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INVESTIGATION INTO THE EFFICIENCY AND EFFECTIVENESS OF RISK BASED INSPECTION (RBI)

by

Sipho Ziphozonke Theophelus Mkhabela

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Full names of student: Sipho Ziphozonke Theophelus Mkhabela

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ABSTRACT

Risk Based Inspection (RBI) is a risk assessment and management tool that addresses an area not completely addressed in other organisational risk management efforts such as Process Hazards Analyses (PHA) or Reliability-Centred Maintenance (RCM) [11]. It complements these efforts to provide a more comprehensive risks assessment associated with equipment operations. RBI yields Inspection and Maintenance Plan for equipment which identifies the actions that should be implemented to provide reliable and safe operation. RBI is a preventive maintenance strategy that combines predicting the expected failure time and condition monitoring as an effort for preventing potential equipment failures.

A literature review was conducted to obtain a wide understanding of the RBI field and to capture some of the improvement methods which may have been highlighted by other researchers for baseline purposes. An RBI implementation case study was performed, focusing on the largest power producing utility in Africa, to investigate the efficiency and effectiveness of RBI implementation, thus the results obtained from this case study could have a significant impact in the RBI and Asset Management environment. Efficiency in this study refers to achieving financial benefits, while effectiveness means serving the technical and risk mitigation purpose of a RBI implementation.

To evaluate the efficiency of RBI implementation, costs for executing scopes of work prior to RBI implementation were compared to RBI scopes Pre-Outage and Post-Outage scopes execution costs on two power stations that were identified as the most advanced in RBI implementation roll-out plans. Effectiveness was evaluated by assessing the RBI implementation against typical organisation's objectives through audit findings, interviews, and lessons learnt.

Data Analysis was performed as described below:

- Cost analysis was performed, comparing the RBI versus Prior RBI maintenance scopes execution costs on the two identified power stations through an excel Model.
- Most recurring audit findings were identified through reviewing the audit reports.
- A bow-tie risk assessment was performed for the identified eight most recurring audit findings, and probabilities and consequences mitigations were recommended.
- Lessons learnt were compiled from the audit findings, bow-tie risk analysis mitigations, interviews results, and RBI sharing sessions.

A proposed framework was developed for RBI implementation improvement methods. The results showed that RBI is generally a cost effective process when the prior RBI scope execution cost was compared to RBI scope execution cost. RBI could reduce the maintenance costs through scope optimisation and downtime reduction. The RBI implementation process was found deficient for the specific instances, based on the audit findings and bow-tie risk assessment conducted in the case study. The most significant improvement areas identified included, ensuring that RBI scopes have are uploaded into the Computerised Maintenance Management System and there is only one consolidated final inspection scope submitted to Outage Department and tracked for tasks completion during the outage.

This study revealed that the case studied organisation is currently not efficient in implementing RBI, and could benefit significantly if they improve through executing the RBI maintenance inspection scopes as planned. The conducted interviews, recurring audit findings, and lessons learnt analysis demonstrated that the organisation is not effective, as it was successful in meeting only one from a total of six RBI implementation objectives. Extending the inspection frequencies to 72 months and beyond for some low risk components through RBI implementation was the only RBI objective in which the organisation was met successfully.

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ABBREVIATIONS

AKZ	German power plant classification system
API	American Petroleum Institute
ASME	The American Society of Mechanical Engineers
CBM	Condition Based Maintenance
CoC	Certificates of Compliance
CoF	Consequences of Failure
CPI	Chemical Process Industries
DF	Damage Factor
DNV	Det Norske Veritas
FAC	Flow Accelerated Corrosion
F_{MS}	Factor for Management Systems
GFF	Generic Failure Frequency
GO	General Outages
HP	High Pressure
KKS	Identification System for Power Station (Kennzeichnen System)
KPI	Key Performance Indicators
kWh	Kilowatt hour
NC	Non-conformance
NDT	Non-destructive Testing
PER	Pressure Equipment Regulations
PM	Planned Maintenance
PMO	Plant Maintenance Optimisation
PoF	Probability of Failure
PRA	Probabilistic Risk Assessment
PS	Power Station
RBI	Risk Based Inspection
RIMAP	Risk-Based Inspection and Maintenance Procedure for European Industry
RIPBA	Risk Informed Performance Based Applications
SANS	South African National Standard
SAP	Systems, Applications and Products
SEP	Sound Engineering Practice
SoW	Scope of Work
SSCC	Sulphide Stress Corrosion Cracking
TOFD	Time-of-Flight Diffraction
UCLF	Unplanned Capability Loss Factor
VuP	Vessels under Pressure

1. INTRODUCTION

Risk Based Inspection (RBI) is a risk assessment and management tool that addresses an area not completely addressed in other organisational risk management efforts such as Process Hazards Analyses (PHA) or Reliability-Centred Maintenance (RCM) [11]. It complements these efforts to provide a more comprehensive risks assessment associated with equipment operations. RBI yields Inspection and Maintenance Plan for equipment which identifies the actions that should be implemented to provide reliable and safe operation. RBI is a preventive maintenance strategy that combines predicting the expected failure time and condition monitoring as an effort for preventing potential equipment failures.

1.1 BACKGROUND

Maintenance strategy defines the procedure for the sequence of planned maintenance (PM) work, contains general scheduling information, and can therefore be assigned to as many PM task lists and maintenance plans as required. An effective maintenance strategy is one that is aligned with an organisational objectives, and an efficient maintenance strategy has to balance costs, risks, and performance on different timescales. Maintenance strategies framework is shown in Figure 1 below to demonstrate the overview of maintenance philosophy.

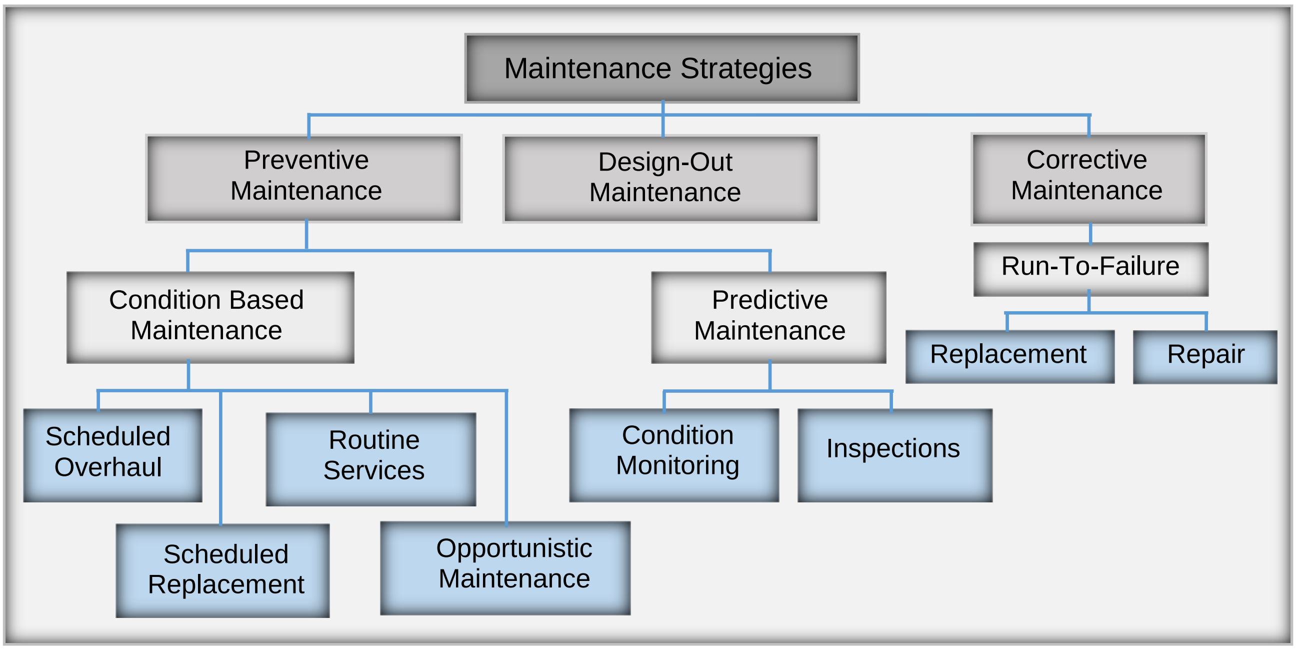


FIGURE 1: MAINTENANCE STRATEGIES [28]

The main subsections of the maintenance strategies shown in Figure 1 are described below:

- *Preventive maintenance* can be condition based or use based selection, all maintenance strategies must be aimed at preventing failure before occurrence.
- *Design-Out Maintenance* is not a pure maintenance strategy, but is mentioned as such because it is extensively used by maintenance engineers. Its objective is to decrease the need for maintenance by removing unwanted failure modes, this is achieved by redesigning the particular system or component.
- *Corrective Maintenance* is a 'do nothing' or 'wait for failure' strategy, this means there is no effort made to determining the component failure time or doing anything at all to prevent failure from occurring. This strategy is used when there is no other option that can be applied with better end results. The component is replaced or repaired upon failure, if this strategy is applied. It is crucial to evaluate costs implications when a decision is made on selecting the strategy to be used for a particular failure mode, for cost effectiveness purposes.

RBI contributes significantly in maintenance inspection planning development, thus it is essential to discuss some of the maintenance logistics. Figure 2 demonstrate the prediction of maintenance costs with increasing level of prevention. The cost of breakdowns decreases in hyperbolic fashion as the level of prevention increases while the cost of prevention increases. The total cost of maintenance is the sum of cost of prevention and cost of breakdowns. Total cost of maintenance is observed to be minimum at optimum as marked in Figure 2, this is the level of prevention that needs to be achieved for best maintenance benefits [28].

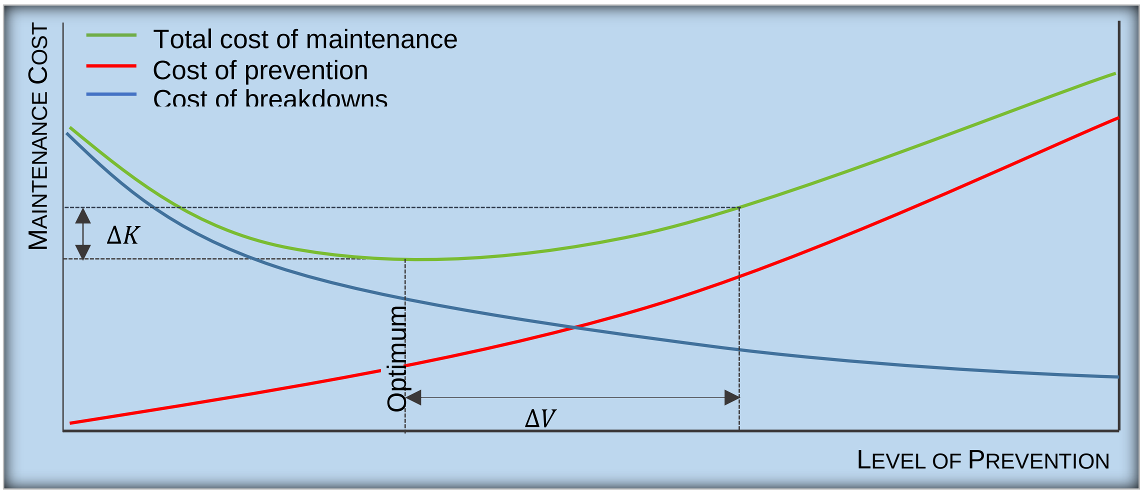


FIGURE 2: EVALUATION OF OPTIMUM MAINTENANCE COST [28]

The development of Risk Analysis methods for the power industry began in the late 1980's, and the principal focus group for this development was the American Society of Mechanical Engineers (ASME) Research Committee on Risk Based Inspection Guidelines. The focus of this committee was on nuclear power plants due to regulatory complications, although the group comprised of members from the fossil power, aircraft, insurance, and marine industries.

In the early 1990's this committee's name was changed to the ASME Research Committee on Risk Technologies and began to also focus on fossil power plants because of the obvious financial benefit that could be achieved due to significant capital decisions that were being made. Simultaneously the refining and petrochemical industry began to focus on RBI methods through the American Petroleum Institute (API) Committee on Risk Based Inspection due to regulatory issues [39].

RBI allows the user to determine inspection frequencies based on the results of the risk assessment. RBI enables engineers to have an overview of their component risks, also to have better knowledge on plant historical failures, repairs, and modifications that might have been performed in the plants. This empowers engineers to prioritise maintenance based on the component risk levels (e.g. Very Low, Low, Medium, or High), which could improve maintenance and planning effectiveness.

1.2 PROBLEM STATEMENT

Prior to RBI, boiler or pressure vessels were maintained through Vessels under Pressure (VuP) regulations which required these equipment to be subjected to hydraulic pressure test at 1.25 times the maximum permissible safe operating pressure, performed by competent personnel on a 36 months interval. PER was introduced in October 2009 to supersede the VuP regulations, and RBI approach is a provision in the PER that allows a user to determine inspection frequencies based on the risk assessment results. Many organisations have implemented RBI process, but the efficiency and effectiveness of the process proves to be challenging. Efficiency in this study refers to achieving financial benefits, while effectiveness means serving the purpose of RBI implementation.

Abdul Hameed et al. [22] mentioned that effective inspection and maintenance are critical elements for operating facilities, and shutdown interval forms part of the most important factors in determining an effective inspection and maintenance policy. Márcio das Chagas

Moura et al. [52] proposed a combination of RBI methodology and Multi-Objective Genetic Algorithm (MOGA) for defining efficient inspection programs in terms of inspection costs and risk level, as an effort for improving the RBI efficiency. In addition, Imad Alsyouf [55] presented a model enabling the decision-makers to identify how an effective maintenance policy could influence the productivity and profitability through direct impact on quality, efficiency, and effectiveness of operation. Christopher D. Wickens et al. [56] defined human error as inappropriate human behaviour that reduces the levels of system effectiveness or safety, and this is one of the key challenges in RBI implementation.

DNV recommended practice guideline [57] mentions that the effectiveness of the inspection activities should be assessed periodically where the frequency and the revision of planned activities should provide constant assurance of technical integrity. This guideline also recommends that reports of effectiveness of the planned activities in assuring the required integrity and reliability shall be produced and reviewed by management, to ensure that the inspection activities are achieving the required performance.

Based on the emphases on the importance of maintenance inspection efficiency and effectiveness in the above mentioned articles, as well as the understanding that the implementation of RBI as a replacement for conventional maintenance approaches, is primarily focussed on economic benefits, whilst achieving the same or reduced integrity and reliability risks, the need for research focussing on the efficiency and effectiveness of Risk Based Inspection, becomes evident. The objective of this research is therefore to investigate the efficiency and effectiveness of RBI implementation in an organisation, to outline some of the key methods that could contribute in improving these factors.

1.3 RESEARCH APPROACH

The following process was followed to achieve the objective of this research:

- An understanding of RBI environment was accumulated through literature review, this assisted in acquiring knowledge of previously conducted researches related to efficiency and effectiveness of RBI.
- Standards and procedures associated with RBI were studied to understand their applicability.
- Two hypotheses were identified for this research and their significance was assessed on a case study basis, see paragraph 3.1.

- A case study was conducted to evaluate the efficiency and effectiveness of RBI in a specific organisation, namely a large power producing utility in Africa, thus the results obtained from this case study could have a significant impact in the RBI and Asset Management environment.
- Required data to enable the evaluation of efficiency and effectiveness evaluation was gathered, these included historical maintenance scopes and execution costs, audit finding reports, and lessons learnt during RBI implementation.
- Interviews were conducted on site based Risk Engineers to enhance the RBI effectiveness knowledge.
- Cost benefit analysis was performed to evaluate the efficiency of RBI implementation.
- The data was analysed, results discussed, the RBI implementation efficiency and effectiveness improvement methods were defined, and the research was concluded.

1.4 Document Structure

This document was developed based on the following structure:

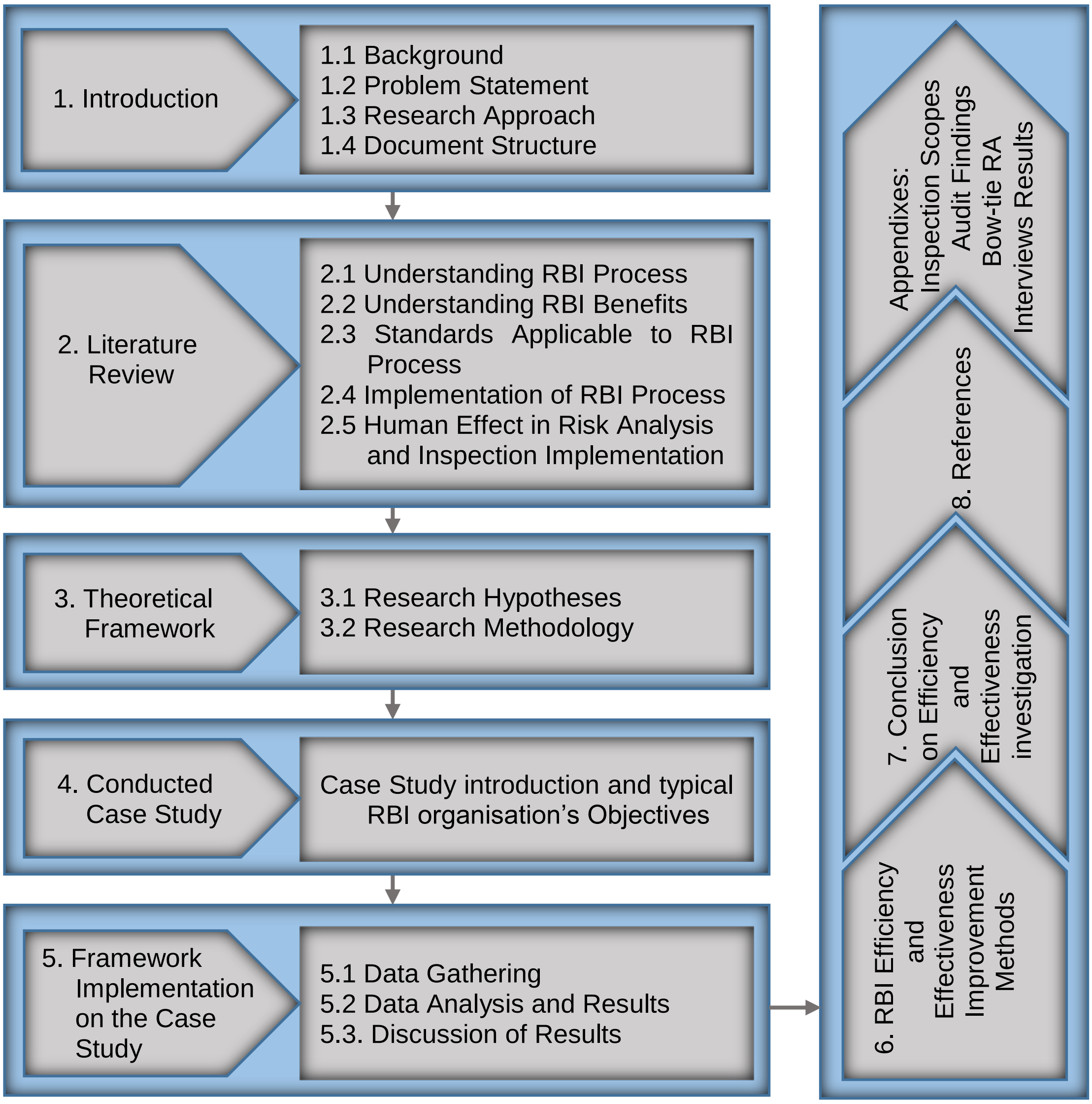


Figure 3: Document Strucure

2. LITERATURE REVIEW

The following reviews were performed to obtain a wide understanding on the RBI field, also to have an appreciation of what other researchers are working on.

2.1 UNDERSTANDING THE RBI PROCESS

2.1.1 Understanding the need for RBI

Risk-Based Inspection considers the probability and consequences of failure. This technique aims to bring better value for money from inspection, through inspection optimisation based on risk understanding. "*It is now widely accepted that the traditional time-based approach to planned plant inspection by a competent person has a number of shortcomings* [12]".

The use of fixed intervals between inspections may be too conservative and eliminate the possibility to benefit from good operating experience. The introduction of goal setting legislation has facilitated a move towards risk-based strategies that promote focusing inspection resources on plant components that carry greater risks where preventing failure will lead to greatest benefit [12].

RBI is a process aimed to reinforce and direct planned plant inspection, if these inspections are not conducted as planned it becomes challenging to realise its benefits. It claims to offer the vision of cost savings resulting from the better focusing of resources utilisation. RBI recognises that it is not best practice to spend good money on very frequent inspection of something that is very unlikely to fail, or would have little financial or safety consequence if it failed. The money saved could be better spent elsewhere, this is in line with the principles of 'as low as reasonably practicable' (ALARP) [12].

2.1.2 Risk-Based Inspection

As per the definition of the risk, the product of the probability of corrosion event and the corrosion consequences determines the risk. If this risk is unacceptable, risk mitigation recommendations should be developed and implemented before the risk materialises to restore good plant condition. RBI is a multi-disciplinary team process as it requires specialists from various plant areas and technologies such as metallurgists, specific plant areas experts, risk assessment engineers, etc. Data accuracy is a very crucial part of this process, as all the decisions made during the assessments are purely dependent on the available information. Thus it is important to validate the data before and during the risk assessment to ensure high data quality.

High level RBI process flow diagram is shown in Figure 4 below with the following steps respectively:

- Data Gathering – Data is collected and validated, this may include design drawings, and inspection and failure history.
- Likelihood Probability Rating – Likelihood for failure occurrence is rated, ranging from less likely to highly likely to occur.
- Consequences of Failure Rating – Consequences of failure are rated, ranging from harmless to catastrophic.
- Risk Ranking Matrix – is generated based on the likelihood and consequences of failure, ranging from low to high risk.
- RBI Recommended Inspections – required RBI inspection are developed, based on identified damage mechanisms mitigations.
- Scope Execution – required RBI Inspections are carried out during the planned maintenance.
- Re-assessment – the equipment risks are reviewed at this stage with consideration of the recently performed inspections.

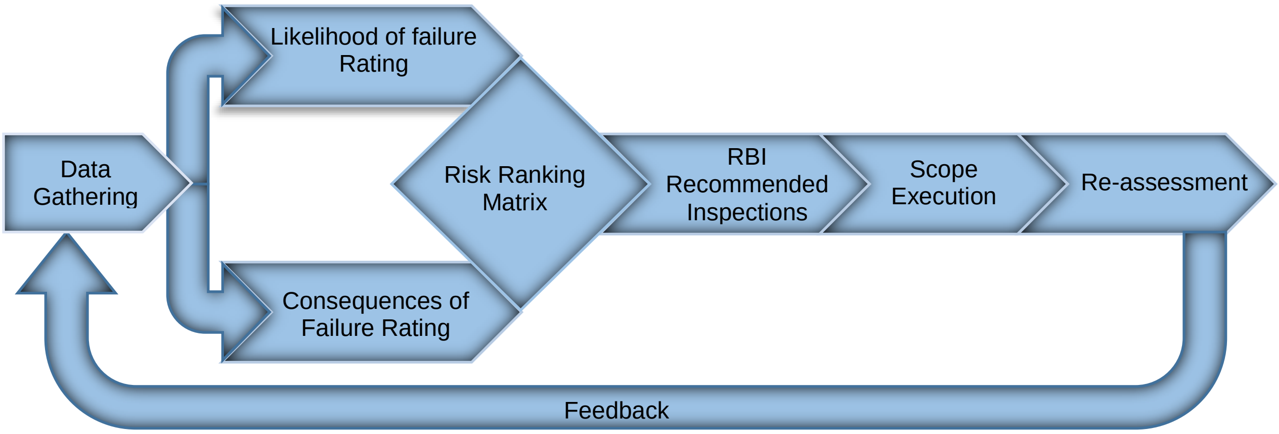


FIGURE 4: SIMPLIFIED RBI PROCESS FLOW DIAGRAM [10]

2.1.3 *The Aim of Risk Based Inspection*

Risk-Based Inspection is a risk assessment method used for identifying and managing the risks associated with the integrity of pressure systems to reduce the risks to an acceptable level or mitigate them completely. This method is used as a basis for prioritising and managing the efforts of an inspection strategy to ensure that inspections are implemented in a cost-effective manner and in compliance with the applicable legislation, industry guidance, and company requirements [7].

Deliverable of RBI assessment:

- Prioritisation of high risk components – schedule and implement inspections for high risks followed by medium high before they materialise. Medium and low risks should be monitored and scheduled for inspection when they escalate towards high.
- Determination of inspection intervals – evaluate the time for risk to materialise and determine the inspection interval before time to materialise. This time interval should not be too close to the time for risk to materialise as there may be delays in inspection implementation.
- Expected damage mechanisms – identify the expected damage mechanisms based on the component data e.g. design, operating, and failure history.
- Selection of the best inspection method – select the best inspection methods to detect the expected damage mechanisms.
- Data requirements for continuous improvement – perform process audits on work performed to identify and rectify deficiencies to improve the process. Engage in benchmarking activities, gather lessons learnt, and improve the RBI process.

2.1.4 Plant Risks Understanding

One of the objectives of the RBI assessment is to better understand the risks involved in the operation of a plant or process unit and to understand the effects that inspection, maintenance, and mitigation actions have on the risks. This is usually conducted to improve the safety of the plant. An inspection strategy that optimises the use of inspection and plant maintenance resources may be designed based on the understanding of risks [11].

2.1.5 RBI Best- Practice for Successful Implementation

"*Best practice RBI Technology brings immense benefits to a plant site. However it is emphasised that there is no short cut to effective implementation of RBI in order to ensure improvement in plant reliability and safety, whilst optimising inspection requirements and inspection intervals of static equipment items of plant*" [8].

Senior management commitment at plant site is critical to support the best practice in RBI, such as providing resources, allocating time for RBI assessment team to perform risk analyses, and enforcing the implementation of the RBI requirements [8].

This paper describes a proven technology process which is believed to be at the leading edge of best-practice in RBI technology application and outlines the established procedures for successful implementation and subsequent management at plant sites [8].

Many organisations that have implemented RBI reported achieving benefits exceeding their initial expectations in terms of reliability, safety, and financial improvements [8].

The following are some of RBI best practice to enable well implemented process:

- Well-structured and functional Document Management System – enables data gathering process to be faster, as the documents can be retrieved with ease.
- Well-developed RBI assessment tool (spreadsheet / software) – this should be developed based on a particular standard (e.g. API 580/ 581, RIMAP-CWA 15740, SANS 347, etc.). This tool must have a capability to be updated as standards are updated from time to time.
- High quality data gathering – on completion of populating the data on to the RBI tool, it is critical to validate that the data has been copied accurately from the data sources. In addition, the practicality and correctness of the data needs to be verified by the plant expert to ensure the correlation of the data to the plant. This is the most important part in the RBI process as all the decision making during the risk assessment relies on the data, meaning the quality of the risk assessment team is pointless without accurate plant data.
- Multi-disciplinary Risk Assessment Team – It is critical to select a best-qualified and experienced available members when assembling the team, as personnel's safety depends on the decisions taken by this team.
- Selection of inspection intervals – It is important to ensure alignment on inspection intervals for all plant areas (e.g. Boiler and Turbine high risks should be inspected on the same interval to prevent shutting the plant down twice unnecessarily). This will assist in minimising downtimes, thus improve the plant productivity.

- Reporting – Inspection requirements need to be well documented, supported by the design drawings with indicated positions for identified NDT inspections, and any other supporting documents that may provide clarity to the inspection executing team.
- Implementation of RBI scopes – all required inspections for the upcoming downtime (prioritised based on the risk ranking) must be executed as planned. It is critical to implement required inspections, as the risks cannot be reduced without implementing required risk mitigations.
- Continuous training must be provided to all personnel involved in RBI process to ensure resources competency sustainability. This can be a formal classroom training and/or practical training (on the job). It is recommended to have more than one resource trained in RBI assessment for skills sustainability.
- Auditing – assessing the RBI implementation process against the RBI procedures is important for continuous process improvements.
- Benchmarking – engaging with other organisations that have implemented RBI could contribute significantly in the process improvement, and preventing process failure. This can be in the form of the forums in which lessons learnt could be shared.

2.1.6 Application of confidence criteria

A well-developed RBI system should account for the degree of confidence that can be expected in any assessment. Confidence should consider the accuracy of the assessment technique, effectiveness of the inspection technique, predictability of operating conditions, and the integrity of the item under consideration. [36]

Some form of confidence index is necessary to address the degree of accuracy for models used to assess the deterioration rate. Factors to be considered are the inherent accuracy of the deterioration model, its degree of conservatism (e.g. creep calculations and fracture assessments often use very conservative material property data), and the comparison of predicted deterioration rates with actual measured rates. Even the most robust RBI system could be challenged to some degree by the processes that feeds into it, like some mentioned above.

Failures often approximate a ‘bath tub’ curve shown in Figure 6 below, where early in the plant life several failures occur due to design errors, undetected manufacturing defects, etc. Following this initial operating period, failures decline to a minimum level, and then increase once again toward the end of the plant design life cycle. This is usually the trend followed by mechanical components, some components may follow a different trend. As a result, confidence is never a constant, but changes with time.

