RBI in Power Generation

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Abstract

Risk assessment and Risk Based Inspection (RBI) are well established within the refining and petrochemical industries. The fossil fuel power generation industry, however, has not generally used a formalised RBI process for managing the integrity of its pressure equipment. Due to legislative changes in South Africa (SA) the national electricity producer (Eskom) has embarked on what is perhaps the largest roll-out of an RBI process in power generation in the world (more than 80 units totalling more than 40,000MW). The Eskom RBI process RBI was based on the European RIMAP process. This paper will describe some of the challenges faced in the development and implementation of the process.

1. Introduction

In 2009 the South African Department of Labour revised the pressure equipment regulations [1]. The revision requires that all pressurised equipment must be subject to hydraulic testing every 3 years unless an RBI process is used to demonstrate that the level of risk associated with continued service of the vessel is at an acceptable level. Historically Eskom had an exemption from the 3 year pressure vessel hydraulic test rule and only needed to test every 6 years i.e. in alignment with the Eskom's major outage frequency. Eskom consequently decided to initiate the development and implementation of an RBI process not only to meet regulatory requirements but to also to also focus on, and improve, plant safety. This process will eventually become the basis of all future inspection planning. This paper describes some of the main aspects of the development and implementation of at Eskom.

2. Background

During the life cycle of a plant, inspection, testing and maintenance programs are established to detect and evaluate deterioration and damage arising from operation. Regular inspection is generally implemented to provide a periodic assurance of integrity, and thus safety and reliability and is particularly important for plant that are subject to time dependent degradation. Historically the high frequency and consequences of failing pressure vessels resulted in the development of design rules [2] and eventually statutory inspection requirements for many countries. Over and above these requirements many strategies were developed within the various industries utilizing pressure equipment for these activities and traditionally they have been based on general and specific experience, reinforced by statute, requirements, consensus view within the industrial sector and perceived company need, according to the criticality of the item. Naturally, concepts such as failure likelihood and failure consequence are implicit in the thinking behind common practice, but it is only recently that they have been treated as a defined process

The value of inspection as a means of detecting incipient plant failure is well known. There are numerous examples where inspection has identified cracking which, if not detected, would have led to failure with potential for loss of life and commercial penalties through lost production and the costs of covering/repairing consequent damage. However, the costs of inspection and maintenance related activities are increasing being examined, particularly in competitive markets, in order to find areas in which savings can be made.

The risk based approach to defining plant inspection programs possibly has its origins in the nuclear industry in the late 1970's [3], and the off-shore industry's work on structural integrity. These were developing hazard based inspection methods which became reasonably well established in these industries. This approach has found ready acceptance in the refinery and chemical industries, as a means of optimizing the cost of inspection whilst ensuring safety, health and environment. The approach developed for these industries is detailed in API 580 and 581 [8]. Many of the larger companies have also developed their own in-house based procedures.

The potential benefit of application of risk based methods within the fossil power industry has attracted much interest but, even though a fossil fuel related process was developed [4], to date, application has been limited as statutory requirements with defined inspection intervals, have been slow to change. The recent change in the South African (SA) pressurised equipment legislation [1] has led to an increased interest in RBI within SA as a means of ensuring safe operation of such equipment without the need to conduct hydraulic pressure testing.

Risk based inspection (RBI) is a process that uses an assessment of a component's risk to determine if the component needs to be inspected and if so to what extent. Risk is the product of the likelihood or probability of a component to fail and what consequences will result if the failure occurs i.e.

Risk = Probability of Failure (PoF) X Consequence of Failure (CoF)

Consequences are typically defined in terms of safety, commercial, environmental etc.

A risk based approach is generally applied in a progressive manner such that all equipment is identified and addressed by qualitative methods and only the most critical items are analyzed quantitatively. At all levels, both the probability and consequences of failure are determined to calculate the risk exposure. At the quantitative levels, the variation of risk with service time is also determined where relevant.

The main objective of this approach is to focus inspection activities where risk is high. This obviously has the potential to reduce inspection related costs without increasing the overall level of risk. A number of risk assessments have indicated that risk follows the Pareto principle or 80:20 rule in that typically about 80% of risk is associated with about 20% of the components on a site [6] which indicates that correct focussing of inspections can be cost effective.

1. Process Development at Eskom

2. Technical Requirements

The principle requirements for the Eskom process were as follows:

- Alignment with RIMAP process

- Needed to be simple and robust
- Focus on safety
- Repeatability and consistency of results
- 6 year look ahead for PoF
- Alignment with existing Eskom plant life and integrity management processes
- Certified by designated RBI auditors
- Sustainable

3. Project Requirements

In addition to the technical requirements Eskom required to control the implementation of the process via detailed project management involving several key areas including:

- Steering committees
- Training of staff
- Weekly and monthly feedback reporting
- Change management
- Internal audit checks
- Communications between various departments within Eskom
- Project risk management

Eskom ensured a dedicated team of resources with the necessary skills were made available to the project. Project risks where assessed, reviewed and mitigated on a regular basis by a dedicated team using the Eskom integrated risk management process.

