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Experiences in Implementing Risk-Based Inspection

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ADOPTION OF RBI PLANNING FOR PRESSURE SYSTEMS

Some of the ‘early adopters’ of risk-based inspection (RBI) failed to cross the RBI technology chasm because as pioneers, they were essentially experimenting with the suitability of this new technology, Figure.1. The followers (‘early and late majority’) can benefit from the experiences (failures and successes) of these trailblazers.

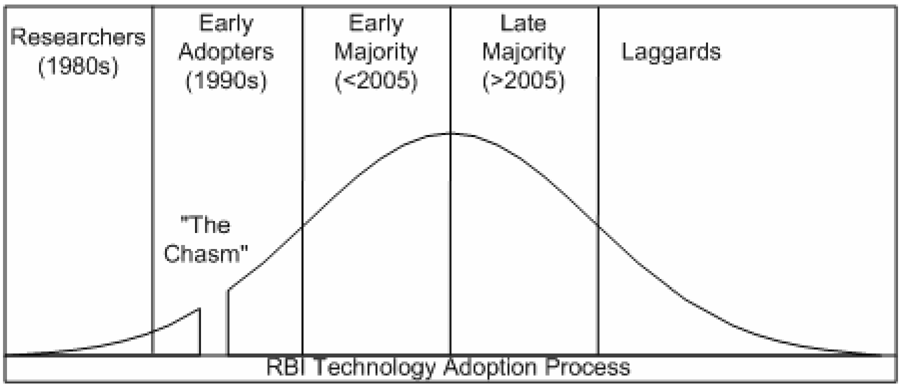


Figure 1: **Adoption process for RBI planning for pressure systems**

RBI has received considerable attention since the American Society of Mechanical Engineers (ASME) [1] and the American Petroleum Institute (API) [2] began publishing guidelines on risk-based inspection and maintenance planning methods in the late 1980’s.

The Bahrain Petroleum Company (BAPCO) was one of the first operators in Bahrain to implement RBI. Since RBI planning continues to generate considerable interest in the Middle East, some of the practicalities of applying RBI are also presented in this paper. These experiences arose during a pilot study with TWI, conducted on process plant, storage tanks, boilers and pipelines at BAPCO in 2003.

USER-EXPERIENCE OF RISK-BASED LIFE MANAGEMENT PRACTICES

As part of a major joint industry project [3], TWI carried out a questionnaire-based industrial survey in 2001, to gain a better understanding of the reality of RBI usage and the needs of operators. Approximately 90 of the questionnaires that were distributed worldwide, were returned to TWI. Some of the more interesting findings, are reported in this paper for the benefit of operators new to RBI.

At the time, respondents indicated that there is no substantial increase in the accuracy of semi-quantitative RBI compared to qualitative RBI. However, respondents believed that qualitative methods were substantially faster to apply than semi-quantitative RBI methods. Quantitative (probabilistic) methods were considered to be the most accurate of the three methods, but also the slowest of the three to execute.

At the time, only 57% of all respondents indicated that their safety regulating authority accepted RBI as an alternative basis for determining inspection and maintenance intervals. There was also no single region in the world in which RBI was entirely accepted as an alternative basis for determining inspection intervals.

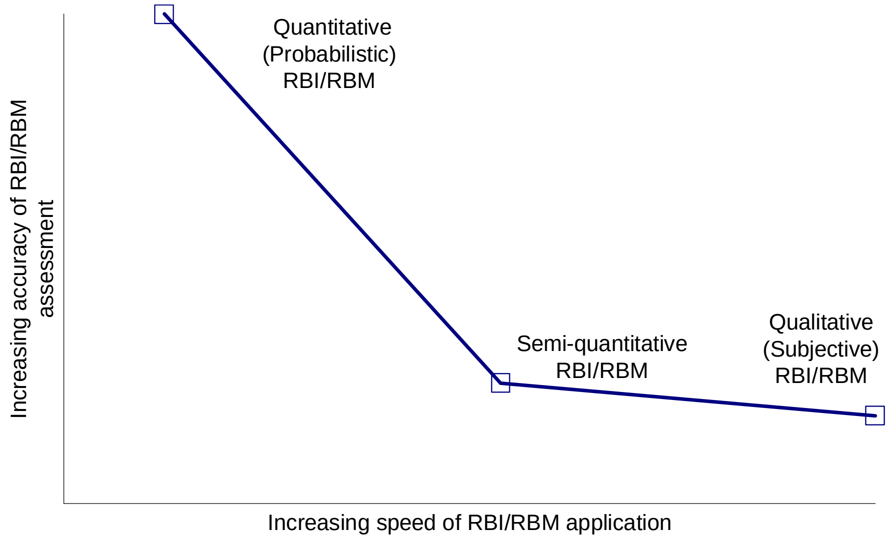


Figure 6: Relative ranking of the accuracy and speed of RBI methods.