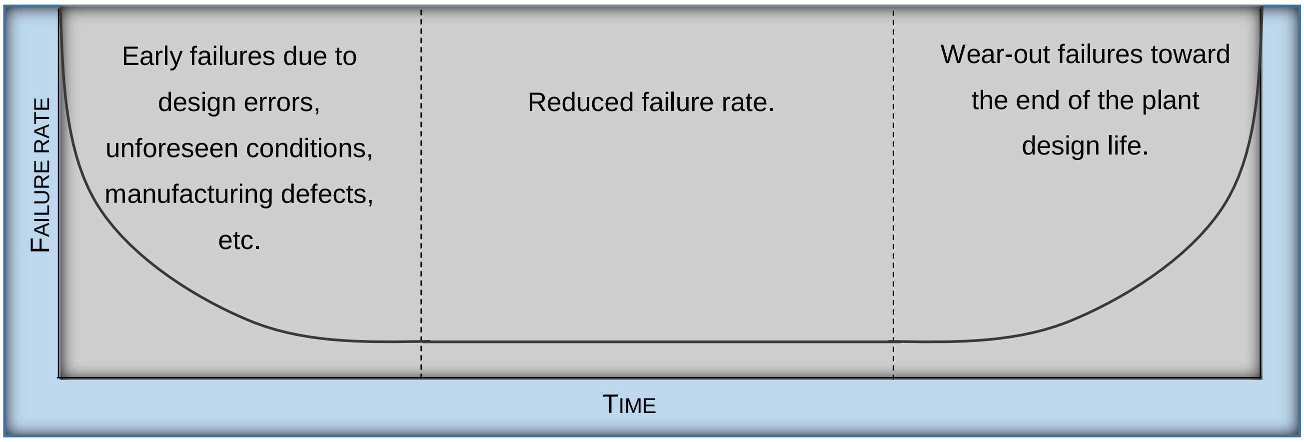


FIGURE 5: 'BATH TUB' CURVE OF HYPOTHETICAL FAILURE RATE VERSUS TIME [36]

For new facilities, a confidence index should be employed to promote early inspections to detect any active deterioration mechanism not identified, this can be performed through the RBI assessment. These inspections should include a general type of inspection like a detailed internal visual examination, which has the capability of detecting unexpected deterioration such as previously undetected manufacturing defects.

In the middle of the plant life cycle, when deterioration rates are confirmed by several inspections, inspection interval may be extended, provided in-service inspections have confirmed that the rate of deterioration is both reasonable and predictable. Toward the end of the plant life cycle, when the equipment is approaching the end of its serviceable life, confidence in the integrity of the component is necessarily reduced and inspections should be performed more frequently to prevent unexpected failures.

2.1.7 Consequences of Failure (CoF)

CoF is defined for all possible consequences that may result from every possible failure in the risk assessment, such as a number of people affected (injured or killed), property damage, amount of a spill, area affected, outage time, mission delay, money lost, or any other measure of negative impact for the quantification of risk. Consequence is usually divided into three categories (safety, economic, and environmental consequence) [21].

Economic consequence will be discussed further as it is one of the important aspects in RBI efficiency. Economic consequence concerns both the business loss of production and the cost of repairs due to component failures. Economic consequences due to business interruption or deferred production related to costs due to the shutdown of the plant and contract penalties in some cases, these can be extremely high. The use of high fuel cost peaking power plants (e.g. gas turbines) play an important role in maintaining the production as an effort to meet electricity demands, but it has a negative impact economically.

2.1.8 Inspection Records and Reports

Complete and auditable inspection records should be preserved to enable trends identification. For each inspection, the following information should be recorded as a minimum:

- Date of inspection/test
- Name of inspector/tester
- Serial number of equipment/ Equipment Identification Number (e.g. KKS, AKZ, etc.)
- Description of test
- Results of test.

The final deliverable of an inspection is the formal report from the inspector to the facility managers. The report should outline the general findings of the inspection and highlight defects and areas of concern. Frequently the inspectors will issue these reports at the end of each day or inspection phase, this is particularly important if they identify a serious issue that requires immediate attention.

The overall inspection results should be reviewed preferable annually and a management summary report prepared. The inspectors should follow the same reporting process as much as possible. Various inspectors with the same qualifications would ideally issue the same findings in roughly the same format [44].

2.2 UNDERSTANDING RBI BENEFITS

It was important to understand the possible benefits that come with implementing the RBI process in an organisation to relate with the expectations that an organisation might have when implementing RBI. Thus the following knowledge was accumulated literature review.

2.2.1 Maintenance Cost Reduction

Reducing inspection costs is usually not the primary objective of a RBI assessment, but it is a benefit that comes with inspection optimisation. An optimised inspection strategy based on understanding plant risks may yield the following cost reduction benefits: [11]

- Ineffective, unnecessary, or inappropriate inspection activities may be eliminated.
- Inspection of low risk items may be reduced or eliminated in a short term plan.
- Non-aggressive or online inspection methods may be used instead of aggressive methods that require equipment shutdown where possible.
- More effective occasional inspections may be used instead of less effective frequent inspections.

2.2.2 The monetary benefit of Probabilistic Risk Assessment

Probabilistic Risk Assessment (PRA) used in Nuclear Power Plants is required for new reactor licenses to satisfy regulatory safety compliance to the United States Nuclear Regulatory Commission’s Risk-Informed Regulatory framework [5]. Included in this study was the following:

- Cost benefit analysis to formulate the net value of PRA based on the net value of Risk Informed Performance Based Applications (RIPBA).
- Causal modelling to systematically model the operational scenarios leading to costs and benefits associated with RIPBA.

The above were necessary as their results could assist decision makers to evaluate investment strategies in PRA, and this could contribute beyond compliance to maximise the organisation profit while maintaining regulatory safety targets. This study proved to require more time than allocated to acquire noticeable benefits of PRA to the organisation’s safety performance, it requires to be supplemented by a long-term road map for outlining the market value of PRA to support wider industry adoption.

A possible benefit of PRA in the heavily regulated commercial nuclear power domain is to assist in showing where the regulatory initiatives may be unjustified, based on the risk reduction versus the cost of such initiatives. A risk assessment can be used to demonstrate where greater benefit may be realized at less cost to the regulated industry. It must be noted that in the process of optimising costs benefit, safety is not compromised, and regulations compliance remains critical. These risk assessments are useful for prioritising expenditures and for making efficient use of existing resources based on safety benefit [6].

2.2.3 The Power of Risk Based Inspection (RBI)

"*Historically, steam-generating boilers were inspected and maintained as single items, driven by legislative requirements* [1]". ABB was tasked to evaluate the possibility of extending the intervals between full overhauls of four steam-generating units with the use of RBI study. Inspection arrangements can be optimised after assessing the risk with the consideration of both the operating conditions of individual equipment items and the deterioration mechanisms to which they are susceptible [2].

All units were over 20 years old with a history of repairs. A multi-disciplinary team consisting of all required stakeholders was assembled to carry out this task. *"This team was highly experienced in conducting a detailed review of the operating conditions and maintenance histories of each component* [1]". The boilers were not assessed as a single unit during this RBI study, but broken down into component level.

Results of the ABB case study:

The RBI study resulted in the interval between boiler overhauls being extended from 4 to 6 years. The following outcomes were key to achieving this without compromising safety [1]:

- Performing limited inspections of key components at intermediate inspections.
- Increasing the use of online monitoring of water quality, fuel composition, and header temperatures as part of the components condition monitoring.
- More targeted and repeatable inspections during thorough examinations, including wide range use of non-aggressive techniques.
- Establishing a clear basis for developing a maintenance strategy of the equipment.
- Improved operating team's understanding of activities that affect reliability and integrity.

Benefits achieved as a result of RBI implementation through ABB case study:

The following were the benefits observed as a result of implementing RBI on the steam-generating boilers:

- Extending the boilers overhauls interval saved two million pounds (£2 M).
- An increase in online operating time, resulting in production increase.
- A reduction in inspection cost, due to optimised inspection scopes.

- A foundation for maintenance strategy for the equipment.
- An increased lifecycle for specific components due to good maintenance practice.

The key was to use all available techniques, analysis, and historical information to maximise the interval for each piece of equipment and then set up a maintenance strategy to achieve the required work with the minimum total cost over the operational life of the equipment [1].

2.2.4 Evaluation of maintenance strategy using RBI

The purpose of this study was to conduct RBI and evaluate if the following could be accomplished [4]:

- Moving away from time-based inspection often governed by minimum compliance with rules, regulations, and standards for inspection.
- Applying an optimised maintenance strategy for preserving integrity and improving reliability and availability of the assets by implementing only the essential inspections.
- Providing economic benefits through reduced inspections, less downtimes, and increased production.

RBI was performed based on API 580 and 581 standards. The risk categories on the risk matrix were favourable, acceptable, tolerable, unsatisfactory, and critical ranging from 1 to 5 respectively.

The following were the case study results:

The results shown in Table 1 below means that the organisation can focus on 24.4% (Unsatisfactory and Critical) of the components in short term risk management and manage the remaining risks over a long term period. This evaluation demonstrates that all the objectives of the organisation will be accomplished through RBI.

TABLE 1: RISK RANKING RESULTS IN PERCENTAGE [4]

Risk Ranking	Percentage (%)
Favourable	27.9
Acceptable	3.5
Tolerable	44.1
Unsatisfactory	23.8
Critical	0.6

2.3 STANDARDS APPLICABLE TO RBI PROCESS

The RBI process can be implemented through the American Petroleum Institute (API) or Risk-Based Inspection and Maintenance Procedure for European Industry (RIMAP) standards. API is applicable in petroleum industry, whereas the RIMAP is appropriate in power plants. The following standards are also associated with RBI for various functions as defined below, but they are not RBI process implementation standards:

- SANS 347 – Categorization and conformity assessment criteria for all pressure equipment.
- SANS 17021 – Conformity assessment: Requirements for bodies providing audit and certification of management systems.
- SANS 10227 – Approved Inspection Authority (AIA) regulating standard, it outlines the criteria for the operation of inspection authority performing inspection in terms of the Pressure Equipment Regulations.

For the purpose of this research, only the RBI process implementation standards will be discussed further.

2.3.1 API Risk analysis methodology

In API RBI methodology, failure is defined as loss of containment. The risk of failure is calculated using the following equation:

$Risk_{failure}(t) = PoF(t) \times CoF$, where the risk and the PoF are functions of time (t) as indicated in the equation.

The probability of failure (PoF) is determined using applicable damage factors (mechanisms), a generic failure frequency, and a management system factor [43]:

$$Pof(t) = 1 - e^{-GFF \times F_{MS} \times DF(t)}$$

- GFF is the generic failure frequency
- F_{MS} is the management system factor
- DF(t) is the overall damage factor

The CoF can be calculated in two ways, area-based and financial-based. The area-based consequences are calculated based on the type and phase of fluid and equipment operating condition. Then financial consequences are directly calculated by multiplying the affected area by costs per unit area and then adding this to cost of business interruption and environmental clean-up costs [23].

2.3.2 API 510 inspection planning

Internal Inspection is an inspection performed from the inside of a pressure vessel using visual and/or non-destructive examination (NDE) techniques. External Inspection is an inspection performed from the outside of a pressure vessel to find conditions that could impact the vessel's ability to maintain pressure integrity or conditions. On-stream Inspection is an inspection performed from the outside of a pressure vessel while it is on-stream using NDE procedures to establish the suitability of the pressure boundary for continued operation [25]. Based on API 510, Higher-risk vessels shall be inspected as follows [26]:

- External inspections shall be performed when an internal or on-stream inspection is performed or at shorter intervals determined by the owner or user.
- Internal or on-stream inspections shall be performed at least every 10 years or 1/2-remaining corrosion rate life, whichever is less.
- Inspection interval may be the full remaining life up to a maximum of two years, in cases where the remaining life is estimated to be less than four years. It is recommended that consideration should also be provided to increasing the number of vessels inspected within that class to improve the likelihood of detecting the worst-case corrosion.
- Any signs of deterioration or leakage detected in the interval between inspections shall require an internal or on-stream inspection of that vessel and a re-evaluation of the inspection intervals for that vessel class.

2.3.3 The Value of Inspection (API 581) – Inspection Effectiveness

An estimate of the probability of failure for a component is dependent on how well-known are the independent variables of the limit state [37]. Once a possible damage mechanism has been identified, the inspection program should be evaluated to determine the effectiveness in detecting the identified mechanism. The effectiveness of an inspection program may be restricted by:

- Lack of coverage of an area subject to deterioration.
- Inherent limitations of some inspection methods to detect and quantify certain types of deterioration.
- Selection of inappropriate inspection methods and tools.
- Application of methods and tools by inadequately trained inspection personnel.
- Inadequate inspection procedures.

- The damage rate under some conditions (e.g. start-up, shut-down, or process upsets) may increase the likelihood that failure may occur within a very short time. Even if the damage is not found during an inspection, failure may still occur as a result of a change in conditions.
- Inaccurate analysis of results leading to inaccurate trending of individual components.
- Probability of detection of the applied NDE technique for a given component type, material properties, temperature and geometry.

Determination of inspection effectiveness should consider the following: equipment or component type, active and credible damage mechanisms, susceptibility and rate of damage, NDE methods, coverage and frequency, and accessibility to expected deterioration areas.

2.3.4 The RIMAP Approach

RIMAP process was initiated as a European project with the objective of developing a unified risk-based decision making process within the inspection and maintenance environment. This approach is applicable to the power, chemical, petrochemical, and steel industries [2]. The process for assessing the risk is based on a combination of the probability and consequence of failure. The probability and consequence of failure are assessed using a bow-tie approach, in which the overall risk associated with the component is calculated by multiplying the highest consequences of failure (CoF) value with the sum of the probability of failure (PoF) values for all the active damage mechanisms [2].

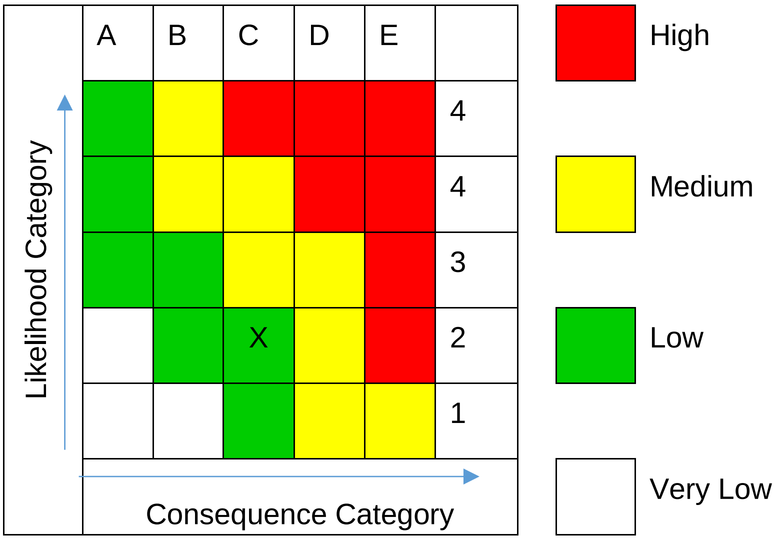
RIMAP process depends on the application of sound engineering practices as it is mainly based on expert judgement. It is crucial to ensure that the risk acceptance criteria and the objectives of the assessment are clearly defined and understood by all assessment team members [2].

The assessment team must be a multi-disciplinary team with a range of engineering competencies within inspection and maintenance, specific equipment disciplines (e.g. materials, corrosion, electrical, fixed and rotating equipment), safety and health issues, plant operation and process, and reliability and risk assessment.

RIMAP Process flow steps in line with Figure 7 are listed and discussed below:

- Initial Planning and Gap Analysis – Define the objectives and boundaries for the assessment. Setup the assessment team and identify the data sources. Define the necessary software requirements. Identify the deficiencies in the existing risk management system.
- Data Gathering and Validation – Collection of the data and population into the assessment tool (spreadsheet or software). The accuracy of the data is critical for RBI process as the plant safety depends on it, hence the data must be validated.
- Multi-level Risk Approach – The risk analysis can be multi-level both in terms of qualitative or quantitative and in terms of going in depth into plant equipment hierarchy. Both qualitative and quantitative approaches may be used, ranging from screening to more detailed stages.
- Decision Making and Action Plan – A multi-disciplinary risk assessment team must develop the optimal inspection strategy, based on the risk assessment outcome. The objective of this strategy is to ensure the optimisation of costs and resource utilisation.
- Execution Reporting – Upon the implementation of the maintenance plan developed by the risk assessment team, the findings of the maintenance inspections must be recorded in the inspection reports, noting the condition of the component. These findings should then be used as an input into the risk assessment to further refine the risks [2].
- Performance Review – The purpose of the risk-based decision making process evaluation is to assess the effectiveness and impact of the process in establishing the inspection and maintenance programs, thus enabling continuous improvement of the risk management system. The evaluation process involves both internal and external assessment conducted by the internal operating organisation and by independent third party experts, respectively [2].

A risk ranking profile is generated and used to monitor the risks, this influences the maintenance scope as the ultimate goal is to minimise the risk while saving costs on maintenance where possible. A risk ranking matrix example is shown in Figure 6 below. The higher the risk, the more prioritisation is given to that particular risk to be mitigated through recommended inspections.



	A	B	C	D	E	
	🟩	🟨	🟥	🟥	🟥	4
	🟩	🟨	🟨	🟥	🟥	4
	🟩	🟩	🟨	🟨	🟥	3
	⬜	🟩	🟩 X	🟨	🟥	2
	⬜	⬜	🟩	🟨	🟨	1

🟥	High
🟨	Medium
🟩	Low
⬜	Very Low

Figure 6: Risk Ranking Matrix [2]

2.3.5 Overview of RIMAP in Power Plants

This article provides an overview on the following, thus providing an introduction of the RIMAP methodology for power plants:

- The RIMAP and its main deliverables relevant for the application of RBI for power plants.
- Demonstration of how the main RIMAP documents cover the RBI issues of various levels (general concept, procedure, detailed workbooks)
- An outline of their practical application on examples in power industry (piping, boiler, and turbine).

The RIMAP procedure provides guidance for developing and maintaining a risk-based inspection and maintenance program. The procedure is applicable to many industries and different types of equipment, this may include static equipment, rotating equipment, safety systems, and electrical/instrument equipment. The steps in the procedure are the same for all cases, even if the models and tools for assessing probability or consequence of failure vary from one application to the other [10]. The main deliverable of RIMAP within the European Guideline is the procedure shown in Figure 7. Deliverables more applicable to power plant are as follows:

- Identify applicable damage mechanisms – this is identified based on the area of operating conditions, with consideration of component design.
- Assessment of the probability and consequences of failure – this is assessed based on the failure history, design, and operating data.

- Acquire a software with PoF and CoF estimation method aligned to the RIMAP – an intelligent software systems capable of analysing large quantities of data in order to assess the remaining component life. Also capable of keeping together all sorts of data required for analysis and using data mining techniques to achieve the results [9].
- RIMAP application workbook for power industry – this workbook describes and specifies the use of the RBI methodology practically, setting up inspection and maintenance program for power plants [9].

A basic process flow representation of the RIMAP procedure is shown in Figure 7 below.

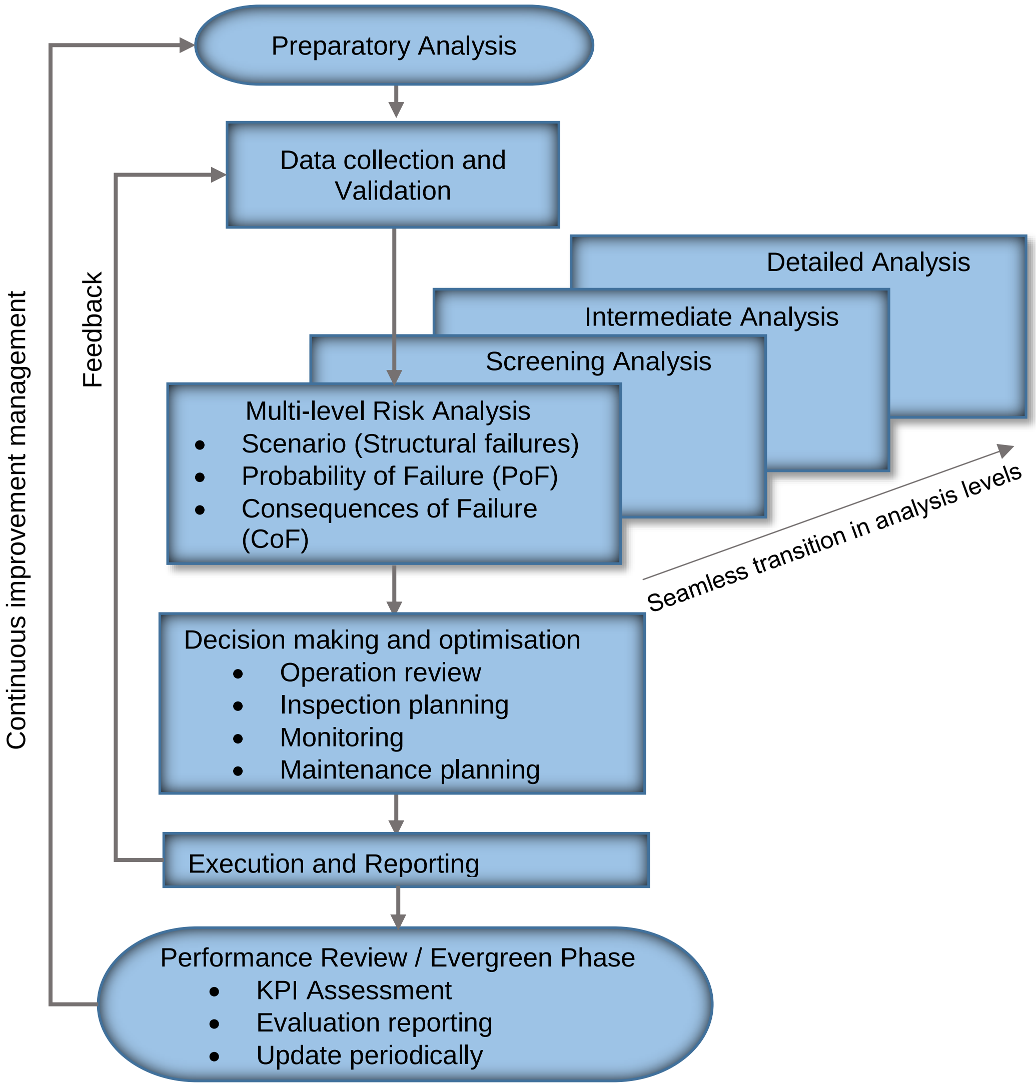


FIGURE 7: BASIC REPRESENTATION OF RIMAP PROCEDURE [9]

2.4 IMPLEMENTATION OF RBI PROCESS

The objective for RBI process implementation should be understood by the implementation team members. Scopes developed through RBI assessments must be executed as planned to achieve the intended objectives. The focus of this research was on the power plants, thus the RIMAP standard was applicable, and the following are important to understand when implementing the RBI process.

2.4.1 Life Management of Coal Power Plants

The European standard RIMAP formulates the procedure for a risk-based approach, thereby supporting optimisation of Operations and Maintenance (O&M) as well as asset management. The methodology addresses the following issues [19]:

- All types of equipment (e.g. pressure-containing, rotating, electrical, instruments and safety devices). When performing RBI for PER scope, only the design, manufacture, operation, repair, modification, maintenance, inspection, and testing of pressure equipment with a design pressure ≥ 50 kPa shall be considered [20].
- Inspection, maintenance, production, and operation.
- Technical and management aspects of maintenance and inspection planning.
- Asset management related to inspection, maintenance, and life assessment for plant components.

It is critical to integrate RBI implementation with other existing life management processes in the power plant. The integration will prevent scopes duplication or omission, the product of integrated life management processes is one final inspection scope to be executed during shutdowns. Successful integration of plant life management processes will result in better scopes optimisation, inspection costs savings, and less unplanned plant downtime. It must be noted that all these benefits depend on the quality of scope execution.

Decision-making and planning:

Conservative inspection and maintenance is an efficient approach when the mitigating actions are cheaper than executing an optimised inspection and maintenance plan [19]. Programs with predetermined intervals are developed for management of inspection and maintenance on a daily basis. Although these programs are developed by experts in the field of assets risk management, the experience of the team that make decisions on risk mitigations and inspection plan is critical as the safety of the human and equipment of the plant depends on these decisions.

Performance Review:

The purpose of the evaluation of the risk based decision-making process is to assess its effectiveness and impact in improving the developed inspection and maintenance programs. This will allow the identification of areas in which modifications and improvements are required. Evaluation consists of the following tasks as a minimum [19]:

- Assessment of the effectiveness of the risk-based decision-making process in achieving the intended objectives, this can be performed in a form of an audit.
- Updating the risk-based decision-making process by incorporating possible plant changes and available new knowledge, this should be performed periodically.
- Benchmarking with similar industries practicing risk-based decision-making processes is also one of the best methods of improving these risk-based programs.

2.4.2 Semi-quantitative approach for Risk Based Inspection

A study was conducted as a result of internal and external factors that affected the organisation from producing electricity in a safe and sustainable manner to ensure electricity supply security [2]. Eskom decided to implement RBI to meet the statutory and safety requirements as stipulated by the Depart of Labour, also with intentions of benefiting from potential maintenance costs reduction [2]. The CWA15740 Risk-Based Inspection and Maintenance Procedure for European Industry (RIMAP) approach was used to develop the Risk Based Management System [2].

A major factor that was affecting the organisation was to perform pressure test every 36 months on the pressure regulated vessels, and this proved to be challenging as it became difficult to meet the South Africa’s power demands due to high power outages to perform these pressure tests [2]. During the RBI implementation, the Department of Labour granted a 72 months pressure testing interval exemption for pressure vessels [2]. This exemption provided some relief and enabled the organisation to cope with the South Africa’s power demand during the RBI implementation [2].

2.4.3 Risk-Based Application in the Power Industry

Application of RBI within the coal fired power generation is limited, as there are few coal fired power stations applying this philosophy. It is a requirement in South Africa to have the RBI Management System certified by the independent third party, this is not a requirement in other countries. The Certification Body must be identified and communicated to the Department of Labour as part of the application letter for RBI implementation. National Thermal Power Corporation in India is the "*world's third largest power utility, they have successfully implemented RBI to all of their 105 power units*" ensuring that the units run safely and reliably [2].

Progress Power in the United States "*implemented RBI to 19 of its power generating units*, *this enabled the replacement of 140 major tube components for $70 million less that the convention approach*" which treats all hazards equally [2]. Historical experience in power distribution systems demonstrates that the majority of system failures are contributed from a small number of high risk components. Risk-Based Inspection can be utilised to identify and prioritise maintenance activities of these high risk components effectively to prolong the useful life of the component while achieving the same level of risk [2].

2.4.4 Corrosion Risk Analysis

Corrosion is a major damage mechanism in the chemical process industries (CPI) and it affects process equipment, pipelines, and structures. RBI can be used to prevent the unexpected failures, including the corrosion, leading to proper inspection activities planning to achieve optimal plant safety, reliability, productivity, and profitability. RBI classifies the risks as low, medium, and high categories. This enables the user to prioritise on medium and high risk categories.

It is important to note that the low risks are not neglected, they continue to be monitored, and when their risk category increases, the mitigations are implemented. This allows the equipment operation to be safe and more reliable, with improved productivity and profitability.

Having gathered all the required plant data input, corrosion risk analysis can be conducted using the RBI process. Corrosion damage mechanisms could lead to leakage of the process fluid to the environment, this could lead to injuries, fatalities, environmental pollution and affect the cash flow of the organisation. In addition, it could affect the production due to pressure losses that comes with leaks. Typical corrosion damage mechanisms are shown in the Table 2 below.

TABLE 2: TYPICAL CORROSION DAMAGE MECHANISMS [3]

Damage Type	Description
General or Uniform Corrosion	A relatively uniform loss of material over an entire area and in a general thinning of that affected area.
Localized Corrosion	Occurs at discrete sites on the metal surface, the predominant forms of localized types of corrosion are pitting, crevice corrosion. Galvanic corrosion is also a localized form of corrosion.
Surface Connected Cracking	Stress Corrosion Cracking (by chloride, caustic, sulphide, amines etc.), Corrosion Fatigue, and Liquid Metal Embrittlement.
Sub-surface Cracking	Hydrogen Induced Cracking and its variations for instance blistering, hydrogen embrittlement etc.

2.4.5 RBI Case Study on a Hydrocarbon Condensate Pipeline

In this case study, a corrosion risk analysis was performed for a proposed condensate pipeline. The pipeline was considered to be long, as it was few kilometres in length. The material of construction was a plain carbon steel and the pipeline was seamless [3].

The condensate contained small quantities of condensed moisture with dissolved carbon dioxide, hydrogen sulphide, and hydrocarbon liquids. The purpose of the study was to develop a risk-based inspection plan.

The following were noted during the risk assessment:

- Hydrocarbons are not corrosive.
- Corrosion due to carbon dioxide was neglected as the carbon dioxide content was relatively low.
- Hydrogen sulphide content and its partial pressure were such that sulphide induced corrosion could occur, including sulphide stress corrosion cracking.
- Sulphide stress corrosion cracking (SSCC) was identified to be the most likely damage mechanism to occur, due to hydrogen sulphide presence.
- Likelihood of failure was rated as 2 (see Figure 6), due to good inspection history (performed yearly) and effective inspection techniques.
- Consequence of failure was rate as C (see Figure 6), due to possibility of hydrocarbons leaking through the cracks caused by SSCC, consequentially fire and/or explosion. In addition, the pipeline is long and contains a flammable fluid.

Phased Array UT is the effective method to detect Stress Corrosion Cracking on heavy wall reactors compare to Time-of-Flight Diffraction (TOFD) or any other conventional NDT techniques. However the challenges always remain on sizing and plotting the orientation. "*This can be overcome by additional focused scans as well as effective evaluation and plotting the orientation* [6]".

The study result came out to be a low risk as indicated with a red cross (X) in Figure 6 based on the organisation risk matrix. The location of each piece of equipment on the risk matrix is determined based on the calculated DF and CoF [24]. RBI recommended the inspection to be performed once a year, focussing specifically on detecting SSCC in stressed areas, for example bends and elbows of the pipeline.

Routine maintenance inspections of the general pipeline, using techniques such as thickness measurements, coupon exposures, dye penetrant tests of weld joints, etc., were reduced as they would not provide useful information on the condition of the line. The recommended strategy could offer savings on inspection costs, and also reduce the risk of unexpected failure significantly.

2.4.6 Optimised Inspection Plan

The inspection plan is best optimised when the plant risks evaluation is completed and the risk ranking exists. High risks take priority in the inspection plan, meaning in the event of limited time for inspection plan execution, high risks are the first to be carried out followed by medium risks, and then low risks. The higher the risk rank, the more frequent the inspection is performed [21]. Shown in Figure 8 below are different levels of inspections with different effectiveness indicated as A, B, C, and D.