4. Eskom RBI Process

The Eskom RBI process is based on a European multi-industry based process (RIMAP) [14] which allows flexibility in the methodology used to determine risk provided specific aspects of the process are included.

The Eskom process covers all of the essential aspects required by the RIMAP process as shown in Table 1 below.

RIMAP	Eskom RBI Process

Policy statement and commitment of Senior management	Integrated into existing SHEQ policy and signed-off
Initial analysis and planning	Detailed in Process manual
Data Collection	Detailed process documented within process procedures
Data Validation	Validation and sign-off process developed
Risk Analysis	
Critical equipment List	All equipment listed and screen based on SANS categorisation
Damage Mechanisms	Developed within project based on ASME PCC-3 [12]
Develop risk matrix and criteria	Eskom RBI risk matrix (5x5) and risk level action criteria developed
Screening	
Identify Hazard	Component specific defaults developed for the type of failure and the Generic Failure Frequencies for each degradation mechanisms.
Procedure for determining Consequences	Simplified calculation developed for Safety, Commercial and Environmental
Procedure for determining Likelihood	Simplified assessment procedure developed
Screening process (level 1: Qualitative) – conservative	Checks on the screening process indicated it is conservative in the vast majority of cases.
Escalation criteria **(to detailed assessment (level 2: Semi-Quantitative))**	Conservative risk level basis for escalation to Level 2 documented.
Detailed Assessment	
Bowtie Assessment of Risk	Not used* except for consequence mitigation
Mitigation procedures	Some available

Procedure for determining Consequences -(level 2: Semi-Quantitative))	Level 2 CoF mainly qualitative – moves to quantitative at Level 3
Procedure for determining Likelihood – level 2: Semi-Quantitative))	Some detailed procedures available for some components e.g. HP piping
Escalation criteria	Defined in terms of risk levels
Integrity Risk register	Available under existing Eskom procedures (IRM) [13]
Decision making **Action Plan**	Procedures developed for short term high Risk items and for assessment of as – found degradation during an outage
Execution	The inspection plan is passed to the outage Team for implementation in accordance with Eskom procedures
Reporting	Detailed component specific Risk assessment summary sheets prepared as part of the overall report
Performance review	The process is Certified at each station via an independent audit, with follow -up audits each year
Evergreen Status/Sustainability	Ongoing

**During the pilot study it was found that aggregating the PoF of different potentially active damage mechanisms with the highest CoF resulted in unrealistically high risk scores.*

Table 1: Comparison of RIMAP process requirements with Eskom RBI Process.

Initially the scope of the Eskom RBI was all pressure equipment operating at 50kPa or over, as well as turbine centreline components, but was later reduced to primarily focus on the pressure equipment operating at 50kPa and 100ºC and above. As such, up to 4000+ components per unit are required to be screened. With this in mind the Eskom RBI was developed using a novel scorecard based process which allows relatively rapid assessment. In keeping with most risk assessment methodologies the process is team based i.e. representatives from operations, system engineers, maintenance, metallurgist, plant specialists etc. are required to be present at the risk assessment meetings.

The Eskom RBI process involves several main stages as follows:

- Definition of scope
- Component data gathering (design, operating etc.)

- Categorisation of components according to SANS 347 [7]
- Pre-outage Risk Assessment
  - Level 1: high level screening (qualitative) assessment for SANS Cat 2, 3 and 4 components) – medium and high risk components go forward to next stage
  - Level 2: semi – quantitative assessment – identifies components required to be inspected at next outage.
  - Development of RBI plan
- Level 3.1: If required conduct a refined assessment of components that are high risk before the outage occurs. This is largely expert opinion based and aligns the Eskom expert view of risk level with the process determined risk level. If required critical high risk components are escalated via Corporate Integrated Risk Management system to force critical inspection outages.
- Perform RBI plan at outage
- Post-outage risk assessment
  - Repeat Level 2 assessment with new inspection data
  - Evaluate risk at different timescales as required
  - Identify re-inspection intervals as required
  - Perform Levels 3.1 and/or 3.2 for high risk components as required
  - Update corporate Integrated Risk Management system

The basic assessment process flow diagram is shown in Fig 1.