For those respondents that had previously undertaken RBI assessments, the two most important reasons for implementing a RBI program were: (a) improving the overall safety of critical plant; and (b) reducing the duration of inspection or maintenance outages. Similarly for those respondents that had previously undertaken RBI assessments, the most critical success factors for RBI programs were: (1) having the 'right' people in the assessment team; (2) appointing a suitable assessment team leader; and (3) the reliability of the RBI analysis methodology.

RBI is a logical prioritisation technique that draws on the experience of personnel involved in inspection, maintenance, materials and corrosion, operations and safety. RBI can mean higher inspection costs, for example, if a facility is operated on the basis of run-to-failure maintenance and has historically done little in-service inspection. In this case the benefits of RBI may be a reduction in the number of unplanned shutdowns and improved safety.

RBI can also lead to lower inspection costs if a facility operates a 'traditional preventative inspection program', i.e. comprehensive internal inspection at fixed intervals. It is in such plants that RBI is likely to reduce inspection costs by extending inspection intervals and eliminating inspections of little benefit.

ESSENTIAL ELEMENTS OF IN-SERVICE INSPECTION PLANNING

There are essentially three drivers for operators to carry out in-service inspection: (1) to ensure the safety of company employees and the general public; (2) to maintain equipment reliability and availability to achieve production targets; and (3) for regulatory compliance, i.e. safety, environment, etc legislation.

When planning in-service inspections, the primary questions operators ask themselves are: Why? What? Where? How? When?

In the past, some operators have undertaken in-service inspections, simply to meet regulatory requirements. In a risk-based planning context, these three drivers are merged into one decision-making framework. Risk-based inspection (RBI) planning, also provides a systematic means of answering the other questions:

What? What pipelines, piping sections, pressure vessel components, etc should be thoroughly inspected? RBI is used to prioritise inspection effort in terms of risk of failure (RoF). Equipment with the highest RoF, i.e. highest likelihood of failure and highest consequence of failure, should be subject to the most comprehensive in-service inspection.

Where? Where should inspection be focused to detect and measure the active or potentially active damage mechanisms? The RBI process includes a thorough evaluation of known or potential in-service damage mechanisms. The process also involves identifying locations for damage, so that inspection and non-destructive testing (NDT) is targeted at the correct location.

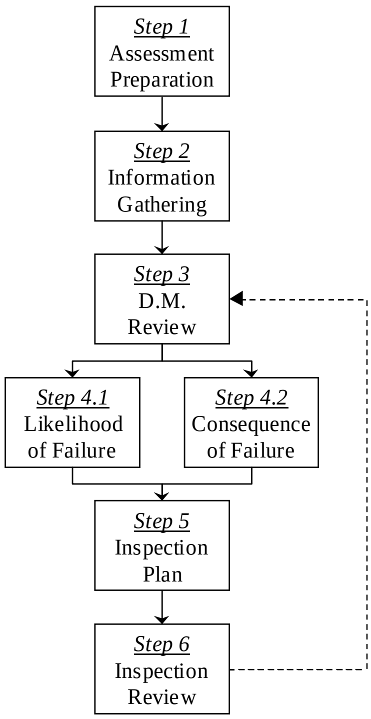
How? How or what NDT methods should be used to detect and measure the potential or active damage mechanisms, at the risk-targeted locations? The use of an inappropriate NDT method (e.g. surface inspection to detect embedded flaws) equates to a nil probability of detection (PoD). An inappropriately selected NDT procedure may result in reduced accuracy of sizing.

When? When should inspections take place to ensure the in-service damage does not propagate to point of failure of the pressure envelope? API has traditionally required inspection intervals to be no greater than half the estimate remaining life of the equipment, ie. the 'half-life rule'. API now permits RBI planning, where failure likelihood is based on an evaluation of time to failure, to avoid failure.

TWI'S APPROACH TO RBI ASSESSMENT AND PLANNING

The UK's Health and Safety Executive (HSE) has sponsored TWI to develop a best practice guide for RBI [3]. TWI's RISKWISE™ semi-quantitative RBI software system incorporates the key recommendations of both this HSE guidance document and the requirements of API RP 580* [2]. Although RBI methods differ in the level of detail of input data and output results, they all have common elements.