Looking at the 2nd inspection date, level C of inspection is observed to be the optimum inspection effectiveness category for the 1st inspection date because after performing level C inspection the risk was determined to be below the risk target, but closest compared to A and B at the 2nd planned inspection date. It is also observed from Figure 8 that if a level D inspection is performed, the risk of the equipment will exceed risk target before the 2nd inspection date (under-inspection). This is unsafe and the equipment failure could cost the organisation dearly .On the other hand, level A or B inspection at the 2nd inspection date would definitely satisfy the risk target criteria, but may not be the most cost-effective (over-inspection).

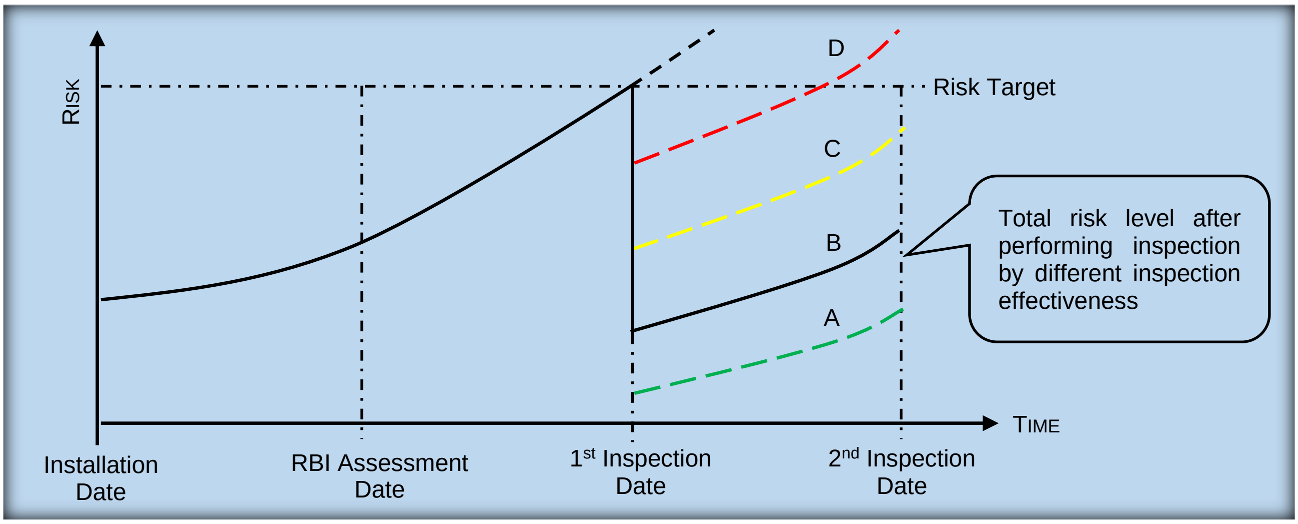


FIGURE 8: SCHEMATIC PRESENTATION OF RISK-BASED INSPECTION PLANNING PROCEDURE [23].

2.4.7 High-level prioritisation

During the process of RBI implementation, it is often difficult to identify where to start to achieve the maximum benefit within an acceptable time frame without compromising the plant safety. The program can take several years to complete one cycle and the availability of resources and budgets are often limited, even with senior management support [27]. Identifying the areas of the plant which are at high risk and which have a great impact on health, safety, environment, and business is fundamental to the success of the prioritisation initiative.

A qualitative (high-level) screening method is employed to accelerate identification of low risk components and deriving a priority plan for a RBI program. At the completion of high level screening, a semi-quantitative method is then employed to evaluate the risk in great details. At this stage, the number of components to be assessed will be at a very small scale compared to the qualitative assessment stage. This stage can then be followed by a quantitative risk assessment, which is the highest level of detailed assessment. Also this is where the number of components to be assessed is the least in the RBI program, as most of the components will fall out in the first two levels of risk assessment.

2.4.8 Combination of prediction and inspection

The optimal combination of plant reliability and plant obligation factor contribute to reliable, economical, and safe plant operation. Components with higher risks potential are inspected based on precise understanding of the degradation mechanism and prediction of degradation risks such as RBI, which contributes to the concentration of inspection resources and rationalism of inspection while simultaneously improving inspection quality.

The secondary effects of RBI are acquisition of qualified data on essential equipment and materials, which contribute to improving the degradation prediction and the major parameters applied for the models. *"The combination of prediction based on degradation models and inspection can contribute to synergetic effects for inspection rationalism and degradation prediction improvement"* [34]. A typical combination of prediction, based on degradation model is shown in Figure 9 below.

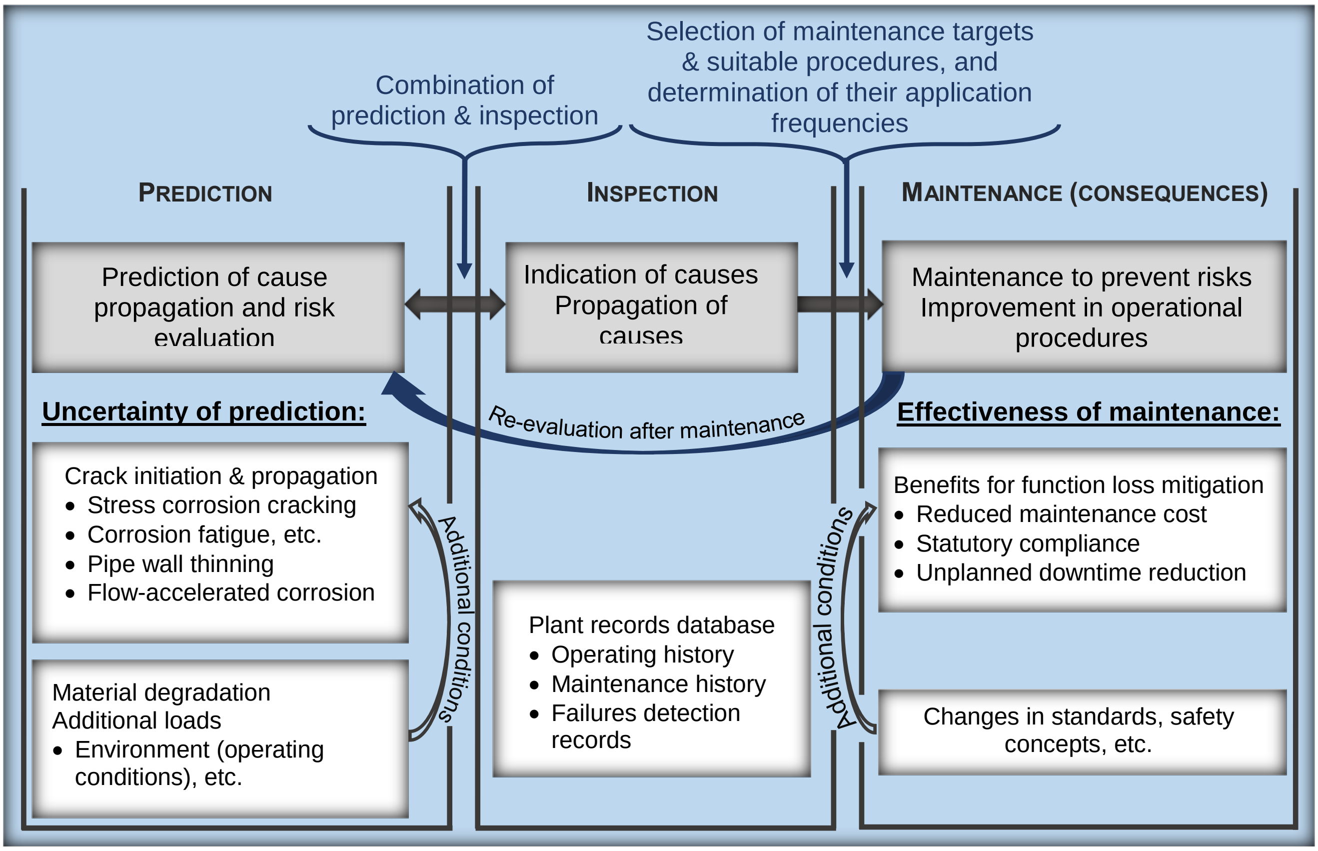


FIGURE 9: CONCEPTUAL SYSTEM SAFETY ASSESSMENT MODEL [34]

2.5 HUMAN EFFECT IN RISK ANALYSIS AND INSPECTION IMPLEMENTATION

Human effect plays a significant role in the success or failure of the RBI implementation. Thus it was necessary to study the human errors in inspection and maintenance, and management and business culture as discussed below.

2.5.1 *Human Errors in Inspection and Maintenance*

Human errors needs to be reduced to as limited as possible to ensure high quality plant maintenance and production. Inspection and maintenance activities are critical in improving the reliability and availability of the components. The inspection and maintenance activities are occasionally performed under enormous pressure, in the shortest possible period of time, under difficult and hazardous conditions to bring the facility up and running. Even with the continuous technical advancement while designing the equipment or machines, human involvement needs to be considered when performing inspection and maintenance.

Human interactions with machines are prone to introduce error while performing inspection and maintenance due to various factors. "*Human errors during inspection and maintenance activities have already produced disastrous outcomes (in millions of dollars) such as Flixborough, Three Mile Island, Piper Alpha and Bhopal accident"* [22]. Human errors such as misinterpretation of maintenance manuals and engineering drawings, inadequate personnel training, poor working environment, time constraint, fatigue, sleep deprivation, and processing hazards are some factors that affect human performance. The degree to which these factors affect human performance can range from slight to catastrophic [48].

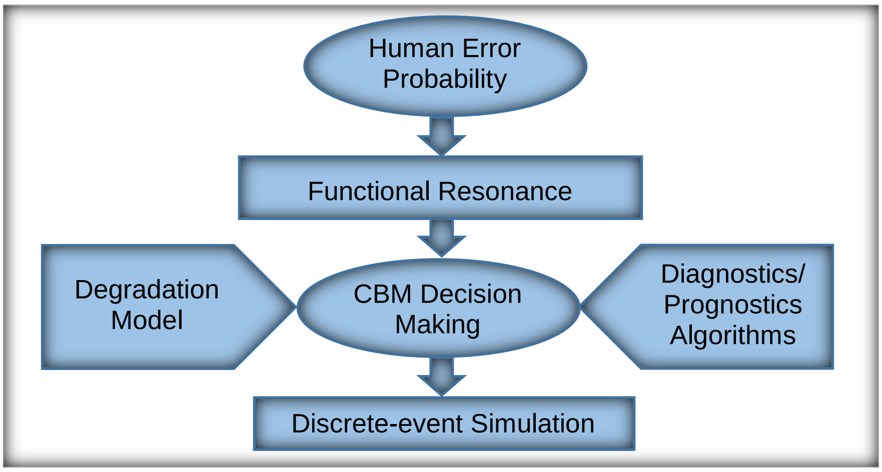


FIGURE 10: INTEGRATED SYSTEMIC MODEL [46]

The integrated systemic model shown in Figure 10 above has an advantage in a way that it emphasises that incidents analysis must be based on an understanding of the functional characteristics of the system [46]. Human error is a major contributor to risk, and human error probability needs to be quantified in the risk assessment processes.

2.5.2 Management and Business Culture

It is important to have a strong management involvement in any process improvement. The working environment and expectations become important when optimising maintenance. Creating a positive work environment that promotes a learning organization is vital. Many fossil plants have a reactive working culture, whereas plant maintenance optimisation (PMO) emphasizes a 'planned' working environment where 'firefighting' is minimized. This requires a change in the management and staff behaviour, which can only be achieved by strong leadership and an organisation structure that promotes PMO [40].

Benchmarking, Goals / Business Plan, Organisation, Leadership, Communication, Metrics / KPI, Accountability / Ownership, and Continuous Improvement are key elements for PMO. Maintenance objectives should be developed through measuring the organisation performance in terms of management team's direction as stipulated in the policy document. These objectives should be in line with the framework as defined in the maintenance policy. The maintenance management team should maintain and update the maintenance objectives at least annually [28].

RBI Efficiency and Effectiveness Improvement Methods captured through literature review:

- Senior management commitment at plant site – is critical to support the best practice in RBI, such as providing resources, allocating time for RBI assessment team to perform risk analyses, and enforcing implementation of the RBI recommendations.
- Well-structured and functional Document Management System – enables data gathering process to be faster, as the documents can be retrieved with ease.
- Well-developed RBI assessment tool (spreadsheet / software) – should be developed based on a particular standard (e.g. API 580/ 581, RIMAP, SANS 347, etc.). This tool must have a capability to be updated as standards are updated from time to time.
- Multi-disciplinary Assessment Team – It is critical to select a best-qualified and experienced available members when assembling the team, as personnel's safety depends on the decisions taken during the assessments.
- Selection of inspection intervals – It is important to ensure alignment on inspection intervals for all plant areas (e.g. Boiler and Turbine high risks should be inspected on the same interval to prevent shutting the plant down twice unnecessarily). This will assist in minimising downtimes, thus improve the plant productivity.

- Non-aggressive or online inspection methods – may be used instead of aggressive methods that require equipment shutdown where possible.
- Extension of inspection intervals – increases the production period, consequently improved the profitability.
- Inspection scopes optimisation – reduces may reduce the downtime and inspection costs.

3. THEORETICAL FRAMEWORK

The theoretical framework provides a description of the intended research deliverables and the methodology to achieve the research outcome. Efficiency refers to the RBI financial impact on the maintenance scopes, and effectiveness refers to the RBI implementation serving the purpose of an organisations objectives in this research.

3.1 RESEARCH HYPOTHESES

Hypothesis is a speculation or theory based on insufficient evidence that requires further testing and/or experimentation. Null hypothesis is a hypothesis where there is no statistical significance between the two variables in the hypothesis. Two hypothesis listed below were identified for this research:

- Hypothesis 1: Understanding the RBI contribution into the maintenance costs reduction will improve the efficiency of RBI implementation.
- Hypothesis 2: Lessons learnt during RBI implementation contribute in improving the RBI process effectiveness

The significance of these hypotheses will be assessed through efficiency and effectiveness evaluations respectively.

3.2 RESEARCH METHODOLOGY

An understanding of the RBI process and previously conducted studies was captured through literature reviews. A case study was identified as a suitable method to investigate the efficiency and effectiveness of RBI implementation. Required data for efficiency and effectiveness evaluation was gathered for a case study that was conducted.

The evaluation of RBI efficiency was conducted through cost benefit analysis. The evaluation of RBI effectiveness was conducted through analysing audit findings and lessons learnt during RBI implementation, and interviewing site based Risk Engineers. Data analysis was performed and results were established. Results were discussed, hypotheses significance was concluded, and improvement strategies for RBI efficiency and effectiveness were provided based on the case study results. The framework that was followed during this case study is shown in Figure 11 below.

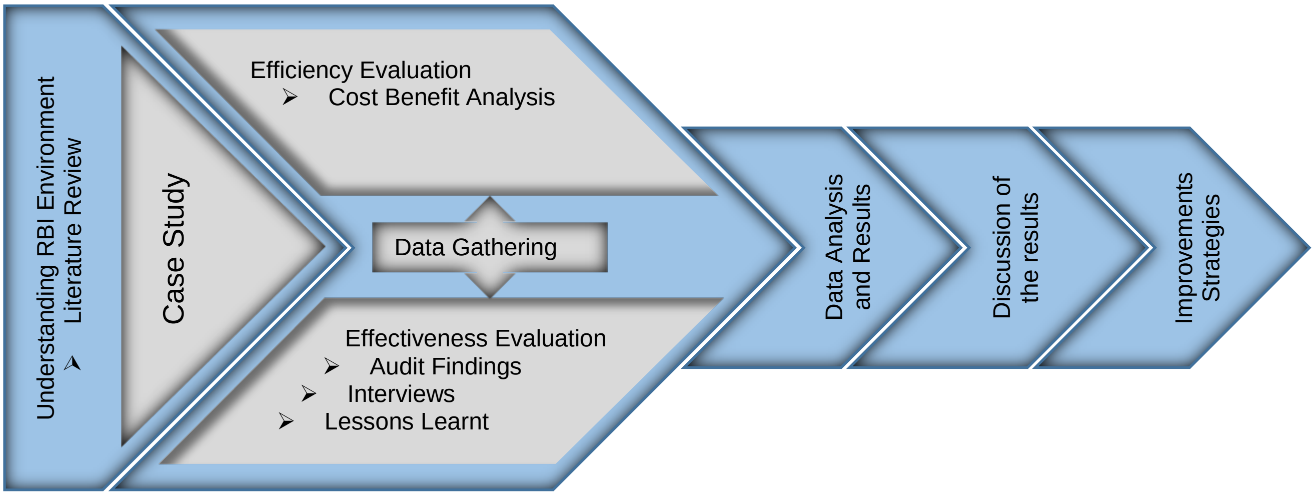


FIGURE 11: RESEARCH FRAMEWORK

3.2.1 *Efficiency Evaluation*

Prior-RBI, RBI Pre-outage, and Post-outage inspection scopes execution costs were compared. The inspection costs for implementing the scopes were calculated and the observation of the cost benefit analysed through an excel model.

The following were evaluated to investigate the RBI implementation efficiency:

- Possible financial benefits achieved due to RBI scopes optimisation
- Possible financial benefits achieved due to RBI downtime reduction

The significance of hypothesis1 will therefore be evaluated based on the efficiency evaluation results.

3.2.2 *Effectiveness Evaluation*

Human involvement, systems, and procedures contribute significantly to the effectiveness of RBI. The following were performed to investigate the RBI implementation effectiveness:

- Audit findings analysis to capture lessons learnt for continuous improvement of the RBI implementation process.
- Risk Engineers interviews through 11 effectiveness evaluation criteria shown in Table 3, on 9 randomly selected power stations from a total of 14 RBI certified power stations of this specific organisation.
- Lessons learnt assessment to evaluate RBI process improvement due to implementation of these lessons.

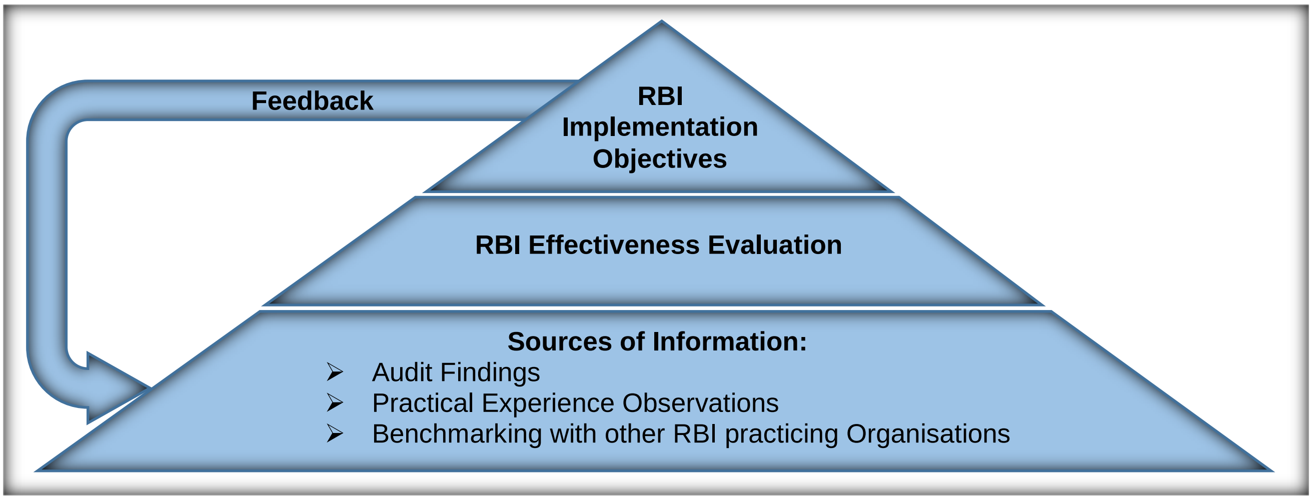


FIGURE 12: RBI EFFECTIVENESS EVALUATION FRAMEWORK

A typical RBI effectiveness evaluation framework shown in Figure 12 above was applied to evaluate the process effectiveness. RBI effectiveness was measured against an organisation's RBI objectives as listed in paragraph 4 to evaluate whether the process serves the intended purpose. The effectiveness is intended to be improved based on the information sources listed in Figure 12 above.

Audit findings were studied to identify the most common and significant findings during the Conducted Case Study. These findings were analyse using the bow-tie risk analysis shown in Figure 13 below. Causes and consequences were analysed in details, with the observation of people, systems, and procedures influence to the effectiveness of the RBI process. Bow-tie Risk Analysis is a combination of an event probability and its consequences, it requires a multi-disciplinary team, and has the following characteristics:

- It enables visualization of the relationship between undesirable event, its causes, accidental scenarios, the preventive and mitigation measures to limit the consequences.
- It demonstrates the effectiveness of existing controls
- It enables structured risk analysis where quantification is not possible or desired
- It is extremely versatile and successful in various applications

Once the causes and consequences have been identified through the bow-tie process, mitigations and controls needs to be put in place for continuous improvement of the process. Figure 14 below shows the process flow for mitigations and controls for the causes and consequences in a Bow-tie Risk Analysis.

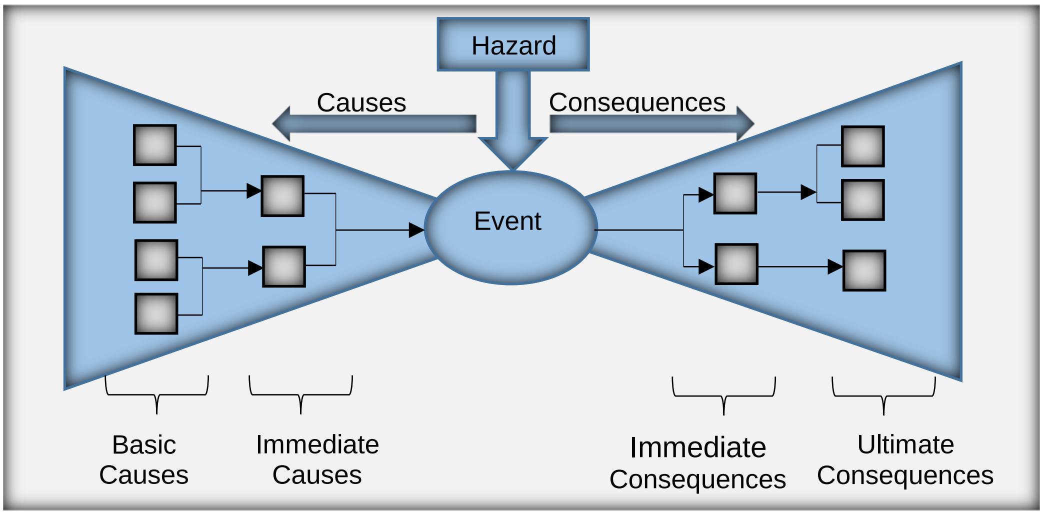


FIGURE 13: BOW-TIE RISK ANALYSIS [54]

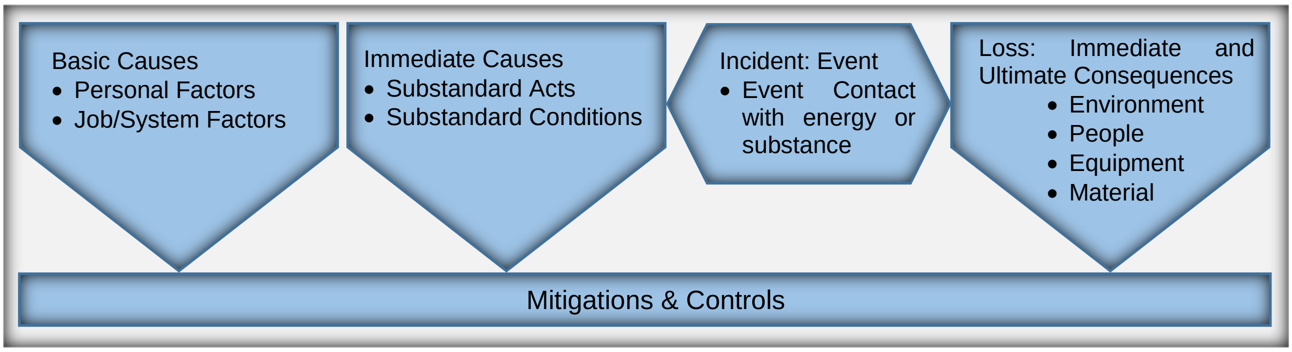


FIGURE 14: MITIGATIONS & CONTROLS [54]

The significance of hypothesis 2 will therefore be evaluated based on the effectiveness evaluation results.

4. CONDUCTED CASE STUDY

A case study was performed to investigate the efficiency and effectiveness of RBI implementation based on a specific power plant organisation. This organisation is believed to be a relatively reasonable choice as it is the largest power producing utility in Africa, thus the results obtained could contribute significantly in the engineering and science field.

This organisation experienced many challenges in meeting their customers’ electricity demand around 2008. Most of this organisation’s power plants were at the mid-to-late stages of their lifecycles, thus performing proper maintenance in these plants was critical to prevent unplanned plant shutdowns and trips. RBI approach is a provision in the Pressure Equipment Regulations (PER) that allows a user to determine inspection frequencies based on the risk assessment results. PER was introduced in 2009 to supersede the previously used Vessels under Pressure (VuP) regulations.

The organisation had a choice of continuing with VuP on the components that were commissioned prior PER introduction or adopting PER on all their components. The organisation decided to implement RBI as it was not practical to continue with VuP due to boiler pressure testing shutdown frequency of 36 months requirement, since this reduced the organisation’s total power production much needed to meet South Africa’s electricity demand profile. To date 1 nuclear and 13 fossil power stations have been RBI certified by a third party through RBI implementation, and audit process.

The objective of this study was to investigate the efficiency and effectiveness of RBI, and is intended to assist organisations in improving the RBI implementation process. The study was sample based, in which power stations with decent data availability were selected. RBI efficiency evaluation was performed based on the cost benefit analysis through an Excel Model. RBI effectiveness evaluation was performed through analysing audit findings, and interviewing site based Risk Engineers, and assessing lessons learnt during RBI implementation based on the typical organisation’s RBI objectives listed below:

- Delivering the RBI implementation on planned timelines to ensure scope readiness for the planned upcoming outages.
- Extending the maintenance inspection frequencies intervals where possible to cope with high electricity demand while maintaining high safety level in the plants.

- Reducing maintenance inspection scopes where risk assessment results allow to reducing the planned downtimes, leading to improved plant productivity.
- Eliminating unexpected plant failures, thus minimising unplanned downtimes and leading to improved plant productivity.
- Acquiring high competency for the resources involved in RBI implementation to improve the process accuracy.
- Closing audit findings to ensure continuous RBI implementation process improvement.
- Fully Implementing RBI scopes during the outages to reduce unplanned downtimes due to component failures caused by unexecuted inspections.

5. FRAMEWORK IMPLEMENTATION ON THE CASE STUDY

After the completion of literature reviews, the case study began with the data gathering of the information required to enable the evaluation of the efficiency and effectiveness of RBI in a specific power plant organisation as described below:

5.1 DATA GATHERING

There were two sets of data required, one for performing efficiency evaluation and the other for evaluating the effectiveness as described below. There were challenges experienced regarding the suitability of the provided information in fulfilling, but the adjustments made where necessary enabled the study to be conducted successfully.

5.1.1 Efficiency Evaluation Data

The advancement of all 14 power stations in RBI implementation process on a specific organisation was assessed. Two power stations were identified as most advanced in RBI implementation based on the results of this assessment and selected to be used for the efficiency evaluation. Historical actual maintenance costs were requested from the Outage Department on these two selected power stations. These costs were declared not usable as they only displayed a single total amount, which made it impractical to extract the exact costs per component.

In the absence of these costs breakdown, new quotations for executing the scopes listed below were required to enable scopes cost comparison for RBI implementation cost benefit analysis. The following maintenance scopes from the two selected power stations were gathered and submitted to the NDT supplier for quotations request:

- Prior RBI implementation
- RBI Pre-Outage
- RBI Post-Outage

Quotations with cost breakdown sufficient to perform this study were provided by the NDT supplier. It must be noted that there was no power station that had managed to perform Post-Outage at least twice on any unit at the time of this study as the planned shutdowns are still in the future, hence the costs evaluation was based on projections from the second outage onwards.

5.1.2 Effectiveness Evaluation Data

Populated interviews questionnaires, audit findings reports, and lessons learnt were gathered for the RBI implementation effectiveness evaluation.

5.1.2.1 AUDIT FINDINGS

RBI process audits reports were gathered and studied for all 14 RBI certified power stations to identify the most recurring findings from the first to latest audit report at a time of the data gathering phase of this study, conducted in February 2019. The findings extracted from these reports are attached in Appendix C.

5.1.2.2 INTERVIEWS

The interview questionnaire with 11 criteria shown in Table 3 below was developed for effectiveness evaluation data gathering purpose. The populated interviews questionnaires are attached in Appendix E.

TABLE 3: INTERVIEW CRITERIA AND MEASUREMENTS

Criteria	Description	Measurement
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).
3	RBI Scope execution during the outage.	Inspection reports: Compare the RBI scopes submitted to outage vs executed scope through inspection reports.
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's validity from the AIA / Statutory Compliance list: assesses if there are any CoC's that have been due to RBI/ Mini-RBI implementation.
5	Unexpected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes - has there been any unexpected RBI assessed component failures (Risk Engineer/ RBI Representative to attend the meeting).
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.
7	Resource Training	Training plan: Compare the required vs actual executed through the training planned.
8	Steering committee	Terms of Reference (TOR): assess if meetings take place as planned, and provides resolutions to the escalated challenges.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI participating members.
10	RBI Internal Audits	Audit Findings: Evaluate if all nonconformities and opportunities for improvements are closed/ addressed.
11	RBI External Audits	Audit Findings: Evaluate if all nonconformities and opportunities for improvements are closed/ addressed.