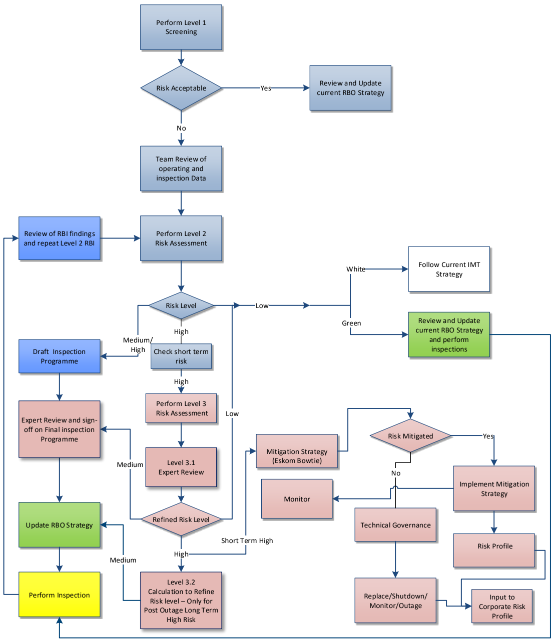

Figure 1: Eskom Risk assessment flow diagram

The level 1 assessment uses 10 criteria to determine the PoF and 3 criteria for safety CoF. At Level 2, which requires a more detailed assessment, 19 criteria are used to determine the PoF and 5 criteria for the safety CoF. The results of the RBI assessment are plotted on a risk matrix as shown in Figure 2. The process currently focusses on **safety** related risk with commercial risk a secondary factor.

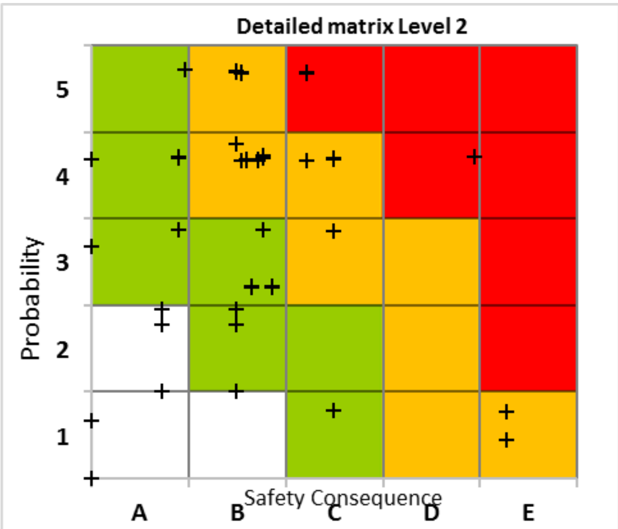

Figure 2: Example output of Level 2 Boiler Component Risk levels

Once the RBI plan has been implemented at the outage the Level 2 assessment is repeated (i.e. a post–outage risk assessment with the new inspection findings) to establish the risk profile over the next 6 years and identify any components requiring inspection before the next major outage.

The Eskom RBI process was initially trialled on a pilot unit and after some modifications has been implemented on one unit at almost all 14 coal fired power stations. In addition, the process was implemented at the nuclear power station's secondary cooling system and other non-primary cooling related components. Due to outage deferrals many of the post-outage assessments have yet to be undertaken. The first post outage assessment was completed early in 2016 with others now ongoing.
As mentioned above a key objective of the EskomRBI is to establish the risk associated with pressure equipment. Once established it can be used to justify **not** pressure testing pressure vessels. This has potentially significant time and cost savings for Eskom and avoids the statutory requirement to pressure test every 3 years, and maintaining (and potentially extending) the historical 6 year hydraulic test interval.

5. Challenges

Developing a new RBI process and implementing it is not without its challenges. A few of the challenges faced, and how they were overcome, are discussed below.

5.1 Generic Failure Frequency (GFF)

In a similar fashion to the API process the Eskom process uses a GFF to determine the PoF. Indeed, in Level 2 a GFF is required for each potentially active degradation mechanism. In API there are some data on the frequency of occurrence of damage relating to hole size [8]. These data predominantly relate to corrosion degradation mechanisms many of which are rarely found in power generation plant equipment and as such the use of such data was considered questionable. Unfortunately, within power generation, there is no similar database of failure frequencies for most components types (Eskom, along with other large utilities, have detailed information on the failure frequency and associated degradation mechanisms associated with boiler tubing but not on other component types). Whilst some information is available from NERC generation availability reports [9] there is often insufficient detail on specific components. A detailed review of the literature was also carried out but the majority of information came from small sample sizes and did not relate to specific degradation mechanisms. These data were therefore considered not to be appropriate. It was therefore decided to use an indicative GFF and apply a concept of "relative" PoF rather than "absolute" PoF.

Due to the size of the Eskom fleet (more than 80 units) it is envisaged that, over time, Eskom specific component failure frequencies will become available and will eventually be used in place of GFF. This should ultimately improve the estimate of the probability of failure.

