

- What type of damage to look for,
- Where to look for,
- How to look for the damage (inspection techniques),
- When or how often to look for.

As the risk is set for a given inspection strategy: it is a risk at a given date in the future with a given inspection effectiveness.

The comparison of the risks linked to several inspection strategies will provide a framework for decision. Operators can prefer to maintain the risk as low as possible even if the associated costs are higher, or to limit their expenses as much as possible without, of course, over passing their acceptability limit of risk.

So, taking into account several strategies and analysing their likelihood variation with time, we could choose the best one according our objectives and priorities. Fig 4. tries to localise the inspection plan elaboration through the entire methodology.

6. CONCLUSIONS

Risk Based Inspection allows inspection, test, and maintenance efforts to focus on the most important pieces of equipment. By using the RBI method it is possible to rank all process components according

to risk, to indicate the time to next inspection and to perform a cost optimization based on risk.

The likelihood (estimation of the likelihood of a functional failure of the equipment item) and consequence (estimation of the impact or cost of the failure) rankings are determined independently, and then are used to establish criticality assessment. Knowing criticality allows maintenance strategies to be developed which focus appropriate effort on all equipment items. Here are some examples of applications of Risk Based Inspection Programs implemented by BV Abu Dhabi in oil & gas industry on the Middle East.

7. EXAMPLES

7.1. QATAR PETROLEUM (Formerly QGPC)

QP conducts oil & gas exploration, development and production operations offshore Qatar on production platforms Maidan Mahzan (PS2), Bul-Hanine (PS3). Crude oil is transported via pipe lines to the crude oil terminal situated on Halul Island.

QGPC ordered for an inspection strategy for the static equipment on the above mentioned locations to be set up. This strategy was to indicate the intervals between inspections, techniques to be used as alternative method of inspection and monitoring to eliminate the unnecessary cost while preserving the asset integrity.

BUREAU VERITAS services included:

- the study of past inspection and equipment failures, plant design and business of facility
- the performance of complete criticality assessment for all equipment
- the production and submission of inspection schedules including proposed inspection methods and non-intrusive inspection techniques

A complete Computerised RBI system was developed in-house to manage the large quantity of data.

The Project was completed in 2 years, and delivered to QP in summer 2000.

7.2. OCCIDENTAL OF QATAR

After taking over from QGPC the PS-1 production station, which consists of a number of oil process, gas process, utilities and accomodation jackets interconnected to bridges, Occidental Petroleum of Qatar decided to implement a Risk Based approach for the scheduling of inspections of their production process and piping. The aim was to identify critical items and obtain a user friendly tool allowing to follow-up and monitor the shape of the installations, while implementing a cost effective yet more efficient inspection strategy. One additional objective for OXY was to be able to report the actions and inspections carried out on their installations to QGPC at the end of the leasing period in a clear and straight forward manner.

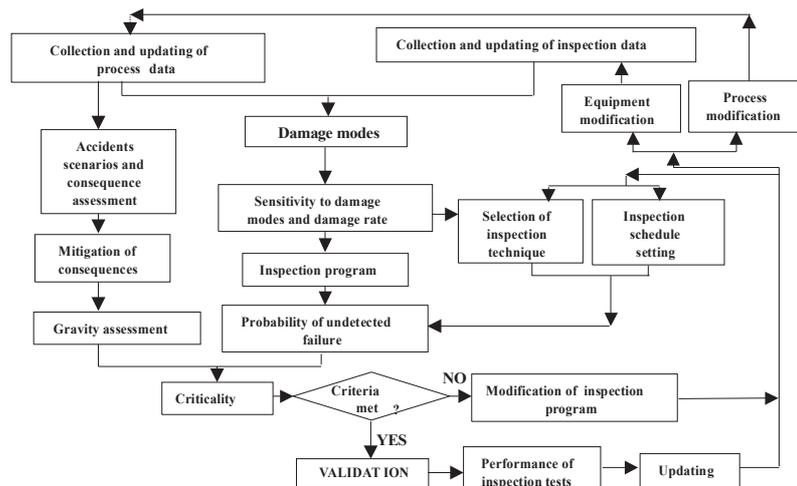


FIG. 4. Summary of the overall methodology

Bureau Veritas proceeded along the following steps

- 1- Screening of the inspection scheme in place,
- 2- Set up of a proprietary dedicated RBI Manual,
- 3- Dedicated database and associated software development,
- 4- Data gathering,
- 5- Pilot Case and experience feedback,
- 6- Deployment,

Most of the work was carried out on site, thus facilitating the input from the Operator's expertise and knowledge of the installations.

7.2. OCCIDENTAL OF OMAN

In order to optimize the inspection strategy, OCCIDENTAL PETROLEUM OF OMAN Inc. decided to change from a policy of a 2-year shutdown period to a 'Level 2, semi-qualitative RBI' strategy.

This strategy will be applied to all static equipment and pipework in the Suneinah concession block. The program is to be implemented in stages and completed by end of year 2002.

The Units covered by the Scope are :

- 100 Unit - crude stabilization
- 400 Unit - crude topping plant
- 500 Unit - NGL recovery plant
- 600 Unit - Gas re-injection plant
- K-102 A-G Unit - Residue gas re-injection
- K-103 A-D Unit
- IP gas boosters
- 4 production stations located at : # Safah Central & satellite # Al Barakah # Wadi Latham

An overall amount of about 300 equipment and 600 approx. is included in the study.

During this Project, Bureau Veritas acts as a Consultant with a view of :

- defining the global RBI approach to be adopted by Occidental Petroleum Oman,

- training the Occidental personnel to the application of this methodology,
- initialising the chosen software and start the implementation process.

Acknowledgements

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Eric Veith obtained his Master degree in Corrosion Science from UMIST (Manchester) in 1989. After few years with a subsea works company, he joined Bureau Veritas in 1994 as a Corrosion/inspection specialist. Eric is presently Energy & Process Business Line Manager for this Company in the United Arab Emirates."