5.1.2.3 LESSONS LEARNT

Lessons learnt were captured through information sharing sessions, RBI practical experience, Risk Engineers interviews results, and audit findings reports. The lessons learnt were compiled by the RBI team, presented, and discussed in the RBI Forum in 2016 where all Risk Engineers were invited. These lessons learnt are occasionally updated and presented in the RBI Forums as and when required. Some of the lessons learnt captured are listed below:

- Data required for risk assessments can be challenging to find. This may be the result of poor commissioning, handover process, and documentation management system.
- It may be challenging to implement the RBI process effectively without full support of the senior management. This may result in lack of RBI team resources allocation, and poor risk assessments attendance from the required resources.
- Continuous training of the resources is critical for the improvement and sustainability of high quality process.
- It is important to have high quality and conclusive inspection reports. Inspection reports must cover the results, and conclude on the status of the component being inspected whether it will be safe to operate that component till the next planned outage.
- Frequent planned outage movements may impact negatively to the rollout plan of RBI. Outage movements delay the implementation plan and quality of the RBI process as the rollout plan stops to perform risk assessments of the components with the expiring Certificates of Compliance (CoC). This is usually performed on tight unplanned schedule which reduces the risk assessment integrity and quality.
- Using one plant coding (KKS or AKZ) for all power stations will be beneficial in comparing risks ranking, inspection scopes, and scope execution costs [14].
- Recommended RBI scope should be fully implemented to achieve the benefits of scope reduction [14].
- Quality of the risk assessment minutes should be accurately written as they are audited for the certification management process, and could be legally binding in the case of plant failure incidents investigation [14].

5.2 DATA ANALYSIS AND RESULTS

A 72 months inspection intervals exemption was granted by the Department of Labour based on a successful application to implement RBI. The following conditions were considered for Cost Analysis Excel Model that was used to simulate projected maintenance and downtime costs:

- Required NDT inspections were inspected on a 36 months interval Prior RBI.
- Prior RBI scope maintenance costs were kept constant for the duration of the simulation.
- 72 months interval General Outages (GO) was targeted to implement RBI scopes. The scope execution duration is driven by the turbine (Centreline scope) as its maintenance takes longer in GO’s.
- The Interim Repairs (IR) scopes were sometimes used to implement high risk RBI scopes for CoC extension purposes. However, RBI scopes implementation costs during IR were neglected as it is very minimal.
- GO duration was considered to be approximately 130 days on average based on the outage plan between 2014 and 2022.
- Scope execution preparation costs were also neglected, e.g. scaffolding installation, etc.
- Eskom charged 140.25 c/kWh calculated based on published 2018/2019 tariffs.
- Post outage scope was assumed to remain consistent throughout the modelling as a worst case scenario.
- Tariffs were kept constant throughout the modelling.
- Inflation rate was not considered for the duration of modelling which is 18 years.
- Initial RBI implementation including the certification costs were neglected, as internal resources are generally used for RBI implementation and certification costs considered to be reasonably low.

5.2.1 Cost Analysis

The results extracted from the Cost Analysis Excel Model for the two power stations.

5.2.1.1 POWER STATION 1 RESULTS

TABLE 4: POWER STATION 1 – COST ANALYSIS RESULTS

CRITERIA	INSPECTIONS WITHOUT RBI	INSPECTIONS WITH RBI (PRE-OUTAGE)	INSPECTIONS WITH RBI (POST-OUTAGE)
Maintenance Inspection intervals (months)	36	72	72
Downtime due to planned outage (days)	130	130	130
Loss of production cost rate (R/kWh)	1.4025	1.4025	1.4025
Lost production due to downtime (kWh)	1 996 800 000	1 996 800 000	1 996 800 000
Downtime costs per planned outage (R)	R 2 800 512 000	R 2 800 512 000	R 2 800 512 000
36 months Maintenance Costs (R)	R 6 867 965	R 0	R 0

INSPECTIONS WITHOUT RBI

Outage No.	Inspection Interval in years (months)	Maintenance costs	Downtime costs	Cumulative Maintenance costs	Cumulative Downtime costs
1	0 (0)	R 6 867 965	R 2 800 512 000	R 6 867 965	R 2 800 512 000
2	3 (36)	R 6 867 965	R 2 800 512 000	R 13 735 929	R 5 601 024 000
3	6 (72)	R 6 867 965	R 2 800 512 000	R 20 603 894	R 8 401 536 000
4	9 (108)	R 6 867 965	R 2 800 512 000	R 27 471 858	R 11 202 048 000
5	12 (144)	R 6 867 965	R 2 800 512 000	R 34 339 823	R 14 002 560 000
6	15 (180)	R 6 867 965	R 2 800 512 000	R 41 207 787	R 16 803 072 000
7	18 (216)	R 6 867 965	R 2 800 512 000	R 48 075 752	R 19 603 584 000
		R 48 075 752	R 19 603 584 000	Total Costs = R 19 651 659 752	

INSPECTIONS WITH RBI

Outage No.	Inspection Interval in years (months)	Maintenance costs	Downtime costs	Cumulative Maintenance costs	Cumulative Downtime costs
1	0 (0)	R 7 618 600	R 2 800 512 000	R 7 618 600	R 2 800 512 000
2	6 (72)	R 6 107 000	R 2 800 512 000	R 13 725 600	R 5 601 024 000
3	12 (144)	R 6 107 000	R 2 800 512 000	R 19 832 600	R 8 401 536 000
4	18 (216)	R 6 107 000	R 2 800 512 000	R 25 939 600	R 11 202 048 000
		R 25 939 600	R 11 202 048 000	Total Costs = R 11 227 987 600	

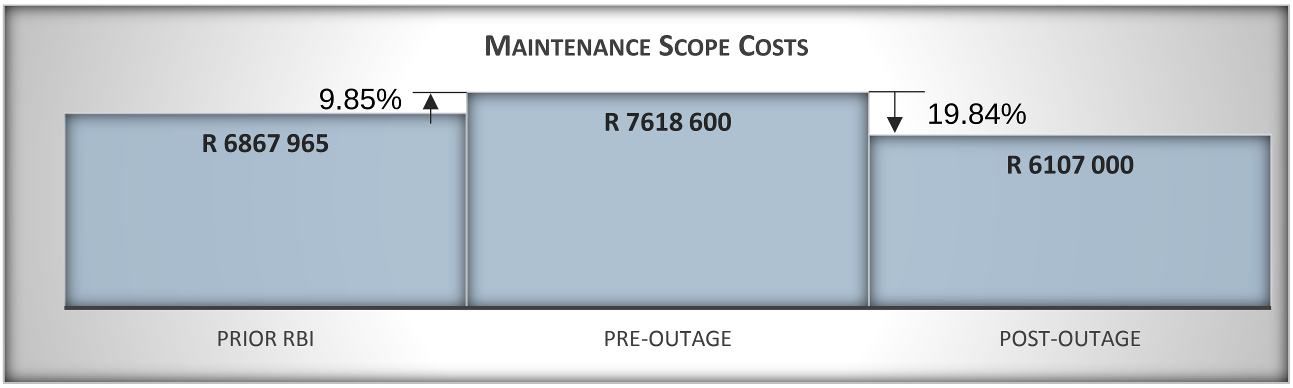


FIGURE 15: MAINTENANCE SCOPE COSTS FOR POWER STATION 1

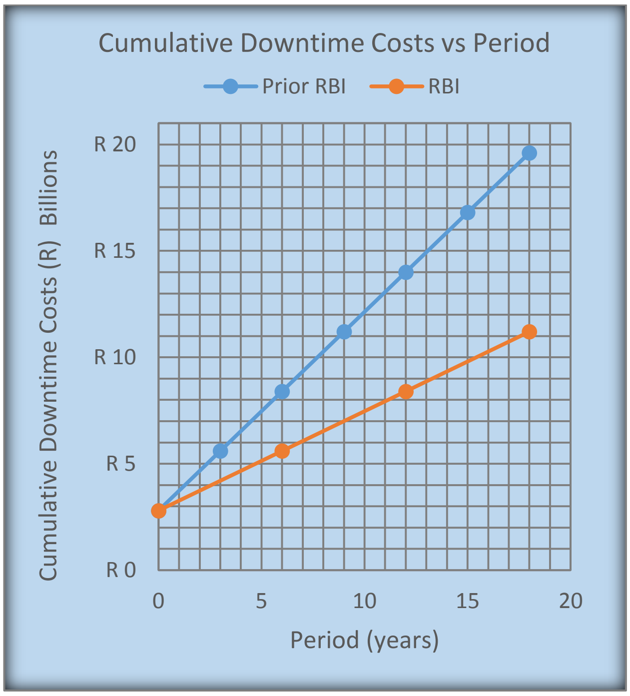


FIGURE 17: CUMULATIVE DOWNTIME COSTS POWER STATION 1

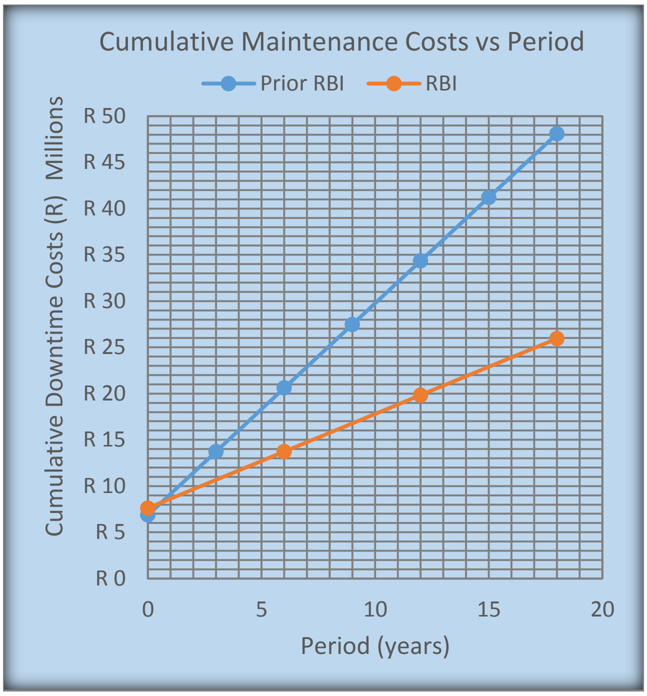


FIGURE 16: CUMULATIVE MAINTENANCE COSTS POWER STATION 1

5.2.1.2 POWER STATION 2 RESULTS

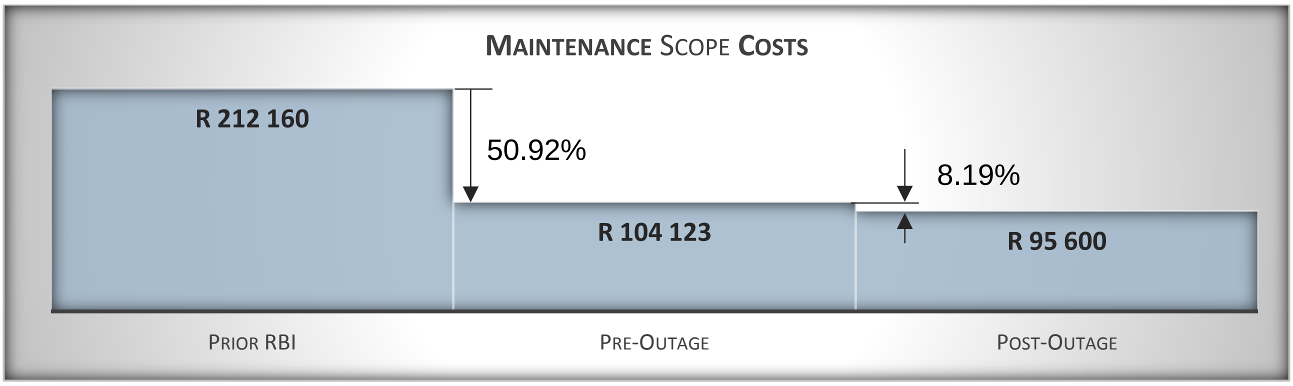


FIGURE 18: MAINTENANCE SCOPE COSTS FOR POWER STATION 2

Table 5: Power Station 2 – Cost Analysis Results

Criteria	**Inspections without RBI**	**Inspections with RBI (Pre-Outage)**	**Inspections with RBI (Post-Outage)**
Maintenance Inspection intervals (months)	36	72	72
Downtime period due planned outage (days)	130	130	130
Loss of production cost rate (R/kWh)	1.4025	1.4025	1.4025
Lost production due to downtime (kWh)	1 825 200 000	1 825 200 000	1 825 200 000
Downtime costs per planned outage (R)	R 2 559 843 000	R 2 559 843 000	R 2 559 843 000
36 months Maintenance Costs	R 212 160	R 104 123	R 95 600

Inspections Without RBI

Outage No.	Inspection Interval in years (months)	Maintenance costs	Downtime costs	Cumulative Maintenance costs	Cumulative Downtime costs
1	0 (0)	R 212 160	R 2 559 843 000	R 212 160	R 2 559 843 000
2	3 (36)	R 212 160	R 2 559 843 000	R 424 320	R 5 119 686 000
3	6 (72)	R 212 160	R 2 559 843 000	R 636 480	R 7 679 529 000
4	9 (108)	R 212 160	R 2 559 843 000	R 848 640	R 10 239 372 000
5	12 (144)	R 212 160	R 2 559 843 000	R 1 060 800	R 12 799 215 000
6	15 (180)	R 212 160	R 2 559 843 000	R 1 272 960	R 15 359 058 000
7	18 (216)	R 212 160	R 2 559 843 000	R 1 485 120	R 17 918 901 000
		R 1 485 120	R 17 918 901 000	Total Costs = R 17 920 386 120	

Inspections With RBI

Outage No.	Inspection Interval in years (months)	Maintenance costs	Downtime costs	Cumulative Maintenance costs	Cumulative Downtime costs
1	0 (0)	R 104 123	R 2 559 843 000	R 104 123	R 2 559 843 000
2	6 (72)	R 95 600	R 2 559 843 000	R 199 723	R 5 119 686 000
3	12 (144)	R 95 600	R 2 559 843 000	R 295 323	R 7 679 529 000
4	18 (216)	R 95 600	R 2 559 843 000	R 390 923	R 10 239 372 000
		R 390 923	R 10 239 372 000	Total Costs = R 10 239 762 923	

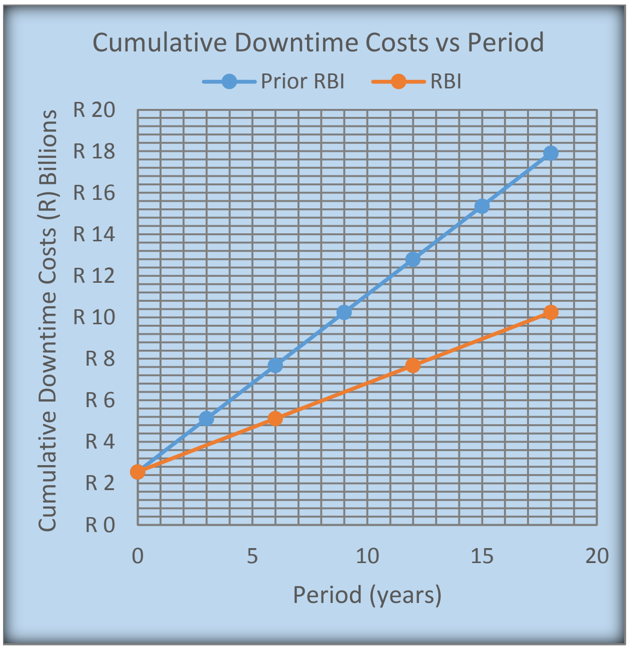


Figure 19: Cumulative Downtime Costs Power Station 2

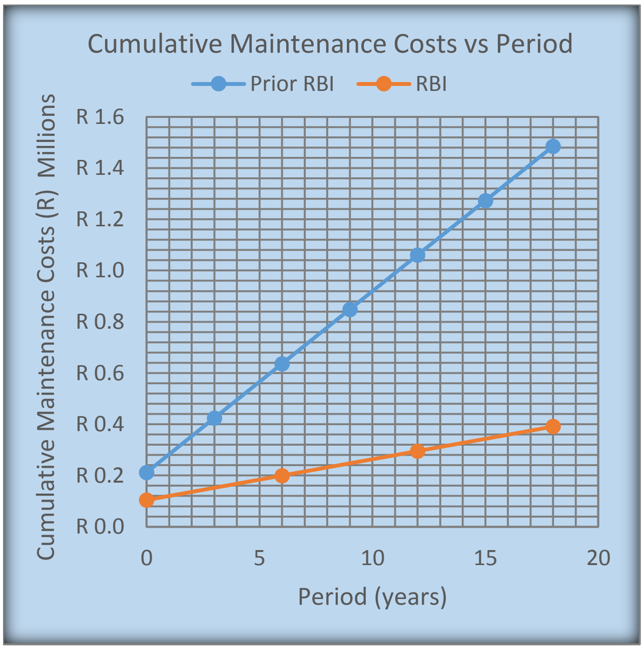


Figure 20: Cumulative Maintenance Costs Power Station 2

5.2.2 Audit Findings Analysis

The effectiveness of RBI process was evaluated as described in paragraph 3.2.2. Below is the summary of the most occurring audit findings extracted from the tables in Appendix C.

TABLE 6: MOST RECURRING AUDIT FINDINGS ACROSS ALL POWER STATIONS OF THE ORGANISATION

No.	Finding (NC)	Occurrence
A	RBI recommendations not incorporated in the final maintenance scope. Deviation between the RBI recommendations, final maintenance scope, and executed inspections. Additional maintenance inspections and tests after the finalised RBI scope.	17
B	Data inserted Incorrectly in the assessment tool (Spreadsheet), assessments incorrect performed due to data input errors.	10
C	Credits taken for poor NDT techniques or unperformed inspections during the RBI assessments, leading to inaccurate recommendations for inspection scope.	6
D	No Risk assessment updates (including Common Plant reviews) after inspections were performed. Post inspection assessment should be performed within 6 months post outage completion as per the RBI process.	6
E	RBI recommendations were incorporated in the final maintenance scope, but not completely executed during the outage.	5
F	Poor inspection reporting due to no results measurements, analysis, and FFS (fit for service) calculations performed where results are alarming (e.g. measured wall thickness below design or calculated minimum allowable thickness), or any justification why the plant is safe to operate.	3
G	RBI level 2 assessment recommended level 3.1 assessment to be performed immediately due to high risk ranking of some components, but not performed or incorrectly performed (e.g. no mitigations or escalation to higher committees .	3
H	RBO Strategies not updated with RBI low risk components recommendations.	2

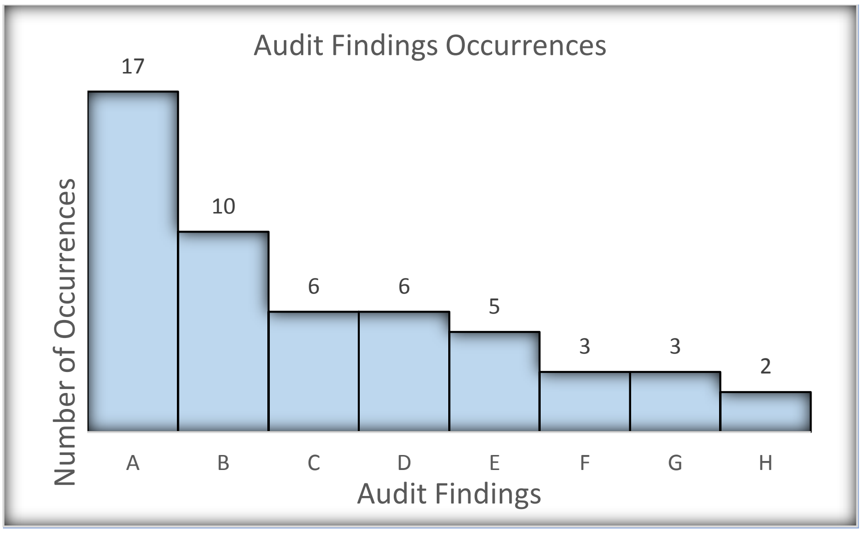


FIGURE 21: AUDIT FINDINGS VS OCCURRENCES

5.2.3 Interviews Data Analysis

Interviews were conducted with 9 power station Risk Engineers based on the 11 interview criteria shown in Table 3 and detailed results are attached in Appendix E. Interviews analysis was performed, and the Table 7 below illustrations the results.

TABLE 7: EFFECTIVENESS EVALUATION RESULTS

Effectiveness per Station	
Power Stations	Effectiveness
PS1	73%
PS2	91%
PS3	100%
PS4	64%
PS5	82%
PS6	73%
PS7	82%
PS8	82%
PS9	73%

Overall Effectiveness per Criteria	
Criteria	Effectiveness
1	56%
2	78%
3	78%
4	100%
5	89%
6	56%
7	56%
8	78%
9	100%
10	100%
11	100%

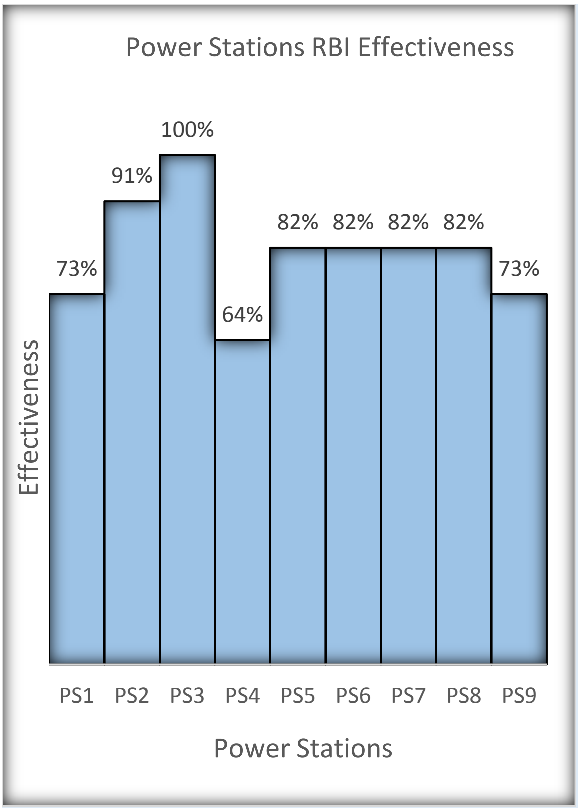


FIGURE 22: RBI EFFECTIVENESS EVALUATION RESULTS PER POWER STATION

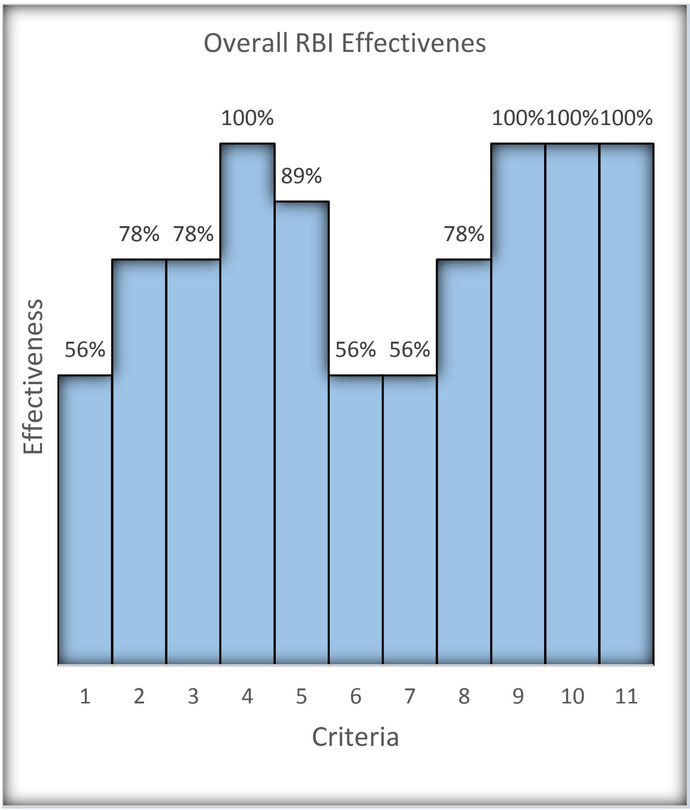


FIGURE 23: OVERALL RBI EFFECTIVENESS EVALUATION RESULTS PER CRITERIA

5.3 DISCUSSION OF RESULTS

The results for efficiency and effectiveness of RBI implementation evaluation obtained from the data analysis are discussed below based on the conducted case study.

5.3.1 Efficiency Results

It was observed during the data gathering of the maintenance scope execution costs that the NDT service providers only supply a lump sum value on requested quotations. This made it difficult to use the historical quotations for this case study. Thus new quotations were requested with a specific request to breakdown the cost to the inspection techniques level as demonstrated in Table 8 below. Breaking down the cost to inspection technique level enabled accurate scopes comparison as the same components scopes variation between outages could be directly compared, thus scope reduction optimisation could be performed which results in scope reduction and ultimately cost reduction. The results from the two selected power stations are presented per power station.

TABLE 8: EXAMPLE OF INSPECTION TECHNIQUE LEVEL BROKEN DOWN COSTS

Plant Area:	Boiler Pressure Parts	
Component:	Blowdown Vessel	
Damage Mechanisms:	Inspections Technique:	Cost (R):
Erosion	Visual inspection inside.	
	Wall Thickness Measurement (WT) on the suspected areas.	
Mechanical Fatigue	Visual inspection inside.	
	Ultrasonic Test (UT) 20% of main welds.	
Flow Accelerated Corrosion (FAC)	Visual inspection inside.	
	Wall Thickness Measurement (WT) on the suspected areas.	

5.3.1.1 POWER STATION 1

Power station 1 results are discussed below, comparing the Prior RBI with the RBI downtimes and maintenance costs. These results demonstrated that RBI implementation contributes considerably in reducing the downtime and maintenance costs.

5.3.1.1.1 Downtime Costs Results:

It was observed from cumulative downtime costs plot (see Figure 17) that a great amount of production costs are lost through frequent downtimes. A total of about R 19.6 billion could be lost due to maintenance frequency of 36 months over a period of 18 years Prior RBI implementation. This is an average rate of about R 1.1 billion per annum including the initial downtime costs on year zero with 7 outages totalling to 910 days of downtime.

With the RBI approach, a total of about R 11.2 billion could be lost due to maintenance frequency of 72 months over a period of 18 years. This is an average rate of about R 622 million per annum including the initial downtime costs on year zero, with 4 outages totalling to 520 days of downtime (see Table 9). It was also observed that the organisation could save R 8.4 billion over 18 years with an average of about R 467 million per annum savings through RBI implementation.

TABLE 9: POWER STATION 1 DOWNTIME COSTS SUMMARY

Downtime Costs Summary (Lost Profit Through Downtime)		
Period:	Over 18 years	Per annum
Prior RBI:	R 19 603 584 000	R 1 089 088 000
With RBI:	R 11 202 048 000	R 622 336 000
Downtime Costs Savings (Gained Profit Though RBI Implementation)		
With RBI Implementation:	R 8 401 536 000	R 466 752 000

5.3.1.1.2 Maintenance Costs Results:

It was observed from cumulative maintenance costs plot (see Figure 16) that RBI maintenance costs are higher than that of Prior RBI in the beginning. This is due to large Pre-Outage scope for baselining the RBI scope, it becomes reduced in the Post-Outage scope due to better plant risks understanding. A total of about R 48.1 million could be spent on maintenance over a period of 18 years if the organisation was to continue with the Prior RBI scope on a frequency of 36 months. This is an average rate of about R 2.7 million per annum including the initial maintenance costs on year zero.

With the RBI approach, a total of about R 25.9 million could be spent on maintenance over a period of 18 years if the organisation adopts the RBI scope on a frequency of 72 months. This is an average rate of about R 1.4 million per annum including the initial maintenance costs on year zero (see Table 10).

TABLE 10: POWER STATION 1 MAINTENANCE COSTS SUMMARY

Maintenance Costs Summary		
Period	Over 18 years	Per annum
Prior RBI	R 48 075 752	R 2 670 875
With RBI	R 25 939 600	R 1 441 089
Maintenance Costs Savings (Maintenance Cost Reduction Through Scope Reduction)		
With RBI Implementation	R 22 136 152	R 1 229 786

The maintenance cumulative costs over a period of 18 years were only 0.25% of the downtime costs for this power station under Prior RBI operation and 0.23% with RBI implementation. This is an important observation as it demonstrates that minimising downtimes of the power plant could improve the financial status of the organisation significantly. In this study, it was demonstrated that costs lost due to downtime could be reduced by 42.86%, and the maintenance scope execution costs could be reduced by 46.04% through RBI implementation for power station 1.

5.3.1.2 POWER STATION 2

Power station 2 results are discussed below, comparing the Prior RBI with the RBI downtimes and maintenance costs. It should be noted that the RBI scope used for this power station was a very small scope, hence the results might not provide a full picture of the RBI implementation impact. However it must be noted that these results are aligned with power station 1 results as they also demonstrated that RBI implementation contributes considerably in reducing the downtime and maintenance costs, with the difference in percentage of reduction.

5.3.1.2.1 Downtime Costs Results:

It was observed from cumulative downtime costs plot (see Figure 19) that a great amount of production costs are lost through frequent downtimes. A total of about R 17.9 billion could be lost due to maintenance frequency of 36 months over a period of 18 years Prior RBI. This is an average rate of about R 995 million per annum including the initial downtime costs on year zero with 7 outages totalling to 910 days of downtime.

With the RBI approach, a total of about R 10.2 billion could be lost due to maintenance frequency of 72 months over a period of 18 years. This is an average rate of about R 569 million per annum including the initial downtime costs on year zero with 4 outages totalling to 520 days of downtime (see Table 11). It was observed that the organisation could save R 7.7 billion over 18 years with an average of about R 427 million per annum savings through RBI implementation.

TABLE 11: POWER STATION 2 DOWNTIME COST SUMMARY

Downtime Costs Summary (Lost Profit Through Downtime)		
Period:	Over 18 years	Per annum
Prior RBI:	R 17 918 901 000	R 995 494 500
With RBI:	R 10 239 372 000	R 568 854 000
Downtime Costs Savings (Gained Profit Though RBI Implementation)		
With RBI Implementation:	R 7 679 529 000	R 426 640 500

5.3.1.2.2 Maintenance Costs Results:

It was observed from cumulative maintenance costs plot (see Figure 20) that Prior RBI maintenance costs are higher than that of RBI in the beginning, and remains high for the rest of the maintenance cycles. This is due to the small scope in this specific power station as highlighted in the beginning of the results, usually the RBI scope execution costs are higher at the beginning as demonstrated in power station 1. A total of about R 1.49 million could be spent on maintenance over a period of 18 years if the organisation was to continue with the Prior RBI scope on a frequency of 36 months. This is an average rate of about R 82.5 thousands per annum including the initial maintenance costs on year zero.