These common elements are: assessment preparation to determine the scope; historical maintenance and inspection information gathering; damage mechanism (DM) review; risk assessment to determine likelihood and consequence of failure; risk-based inspection planning and prioritisation; and inspection review and updating following future inspections (ie. based on the results of future inspections), Fig.3.



* This recommended practice does not prescribe any specific method of RBI but instead describes the elements of a competent RBI management programme.

Figure 3: Generic RBI assessment process

The damage mechanism review is important because at this stage estimates of the rate of damage must be made by the RBI team. The sources of information for this are:

- Trended historical inspection and NDT results, e.g. from PCMS;
- Historical maintenance and inspection records; and/or
- Published data, e.g. in API RP 571 [5], and damage models (if necessary).

Wherever quantitative rates of damage are not available, an element of expert judgement must be exercised by the RBI study team, i.e. on the basis of the operator's in-service operating experience with the equipment.

Several factors are considered in RISKWISE to determine the likelihood of failure (LoF) including, e.g. current condition, inspection effectiveness, operation in relation to design limits, cathodic protection, recurring repairs, etc. Similarly, several factors are considered to determine the consequence of failure (CoF) including, e.g. product loss, toxicity, effect of item failure on production, time taken to rectify item failure, threat to personnel and environment, engineered safety features, etc. The resultant LoF value is plotted on the vertical axis, and the CoF value is plotted on the horizontal axis, as an assessment point on a dimensionless five-by-five risk matrix.

In most cases, LoF increases with time as in-service damage propagates. Consequently, the rate of change of the LoF over forward periods of time will provide a basis for estimating remaining life. This is analogous to the calculation of a remaining life for a time-dependent damage mechanism such as corrosion, as follows:

$$RL = \frac{Damage_{failure} - Damage_{current}}{Rate_{damage} \times FoS}$$

where $Damage_{failure}$ is the level of damage at which failure will occur, $Damage_{current}$ is the current level of damage, $Rate_{damage}$ is the expected rate of damage, and FoS is a Factor of Safety. In this way, RISKWISE determines a remaining life indicator (RLI) as follows:

$$RLI = \frac{Likelihood_{max} - Likelihood_{current}}{Rate_{likelihood} \times FoS}$$

where $Likelihood_{max}$ is the maximum likelihood of failure (LoF) value in RISKWISE, and $Likelihood_{current}$ is the current likelihood of failure (LoF_{1AP}), as determined by RISKWISE. FoS is a factor of safety that can be assigned on the basis of the CoF. $Rate_{likelihood}$ is equivalent to the rate of change of likelihood of failure between that at the time of assessment (LoF_{1AP}) and the future likelihood of failure (LoF_{3AP}), and is calculated as:

$$Rate_{likelihood} = \frac{LoF_{3AP} - LoF_{1AP}}{\Delta AP}$$

where ΔAP is the forward time period between 1AP and 3AP.

The reliability of the calculated RLI, as a conservative tool for establishing inspection intervals, has been calibrated by TWI against calculated remaining lives. It should be noted that the RLI is not a prediction of remaining life. The RLI is a period of time during which the equipment will not fail, due to the associated damage mechanism.

SCOPE OF THE RBI PILOT STUDY FOR BAPCO

BAPCO's refinery in Bahrain selected TWI to conduct a RBI pilot study, on a representative selection of their plant, as follows:

- All fixed equipment within a vacuum distillation unit (VDU);
- One process piping circuit within this VDU;

- Two above ground storage tanks and two off-site pipelines; and
- One utility water-tube boiler.

The advantage of a pilot study is that it is relatively quick to undertake so it provides a cost-effective means of appraising the benefits of RBI before deciding on the extent of any company-wide implementation. A secondary aim of the project at BAPCO was to provide on-the-job and formal training to BAPCO staff, in the use and implementation of RBI methods and software tools.

The VDU was commissioned in 1973 and has since experienced eight major inspections, at intervals varying between three and four years. The principles of vacuum distillation resemble those of crude distillation except that larger diameter columns are used at higher temperature and reduced pressure (near vacuum) to prevent thermal cracking, Fig.2.

Recently, following a comprehensive internal study, an extended run-length of five years between turnaround and inspections (T&Is) has been approved within BAPCO. The basis for setting inspection intervals was standard practice, ie. by detailed evaluation of historical inspection findings, and corrosion rates from ultrasonic thickness measurement (using a software system called PCMS[+]). PCMS output and inspection findings and recommendations are stored within BAPCO's computerised maintenance management system (EMPAC), along with future inspection worklists.