5.2 Consistency of Assessments

The determination of the relevant GFF was initially left to the various RBI teams but review of the results indicated significant variations in risk levels for the same component. This could obviously arise merely from different responses to the assessment criteria but on closer examination much of the variability stemmed from different inputs for some key CoF criteria and GFF. It is not uncommon for risk assessments carried out by different teams to yield significantly different results. A result of one such comparison [10] is shown in Table 2. These results are based on assessments carried out by different companies (A, F, E, G) using their RBI process on the same vessel with same operating information. Similar comparisons with other vessels types in this study yielded similarly variable results.

Damage Mechanism	A	F	E	G
Internal corrosion	VT + some UT	√	UT	UT ?*
External corrosion	VT,UT	√		UT?*
Under lagging corrosion	UT		VT, creep UT	**some VT**
Brittle fracture			TOFD*	**TOFD*?**
Deformation/buckling	VT			**?**
Fatigue	MPI/EC + some UT		**TOFD/MPI***	**UT?/MPI?some TOFD**
SCC	MPI/EC + /some UT*	√	UT	**UT?/MPI?***
HIC	MPI/EC + some UT*	**MPI (UT) or UT***	UT(MPI,TOFD)	**UT?/MPI?**
Erosion			UT	**UT/MPI?**
Creep	√			√
Cavitation				√

* Mechanisms considered by participants to be active or having a possible or higher likelihood of occurrence.
√ means mechanism considered but no specific NDT method referenced
NDT1 (NDT2) means NDT method 1 recommended as primary method and NDT method 2 recommended if degradation detected.
Some NDT means recommended at specific locations
UT? means not explicitly stated but most likely method

Table 2: UK Health and Safety Executive RBI comparison (taken from Ref)

As can be seen there is a large difference in degradation mechanisms considered by the various practitioners and in the proposed inspection that is required.

It is important for Eskom to be able to compare component risk levels between units and between different Stations. To improve the comparability of results a set of “default” component specific degradation mechanisms, expected failure type and GFF’s was developed. It is considered that if the same starting point is used for a potentially active degradation mechanism of a specific component, then the various assessment criteria will change the PoF making comparison between the same components in different units directly comparable. In the main the results have been consistent with industry expert expectations and tend to confirm and justify the existing Eskom integrity management programmes currently in place. For example, the current high temperature piping programme [11] is comprehensive in application of inspection techniques to monitor creep related degradation and the existing programme has been seen to integrate well with the RBI process.

5.3 Certification of Process

A critical element of the project was to ensure that the process would be certified by independent auditors. This required the preparation of a suite of RBI related documents detailing all technical and procedural aspects of the RBI process. In total 13 documents have been produced covering a variety of topics ranging from qualifications of RBI engineers, meeting attendance requirements, system definitions as well as the technical assessment procedure etc. In order to prepare for the independent audits a team of internal auditors reviewed all aspects of the risk assessments in advance and highlighted any areas for improvement both at head office and at the individual stations. This proved to be extremely successful with all Stations assessed to date being certified.

5.4 Process Development

As with any new process there will always be some areas for improvement. As more results become available areas for improvement have been highlighted and after detailed consideration by the technical steering committee have been introduced into the process manual. In some instances, changes were made to weighting factors of specific criteria e.g. the weighting associated with one of the PoF criteria which deals with design aspects of components was increased to ensure that both operational and mechanical design aspects were more accurately accounted for. Elsewhere definitions have been improved and aspects of procedures clarified. In keeping with Eskom's own philosophy and the "evergreen" requirement of RIMAP, the process will continue to be modified and enhanced over the coming years.

5.5 Transition

It is always difficult for seasoned staff to accept changes in the way that things are done. Moving from a long established expert based integrity management culture to an RBI based process, has, as expected, not been without some challenges. A comprehensive programme was developed to manage this challenge. This consisted of an extensive communication programme, training (>100 staff trained to date), workshops and involvement of both plant experts, metallurgists and station engineers in the development of the process and creation of its supporting documents. The RBI related training has improved staff understanding of the various degradation processes that can affect their plant. This approach has allowed a gradual move towards ownership of the new process. Indeed, some of the staff that were initially reticent to the change have now become staunch advocates of it.

Looking to the future, Eskom has already focused on the sustainability of the process by continued development of training programmes including "training of trainers" for the future. Whilst there is still much work to be done to fully embed the process throughout all of the stations and the supporting technical departments the current evidence is that Eskom will become the first power utility to fully adapt RBI as the primary tool for ensuring plant integrity and safety.

6. Concluding Remarks

The Eskom RBI process has been successful in fulfilling all of the original requirements of the process. The process has been independently Certified according to the SA statutory requirements of the Occupational Health and Safety act. In several instances the process has highlighted some areas which had been overlooked by the current programmes and has identified some areas where inspection programmes can be reduced. Such factors, together with the increased staff awareness of degradation related risks, the increased focus on safety, and the ability to continue with or even extend the 6 year inspection interval for pressure vessels are clear benefits to Eskom.

7. Acknowledgements

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