With the RBI approach, a total of about R 391 thousands could be spent on maintenance over a period of 18 years if the organisation adopts the RBI scope on a frequency of 72 months. This is an average rate of about R 22 thousands per annum including the initial maintenance costs on year zero (see Table 12 below).

TABLE 12: POWER STATION 2 MAINTENANCE COSTS SUMMARY

Maintenance Costs Summary		
Period:	Over 18 years	Per annum
Prior RBI:	R 1 485 120	R 82 507
With RBI:	R 390 923	R 21 718
Maintenance Costs Savings (Maintenance Cost Reduction Through Scope Reduction)		
With RBI Implementation:	R 1 094 197	R 60 789

The maintenance costs were only 0.01% of the downtime costs for this power station Prior RBI and 0.004% with RBI. This is an important observation as it demonstrates that costs lost due to downtime are by far the most contributing costs, minimising downtimes of the power plant could increase the financial status of the organisation significantly. In this study, it was demonstrated that the downtime costs could be reduced by 42.86%, and the maintenance scope execution costs could be reduced by 64.57% with RBI implementation for power station 2.

5.3.2 Effectiveness Results

5.3.2.1 AUDIT FINDINGS

A bow-tie risk assessment analysis was performed for all recurring audit findings as listed in Table 6, and a detailed bow-tie risk assessment is attached in Appendix D. These findings are arranged from most to less occurring, (A) to (H) respectively.

SAP tools provide full end-to-end performance tracking across tiers while maintaining the performance history. The major cause of the most recurring finding (A) is the absence of one point of scope submission to outage department. SAP could be the best way of combining all scopes in one SAP PM template for a specific component to prevent scopes duplication, omission, enable improved RBO strategies updating management, and thus mitigating audit finding (H). Additional scopes to the finalised RBI scopes could also be managed through administration rights in SAP to ensure that only the authorised personnel can make changes to the final maintenance scopes, most likely the site Risk Engineers.

SAP could also contribute in mitigating findings (D) and (E), by introducing the reminder to ensure that post outages are performed within 6 months after the unit returned from outage and tracking the completion of inspection tasks during the outage respectively. It was observed that implementing a properly functioning SAP system could resolve 50% of the most recurring findings. Thus it is significant to emphasising the importance of incorporating the RBI scopes into SAP to have one consolidated final inspection scope to be submitted to Outage Department and tracking tasks completion during the maintenance shutdowns.

The second most recurring finding (B) could be mitigated by performing the data validation as a team and educating the data validation team on the importance of the data accuracy in the risk assessment process. Finding (C) could be mitigated by ensuring that all the critical members (Metallurgists, Plant SME, AIA, etc.) are present during the inspection report capturing validation and have the required experience to analyse the reports.

Finding (F) could be mitigated by improving the inspection report writing, this could be achieved through ensuring that all the stakeholders assigned to review and sign the inspection reports actually review reports before signing. These reports should be reviewed and signed daily to prevent working under pressure trying to complete the report reviews for the unit to return from shutdown in time. Fit for service analysis should be performed for all alarming inspection results.

To mitigate finding (G), risk assessment tool should be modified to popup a warning message for a triggered level 3 risk assessment up on completion of level 2 assessment and providing a bow-tie training to the RBI team. All the critical members should be present during the risk assessment sessions with the required damage mechanisms understanding in order to provide accurate inspection recommendations. Having all essential stakeholders with the required experienced during the risk assessment sessions is critical for accuracy and quality improvement of risk assessment results.

5.3.2.2 INTERVIEWS

The following was observed from Figure 22, these results are based on the questionnaire used during the interviews to determine RBI implementation effectiveness per power station:

- Power Station 3 was the most effective with 100% effectiveness.
- Power Station 2 was the second most effective with 91% effective.
- Power Stations 5, 6, 7, and 8 were third most effective all with 82% effective.
- Power Stations 1 and 9 were all 73% effective.
- Power Station 4 was least effective in RBI implementation process with 64% effectiveness.

The organisation has an average of 81% effectiveness when considering the average effectiveness of all 9 interviewed power stations across all 11 criteria.

The following was observed from Figure 23, these results are based on the questionnaire used during the interviews to determine overall organisation RBI implementation effectiveness per criteria:

- The organisation was 100% effective in criteria 4, 9, 10, and 11.
- The organisation was 89% effective in criteria 5.
- The organisation was 78% effective in criteria 2, 3, and 8.
- The organisation was 56% effective in criteria 1, 6, and 7.

The organisation has an average of 81% effectiveness when considering the average effectiveness of all 11 criteria across all 9 interviewed power stations. The interviews conducted revealed that there was one unexpected failure experience on an RBI assessed component over a period of 7 years of RBI implementation. A cold reheat pipe cracked vertically, this failure was not detected during the inspection as tests were performed horizontally. This affected the effectiveness of RBI implementation negatively as one of the RBI objectives was to eliminate unexpected failures.

5.3.2.3 LESSONS LEARNT

RBI implementation improvements were recommended based on the assessment of the lessons learnt. Most of the lessons learnt have been incorporated into the RBI implementation procedures to prevent repeating some of the shortcomings that were observed in the process. A reduction in repeat findings was observed in the latest conducted audits during the audit findings analysis. This demonstrated that lessons learnt contributed considerably in improving the RBI implementation process. Thus hypothesis 2 was observed to be acceptable based on the case study results, see for Hypothesis 2 description in paragraph 3.1.

Audit findings and lessons learnt are closely related as most of the lessons learnt were observed during the audit sessions. Hence it is also accurate to say that audit findings play a significant role in providing opportunities for improvements to the RBI process.

6. RBI EFFICIENCY AND EFFECTIVENESS IMPROVEMENT METHODS

A proposed framework for the RBI improvement methods is shown in Figure 24 below. Implementation of these improvements could result in an enhanced RBI implementation for an organisation.

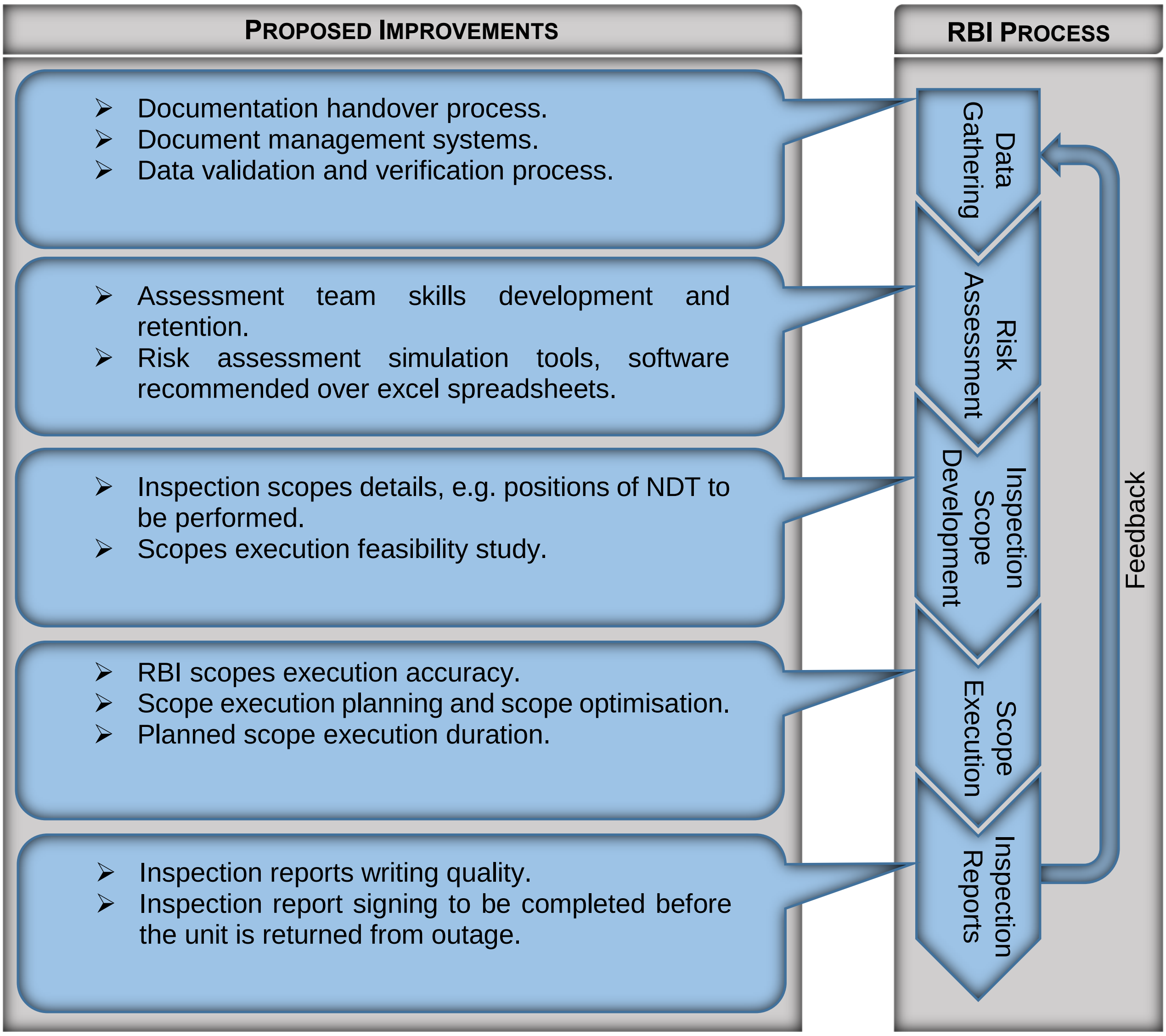


FIGURE 24: PROPOSED RBI IMPLEMENTATION IMPROVEMENT METHODS FRAMEWORK

The following efficiency and effectiveness improvement methods were identified for RBI implementation based on the results of the conducted case study, and are aligned with the methods captured in the literature review:

- All the design and operating documents should be handed over to the plant owners during the commissioning of the plant, these could contribute significantly in reducing the roll-out timelines as the data gathering duration could be reduced due to improved data availability.

- Good documentation management system has to be auditable, this is significant in ensuring the data availability for performing RBI assessments. Data unavailability leads to escalated risk profiles as the worst case scenarios are applied for conservativeness purposes.
- High quality and accuracy in gathering required data for the RBI assessments is significant in achieving best results.
- High experience in the assessment team members and willingness to perform the risk assessments plays a major role in decision making which influences the productivity, e.g. scope reduction, inspection intervals, etc.
- The RBI maintenance scopes should be fully executed during outages to realise the RBI implementation benefits. If these scopes are not fully executed, they might force the plant to be shutdown sooner than planned due to their risk level being escalated. Thus increasing the Unplanned Capability Loss Factor (UCLF).
- Performing inspection scopes feasibility study in significant to verify the practicality of the recommended inspections, e.g. the methods and position of the NDT to be performed could reduce the probability of the inspection not executed due to constrains.
- Developing SAP PM Templates with a capability of selecting all possible inspection tasks required for a specific component to be performed during the upcoming planned downtime, and tracked for completion could play a significant role in improving maintenance inspection scopes execution.
- Outage movements should be limited as this may result in escalated unplanned shutdowns due to components failures.
- Inspection scopes should be executed on planned outage duration, to minimising noncompliance on statutory regulated components, e.g. expiring of Certificates of Compliance.
- Outage Department should prepare well in advance for the upcoming planned outages, e.g. Spares, Scaffolding installation, NDT contracts, etc. must be available to prevent outage deferrals.

- Senior management support is very important in ensuring efficient and effective RBI implementation, as they have the power to drive processes in an organisation. They should established the organisation’s RBI objectives to be achieved.
- Continuous training is important to ensure sustainability of competency in the assessment team members. Formal classroom, online, and practical (“on job”) trainings could be utilised to accomplish the required competency.
- Frequent self-auditing of the RBI process implementation is necessary to ensure continuous improvement of the process.
- Benchmarking with other personnel engaged in RBI process within and outside the organisation is important to share lessons learnt, this will contribute significantly in improving RBI process.

Risk-Based Inspection is highly effective in improving plant safety when properly implemented, compared to conventional code-based inspection programs.

7. CONCLUSION

Based on the case study conducted, the efficiency and effectiveness of RBI implementation in a specific organisation is be discussed below.

7.1 EFFICIENCY

Cost savings were realised in both sampled power stations based on projected values, thus demonstrating that RBI implementation could be an investment for the organisation if it's well-executed. Costs lost due to downtime were observed to be reduced by 42.86% on both power stations as a results of inspection interval extension through RBI implementation. Maintenance scopes execution costs reduction of 46.04% and 64.57% from power stations 1 and 2 respectively were observed as a result of reduced inspection scopes through RBI implementation.

The RBI Pre-Outage maintenance scope costs indicated 9.85% increase when compared to the Prior RBI scope costs, and the RBI Post-Outage maintenance scope costs indicated 19.84% reduction compared to the Pre-Outage scope costs for power station 1 (see Figure 15). The RBI Pre-Outage maintenance scope costs indicated 50.92% reduction compared to the Prior RBI scope costs, and the Post-Outage maintenance scope costs indicated 8.19% reduction from the Pre-Outage scope costs for power station 2 (see Figure 18).

It is an important observation to note that the results from both power stations are aligned in demonstrating that RBI implementation reduces the maintenance scopes execution costs through scope reduction. The maintenance scopes reduction was possible through better plant risks understanding which enabled scopes optimisation. The cost analysis performed during the case study revealed that the following RBI contribution into maintenance costs reduction:

- RBI could be used to extend the maintenance inspection intervals, thus allowing longer production periods and subsequently improving the organisation's profitability.
- RBI assists the risk assessors to improve the plant risk understanding, enabling decision making for scope optimisation in reducing the maintenance scopes safely.

The RBI contribution into the maintenance costs reduction listed above could assist the organisation significantly in cutting down on the maintenance costs if adopted, thus improve the efficiency of RBI implementation. This is in agreement with hypothesis 1 of this research.

The organisation invested time in implementing the RBI process, but do not use it to their advantage in reducing the maintenance costs, this demonstrates lack of understanding the RBI contribution into the maintenance costs reduction. Thus the organisation is not efficient in RBI implementation, as they are not using RBI to extend the inspection intervals and scopes optimisation performed to reduce the maintenance scopes.

It should be noted that executing the maintenance scopes as recommended by RBI plays a significant role in organisation’s efficiency. The following were identified as the main reasons for the organisation not to be efficient in RBI implementation:

- There were additional scopes being executed over and above RBI recommendations. This affects the scope optimisation and consequently the maintenance cost savings negatively.
- Planed downtimes are lengthy (averaging at 130 days), and frequently units do not return to service on planned time. This has a negative impact financially on the organisation as it increases the plant downtime and requires attention if being profitable is required.

7.2 EFFECTIVENESS

It was concluded that the organisation is not effective as it was successful on meeting only one of the RBI implementation objectives as listed in paragraph 4. A summary of how the organisation performed against its objectives is outlined below:

- The interviews conducted revealed that the organisation was 56% effective on implementing the RBI within planned timelines, thus unsuccessful to ensure RBI scope readiness for planned upcoming outages.
- The organisation was successful in extending the inspection frequencies to 72 months and beyond for some low risk components through RBI implementation, as the risk assessment results revealed this inspection frequency to be safe for all assessed components.
- The RBI Post-Outage inspection scopes revealed maintenance costs reduction when compared to Pre-Outage during the cost analysis based on projected values, these costs reduction could only be realised if the RBI recommendations are fully executed during the planned outages. The interviews conducted revealed that the organisation scored 78% on scopes execution, thus unsuccessful to realise maintenance costs reduction benefit through RBI implementation.

- The organisation was unsuccessful on eliminating the unexpected failures, as one of the power stations confirmed to have experienced this during the conducted interviews.
- The organisation scored 56% on resource training during the conducted interviews, thus unsuccessful to get all the RBI participating personnel trained to achieve the required level of competency.
- The organisation was also unsuccessful in closing audit findings to ensure continuous improvement of RBI implementation, this was revealed through the eight recurring audit findings discovered during the audit findings analysis.

The RBI implementation process was improved with the implementation of the lessons learnt. However, not all the lessons learnt have been implemented. Hence there are still opportunities for improvement in the RBI process, Senior Management Support being the main challenge on some power stations. Senior management support is key to the successful implementation of RBI as they have authority to empower the process, e.g. avail the required resources.

7.3 RESEARCH CONTRIBUTION INTO THE SCIENCE ENVIRONMENT

This study contributes to science and asset management environment through the following:

- It presents a quantified actual cost saving from a practical RBI process implementation.
- It compares the potential benefits with the realised benefits and highlights the reasons for discrepancies.
- It presents a practical framework on how to implement the improvements identified though the gap analysis.
- It reveals that cost benefit though maintenance cost reduction is almost negligible compared to that through downtime reduction with the RBI process implementation.
- It reveals that obtaining maintenance scopes quotations with the cost breakdown to the lowest level (e.g. component, damage mechanisms, and inspection techniques) enables better historical maintenance cost assessment as it empowers the user to effectively focus on a single component historical maintenance costs to enhance maintenance planning.

This study was based on a large scale RBI process implementation, and therefore contributes significantly to the knowledge base of what is required to efficiently and effectively implement RBI process.

7.4 FUTURE WORK

In the future, the plan is to expand the research scale. This means that the research will focus on additional power stations units to have a comprehensive understanding on efficiency and effectiveness evaluation of RBI implementation. A wide range of maintenance scopes will be used for the study to improve the results. To have a more conclusive investigation, power stations that have performed more than one Post-Outages should be targeted. This will enable practical trend observation for maintenance scopes and cost fluctuation, currently there is no power station in the studied organisation that has performed more than one Post-Outages.

The future research scope may include experimental research to determine if the organisation could benefit from implementing RBI on peaking power stations e.g. Gas Power Plants. During that research, the current maintenance strategy for Gas Power Plants will be compared to the RBI maintenance strategy taking into consideration of the inspection tests and frequencies, and observe if there is any maintenance scopes reduction that may lead to maintenance cost reduction.

Advantages and disadvantages for implementing RBI at Peaking Power Plants will be additional to this current study’s deliverables. Currently, the peaking team is under the impression that there is no need for implementing RBI in their sites as they have more than enough planned downtimes, since they only operate when there is a need to increase the power on the grid, not on base load conditions.

The study could also be expanded into Risk Based Inspection and Maintenance (RBIM) to include the risk based maintenance (RBM) part of asset management, which is included in the RIMAP approach. It will be interesting to compare the projected cost values with the actual outage costs, as this costs were not available at the time is the current study.

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9. APPENDIX A _RBI INSPECTION SCOPES POWER STATION 1 (UNIT 4)

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
BOILER MAINTENANCE INSPECTIONS SCOPE						
1	Economiser Inlet Lead Pipe LAB71BR001 & LAB72BR001	No Inspection	Mechanical Fatigue	MPI on T-Piece (All 3 welds). Hanger inspections.	Corrosion Fatigue	Low risk in 6 years; no RBI SOW issued.
2	Economiser Inlet Header HAC10BR010	UWT, MPI, UT on Economiser Inlet Header Stub Element 1-3 i.e. Tube no.1-3 (position 1-12, location 1-7). UWT, MPI, UT on Economiser Inlet Header Stub Element 154-156 i.e. Tube no.1-3 (position 1-12, location 1-7). Upon Engineering instruction, continue to do the following: UWT, MPI, UT on Economiser Inlet Header Stub Element 35-42 i.e. Tube no.1-3 (position 1-12, location 1-7). UWT, MPI, UT on Economiser Inlet Header Stub Element 115-122 i.e. Tube no.1-3 (position 1-12, location 1-7).	Thermal Fatigue	Perform UT and MPI on all circ welds of one tee and one end cap (e.g. CW01 - CW04). UT and MPI on stub to pipe welds at stubs indicated in Carab Generic SOW_GO (72) and 6 tube rows at centre of header.	Corrosion Fatigue	No RBI SOW issued. Low risk in 6-12 years for Mechanical Fatigue, Pitting Corrosion, Thermal Fatigue. Low risk in 6yrs-Medium risk in 12 years for Corrosion Fatigue.
3	Economiser NRV LAB60AA601	Visual inspection of valve interior. Dye penetrant testing of valve interior.	Erosion Mechanical Fatigue	Internal visual inspection on valve body. MPI on valve body. MPI on first connecting welds to pipe.	Mechanical Fatigue	No RBI SOW issued. Low risk in 6-12 years for Erosion, Pitting Corrosion, Mechanical Fatigue and Thermal Fatigue.
4	Economiser Recirculation/Isolation Valve HAC01AA101	Visual inspection of valve interior. Dye penetrant testing of valve interior.	Mechanical Fatigue	MPI on valve body. MPI on first connecting welds to pipe	Mechanical Fatigue	MPI on valve body. MPI on first connecting welds to pipe

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
5	Economiser Outlet Header HAC10BR020	Visual inspection via Endoscope and WT measurements on Element no. 1- 5 i.e. tube no. 1-3 (position 1-2; location 3-5) Element no. 152 - 156 i.e. tube no. 1-3 (position 1-2; location 3-5).	Thermal Fatigue	Perform UT and MPI on all circular welds of one tee and one end cap (e.g. CW01 - CW04). UT and MPI on stub to pipe welds at stubs indicated in Carab Generic SOW_ GO(72) and 6 tube rows at centre of header.	Thermal Fatigue	No RBI SOW issued. Low risk in 6-12 years for Corrosion Fatigue, Mechanical Fatigue, Pitting Corrosion, Thermal Fatigue and Fly Ash Erosion
6	Economiser Outlet Link HAC21BR010, HAC22BR010, HAC31BR010, HAC32BR010, HAC33BR010	No Inspection	Thermal Fatigue Mechanical Fatigue	MPI and UT 50% of welds on outlet links, or select one outlet link (e.g. Left): MPI and UT welds on bend 1, 2/3 and 4 (CW03 and CW04; CW07 and CW08, CW09 and CW10; CW11 and CW12) and two other easy access circ welds on straight sections. CW Select one drain line: MPI all circ welds. Internal visual of drain lines (Endoscope)	Corrosion Fatigue	No RBI SOW issued. Low risk in 6-12 years for Corrosion Fatigue.
7	Main Steam Leg A,B,C,D (Main Branch Pipes, Bends, Circ Welds, Terminal Welds) LBA	Replication (for Creep), MT (for Mechanical Fatigue), UT (for Thermal Fatigue) on the following areas as per HP Piping scope tracking sheet i.e. Branch weld (Boiler connection)S53; Bend MA2/1	Creep Thermal Fatigue	Continue with current inspections as indicated on HP Piping Scope. (Replication, MPI, UT and dimensional measurements .) i.e. on Branch weld (Boiler	Creep Thermal Fatigue Mechanical Fatigue Creep Fatigue	Replication (for Creep), MT (for Mechanical Fatigue), UT (for Thermal Fatigue) on the following areas as per HP Piping scope tracking sheet i.e. Branch weld (Boiler connection)S53; Bend MA2/1

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
		Butt weld S54A,Branch weld (S V/V)MA3A.Branch weld (S V/V)MA3B Butt weld S57;Butt weld S63 Butt weld S64;Butt weld S65 Butt weld S69;Butt weld S71 Butt weld S74;Spherical Header (Y-piece) MF2/1 Butt weld S75;Butt weld S77 Butt weld S78;Butt weld S82 Butt weld S83;Bend MA29/1 Butt weld S88;Butt weld S88A ButtweldS88B; BendMA30/1 Butt weld S89; Butt weld (Form-piece to turbine) TK4/1.		connection)S53; Bend MA2/1, Butt weld S54A,Branch weld (S V/V)MA3A.Branch weld (S V/V)MA3B, Butt weld S57;Butt weld S63 Butt weld S64;Butt weld S65; Butt weld S69;Butt weld S71; Butt weld S74;Spherical Header (Y-piece) MF2/1 Butt weld S75;Butt weld S77; Butt weld S78;Butt weld S82; Butt weld S83;Bend MA29/1 Butt weld S88;Butt weld S88A; ButtweldS88B; BendMA30/1 Butt weld S89; Butt weld (Form-piece to turbine) TK4/1.		Butt weld S54A,Branch weld (S V/V)MA3A.Branch weld (S V/V)MA3B Butt weld S57;Butt weld S63 Butt weld S64;Butt weld S65 Butt weld S69;Butt weld S71 Butt weld S74;Spherical Header (Y-piece) MF2/1 Butt weld S75;Butt weld S77 Butt weld S78;Butt weld S82 Butt weld S83;Bend MA29/1 Butt weld S88;Butt weld S88A ButtweldS88B; BendMA30/1 Butt weld S89; Butt weld (Form-piece to turbine) TK4/1.
8	Steam Drum Overpressure Protection/Safety Valve HAD60AA551, HAD60AA552, HAD60AA553, HAD60AA554, HAD60AA555, HAD60AA556	Internal visual inspection.	Thermal Fatigue Mechanical Fatigue	MPI on valve body. MPI on first connecting welds to pipe	Thermal Fatigue Mechanical Fatigue Pitting Corrosion	No RBI SOW issued. Low risk in 6-12 years for Thermal Fatigue, Mechanical Fatigue, Pitting Corrosion. Valves were replaced during 2016-Outage.
9	Downcomer 1, 2 ,3, 4, 5 and 6	No Inspection	Mechanical Fatigue	MPI and UT on circ welds to steam drum	Corrosion Fatigue	VI- external on easy to access

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
			Thermal Fatigue	nozzles and to suction manifold. Internal visual via steam drum and suction manifold (CW01 and CW04). Select one downcomer: Additional UT and MPI + VT (ext) of one additional easy access weld (CW02 or CW03).		weld: CW02 or CW03. MT&UT on circ welds to steam drum nozzles and to suction manifold (CW01&CW04).
			Corrosion Fatigue			
10	Furnace Rear Waterwall Lower Drum, Furnace Front Waterwall Lower Drum, Furnace Side Waterwall Lower Drum (LHS) & Furnace Side Waterwall Lower Drum (RHS) HAD10BR010	Internal/ External Visual inspection.	Thermal Fatigue	Internal visual inspection at manhole access points + Endoscope at corner discharge line nozzles (remove perforated plates). Remove lagging and perform UT and MPI on 2 of 4 corner circ welds (One on each side of header). MPI Vent pipe welds, A-Frame support lug welds and 6 rows of tubes at one end, centre and mid-point between end and centre. UT and MPI of 3 inlet nozzle welds if accessible. Remove perforated panels (e.g. 1 of 27) and	Mechanical Fatigue	No RBI SOW issued. Low risk in 6-12 years for Corrosion Fatigue, Mechanical Fatigue and Pitting Corrosion
			Mechanical Fatigue			
			Corrosion		Pitting Corrosion	
			Corrosion Fatigue		Corrosion Fatigue	
			Creep Fatigue			

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
				perform endoscope of tube stub holes on one side.		
11	Main Steam Leg A, Main steam drain LBA	Replica only on stub weld for creep. MPI and UT/RT on the stub weld and first butt weld for fatigue cracks and welds defects.	Creep Thermal Fatigue Mechanical Fatigue Creep Fatigue	Replica only on stub weld for creep. MPI and UT/RT on the stub weld and first butt weld for fatigue cracks and welds defects.	Creep Thermal Fatigue Mechanical Fatigue Creep Fatigue	Continue with HP Pipework SOW i.e. Replica only on stub weld for creep. MPI and UT/RT on the stub weld and first butt weld for fatigue cracks and welds defects.
12	Turbine Drain Manifold to Blowdown Vessel	No Inspection	Erosion FAC	Continue with FAC scope (As per submission from System Engineer) i.e. 3Yr-UWT on the T piece area and bottom of the Manifold.	FAC Erosion General Corrosion	3Yr-UWT on the T piece area and bottom of the Manifold.
13	Boiler Drain Manifold to Blowdown Vessel	No Inspection	Erosion FAC	Continue with FAC scope (As per submission from System Engineer) i.e. 3Yr-UWT on the T piece area and bottom of the Manifold	FAC General Corrosion	3Yr-UWT on the T piece area and bottom of the Manifold. Low Risk in 6-12 years for Erosion.
14	Main steam warming line	No Inspection	Thermal Fatigue	MPI and UT on welds (Min	Mechanical Fatigue	

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
	after control valve LBA		Mechanical Fatigue Corrosion Fatigue	20% - do more critical welds). Dimensional measurements.	 Thermal Fatigue	Carry out MPI on all terminal welds. UT as per HP Piping Scope (Carry out UT on all terminal welds).
15	Main steam warming line before control valve LBA	No Inspection	Creep Thermal Fatigue Mechanical Fatigue Creep Fatigue	MPI &UT for fatigue cracks & Weld defects on terminal welds. Replica on stub weld for creep.	Creep	Replication on the stub welds where the WT is more than 11mm. High risk in 3 years for Creep.
16	Cold Reheat Leg A & Leg B LBC	Replicas on Butt weld R2A, Form-piece to Trb (TK13/4) and Form-piece (TK14/4).	Mechanical Fatigue	MPI and UT on all terminal welds, all branch/connecting welds, all butt welds next to valve connection and all welds on low lying areas.	Mechanical Fatigue Corrosion Fatigue Thermal Fatigue Pitting Corrosion	No RBI SOW issued. Low risk in 6-12 years for Mechanical Fatigue, Thermal Fatigue, Corrosion Fatigue and Pitting Corrosion.
17	Cold Reheat Drain LBC	No Inspection	Mechanical Fatigue Corrosion Fatigue	MPI and UT on welds up to the isolation valve.	Mechanical Fatigue Corrosion Fatigue Pitting Corrosion	No RBI SOW issued. Low risk in 6-12 years for Mechanical Fatigue, Corrosion Fatigue and Pitting Corrosion.
18	RH Link & LH Link to Superheater Low Temperature Pendant Inlet Header HAH30BR012	No Inspection	Mechanical Fatigue	UT and MPI on all terminal welds.	Mechanical Fatigue Pitting Corrosion Corrosion Fatigue	Low risk in 6-12 years for Corrosion Fatigue, Mechanical Fatigue Pitting Corrosion.
19	Primary Desuperheater HAH51AH010, HAH52AH010	Internal Visual inspection/ Endoscope.	Thermal Fatigue	MPI on positioning and support screws, UT and MPI on the	Corrosion Fatigue	Low risk in 6-12 years for Corrosion Fatigue,