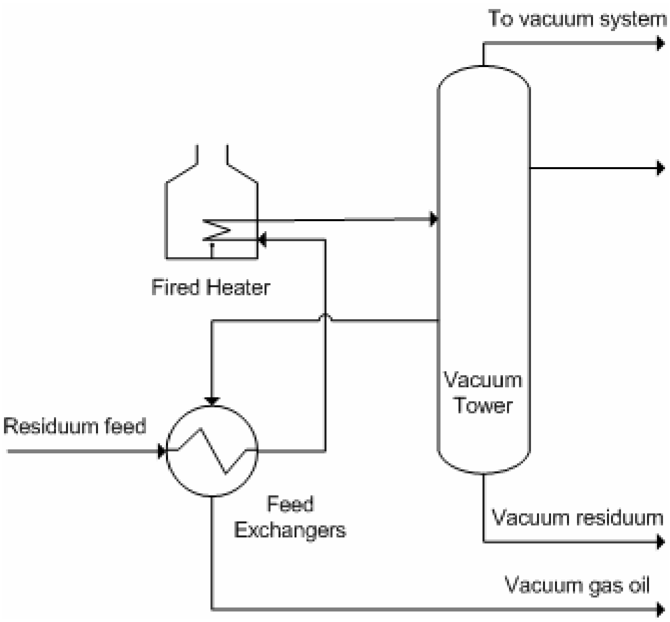


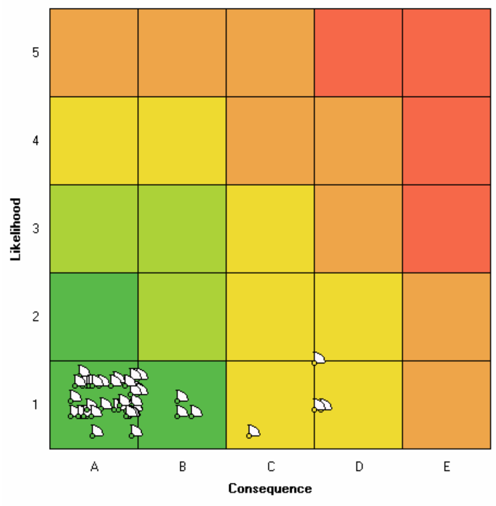
Figure 2: Vacuum distillation process

The two tanks were for naphtha storage (located in the refinery tank farm), and for diesel storage (located at the Sitra tank farm). Both tanks were commissioned in 1948. The selected pipelines are a crude feed and a medium straight run (MSR) product line, which run between the tank farms and associated process units. The 100,000 lbs/hr boiler was commissioned in 1944 and has been subject to biennial mandatory T&I, in accordance with Bahrain's Ministry of Labour (MOL) regulation for fired steam generating plant. For brevity, the RBI results for the boiler, tanks and pipelines are not presented in this paper.

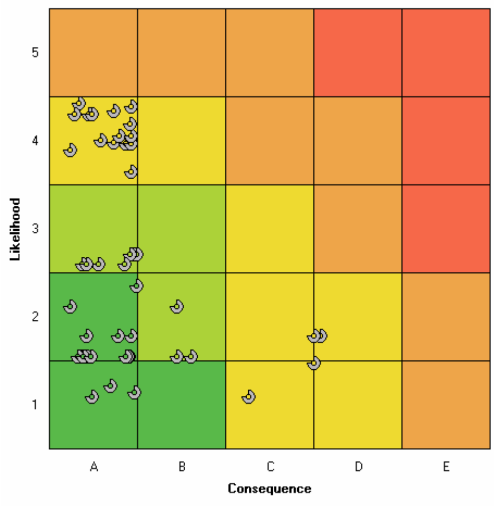
SELECTED RESULTS FROM THE BAPCO PILOT STUDY

The VDU risk plots are presented in Figure 4 and the results of the assessment in terms of RLI are summarised in Figure 5. It is immediately apparent that the majority of equipment have a relatively low RoF and that none of the equipment are considered to be critical within the current run (four years). The increase in LoF to category '4A' from '1A' for some damage mechanisms, Fig.4(b), is associated with the tube bundles in the feed shell and tube heat exchanger.

[+] PCMS calculates corrosion rates and remaining lives from UT measurements, thereby highlighting locations of particular concern with respect to pressure system integrity.



(a)



(b)

Figure 4: (a) Distribution of risk over the next four years, and (b) RoF 12 years from the date of the assessment.

All of the equipment were found to be non-critical in terms of RLI, i.e. the RLI is greater than or equal to the T&I interval of 48 months. Approximately 40% of the equipment have a RLI of 96 months, and approximately 50% of the equipment have a RLI greater or equal to 180 months. The calculated RLIs indicate that the proposed T&I interval of five years (60 months) is entirely acceptable.