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
				downstream Desuperheater to Link weld (this weld is regarded as part of the Link from Superheater Desuperheater (HAH51BR001 , HAH52AH010)). Opening of inspection nozzles and VT (int.) with Endoscope.	Mechanical Fatigue Pitting Corrosion Thermal Fatigue	Mechanical Fatigue, Pitting Corrosion and Thermal Fatigue
20	LH Link & RH Link from Superheater Desuperheater HAH51BR001 & HAH52BR001	No Inspection	Thermal Fatigue Mechanical Fatigue Graphitisation	Internal inspection downstream of thermal shield for thermal fatigue cracking. De-lag 4 meters downstream of thermal shields and visual inspect for bowing. UT and MPI of first circ weld after Desuperheater and two welds at bottom bend. Replication check at one position across weld and on parent metals remote from welds (for graphitisation).	Thermal Fatigue Mechanical Fatigue	Low risk in 6-12 years for Thermal Fatigue and Mechanical Fatigue
21	Superheater Radiant Wall Front LHS & RHS Inlet Header and Superheater Radiant Wall LHS & RHS Inlet header HAH61BR010 & HAH62BR010	No Inspection	Thermal Fatigue	Perform a random check on one part of the front header and preform the following NDTs: MPI and UT on tee welds, flat end cap weld (LHS	Corrosion Fatigue	Dye Penetrant test on Element-tubes and T-pieces (as per Carab_GO_ (72) Stub Inspection scope).
			Mechanical Fatigue		Mechanical Fatigue	MPI on Element-tubes, T-pieces and End caps (as per

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
				or RHS). UT and MPI of stubs on and immediately next to tee piece (e.g. Row A 125 - 135, Row B 125 - 137), and Endoscope of stub and drain holes. MPI on welds of 2 header supports (e.g. HDR SUPP 4 and HDR SUPP 3).		Carab_GO_ (72) scope).
					Thermal fatigue	Ultrasonic wall thickness measurements on circular welds and T-pieces (as per Carab_GO_ (72) scope).
22	Superheater Divisional panel Outlet Header 1, 2, 3 and 4. HAH71BR020, HAH72BR020, HAH73BR020 & HAH74BR020	Internal Visual inspection	Creep	Replication, MPI, UT and dimensional measurements on all circ welds and stubs (10% with highest temp.)	Corrosion Fatigue	Dye Penetrant test on Element-tubes and T-pieces as per Carab_GO_ (72) Stub Inspection scope.
					Mechanical Fatigue	MPI on Element-tubes, T-pieces and End caps as per Carab_GO_ (72) scope.
			Creep Fatigue		Thermal fatigue	Ultrasonic wall thickness measurements on circular welds and T-pieces as per Carab_GO_ (72) scope.
23	SHFPF LH & RH Inlet Header HAH81BR010 & HAH82BR010	Internal/External Visual inspection MPI on SHFPF Inlet Header (Area 1-1, tube 1-20). Welding gauge measurements on SHFPF Inlet Header (Area 2-2, tube 1-1 tube shields & Area 2-2, tube 2-2 tube shields). UWT on SHFPFSCST 1-1	Creep	MPI and UT and Replica on one Flat end cap weld, one round end cap weld and one T-piece weld. Dye Pen/ MPI and replica of stubs welds on minimum four tube rows at the hottest area. Internal	Creep	Low risk in 6-12 years for Mechanical Fatigue, Thermal fatigue and Creep.
			Thermal Fatigue		Thermal Fatigue	
			Mechanical Fatigue		Mechanical Fatigue	

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
		Inlet (Area 1-1, tube 1-1 shields& on SHFPFSCST 20-20 Inlet (Area 1-1, tube 1-1 shields		visual inspection.		
24	SHFPF Outlet Header HAH80BR010	Internal/External Visual inspection MPI on SHFPF Outlet (Area 1-1, tube 1-20) Welding gauge measurements on SHFPF Outlet Header (Area 2-2, tube 1-1 tube shields & Area 2-2, tube 2-2 tube shields). UWT on SHFPFSCST 1-1 Outlet (Area 1-1, tube 1-1 shields-measure positions s01, s02, s03, s04.	Creep	Continue with current inspection scope as indicated on Carab Generic SOW_GO (72) i.e. Tee-piece T1, Tee-pieceT2, Butt weld FW01, Butt weld FW02, Butt weld FW03, Butt weld FW04, Butt weld FW05, Butt weld FW06, Butt weld FW07, Butt weld FW08, Butt weld FW09, Butt weld FW10, Nozzlenear FW10, Stub weld Stub 1, Stub weld Stub 2,	Creep	Low risk in 6-12 years for Mechanical Fatigue, Thermal fatigue and Creep
			Thermal Fatigue		Thermal Fatigue	
			Mechanical Fatigue		Mechanical Fatigue	
25	Main Steam Stop Valves LBA11AA101 & LBA12AA101	Visual inspection and Dye Penetrant Testing inside valve body.	Thermal Fatigue	MPI on valve body. MPI on first connecting welds to pipe. Seat non-magnetic, continue with DP on seat. (Will possibly	Creep	Take replicas at the 1st connection weld to pipe.
			Creep		Thermal Fatigue	MPI on valve body.
			Mechanical Fatigue		Mechanical Fatigue	Dye Penetrant test inside valve body.

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
				show separation between valve body and seat with MPI because the one is magnetic and the other not. No concern). Replica on valve body at steam entry point.	Creep Fatigue	UT at the connection welds to pipe.
26	Hot Reheat Leg A, B, C, D (Bends, Circ Welds, Terminal Points, Attachments & Branches) LBB	HP Piping Scope. (Replication, MPI, UT and dimensional measurements.) i.e. Replication, MPI, UT as per HP Piping Scope (i.e. Butt weld(Boiler connection)R4, BendHA1/1; Butt weld R 5 BendHA2/1; Butt weld R 6; ButtweldR7;BranchweldHRA10A/5; Branch weld HRA10A/7; Branch weld HRA10A/8;Branch weld HRA10A/9;Branch weld HA4A;Branch weld HA4C; Branch weld HA5D;Branch weld HA5E;Branch weld HA5F;Bend HA6/1;Butt weld R18;Branchweld(Crossover)HF1/1; Butt weld R 19; Butt weld R 20; Spherical Header HF 1/3 Weld R20H; Buttweld R21;Buttweld R22;Buttweld R31;Butt weld	Creep	Continue with current inspections as per HP Piping Scope. (Replication, MPI, UT and dimensional measurements .) i.e. Replication, MPI, UT as per HP Piping Scope (i.e. Butt weld(Boiler connection)R4 , BendHA1/1; Butt weld R 5 BendHA2/1; Butt weld R 6; ButtweldR7;BranchweldHRA10A/5;Branch weld HRA10A/7; Branch weld HRA10A/8;Branch weld HRA10A/9;Branch weld HA4A;Branch weld HA4C; Branch weld HA5D;Branch weld HA5E;Branch weld HA5F;Bend HA6/1;Butt weld R18;Branchwe	Creep	Replication, MPI, UT as per HP Piping Scope (i.e. Butt weld(Boiler connection)R4, BendHA1/1;Butt weld R 5 BendHA2/1;Butt weld R 6 ButtweldR7;BranchweldHRA10A/5;Branch weld HRA10A/7; Branch weld HRA10A/8;Branch weld HRA10A/9;Branch weld HA4A;Branch weld HA4C Branch weld HA5D;Branch weld HA5E;Branch weld HA5F;Bend HA6/1;Butt weld R18;Branchweld(Crossover)HF1/1; Butt weld R 19; Butt weld R 20; Spherical Header HF 1/3 Weld R20H; Buttweld R21;Buttweld R22;Buttweld R31;Butt weld R37A;Butt weld R38;Buttweld
			Mechanical Fatigue		Mechanical Fatigue	
			Thermal Fatigue		Thermal Fatigue	
			Creep Fatigue		Creep Fatigue	

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
		R37A;Butt weld R38;Buttweld R39; Branch weld(to LP bypass) HF9/1 Buttweld R40; Buttweld R41.		ld(Crossover) HF1/1; Butt weld R 19; Butt weld R 20; Spherical Header HF 1/3 Weld R20H; Buttweld R21;Buttweld R22;Buttweld R31;Butt weld R37A;Butt weld R38;Buttweld R39; Branch weld(to LP bypass) HF9/1 Buttweld R40; Buttweld R41.		R39; Branch weld(to LP bypass) HF9/1 Buttweld R40; Buttweld R41.
27	Hot Reheat Leg A & C (X-Overs) LBB	(Replication only on connecting branch welds, and other welds if above the min wall thickness 11mm), MPI, UT and dimensional measurements Butt weldR 117 BendHRX1/4 Butt weldR 118 BendHRX2/4 Butt weldR 119	Creep	Continue with current inspections as per HP Piping Scope. (Replication only on connecting branch welds, and other welds if above the min wall thickness 11mm), MPI, UT and dimensional measurements . i.e. Butt weld R 117; BendHRX1/4; Butt weldR 118; BendHRX2/4; Butt weldR 119	Creep Mechanical Fatigue Thermal Fatigue Creep Fatigue	Replication, MPI, UT as per HP Piping Scope i.e. Replication/MT/ UT only on connecting branch welds, and other welds if above the minimum wall thickness 11mm i.e. on Bend HRX 1/4, Bend HRX 2/4.
28	Hot Reheat Drain (Branch, cross overs, strainer drains) LBB	Replication, MPI,UT on Drain Line A,B,C&D.	Creep	Continue with current inspections as per HP Piping Scope (Replication only on connecting branch welds, and other welds if above	Creep Mechanical Fatigue Thermal Fatigue Creep Fatigue	Replication, MPI,UT as per HP Piping Scope on Drain Line A,B,C&D.

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
				the min wall thickness 11mm), MPI, UT and dimensional measurements i.e. on Drain line A, Drain line B, Drain line C , Drain line D.		
29	HP Bypass/ Main Steam Valves BP/Valves LBF10AA001 & LBF20AA001	Visual inspection and Dye Penetrant testing inside the valve body.	Thermal Fatigue Creep Mechanical Fatigue	MPI on valve body. MPI on first connecting welds to pipe. For Creep results from Main Steam Stop Valves Replicas are to be used.	Creep Thermal Fatigue Mechanical Fatigue Creep Fatigue	No RBI SOW issued. Low risk in 6-12 years for Creep, Thermal fatigue, Mechanical Fatigue and Creep Fatigue
30	Blowdown Vessel	Internal Visual inspection and Wall thickness measurements on Blowdown vessel shell, attached inlets and outlets, boiler drains common manifold.	Erosion Mechanical Fatigue FAC	UWT on the suspected areas, Visual inspection inside. UT 20% of main welds.	Internal Corrosion Erosion	VI inside the Vessel Wall thickness measurements as per SE's FAC markings i.e. transition no. S1,S,S3,S4,S5, S6, bends (B1,B2), inlet pipe(P1,P2) and outlet pipe(P3,P4).
31	HP Bypass Spraywater (BD) Valves LAE31AA201 & LAE32AA201	Visual inspection and Dye Penetrant testing inside the valve body.	Mechanical Fatigue	DP testing on valve body (internal).	FAC	On the following valves LAE31AA201, LAE32AA201, LAE31AA001,LAE32AA001, VI inside valve body & Wall thickness measurements as per SE's FAC markings i.e. on IV (weld connection for isolation valve) and CV (weld

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
						connection on control valve).
32	Cold Reheat Backpass Drain Regulation Valve HAN03A101 & HAN03AA403	Visual inspection and Dye Penetrant testing inside the valve body.	Mechanical Fatigue	MPI on valve body. MPI on first connecting welds to pipe	Erosion	Carry out VI internal to the valve body. High risk in 3-6 yrs.
					Mechanical Fatigue	Must be inspected with pipe on terminal welds. High risk in 3-6 yrs.
					Corrosion Fatigue	Carry out visual inspections internal to the valve and if there are indications/suspected do DP. High risk in 3-6 yrs.
					Thermal Fatigue	Carry out visual inspections internal to the valve and if there are indications/suspected then do DP. High risk in 3-6 yrs.
33	Reheater Desuperheater LBC11AH010 & LBC12AH010	No inspection	Mechanical Fatigue	MPI on positioning and support screws, UT and MPI on the connecting welds. Opening of inspection nozzles and VT (int) with Endoscope.	Corrosion Fatigue	No RBI SOW issued. Low risk in 6-12 years for Corrosion Fatigue, Mechanical Fatigue, Pitting Corrosion and Thermal Fatigue.
					Mechanical Fatigue	
			Thermal Fatigue		Pitting Corrosion	
			Corrosion Fatigue		Thermal Fatigue	
34	RHLTH LHS & RHS Inlet	Internal Visual inspection.	Fly Ash Erosion	External visual inspection and	Mechanical Fatigue	No RBI SOW issued. Low risk

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
	header HAJ11BR010 & HAJ12BR010			wall thickness measurement if signs of wall thinning are observed.	Thermal fatigue Corrosion Fatigue Pitting Corrosion Fly ash Erosion	in 6-12 years for Mechanical Fatigue, Thermal fatigue, Corrosion Fatigue, Pitting Corrosion and Fly ash Erosion.
35	RHFP LHS & RHS Outlet Header HAJ11BR020 & HAJ12BR020	Replication, UT hardness test on tube 69, 71, 74, 77, 80, Forged Tee-pieces: MPI and UT all three welds on each Tee(CW02, 03, 04, 07, 08 and 09, replication at 4 pole positions all 3 welds and both crotch and saddle positions on both forgings.	Creep	Continue with current inspection scope as indicated on Carab Generic SOW_GO (72) i.e. Replication, UT hardness test on tube 69, 71, 74, 77, 80, Forged Tee-pieces: MPI and UT all three welds on each Tee (CW02, 03, 04, 07, 08 and 09, replication at 4 pole positions all 3 welds and both crotch and saddle positions on both forgings.	Creep	Replication and hardness (stub/weld/header) on tube 69, 71, 74, 77, 80, Forged Tee-pieces: MPI and UT all three welds on each Tee (CW02, 03, 04, 07, 08 and 09, replication at 4 pole positions all 3 welds and both crotch and saddle positions on both forgings.
			Thermal Fatigue		Thermal Fatigue	UT to be done on the areas where replicas were taken.
			Mechanical Fatigue		Mechanical Fatigue	No RBI SOW issued. Low risk in 6-12 years for Mechanical Fatigue
36	Hot Reheat Overpressure Protection/Safety Valves (x12) LAB11AA501, LAB11AA502, LAB11AA503, LAB11AA504, LAB11AA505, LAB11AA506, LAB12AA501, LAB12AA502, LAB12AA503, LAB12AA504, LAB12AA505, LAB12AA506	Visual inspection and Dye Penetrant testing inside the valve body.	Thermal Fatigue	MPI on valve body. MPI on first connecting welds to pipe. Internal visual inspection on valve body.	Thermal Fatigue	MPI on valve body and also 1st connection weld to pipe.
			Erosion			
			Mechanical Fatigue			
37		No inspection	Erosion	Wall thickness testing on	Erosion	WT on bends: min 10% of the

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
	Sootblower Piping HCB11BR100			bends (Min 20% of bends - focus on 90deg bends). MPI on all terminal welds.		bends Focus on 90 deg. Bends
			Mechanical Fatigue		Mechanical Fatigue	MPI on terminal welds.
38	Sootblower System NRVs, Master Valve's and Pressure reducing valve's, Section Valves HCB11AA601, HCB11AA101, HCB11AA001 and HCB12AA502, HCB12AA101, HCB12AA001, HCB21AA101, HCB22AA101	Visual inspection and Dye Penetrant testing inside the valve body.	Thermal Fatigue	DP Testing. (Internal)	Mechanical Fatigue	MPI on valve body.
			Mechanical Fatigue			
39	Sootblower HP Steam Source HCB12BR100	No inspection	Mechanical Fatigue	MPI on all terminal welds. Replication, UT and MPI on connecting stub weld where wall thickness is above 11mm.	Mechanical Fatigue	MPI on terminal welds on terminal welds
			Creep		Creep	Perform replica tests on main steam to soot-blower line branch weld. Include this component under the HP Piping Creep Management Strategy
			Creep Fatigue		Erosion	WT on bends: min 10% of the bends Focus on 90 deg. Bends.
40	Sootblower system Poppet Valve	MPI on valve body.	Thermal Fatigue	DPI on valve body (Internal and external) – if defects are found, more to be done.	Thermal Fatigue	MPI on valve body (external) - valve too small to do MPI inside.
			Mechanical Fatigue		Mechanical Fatigue	
41	Sootblower system, Drain lines HCB41, HCB42, HCB43, HCB44, HCB51, HCB52, HCB90	No inspection	FAC	Wall thickness measurements /Digital Radiography (Include in the FAC program). MPI on terminal welds.	FAC	No RBI SOW issued. Low risk in 6-12 years for FAC.
			Mechanical Fatigue			

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
42	Blowdown Valves HAN10AA401, HAN10AA101, HAN10AA402, HAN09AA401, HAN09AA402, HAN09AA403.	Visual inspection and Dye Penetrant testing inside the valve body.	Mechanical Fatigue	MPI on valve body. MPI on first connecting welds to pipe.	Mechanical Fatigue	MPI on terminal welds.
43	HP Bypass Piping	For HP BYPASS LEG A (HPA)- MPI & UT on Butt weld HP1, BendHBA2/4, Butt weldHP4, Butt weldHP5, BendHBA4/4, ValveHPAV, Butt weldHP6, BendHBA5/4, Butt weldHP7, Butt weldHP8, BendHBA7/4, Butt weldHP9. And on HP BYPASS LEG B (HPC)- MPI & UT on Butt weldHP10, BendHBC2/4, Butt weldHP13, Butt weldHP14, BendHBC4/4, ValveHPCV, Butt weldHP15, BendHBC5/4, Butt weldHP16, Butt weldHP17, BendHBC7/4, Butt weldHP18	Mechanical Fatigue	Continue with current inspections as per HP Piping scope i.e. For HP BYPASS LEG A (HPA)- MPI & UT on Butt weld HP1, BendHBA2/4, Butt weldHP4, Butt weldHP5, BendHBA4/4, ValveHPAV, Butt weldHP6, BendHBA5/4, Butt weldHP7, Butt weldHP8, BendHBA7/4, Butt weldHP9. And on HP BYPASS LEG B (HPC)- MPI & UT on Butt weld HP10, BendHBC2/4, Butt weld HP13, Butt weld HP14, BendHBC4/4, ValveHPCV, Butt weld HP15, BendHBC5/4, Butt weld HP16, Butt weld HP17, BendHBC7/4, Butt weld HP18.	Pitting Corrosion Mechanical Fatigue Corrosion fatigue	No RBI SOW issued. Low risk in 6-12 years for Pitting Corrosion, Mechanical Fatigue and Corrosion Fatigue. HP Bypass split into: HP BYPASS (ASTM A672) and HP BYPASS (ASTM A106).
44		No inspection	Creep		Creep	

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
	LP Bypass Piping		Thermal Fatigue Mechanical Fatigue Creep Fatigue	Replicas, MPI, UT and dimensional measurements on all welds with terminal welds taking priority.	Mechanical Fatigue Creep Fatigue	Replicas, MPI, UT and dimensional measurements on all welds with terminal welds taking priority.
45	HP Bypass Warming Lines	No inspection	Fatigue Corrosion Fatigue	MPI & UT on terminal welds	Pitting Corrosion Mechanical Fatigue Corrosion fatigue	No RBI SOW issued. Low risk in 6-12 years for Pitting Corrosion, Mechanical Fatigue and Corrosion Fatigue.
46	LP Bypass Warming Lines & Drain lines	No inspection	Creep Thermal Fatigue	Replicas only on stub weld where wall thickness is more than 11mm. MPI on all welds with terminal welds taking priority. UT on selected welds (Min 5%).	Creep	Replication on the stub welds where the WT is more than 11mm, if WT found to be less than 11mm do not replicate, carry out internal oxide measurement and WT measurement. Creep -high risk in 3-6 years.
			Mechanical Fatigue Creep Fatigue		Mechanical Fatigue	Do MPI on terminal welds. Mechanical Fatigue- high risk in 3-6 years.
47	Auxiliary Steam Piping LBG	No inspection	Mechanical Fatigue	MPI and UT on terminal welds when an opportunity is available. Once off. Consider other online methods. (DR) – System Engineer to advice.	Corrosion fatigue	Line too big to conduct Digital Radiography. Isolation of these Auxiliary Steam lines deemed impractical on Units 4&5. Utilise other Auxiliary steam lines inspection findings from Turbine side to estimate

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
						condition of this common line.
					Mechanical Fatigue	If access granted; Carry out MPI on all terminal welds.
48	Sootblower, Air heater HP steam source HCB80BR001	No inspection	Mechanical Fatigue	MPI on all terminal welds. Replication, UT and MPI on connecting stub weld where wall thickness is above 11mm.	Mechanical Fatigue	Carry out MPI on Circular welds and attachment welds as per the Engineering Instruction.
			Creep			
			Creep Fatigue			
49	Sootblower Master Valves, Pressure Reducing Valves, NRVs HCB80AA101, HCB80AA001, HCB81AA601, HCB81AA101	Visual inspection and Dye Penetrant testing inside the valve body.	Thermal Fatigue	DP Testing on valve body (Internal)	Mechanical Fatigue	MPI on valve body.
			Mechanical Fatigue			
50	Sootblower Auxiliary steam source HCB81BR001	No inspection	Mechanical Fatigue	MPI on Terminal Welds	Mechanical Fatigue	Carry out MPI on Circular welds and attachment welds as per the Engineering Instruction.
51	Boiler Air Receiver	Thorough visual inspection externally and internally. MPI support welds and termination welds of attachments. Inspect paint/coating and repair as necessary. UT wall thickness checks on vessel if paint damage is present or visual damage is present.	Mechanical Fatigue	Thorough visual inspection externally and internally. MPI support welds and termination welds of attachments. Inspect paint/coating and repair as necessary. UT wall thickness checks on vessel if paint damage is present or visual damage is present.	Pitting Corrosion	No RBI SOW issued. Low risk in 6-12 years for Pitting Corrosion and Mechanical Fatigue.
					Mechanical Fatigue	
52	Steam Drum Upper Shell	Internal Visual inspection.	Mechanical Fatigue		Mechanical Fatigue	On welds, Continue with

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
	Steam Drum lower Shell	UWT longitudinal (LW01, LW02) and nozzle (01-09) welds		Low risk in 6 years at Pre-Outage.		existing inspection program i.e. Conduct MT on water sample nozzle, feedwater regulating nozzle, hydrawater level water nozzle, safety valve nozzle; test nozzle, vent steam gauge and water level trans. Nozzle. MT also to be done on steam relief stubs ROW A-E, steam drum circular welds, steam drum feed nozzles, steam drum downcomer nozzles, steam drum lifting lugs, steam sampling nozzles.
	Steam Drum head (Left End)		Corrosion Fatigue		Corrosion Fatigue	UT to be done on steam relief stubs ROW A-E, steam drum circular welds, steam drum feed nozzle, drum downcomer nozzles, steam drum lifting lugs, steam sampling nozzles.
	Steam Drum head (Right End)					
53	Circulation Pump Suction Manifold HAG01BR100	No inspection	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	MT on all terminal welds (CW01 and CW04).
					Thermal Fatigue	Carry out surface crack test (MT) and sub-surface inspection (UT) to detect if there are any cracks on the internal

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
						diameter surface.
					Corrosion Fatigue	UT on all butt welds on the manifold.
54	Circulation Pump Suction Manifold Spool Piece 1 HAG01BR100	No inspection	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	MT on all terminal welds (CW01 and CW04).
					Thermal Fatigue	Carry out surface crack test (MT) and sub-surface inspection (UT) to detect if there are any cracks on the internal diameter surface.
					Corrosion Fatigue	UT on all butt welds on the manifold.
55	Circulation Pump Suction Manifold Spool Piece 2 HAG01BR100	No inspection	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	MT on all terminal welds (CW01 and CW04).
					Thermal Fatigue	Carry out surface crack test (MT) and sub-surface inspection (UT) to detect if there are any cracks on the internal diameter surface.
					Corrosion Fatigue	UT on all butt welds on the manifold.
56	Circulation Pump Suction Manifold Spool Piece 3 HAG01BR100	No inspection	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	MT on all terminal welds (CW01 and CW04).
					Thermal Fatigue	Carry out surface crack test (MT) and sub-surface inspection (UT) to detect if there are any cracks on the internal diameter surface.

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
					Corrosion Fatigue	UT on all butt welds on the manifold.
57	Circulation Pump Discharge Pipe 1	No inspection	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	Carry out MPI on all terminal welds. Carry out surface crack test (MT) and sub-surface inspection (UT) to detect if there are any cracks on the internal diameter surface.
	Circulation Pump Discharge Pipe 2	No inspection				
	Circulation Pump Discharge Pipe 3	No inspection			Corrosion Fatigue	Visual inspections to check negative slope in the pipe and if negative slope is found carry UT on CW07 and CW08 or CW09 and CW10 on the worst one. Carry out MPI on all terminal welds.
	Circulation Pump Discharge Pipe 4	No inspection				
	Circulation Pump Discharge Pipe 5	No inspection			Thermal Fatigue	Carry out surface crack test (MT) and sub-surface inspection (UT) to detect if there are any cracks on the internal diameter surface.
	Circulation Pump Discharge Pipe 6	No inspection				
58	SO3 plant - Burner vessel HQT03AV001	VI internal and external inspection. WT on shell	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Thermal Fatigue	VI internal and external inspection. High risk in 3-6 years.
					Erosion	WT on shell. High risk in 3-6 years.
					Strain Aging	WT on shell. High risk in 3-6 years.
59	SO3 plant - Burner Converter vessel	VI internal and external inspection. WT on shell	–	Component not assessed at Pre-Outage i.e. only picked	Thermal Fatigue	No RBI SOW issued. Low risk in 6-12 years for Thermal Fatigue.

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
				up at Post-Outage		
60	6 inch steam drain line/Manual isolation valve HAN09AA401& HAN09AA402	Visual inspection and Dye Penetrant testing inside the valve body.	_	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Erosion	VI inside the valve body.
					Mechanical Fatigue	MPI on valve body.
					Corrosion Fatigue	Dye Penetrant testing inside valve body.
					Thermal Fatigue	MPI on valve body and UT on 1st connection weld.
61	Blowdown 6 inch steam drain line//NRV HAN09AA403	Visual inspection and Dye Penetrant testing inside the valve body.	_	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Erosion	VI inside valve body; if there is damage then DO Wall thickness measurements
					Mechanical Fatigue	MPI on connection welds.
62	Blowdown 3 inch steam drain line/Isolating valve HAN10AA401	Visual inspection and Dye Penetrant testing inside the valve body.	_	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	MPI on connection welds.
63	Blowdown 3 inch steam drain line/Regulating valve HAN10AA101	Visual inspection and Dye Penetrant testing inside the valve body.	_	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	MPI on connection welds.
64	Blowdown Vessel-Exhaust/Vent Pipe	No inspection	_	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Internal Corrosion	VI through expansion joint.
					Erosion	Wall thickness measurements as per SE are marking i.e. straight section between expansion joint and vessel shell (due to access limitations).
TURBINE INSPECTIONS						

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
1	Condensate System MAG10BR001, MAG10BR003, MAG10BR007, MAG10BR009	Wall thickness testing on Pipes MAG10BR001 (from Flashbox MAG10BB001 to Condenser), MAG10BR003 (from Flashbox MAG10BB001 to Condenser), MAG10BR007 (from Flashbox MAG10BB009 to Condenser), MAG10BR001 (from Flashbox MAG10BB001 to Condenser). External replication on welds where wall is more than 11mm (High temp area - entries into pipe).	Internal Corrosion (General)	Wall Thickness Testing	Internal Corrosion (General)	Wall thickness measurements as per SE's markings i.e. bends and braches
			Creep	External replication on welds where wall is more than 11mm (High temp area - entries into pipe)	Creep	External replication on welds where wall is more than 11mm (High temp area - entries into pipe).
2	HP - Preheater 5 LAD51AC001, LAD52AC001 and HP - Preheater 6 LAD61AC001, LAD62AC001	MPI on first shell to nozzle weld and first nozzle to pipe weld. Internal visual for FAC. Wall thickness measurements as per Wall thickness template from SE i.e. HP Heaters 5.1& 5.2 Shell (BD 2), HP Heaters 5.1&5.2 Tubes; HP Heaters 6.1 &6.2 Shell HP Heaters 6.1&6.2 Tubes	Mechanical Fatigue	MPI on first shell to nozzle weld and first nozzle to pipe weld		MPI on first shell to nozzle weld and first nozzle to pipe weld.
			FAC	Internal visual for FAC. Wall thickness measurements .		Internal visual for FAC. Wall thickness measurements as per Wall thickness template from SE i.e. HP Heaters 5.1& 5.2 Shell (BD 2), HP Heaters 5.1&5.2 Tubes; HP Heaters 6.1 &6.2 Shell HP Heaters 6.1&6.2 Tubes
3	HP - Preheater 5 Pipes LAD51BR001 & LAD52BR001 and HP - Preheater 6 Pipes	MPI on weld to valve.	Mechanical Fatigue	MPI on terminal welds.	Mechanical Fatigue	MPI on terminal welds.

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
	LAD61BR001 & LAD62BR001					
4	Feedwater Piping LAB10BR002, LAB20BR002, LAB30BR002	For each pipe; MPI on weld to valve.	Mechanical Fatigue	MPI on terminal welds.	Mechanical Fatigue	MPI on terminal welds.
5	Feedwater Piping LAB11BR001, LAB21BR001, LAB31BR001	For each pipe; MPI on weld to valve.	Mechanical Fatigue	MPI on T-Piece welds.	Mechanical Fatigue	MPI on terminal welds.
6	Feedwater Piping LAB11BR003, LAB21BR003	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	MPI on terminal welds.	Mechanical Fatigue	MPI on terminal welds.
			Erosion	Wall thickness testing on pipe section after valve and on the first bend.	Erosion	Wall thickness testing on pipe section after valve and on the first bend.
7	Feedwater Piping LAB40BR001, LAB41BR001, LAB41BR002, LAB42BR001,LAB42BR002, LAB43BR001, LAB43BR002, LAB50BR001, LAB51BR001, LAB51BR002, LAB51BR003, LAB53BR001, LAB60BR001, LAB52BR001, LAB52BR002, LAB52BR003, LAB60BR002	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	MPI on terminal weld. Hanger inspections on feedwater system pipework.	Mechanical Fatigue	MPI on terminal weld. Hanger inspections on feedwater system pipework.
8	DST Safety Valves LAA10AA003 & LAA10AA004	Internal Visual inspection and MPI on valve body.	Mechanical Fatigue	MPI on valve body.	Mechanical Fatigue	MPI on valve body (Once off to see damage).

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
9	DST/Feedwater Tank LAA10BB001	Internal visual inspection, Wall thickness testing as per Wall thickness templates from SE i.e. shell, dished heads, nozzles. Triple point UT.	FAC	Continue with current inspection scope: Internal MPI, wall thickness testing, internal visual testing. Triple point UT. External support MPI. (Same % as on current inspection scope).	FAC	Internal visual inspection, Wall thickness testing as per Wall thickness templates from SE i.e. shell, dished heads, nozzles. Triple point UT.
10	DST Main Condensate inlet LAA10BB001 and DST Main Steam inlet (S1) LAA10BB001	UT on T-welds inside the DST shell (triple point UT).	Mechanical Fatigue	MPI on nozzle to shell weld and first pipe to nozzle weld. MPI on nozzle to shell weld and first pipe to nozzle weld	Mechanical Fatigue	MPI on nozzle to shell weld and first pipe to nozzle weld. External support MPI. (Same % as on current inspection scope). Internal MPI.
						MPI on nozzle to shell weld and first pipe to nozzle weld
11	DST Piping LAA10BR001	MPI on first pipe to nozzle weld from DST.	Mechanical Fatigue	MPI on first pipe to nozzle weld from DST.	Mechanical Fatigue	MPI on first pipe to nozzle weld.
12	Gland Steam and Leak-off Piping MAW65BR001 & MAW66BR001	No inspection	Corrosion	Internal Visual (Endoscope) (5%) & Wall thickness (5%) measurements on few selected components	Mechanical Fatigue	Surface crack testing (MT) on terminal welds
			Mechanical Fatigue	Surface crack testing (MPI) and volumetric testing (UT or RT) on terminal welds		
13	Gland steam Condenser MAW80AC001	Internal visual inspection. External MPI on nozzle to vessel	Mechanical Fatigue	MPI on terminal welds.	Mechanical Fatigue	MPI on terminal welds.

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
		weld for the nozzles no.2, 3, 4, 9, 12, 24&25.				
14	HP - Preheater 5 Pipes LCH51BR001, LCH51BR002, LCH51BR003, LCH51BR004, LCH52BR001, LCH52BR002, LCH52BR003, LCH52BR004 HP - Preheater 6 Pipes LCH61BR002, LCH61BR003, LCH61BR004, LCH62BR002, LCH62BR003, LCH62BR004	No inspection	FAC	Continue with FAC program i.e. bends, reducers, T-pieces, straight sections, NRV, isolation and control valves	FAC	Wall thickness measurements as per Wall thickness template from SE i.e. bends, reducers, T-pieces, straight sections, NRV, isolation and control valves.
			Mechanical Fatigue	Hanger inspections. MPI on terminal welds.	Mechanical Fatigue	VI- Hanger inspections. MPI on terminal welds.
No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Recommended Inspection	DM	Recommended Inspection
15	HP - Preheater 6 Pipes LCH61BR001 & LCH62BR001	No inspection	FAC	Continue with FAC program i.e. T-piece, Bends CV and straight. Replace damaged sections.	FAC	Wall thickness measurements as per Wall thickness template from SE i.e. T-piece, Bends CV and straight.
			Mechanical Fatigue	Hanger inspections. MPI on terminal welds.	Mechanical Fatigue	Hanger inspections. MPI on terminal welds.
16	HP - Preheater 5 Pipe LBQ50BR003 HP - Preheater 6 Pipe LBQ60BR003	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	Hanger inspections. MPI on termination weld and welds on 2* T-piece (all 3 welds on T-piece).	Mechanical Fatigue	Hanger inspections. MPI on termination weld and welds on 2* T-piece (all 3 welds on T-piece).

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
17	HP - Preheater 5 Pipe LBQ50BR004, LBQ51BR001, LBQ51BR101, LBQ52BR001, LBQ52BR101 HP - Preheater 6 Pipe LBQ60BR002, LBQ61BR001, LBQ62BR001, LBQ62BR101, LBQ61BR101	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	Hanger inspections. MPI on terminal welds.	Mechanical Fatigue	Hanger inspections. MPI on termination welds.
18	None Return Valves LBC01AA001 & LBC02AA001	Internal visual inspection	Internal Corrosion	Internal visual inspection	Internal Corrosion	Internal visual inspection
19	HP E.S. Valves MAA11AA001, MAA21AA001, MAA31AA001, MAA41AA001	Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. Replicas on the Outer Surface & 1st connection weld.	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld, MPI on the outside of the valve and Dye Penetrant Testing inside the valve.	Creep	Replicas on the Outer Surface & 1st connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.
			Creep Fatigue		Creep Fatigue	Replicas on the Outer Surface & 1st connection weld
20	HP GOV. Valves MAA12AA001, MAA22AA001, MAA32AA001, MAA42AA001	Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. Replicas on the Outer Surface & 1st connection weld.	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld, MPI on the outside of the valve and Dye Penetrant Testing inside the valve.	Creep	Replicas on the Outer Surface & 1st connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.
			Creep Fatigue		Creep Fatigue	Replicas on the Outer Surface & 1st connection weld

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
21	IP E.S. Valves MAB11AA001, MAB21AA001, MAB31AA001, MAB41AA001	Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. Replicas on the Outer Surface & 1st connection weld	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld, MPI on the outside of the valve and Dye Penetrant Testing inside the valve.	Creep	Replicas on the Outer Surface & 1st connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.
			Creep Fatigue		Creep Fatigue	Replicas on the Outer Surface & 1st connection weld
No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Recommended Inspection	DM	Recommended Inspection
22	IP GOV. Valves MAB12AA001, MAB22AA001, MAB32AA001, MAB42AA001	Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. Replicas on the Outer Surface & 1st connection weld.	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld, MPI on the outside of the valve and Dye Penetrant Testing inside the valve.	Creep	Replicas on the Outer Surface & 1st connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.
			Creep Fatigue		Creep Fatigue	Replicas on the Outer Surface & 1st connection weld
23	LP - Preheater 1, 2 & 3 LCC10AC001, LCC20AC001, LCC30AC001	Internal visual inspection. On each LP – Preheater. For LCC10AC001: External MPI on nozzle to vessel weld on the nozzles no. S1-S12, T1-T2& Vessel support welds. For LCC20AC001: External MPI on nozzle to vessel weld on the nozzles no. S1-S15, T1-T2&	Mechanical Fatigue	MPI first nozzle to shell weld and first nozzle to pipe weld. All nozzles.	Mechanical Fatigue	MPI first nozzle to shell weld and first nozzle to pipe weld. All nozzles.

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
		Vessel support welds For LCC30AC001: External MPI on nozzle to vessel weld on the nozzles no. S1-S15, T1-T2& Vessel support welds				
24	DST Piping LBS40BR003, LBS41BR001, LBS41BR002, LBS43BR001	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	Pipe hanger inspection. MPI on 300NB and larger T-pieces (All 3 welds)	Mechanical Fatigue	Pipe hanger inspection. MPI on 300NB and larger T-pieces (All 3 welds).
25	LP Attemperating Spray Water Pipes LCE10BR001, LCE20BR001, LCE30BR001, LCE40BR001, LCE41BR001, LCE42BR001	No inspection	FAC	Wall thickness measurements on few selected components (5%)	FAC	Wall thickness measurements on few selected components (5%)
			Corrosion	Internal Visual (Endoscope) (5%)	Corrosion	Internal Visual (Endoscope) (5%)
26	Aux Steam Piping LBG01BR002	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	MPI on termination welds. All 6 * 350NB welds. Hanger inspection.	Mechanical Fatigue	MPI on termination welds. All 6 * 350NB welds. Hanger inspection.
27	Aux Steam Piping LBG01BR104, LBG01BR107, LBG01BR120, LBG01BR123, LBG01BR130, LBG01BR133, LBG01BR136, LBG01BR140, LBG01BR143, LBG01BR150, LBG01BR153, LBG10BR001, LBG10BR002, LBG10BR003, LBG10BR004, LBG10BR107, LBG11BR001, LBG11BR102,	For each pipe; MPI on weld to valve/t-piece/terminal weld to main pipe.	Mechanical Fatigue	MPI on termination welds. Hanger inspection.		

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
	LBG12BR001, LBG20BR001, LBG20BR002, LBG20BR003, LBG20BR004, LBG20BR005, LBG20BR006, LBG20BR007, LBG20BR008, LBG20BR009, LBG20BR010, LBG20BR101, LBG22BR001, LBG23BR001, LBG23BR002, LBG23BR102, LBG23BR105, LBG24BR001, LBG30BR001, LBG31BR001, LBG33BR001, LBG33BR101					MPI on termination welds. Hanger inspection.
28	Aux Steam Valves LBG01AA002, LBG10AA001, LBG10AA002, LBG10AA003, LBG11AA010, LBG11AA011, LBG20AA001, LBG20AA002, LBG20AA003, LBG20AA004, LBG30AA001, LBG30AA002	MPI inside and outside valve body.	Thermal Fatigue	MPI/DPI on valve body (Internal)	Thermal Fatigue	MPI on valve body (Internal); DPI if MPI is proven to be impractical.
29	Main Condensate System, Drain inlet to LP Preheater 3 LCA30BR008	No inspection	FAC	Wall thickness measurements on one bend.	FAC	Wall thickness measurements on one bend.
30	IP - Attemperating spray water pipes LAF10BR001, LAF10BR002, LAF10BR101, LAF10BR102, LAF20BR001, LAF20BR002, LAF20BR101, LAF20BR102, LAF30BR001,	For each pipe; Wall thickness measurements s per wall thickness template from SE i.e. bends, valves, t-pieces.	FAC	Do FAC inspections as per FAC scope.		Wall thickness measurements s per wall thickness template from SE i.e. bends, valves, t-pieces.

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
	LAF30BR002, LAF30BR101, LAF30BR102					
31	Cold Reheat Drains to Condenser LBC01BR101, LBC01BR110, LBC01BR111, LBC01BR701, LBC01BR702, LBC01BR703, LBC02BR101, LBC02BR110, LBC02BR111, LBC02BR701, LBC02BR702, LBC02BR703	Visual inspection and Wall thickness on bends if damage is found/suspected.	Erosion	Wall thickness testing on bends.	Erosion	Wall thickness on bends for erosion.
			Mechanical Fatigue	MPI and UT on terminal welds.	Mechanical Fatigue	MPI and UT on terminal welds.
No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Recommended Inspection	DM	Recommended Inspection
32	Turbine Drains MAL01BR001, MAL02BR001, MAL03BR001, MAL04BR001,	On each pipe, MT- on terminal welds.	Corrosion	Wall thickness measurements on few selected positions (<5%), if wall thinning is identified do Internal Visual (Endoscope)	Pitting Corrosion	No RBI SOW issued. Low risk in 6-12 years for Pitting Corrosion and Creep.
					Creep	
			Mechanical Fatigue	MPI on terminal welds	Mechanical Fatigue	MT- on terminal welds. Mechanical fatigue –low risk in 6 years but medium risk in 12 years.
33		On each pipe, Perform MPI on both terminal welds and	Mechanical Fatigue	Perform MPI on both terminal welds and	Creep	No RBI SOW issued. Low risk in 6-12 years for Creep.

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
	Turbine Drains MAL11BR001, MAL11BR002, MAL12BR001, MAL12BR002, MAL13BR001, MAL13BR002, MAL14BR001, MAL14BR002, MAL17BR001, MAL17BR002, MAL18BR001, MAL18BR002, MAL21BR001, MAL21BR006, MAL21BR007, MAL21BR010	connection (3 welds on T-Piece) to force cooling line.		connection (3 welds on T-Piece) to force cooling line.	Mechanical Fatigue	MT- on terminal welds. Mechanical fatigue –low risk in 6 years but medium risk in 12 years.
34	Turbine Drains MAL26BR001, MAL27BR001, MAL28BR001, MAL29BR001	On each pipe, VI- from the seal weld to the stub connection and also on the supports. PT-on the seal weld and butt joints. Wall thickness &oxide measurements downstream the seal weld.	Creep	DP on seal welds. Perform Digital Radiography on some bends. Perform hanger inspections and confirm drainage slopes. Cut out a section on one line for oxide measurements by RT&D. Perform tube solo for internal oxide measurement.	Mechanical Fatigue	VI- from the seal weld to the stub connection and also on the supports. PT-on the seal weld and butt joints.
					Creep	Take oxide thickness measurements downstream the seal weld.
			Corrosion		Oxidation	"1. PT (Dye Penetrant Testing) on stub seal welds. 2. Perform Digital Radiography to verify TubeSOLO results. Perform hanger inspections and confirm drainage slopes. 3. Perform tube solo for internal oxide measurement.
					Erosion – Steam	Take wall thickness measurements on the extrados of the bends.
					Thermal Fatigue	VI- from the seal weld to the stub

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
					(DM added as per RT&D/MAT /16/294)	connection and also on the supports. PT-on the seal weld and butt joints.
35	Turbine Drains MAL26BR002, MAL27BR002, MAL28BR003, MAL29BR003, MAL33BR001, MAL33BR002, MAL33BR003, MAL65BR001, MAL65BR003, MAL66BR001, MAL66BR002, MAL91BR002, MAL92BR002, MAL93BR002, MAL94BR002, MALBR002	On each pipe, MT-on terminal welds.	Creep	Replicas not possible/practical because of wall thickness. Do wall thickness test and internal oxide test. Metallurgist to use results for determining if Creep may be present.	Creep	No RBI SOW issued. Low risk in 6-12 years for Creep.
					Mechanical Fatigue	MT- on terminal welds. Mechanical fatigue –low risk in 6 years but medium risk in 12 years.
36	LP E.S. Valves MAN41AA001, MAN51AA001, MAN61AA001, MAN71AA001	On each valve; Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. VI inside the valve.	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. VI inside the valve.	Creep	Replicas on the Outer Surface & 1st connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.
			Creep Fatigue		Creep Fatigue	VI inside the valve.
37	LP GOV. Valves MAN42AA001, MAN52AA001, MAN62AA001, MAN72AA001	On each valve; Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve.	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld	Creep	Replicas on the Outer Surface & 1st connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.

No.	**Component**	**Standard Outage SOW Prior RBI Implementation**	**Pre-Outage SOW**		**Post Outage SOW**	
			DM	**Required Inspection**	**DM**	**Required Inspection**
		VI inside the valve.	Creep Fatigue	MPI on the outside of the valve. Dye Penetrant Testing inside the valve. VI inside the valve.	Creep Fatigue	VI inside the valve.
37	LP GOV. Valves MAN42AA001, MAN52AA001, MAN62AA001, MAN72AA001	On each valve; Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. VI inside the valve.	Creep	Continue with NDE Scope from System Engineer i.e. Replicas on the Outer Surface & 1st connection weld MPI on the outside of the valve. Dye Penetrant Testing inside the valve. VI inside the valve.	Creep	Replicas on the Outer Surface & 1^{st} connection weld
			Mechanical Fatigue		Mechanical Fatigue	MPI on the outside of the valve.
			Thermal Fatigue		Thermal Fatigue	Dye Penetrant Testing inside the valve.
			Creep Fatigue		Creep Fatigue	VI inside the valve.
38	Turbine Air Receiver QFA01BB001	Thorough visual inspection externally and internally. MPI support welds and termination welds of attachments. Inspect paint/coating and repair as necessary. UT wall thickness checks on vessel if paint damage is present or visual damage is present	Mechanical Fatigue	Thorough visual inspection externally and internally. MPI support welds and termination welds of attachments. Inspect paint/coating and repair as necessary. UT wall thickness checks on vessel if paint damage is present or visual damage is present.	Mechanical Fatigue	Thorough visual inspection externally and internally. MPI support welds and termination welds of attachments. Inspect paint/coating and repair as necessary. UT wall thickness checks on vessel if paint damage is present.
COMMON PLANT INSPECTIONS						

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
1	Desiccant Air Dryer Tower 40SCA01AT003 KD01 & 40SCA01AT003 KD02	Thorough visual inspection externally and internally. MPI support welds. Inspect paint/coating and repair as necessary. UT wall thickness checks on bottom of vessel. MPI and thickness check drain pipe if present.	Fatigue, Corrosion Pitting, Weld defect	Thorough visual inspection externally and internally. MPI support welds. Inspect paint/coating and repair as necessary. UT wall thickness checks on bottom of vessel. MPI and thickness check drain pipe if present.	Internal Corrosion	No RBI SOW issued. New unit installed. Low risk in 6-12 years.
2	Fuel oil return pipe from Boiler (4 to 6) to oil storage tank 202EGD20BR010	External visual inspection. Wall thickness measurements on x4 Bends x3 Straights	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Erosion External Corrosion Mechanical Fatigue	No RBI SOW issued. ow risk in 6-12 years for Erosion External Corrosion Mechanical Fatigue
3	H2 Plant storage tank No. 1 QGJ10BB0/0	Internal visual inspection. Wall thickness measurements on the shell (position no.1, 2, 3, 4, 5, 6, 7, 8&9).	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	Perform MPI &Dye penetrant on all welds
					Pitting Corrosion	Do internal visual inspection
4	H2 Plant storage tank No. 2 QGJ20BB0/0	Internal visual inspection. Wall thickness measurements on the shell (position no.1, 2, 3, 4, 5, 6, 7, 8&9).	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	Perform MPI /Dye penetrant on all welds
					Pitting Corrosion	Do internal visual inspection
5	H2 Plant storage tank No. 3 QGJ30BB0/0	Internal visual inspection. Wall thickness measurements on the shell (position no.1, 2, 3, 4, 5, 6, 7, 8&9).	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	Perform MPI /Dye penetrant on all welds
					Pitting Corrosion	Do internal visual inspection
6	H2 Plant storage tank No. 4QGJ40BB0/0	Internal visual inspection. Wall thickness measurements on the shell (position no.1, 2, 3, 4, 5, 6, 7, 8&9).	–	Component not assessed at Pre-Outage i.e. only picked up at Post-Outage	Mechanical Fatigue	Perform MPI /&Dye penetrant on all welds
					Pitting Corrosion	Do internal visual inspection
ELECTRICAL GENERATOR PLANT INSPECTIONS						

No.	Component	Standard Outage SOW Prior RBI Implementation	Pre-Outage SOW		Post Outage SOW	
			DM	Required Inspection	DM	Required Inspection
1	HP Receiver 1 (R1) BAC00BB100	Internal and External visual inspection. Wall thickness measurements on the shell.	Mechanical Fatigue	Thorough visual inspection externally (and internally if possible). UT 50% of main welds. If paint must be removed for UT on welds, then MPI should also be performed in this area. MPI support welds. Inspect paint/coating and repair as necessary. UT wall thickness checks on bottom of vessel. MPI and thickness check drain pipe if present. (No need to remove internal paint)	Internal Corrosion Mechanical Fatigue	No RBI SOW issued. ow risk in 6-12 years for Internal Corrosion and Mechanical Fatigue
2	HP Receiver 2 (R2) BAY20BB100	Internal and External visual inspection. Wall thickness measurements on the shell.	Mechanical Fatigue	Thorough visual inspection externally (and internally if possible). MPI all welds. Inspect paint/coating and repair as necessary. UT wall thickness checks on bottom of vessel if any paint damage was present from visual. MPI and thickness check drain pipe if present.	Internal Corrosion	No RBI SOW issued. ow risk in 6-12 years for Internal Corrosion and Mechanical Fatigue

10. APPENDIX B _ RBI INSPECTION SCOPES POWER STATION 2 (UNIT 4)

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope
HPH 5A WATER	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair
HPH 5B WATER	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair
HPH 6A WATER	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair	Fill shell with air to 300 kPa pressure to check for tube leaks test to be conducted on HP heaters to identify/confirm leaking tubes. If there is a tube leak, new leak to be explosively pugged. The previously pugged tubes should be assessed for suitable repair
HPH 5A STEAM	HP heater 5A and 5B NDT will be conducted on the following welds of each heater: • 5% of circumferential welds • 5% of Longitudinal weld o 2 Manhole weld • Sub-cooling zone vent • Steam inlet to shell nozzle 3 on weld 7 and 302 • Steam inlet- nozzle to pipe weld 3 on weld 7 and 302	FAC - Conduct visual inspections where practical and inspect for FAC and/or erosion by doing wall thickness checks shell around distillate nozzle from HPH 6A according to the Unit 4 SOW 15ENG GEN-108. If below min T, generate an engineering Instruction with a repair procedure and agreed to by all parties.	FAC - Conduct visual inspections and wall thickness on window patch area (shell straight) Erosion - Visual inspection of the internal surface of the vessel. Perform wall thickness on areas susceptible to erosion. Mechanical Fatigue - Inspect area where the 90 mm linear indication was removed during the next outage. This is to ensure that the indication was

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope

	• Condensate inlet (cascade)
	• Condensate inlet nozzle to pipe weld (cascade)
	• Condensate outlet to DST o Condensate outlet to DST - nozzle to pipe weld
	• Condensate outlet to condenser heater side
	• Condensate outlet to condenser heater side-nozzle to pipe weld
	• Condensate outlet to condenser (condenser side)
	• Safety valve stub
	• Inlet header to shell
	• Inlet header to water connector
	• Water connector to feed water pipe
	• Inlet header self-sealing enclosure
	• Outlet header to shell o Outlet header to water connector
	• Water connector to feed water pipe
	• Outlet header self-sealing enclosure
	• De-superheating box welds- inside
	• Deflector plate modification-installation/corrections
	• Shell-weld build up
	  ✓ Conduct repairs in all areas with indications
	  ✓ Conduct wall thickness on the steam inlet nozzle
			removed (ripped) correctly. Pitting - Carry out visual inspection on the bottom of the shell to detect any corrosion pitting. Perform visual inspection through manhole as far as possible and endoscope as far as possible.
			Corrosion Fatigue - Do visual inspection on shell bottom section to detect any corrosion - if access is limited use endoscope. If corrosion is noted, perform MT.

HPH 5B STEAM	HP heater 5A and 5B NDT will be conducted on the following welds of each heater: • 5% of circumferential welds • 5% of Longitudinal weld o 2 Manhole weld • Sub-cooling zone vent	FAC - Conduct visual inspections where practical and inspect for FAC and/or erosion by doing wall thickness checks shell around distillate nozzle from HPH 6A according to the Unit 4 SOW 15ENG GEN-108. If below min T, generate an engineering Instruction with a repair procedure and agreed to by all parties.	FAC - Conduct visual inspections and wall thickness on window patch area (shell straight) Erosion - Visual inspection of the internal surface of the vessel. Perform wall thickness on areas susceptible to erosion. Mechanical Fatigue - Inspect area

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope
	• Steam inlet to shell nozzle 3 on weld 7 and 302 • Steam inlet- nozzle to pipe weld 3 on weld 7 and 302 • Condensate inlet (cascade) • Condensate inlet nozzle to pipe weld (cascade) • Condensate outlet to DST o Condensate outlet to DST - nozzle to pipe weld • Condensate outlet to condenser heater side • Condensate outlet to condenser heater side-nozzle to pipe weld • Condensate outlet to condenser (condenser side) • Safety valve stub • Inlet header to shell • Inlet header to water connector • Water connector to feed water pipe • Inlet header self-sealing enclosure • Outlet header to shell o Outlet header to water connector • Water connector to feed water pipe • Outlet header self-sealing enclosure • De-superheating box welds- inside • Deflector plate modification-installation/corrections • Shell-weld build up ✓ Conduct repairs in all areas with indications ✓ Conduct wall thickness on the steam inlet nozzle		where the 90 mm linear indication was removed during the next outage. This is to ensure that the indication was removed (ripped) correctly. Pitting - Carry out visual inspection on the bottom of the shell to detect any corrosion pitting. Perform visual inspection through manhole as far as possible and endoscope as far as possible. Corrosion Fatigue - Do visual inspection on shell bottom section to detect any corrosion - if access is limited use endoscope. If corrosion is noted, perform MT.
HPH 6A STEAM	HP heater 6A and 6B NDT will be conducted on the following welds: • 1% Circumferential weld	FAC - Conduct visual inspections where practical and inspect for FAC and/or erosion by doing wall thickness checks shell around	Mechanical Fatigue - Areas where linear indications were found on the circ. weld and the long weld will need

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope
	• 5% Longitudinal weld • 2 Manhole weld - external Steam inlet nozzle 3 on weld 5 and 314 • Steam inlet nozzle - nozzle to pipe weld 3 on weld 5 and 314 • Safety valve stub • Sub-cooling zone vent - shell attachment and de-superheating box • Condensate outlet (cascade) • Condensate outlet nozzle to pipe weld (cascade) • Condensate outlet (emergency) - heater side • Condensate outlet (emergency)- heater side - nozzle to pipe weld • Condensate outlet (emergency)- condenser side Inlet header to shell o Inlet header to water connector • Water connector to feed water pipe • Inlet header self-sealing enclosure • Outlet header to shell • Outlet header to water connector • Water connector to feed water pipe • Outlet header self-sealing enclosure • De-superheating box weld Conduct repairs in all areas with indications. • Conduct wall thickness on the HP heater shells. The inspection will be done around nozzle 1 and nozzle 18	distillate nozzle from HPH 6A according to the Unit 4 SOW 15ENG GEN-108. If below min T, generate an engineering Instruction with a repair procedure and agreed to by all parties.	to be retested with MT to confirm if the indications did not reappear. Inspect all intersections of the long and circ. welds (T-welds) for indications. Retest the two T-welds that were inspected in 2016 and at least 50% of the other welds. Include MT on the supports. FAC - No further action needed. During 36 month visual inspection (as per erosion recommendation), check for possible FAC damage. Erosion - No significant wall loss noted at nozzle 4 and 18. VI during maximum interval 36 months, shell internal visual as far as possible through manhole to check for possible erosion during tube leak where accessible. Pitting - Carry out visual inspection on the bottom of the shell to detect any corrosion pitting. Perform visual inspection through manhole as far as possible and endoscope as far as possible. Corrosion Fatigue - Do visual inspection on shell bottom section to detect any corrosion - if access is limited use endoscope. If corrosion is noted, perform MT.
HPH 6B STEAM	HP heater 6A and 6B NDT will be conducted on the following welds: • 1% Circumferential weld • 5% Longitudinal weld	FAC - Conduct visual inspections where practical and inspect for FAC and/or erosion by doing wall thickness checks shell around distillate nozzle from HPH 6A according to the	Mechanical Fatigue - Areas where linear indications were found on the circ. weld and the long weld will need to be retested with MT to confirm if the

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope
	• 2 Manhole weld - external Steam inlet nozzle 3 on weld 5 and 314 • Steam inlet nozzle - nozzle to pipe weld 3 on weld 5 and 314 • Safety valve stub • Sub-cooling zone vent - shell attachment and de-superheating box • Condensate outlet (cascade) • Condensate outlet nozzle to pipe weld (cascade) • Condensate outlet (emergency) - heater side • Condensate outlet (emergency)- heater side - nozzle to pipe weld • Condensate outlet (emergency)- condenser side Inlet header to shell o Inlet header to water connector • Water connector to feed water pipe • Inlet header self-sealing enclosure • Outlet header to shell • Outlet header to water connector • Water connector to feed water pipe • Outlet header self-sealing enclosure • De-superheating box weld Conduct repairs in all areas with indications. Conduct wall thickness on the HP heater shells. The inspection will be done around nozzle 1 and nozzle 18	Unit 4 SOW 15ENG GEN-108. If below min T, generate an engineering Instruction with a repair procedure and agreed to by all parties.	indications did not reappear. Inspect all intersections of the long and circ. welds (T-welds) for indications. Retest the two T-welds that were inspected in 2016 and at least 50% of the other welds. Include MT on the supports. FAC - No further action needed. During 36 month visual inspection (as per erosion recommendation), check for possible FAC damage. Erosion - No significant wall loss noted at nozzle 4 and 18. VI during maximum interval 36 months, shell internal visual as far as possible through manhole to check for possible erosion during tube leak where accessible. Pitting - Carry out visual inspection on the bottom of the shell to detect any corrosion pitting. Perform visual inspection through manhole as far as possible and endoscope as far as possible. Corrosion Fatigue - Do visual inspection on shell bottom section to detect any corrosion - if access is limited use endoscope. If corrosion is noted, perform MT.
DA/DST	NDT is also required on the following DST shell nozzles attachment welds: • 4 Equilibrium legs- all welds in/outside • 2 Water connector - water inlet inside and outside	For the next outage: 12 circ welds not inspected during the last outage to be inspected internally with MPI as per marked up drawing 0.61/5188 rev 2. Internal 11 nozzle attachment welds (load	Mechanical Fatigue - RBI scope : Perform external MPI on all support legs to shell as well as web plates to observe if crack like indications appears. Conduct Internal MPI on the T-joint welds in 9 years to check for

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope
	• 3 FWT manholes • Pre-heating pipe outside (shell attachment and pipe attachment welds) • 2 Condensate inlet (HP heater 5A and 5B) • 2 Safety valve stubs • 10 – Longitudinal welds marked on the drawing • 10 - Circumferential weld- both ends of segment (load bearing strakes marked on drawing) • 5 Support legs – outside • Fixed support leg's support ring (around the DST)-external • 6-Support rings – inside • Support rings joints • All Pre-heating pipe support to shell weld • All Pre-heating pipe support to manifold weld • All pre-heating pipe expansion bellows weld • All spray nozzle tap off from the pre-heating pipe • All pre-heating pipe butt-welds • Wall thickness on the pre-heating pipe bend • Conduct repairs in all areas with indications	bearing) to be inspected with MPI as per marked up drawing 0.61/5188 rev 2. FAC - Conduct visual inspections on the inside of tank around nozzles 18A and 18B and inspect for FAC and/or erosion by doing wall thickness checks on nozzle 18A and 18B (distillate inlet pipes from HPH 5) and a 2 x 2 m area on the shell around the nozzle according to the Unit 4 SOW 15ENG GEN-108. If below min T, generate an engineering Instruction with a repair procedure and agreed to by all parties. Internal 6 support rings to be inspected with MPI as per marked up drawing 0.61/5188 rev 2. External 5 support legs to be inspected as per Unit 4 SOW 15ENG GEN-108. External 3 feedpump suction line welds to DST to be inspected with MPI as per marked up drawing 0.61/5188 rev 2. If indications are noted, generate an engineering Instruction with a repair procedure and agreed to by all parties.	fatigue like indications due to vacuum/pressure oscillations. Conduct MPI on feed pump suction nozzles, equilibrium legs (nozzle 4A, 4B, 4C, 4D) external, both water connectors (N6A and 6B) every 6 years. MPI to be conducted on (condensate from HPH 5A and 5B) nozzle 18A and 18B in 3 years, since they were replaced during 2016 outage. Conduct Magnetic Particle Inspection on selected welds, attachments and supports to detect fatigue and mechanical overload. Welds to be selected by the system engineer as per current SOW strategy. FAC - During the next GO (6 years): Visual inspection of tank internal surface, and conduct scope as indicated on FAC spreadsheet latest scope (Dooley areas). Wall thickness to be done on nozzles 18A and 18B and shell grid as per FAC guideline during the next outage opportunity within 3 years. Erosion - To be done on tank internal surface during opportunity maintenance. Maximum inspection interval every 6 years. Pitting - To be done on tank internal surface during opportunity maintenance. Maximum inspection interval every 6 years.