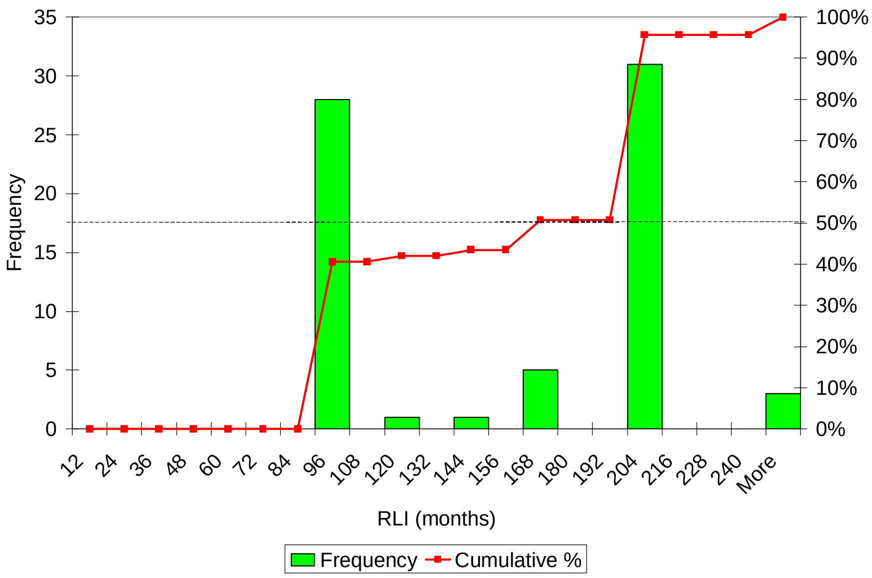


Figure 5: Histogram and cumulative distribution of RLIs for equipment in the VDU.

By undertaking a 'what if' analysis (the so-called Focus/Defocus process in RISKWISE) it is possible to qualitatively evaluate the sensitivity of the calculated RoF to certain assumptions. For example, if the dew point level, were to move into the top of the vacuum distillation column due to a change in reflux temperature, the RLI would be rapidly reduced from 114 months to 11 months. In this way RBI can be used to simulate what affect possible actions may have on the plant.

IMPORTANT CONSIDERATIONS FOR OPERATORS STARTING RBI

RBI takes considerable resources to develop, implement and maintain, and with software-based RBI, the user must be familiar with the basis of the risk models, damage mechanisms technical modules, etc. It is therefore essential that the RBI software is fully understood and accepted by the user is easily used without undue complexity. For increased efficiency, the RBI software could be linked to existing data management systems so that inputs and outputs can be electronically exchanged.

The RBI process should take account of all deterioration mechanisms. Failure databases derived from plant experience together with available material models and associated databases are important input. Most quantitative RBI methods are limited by their lack of technical modules for, e.g. fatigue, stress corrosion cracking, high temperature embrittlement, etc. Quantitative RBI assessment tools that use 'expert system' damage models will not flag fabrication and construction flaws in new equipment. Since comprehensive systems to predict all damage mechanisms do not currently exist, RBI should not be implemented by individuals operating in isolation.

The quality of the final output is as good as the input, therefore ‘two heads are always better than one’. The key unknown in a RBI assessment is damage rate, primarily with respect to changes in process conditions (e.g. temperature, flow rate, partial pressure, concentration of contaminants, etc). Therefore, the damage mechanism assessment, the risk audit, the evaluation of risk mitigation options and the inspection planning stages in RBI are most reliably completed with multi-disciplinary input covering a range of technical competences from experienced plant engineers. Further benefits of an interactive audit team approach are on-the-job training and transference of assessment know-how between team members.

RBI tools that only output a relative risk ranking, no matter how comprehensive, do not necessarily provide the solution that operators are looking for. A more holistic approach is increasingly being required whereby the operator is systematically directed through a series of risk management options. These options should not be restricted to inspection or maintenance actions but should also lead the operator to other measures such as, re-design, operational changes, materials upgrade, fitness for service assessment, etc. The impact of each mitigating action should be retained by the software so that cost-risk-benefit optimisation can be subsequently undertaken.

A RBI method that only outputs a relative risk ranking, whether qualitative or quantitative, leave the user with the problem of selecting an appropriate and safe inspection period. Health and safety regulations do not specifically prescribe inspection intervals and in the self-regulating environment implicit in RBI planning. A competent person is expected to use judgement and experience in deciding inspection intervals. The rational basis for setting safe inspection intervals is an estimate of remnant life, which should be present in any reliable RBI methodology.

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