Component	Pre-RBI Scope	Pre-Outage RBI Scope	Post-Outage RBI Scope
PH 3	NDT will be done on the following sell attachment welds: • Water inlet – internal • Water outlet – internal • 2 Steam inlet – external • 2 Steam inlet to pipe welds – external • Condensate/distillate outlet – external • Condensate/distillate outlet - emergency drain condenser side – external • 2 Manhole • Relief valve nozzle o Tube sheet to shell • Water box to shell • Circumferential-weld water box side • Circumferential-weld steam side • Conduct repairs in all areas with indications	Low risk - NDT as per RBO scope	Low risk - NDT as per RBO scope

11. APPENDIX C _RBI PROCESS AUDIT FINDINGS FOR A SPECIFIC ORGANISATION

Procedure/ Standard		**Finding Description**
CWA 15740:2008, 5.4	A	CWA 15740:2008 requires that the team should have access to all relevant data and risk Analysis. The RBIM plan will contain all relevant details on the strategy level for execution in order to obtain the desired reduction of level of risk as set by the RBIM analysis and process. The deviation identified occurred when the IMT for HP Heaters 5 and 6 did not require UT tests on the nozzle welds as was required in the final RBI report
CWA 15740:2008, 5.4	A	The deviation identified occurred when the approved HP Heater 5 IMT listed additional inspection and test requirements as was required in the RBI assessment report.
CWA 15740:2008, 5.3.2.1		Level 1 risk screening is done on all equipment. On equipment such as the steam drum, HP Heater 5 and various others, no Level 1 risk assessments were performed
CWA 15740:2008, 5.5	A	Inspection plans be developed based on the output of the RBI process. It was found during the audit that the inspection requirements agreed in the risk report were incorrectly listed on the RBO plans. Various inspection activities were left off on the Boiler components
CWA 15740:2008, 5.2.3 RBI Process Manual (3.4.6)	B	Data input review of Hydrogen Separators and Deoxo Driers revealed various mistakes as well as the un-availability of required data in the RBI spreadsheet which resulted in the risk assessment being incorrect.
RBI Process Manual (3.4.7)	B	The Ammonia storage tank's SANS 347 categorisation was based on incorrect fluid classification which excluded the tanks of Level 2 RBI assessment. The inspection strategy could not be updated to include appropriate NDT
CWA 15740:2008, 5.4.2 RBI Process Manual (3.7.6)	A	The IMT for the steam drum was incorrectly updated and the NDT indications are not in accordance with the risk report and minutes of meeting
CWA 15740:2008, 5.6.5.2 RBI Process Manual (3.3)	D	It is required to trigger a risk review when incidents or unexpected deterioration is found: Boiler LH 4th Stage Super-heater weld BJ 001 was classed as Class 1 creep and scheduled for replacement in January 2016. Tests in July 2015 revealed deterioration of the weld and Creep stage 1A was assigned. No proof of any risk review was demonstrated to re-assess the risk and update the inputs into the spreadsheet.
CWA 15740:2008, 5.2.1 RBI Process Manual (3.7.6)	H	The RBO Strategy need to be updated with the new RBI Strategy and be approved: The inspection scope for HP Heater 2 drain nozzle and steam inlet nozzle was not adequately defined to ensure that previous deterioration is re-inspected and the condition confirmed
CWA 15740:2008, 5.4.2 RBI Process Manual (3.6.9)	A	SOW (IMT strategy) need to be developed or updated based on the outcome of the RBI assessment. The SOW for Separator Vessel HAD 32 does not reflect all of the inspection and test requirements stipulated in the RBI spreadsheets.
CWA 15740:2008, 5.1.1.5 RBI Process Manual (3.3)	B	Some of the Ammonia Storage Tank design data was inputted incorrectly and wall thickness reports taken in December 2015 indicated thicknesses below design thickness. Vessel has also not been inspected in accordance with PER 11.1(d) but was not flagged as a high risk.

Procedure/ Standard		**Finding Description**
CWA 15740:2008, 5.5 RBI Process Manual (3.6.9) & (3.10)	A	Some of the Super Heater Headers, Attemperator and Re-heater header's SoW generated for the GO are not in accordance with the RBI inspection requirements as captured in the RBI spreadsheets and Risk report Eng./Gen/Rep/21 Rev 0
CWA 15740:2008, 5.5 RBI Process Manual (3.4.2)		All components of each pressure vessel need to undergo RBI assessment. South De-aerator Vent Condenser tube side was not assessed and no inspection plan was developed.
CWA 15740:2008, 5.5 RBI Process Manual (3.4.9)	B	Inspection and repair history need to be captured and validated for the RBI input. The inspection and test information of the Feed Water Storage Tank Central and Vent Condenser had extensive inspections and tests but the spreadsheet indicated no relevant tests related to the applicable damage mechanisms which increased the risk and inspection requirements. In addition the tube conditions of HP Heater 3A was incorrectly indicated in the spreadsheet. The tube side is 100% plugged and was indicated as only superficially corroded inside the tubes.
CWA 15740:2008, 5.2.3 RBI Process Manual (3.6.4)	B	The data inputs for PoF on the Separator Re-heater KBG-1U1-01743 were inconsistent with the history of the vessel and due to the high weighting assigned to some of the criteria, the risk criticality was influenced.
CWA 15740:2008, 4.3.1(b) RBI Process Manual 2.2 & 3.3.1		Equipment need to be PER compliant and RBI assessments should identify non-compliant equipment. 22KV Breaker vessel API 10 G007 has no CoC as it has not been inspected before and DoL exemption required various inspections which have not been concluded.
CWA 15740:2008, 5.4.2 RBI Process Manual (3.6.9)		The SOW (IMT strategy) need to be developed or updated based on the outcome of the RBI assessment. The SOW for Separator Vessel HAD 32 was not corrected as was stated in the Stage 2 audit NCR closure document which caused the incorrect scope during the past Unit GO.
CWA 15740:2008, 5.4.2 RBI Process Manual (3.7.6)	A	The RBI Process Manual states that IMT plans shall be compiled based on the Level 2 risk assessment results and shall cover all relevant degradation mechanisms. The IMT plans for the De-aerator Tank A and HP Heater 6A IMT plans differ substantially from that of the Level 2 risk assessment inspection plan, and no evidence could be provided for the reasons for these changes.
CWA 15740:2008,5.5.3 RBI Process Manual (3.10)	A	The scope of work required by the RBI process on the Unit 6 equipment were not all completed. Typically, on the Steam Drum and Super-heater 5 Outlet header, various inspections and test were not performed as required on the IMT.
CWA 15740:2008, 5.4.1. RBI Process Manual (3.6,9)	M	During the RBI assessment of Unit 4 equipment, inspection and test plans (IMT's) were not developed and the scopes of work that is currently being executed during the current GO is predominantly based on the existing RBO strategies
CWA 5740:2008,5.3.3.Fig 1 RBI Process Manual (3.7.3)	G	The RBI reviews that were held in January 2016 revealed High risk equipment such as the NHT Heaters and De-aerators and requires immediate Level 3.1 assessments. These have not yet been done.
CWA 15740:2008,5.2.3.1 RBI Process Manual 3.4.9	B	During the risk assessment of HP Heater 5.1 the previous inspection report revealed wall thickness measurements lower than the design thickness which was not detected during the inspection history input. The risk assessment therefor was incorrectly evaluated. Design data was also not accurate and the validation process not adequate.

Procedure/ Standard		**Finding Description**
CWA 15740:2008,5.3.3 RBI Process Manual (3.3.7.4 & 3.9.1)	G	High risk equipment need to undergo Level 3 risk assessment to mitigate risks and if it cannot be mitigated or reduced, it needs to be reported to the Technical Governance Committee and Corporate RBI steering committee. The Blow Down vessel of Unit 2 is on a High risk but no mitigation or upward reporting has been done.
RBI Process Manual 240-84045193 paragraph 3.7.6	H	It is required that the low risk equipment RBO strategies be updated to include the RBI IMT strategies. The RBO strategies for the low risk equipment were not updated.
CWA 15740:2008,5.4.2 RBI Process Manual (3.6.9 & 3.10)	A	Inspection and maintenance strategies are developed and need to be executed as stipulated. During the assessment it was found that there were the following deviations from the agreed RBI recommended inspections. • Feedwater Tank on Unit 5 scope of work differs substantially from the IMT and RBI recommended inspections. • HP Heater 5.1 only required 10% NDT on shell welds although 100% were done in the GO. • Compressed Air Separator T100 requires 100% UT and MT on all welds but no evidence of UT on any welds nor MT on support welds.
CWA 15740:2008, 5.2. & RBI Process Manual , 3.5.2 Table 2	B	The selection of weights regarding the various parameters and condition of pressure equipment in the RBI Scorecard need to be selected accurately as well as history and design inputs. It was found that numerous incorrect weightings were selected during RBI assessments which could have an influence on the risk criticality of the specific equipment. • De-aerator Storage Tank • Re-heater 2 OH
CWA 15740:2008,5.4.2 RBI Process Manual (3.10 & 3.12.)	C	MA – During the post outage RBI reviews various components that were either not adequately tested or incorrectly tested did not reflect the status in the Scorecard and excellent coverage was assigned to the scopes for. Superheater 1 Outlet Header Re-heater 1 Outlet Header De-aerator which impacts the risk assessment of the equipment
CWA 15740:2008,5.2 and RBI Process Manual , 3.4.9	B	MI – Various fields in the Scorecard were found incorrectly populated on the equipment reviewed. In some cases the incorrect NDT methods were stipulated, scopes were incorrect, inspection requirements etc.
CWA 15740:2008,5.5.1 & RBI Process Manual, 3.6.9	C	MI – The RBI scorecard indicates damage mechanisms such as thermal fatigue and corrosion fatigue with recommended inspections. In some equipment, the scopes of work do not require the inspections for these damage mechanisms and need to be reviewed. • HP Heater 1A shell and tube side-Thermal fatigue. • Economizer Outlet Header-corrosion and corrosion fatigue. • Furnace Front Wall Bottom Header- corrosion and corrosion fatigue. The adequacy and technique of previous inspections indicated high confidence in the score card for these damage mechanisms and can also be reviewed.

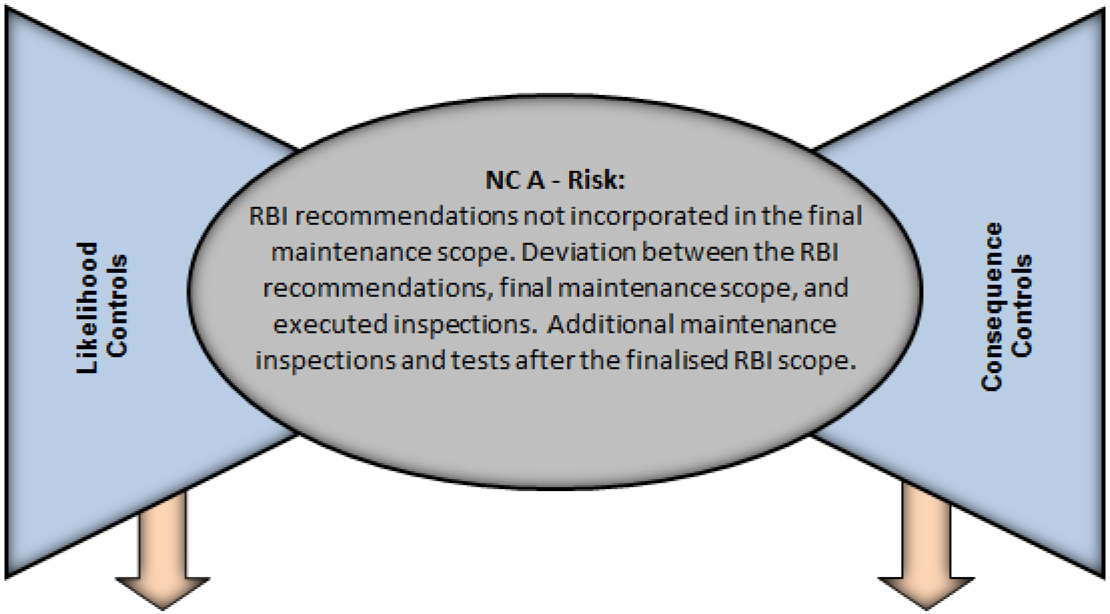
Procedure/ Standard		Finding Description
RBI Process Manual (3.10) CWA15740:2008, 5.4	E	MI – Not all inspections were conducted on Steam Generator No 9 XCA 002 CH during the last inspection in August 2017. IRIS inspection was required on the tube internals and were not done.
CWA 15740:2008, 5.6 RBI Process Manual (3.10) & (3.12)	C	MI – Post RBI risk reviews on Unit 6 revealed numerous errors in determining that RBI scopes were not fully complied to and credit was taken for techniques and scopes that were inaccurate and scoping of future inspections flawed. • De-aerator and Storage Tank A • 1ST Re-heater Header • De-aerator and Storage Tank A • Superheater 4-5 Intermediate Header
CWA 15740:2008, 5.4.1 RBI Process Manual (3.10)	A	MI - Inspections and test requirements are captured on IMT's and should be scoped accordingly. Below listed equipment had limited inspection requirements on each, but during the last outages all welds on all the equipment were tested. No reason for the extensive scopes were documented or stated in the RBI system but it is also unclear if the welds were tested internally as the damage mechanism targeted nozzle to shell welds due to fatigue. • Unit 2 De-aerator • Unit 2 HP Heaters • Unit 3 Feedwater Storage Tank
CWA 15740:2008, 5.5.3 RBI Process Manual (3.11)	F	MA - Significant defects or deterioration should be evaluated and FFS calculations be done where applicable. Centrifugal Separator No 2 revealed wall thickness measurements as low as 2.8mm where the vessel is generally 7.0mm thick. No evidence of any FFS calculations or reasons for the low wall thickness readings could be located
CWA 15740:2008, 5.4.3 RBI Process Manual 3.11	F	MA – Corrosion rates are not being calculated, in particular where wall thickness is below design, to validate continued 6-yearly inspection period (UNIT 3 & 4 HP5.1 Heaters; Common UNIT Hydrogen Vessels)
CWA 15740:2008, 4.2 RBI Process Manual, 2.1.2	F	MA – Pressure equipment not in compliance with PER. • Sandblast Tank KDL-4-CMN-10016 last inspection in 2009; more than 6 years ago • Hydrogen Tank 20 operating with a dome thickness of 17.3mm which is below the min. wall calculation of 17.64mm.
CWA 15740:2008 5.6 RBI Process Manual 3.3.1	B	MI – Updating of design data for Unit 4 and 5 has not been done yet Surveillance 1 NC#2 has been closed without following through on the requirement. No other mechanism is in place to verify that this update will be done in future.
RBI Process Manual 3.4.9 CWA 15740:2008, 5.2.3	C	MI – Inspection history data was not captured and all fields left blank on various Steam Generator component scorecards. Adequacy of inspection scopes and techniques were also mostly rated as Medium although no information was available to support the values. • Economizer Outlet Header • Primary SH Inlet Header • Economizer tubing etc.

Procedure/ Standard		Finding Description
RBI Process Manual & CWA 15740:2008	A	MI – During the audit of Unit 2 Pre-Outage SOW review for Blowdown vessel LTBO-4-BLR-11170, no visual inspection requirements were included as per the RBI Risk Assessment. Also, specific locations (external vs internal) are not always evident.
RBI Process Manual 3.6.8 & 3.7.1 & CWA 15740, 5.4	G	MA – The equipment on Unit 5 identified as High risk during the post outage reviews were not re-assessed for the short term risk in order to assess if Level 3.1 and 3.2 assessments need to be done.
RBI Process Manual , 3.7.5 CWA 15740:2008, 5.5	A	MI- Dry Dust LP Air Receivers 1 and 2 were pressure tested on 30 October 2016, but the RBI scorecard required the inspections to be done as required by the RBO strategy. The RBO strategy requires 36month internal inspections and 72 month pressure tests. The last proof of internal inspection is for 2010 and no evidence could be produced that the vessels were inspected internally in 2013 and 2016.
RBI Process Manual 3.10 & CWA15740, 5.5	E	MA -The following deviations were noted on the RBI post outage review for unit 5 Re-heater: • Not all the welds were tested as was required on the scope of work on the Re -heater 1 Outlet Header. • On the scorecard the drawings for the Superheater Header were referenced. • An NCR was also not raised by the System Engineer for scope not complied with.
CWA 15740:2008, 5.5 RBI Process Manual, 3.10	A	MA- Scopes of work generated for work on Unit 5 Outage differs from what was required in the RBI scorecards and RBI reports. In general, the SoW required more work than what RBI requires. The work that was executed in certain cases again was extensively more than the SoW and in one case much less and different work was executed than what was required in RBI. • De-aerator and Storage Tank A • HP Heater 3A • Boiler Steam Drum
CWA 15740:2008, 5.6 RBI Process Manual, 3.2	D	MI- RBI Process Manual requires post outage reviews to be done within 6 months after inspections. Unit 5 equipment and Unit 4 Hydrogen Drier have not yet started. There is also no formal system to trigger or schedule reviews for equipment inspected in isolation other than relying on human memory
CWA 15740:2008, 5.5.1 RBI Process Manual, 3.10	A	MA – The RBI Process Manual requires the scopes of work which was developed within the RBI Scorecard to be executed but it is found that there are major discrepancies between the RBI Scorecards, Outage SoW and what are actually executed. All three these scopes differ which effects the effectiveness of the RBI process. Example: • Unit 6 Steam Drum • Unit 6 Superheater Stage 3
CWA 15740:2008, 5.6.3 RBI Process Manual, 3.2	D	MI – The RBI Process Manual requires re-assessments to be triggered due to various reasons and it was found on Common Plant equipment that the post inspection review was not triggered, and it was evident that no system is in place other than human memory to trigger the re-assessments. Example: Fire Protection CO2 Storage Tank
CWA 15740:2008, 5.6.3 RBI Process Manual, 3.2	D	MI – Post outage reviews are required to be done within 6 months of inspections and both Unit 2 and Unit 6 equipment are not completed

Procedure/ Standard		**Finding Description**
RBI Process Manual 3.10 CWA 15740:2008, 5.5	A	MI – The scope of work on Unit 3 Hot Re heat Barrel was not stated clearly in the RBI scorecard but the SoW required the welds to be tested on a rotational basis. Welds RB01 and RB03 were tested in 2014 and RB02 and RB04 were required to be tested during the IR in 2017 but welds RB01 and RB03 were again tested in 2017.
RBI Process Manual 3.2 CWA 15740:2008, 5.6	D	MI – The post outage reviews for Units 2 and 3 were not completed within 6 month as required in the RBI Manual. The Common Plant equipment post outage reviews have been scheduled on an annual basis which also does not comply with the required 6 monthly period.
RBI Process Manual 3.6.9 & CWA 15740:2008, 5.4	A	MI – Unit 2 Economizer Inlet Header's score card identified certain damage mechanism and relevant inspection requirements. The inspections and tests however were conducted on feedwater pipe elbows which do not represent the same potential damage and should not be used to represent the condition of the Economizer Header.
RBI Process Manual 3.2 CWA 15740:2008, 5.6	D	MA – Post outage reviews are not performed within the six months period as required in the RBI manual and no process is in place to trigger the RBI reviews. The following are overdue: • Unit 4 equipment • All Common plant equipment • Inspected since RBI certification
RBI Process Manual, Table 6 CWA 15740:2008, Table 3	C	MI – Credit is taken for visual inspections on pressure vessels for fatigue inspections where lagging was not removed, welds not cleaned nor visible which is not in accordance with the RBI Standard and the Eskom RBI Manual
RBI Process Manual, 3.8 CWA 15740:2008, 5.5	E	MI- Inspection scope for RBI was not executed on Liquid Ammonia Storage Tank No 1 as the PM issued for the Tank did not contain the RBI scope. Tank was inspected on 26 November 2018
RBI Process Manual, 3.7.5 CWA 15740:2008, 5.5	E	MA – Previous NCR No 1 has not yet been resolved adequately and the inspections required by the RBI and RBO strategies have not yet been done and are still overdue.
RBI Process Manual, 3.10 & 3.3.1 CWA 15740:2008, 5.5	E	MA – During the Unit 2 GO inspections were not performed as required by the SOW. No scope deviation agreement by RBI Teams were obtained and NCR's were not raised by System Engineers as required in the Eskom RBI Manual. • Unit 2 DST A • Unit 2 HP Heater 6A
RBI Process Manual Table 6 CWA 15740:2008, 5.3	C	MA – Level 2 RBI assessments done on various components and equipment are not in accordance with the inspection histories populated in the scorecards. High confidences were rated in various fields under PoF, where the score card inspection history do not reference the inspections done. • Unit 2 Boiler components • Unit 3 Boiler components • Common plant 18KV Comp Air Rec.
RBI Process Manual par 3.7.6 CWA 15740:2008, 5.5	A	MI –The inspection strategies currently being executed on the Unit 8 equipment GO are not in accordance with the RBI requirements. Most equipment inspection scopes are still based on the existing RBO scopes and extensive inspections and tests are done. In some cases, the SoW is less than what RBI requires.

Procedure/ Standard		Finding Description
RBI Process Manual par 3.7.6 CWA 15740:2008, 5.5	B	MI- The RBI score card entries and risk assessment for Common Plant Air Receivers were done without having crucial information regarding previous inspections, construction details etc. which resulted in inspection requirements that are not accurate and not consistent with the details of the vessels. PoF values are also inconsistent due to lack of critical information.

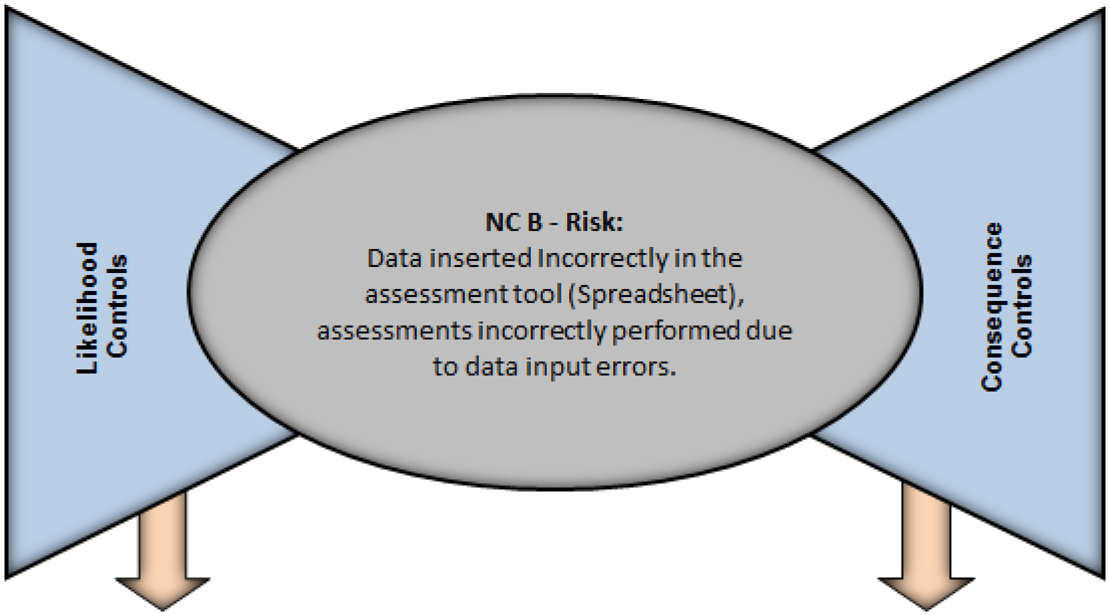
12. APPENDIX D _RISK ASSESSMENT BOW-TIE ANALYSIS



NC A - Risk:
RBI recommendations not incorporated in the final maintenance scope. Deviation between the RBI recommendations, final maintenance scope, and executed inspections. Additional maintenance inspections and tests after the finalised RBI scope.

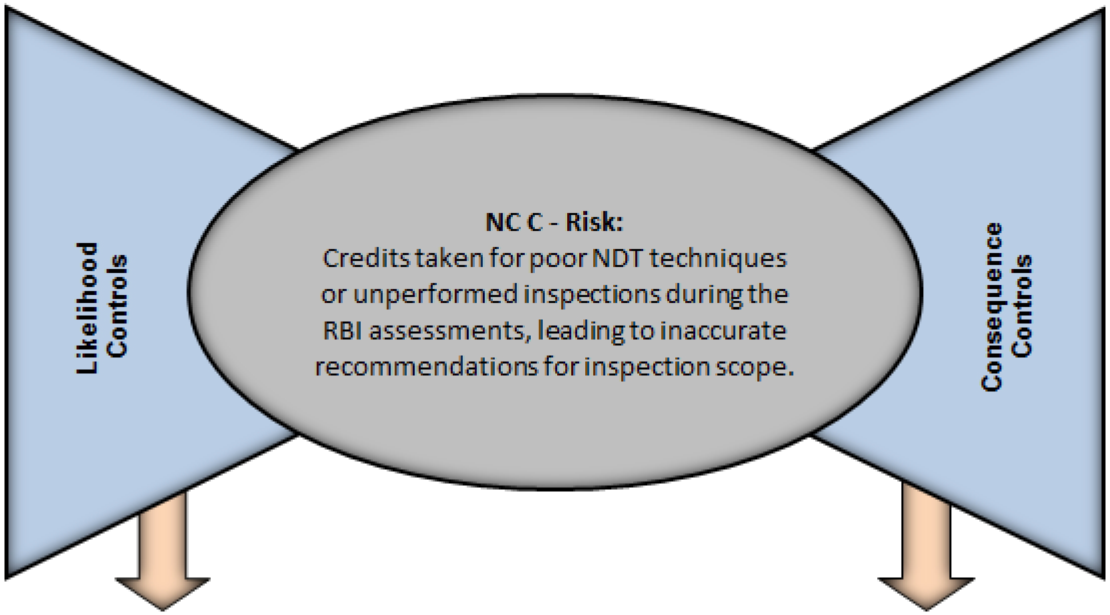
	Mitigations	Causes			Consequences		Mitigations
Process		1	RBI recommendations not uploaded in SAP.		1	Critical scopes not executed	
	Create RBI Scopes SAP Templates		SAP Templates currently do not have a potential of uploading the RBI scope			Increased risk of plant failures	Assess the executed recommendation's inspect reports, and re-evaluate the plant risks (Post-Outage review) and recommend the immediate mitigations. Barricading the affected area to limit human presence could be one of the recommended mitigations.
		2	Final scope not reviewed by RBI team before submission for execution.			Increased risk of components COC (Certificate of Competency) expiring	
	Include a RBI team final scope review step in the RBI process.		The current RBI process does not request for review by RBI team of final scope.			Probability of human injuries / fatalities increases	

	The process must be specific that all RBI scope changes must be done through the RBI team.	3	The current process allows system engineers to edit RBI scopes without consulting the RBI Team.		2	Excessive scopes which may not be fully executed within the allocated outage period, leading to increased risk of components failure.	
		4	System Engineers submitting previous SoW that were developed prior RBI or both prior RBI and RBI scopes.			Unnecessary excessive maintenance costs	
	Prior RBI Scopes to be evaluated during the RBI assessments to refine the prior RBI scope and include the RBI recommendations.		Lack of confidence in RBI recommendations, as system engineers feel that the recommended RBI inspections are not extensive enough compared to prior RBI scopes.				
			Lack of plant experience, thus system engineers will always look for the more conservative scope.				
	Integrate the RBI scopes into SAP PM's.	5	Current RBO SAP PM contains some statutory inspection that belongs to RBI.				
		6	Multiple scopes submission for outage, e.g. RBO, RBI, FAC, HP piping, etc.				



	Mitigations	Causes			Consequences		Mitigations
Process		1	Ineffective data validation and verification process.		1	Inaccurate risk profile	
	Performing the data validation as a team night improve the process quality, as this will improve the error detection probability.		Data validation not performed by a team, but individuals.			Misinterpreted failure time	Perform data review, and update the assessment accordingly
			Individuals performing data validation do not fully understand the criticality of the data validation process.			Excessive scopes, leading to unnecessary high inspection costs.	

	Training needs to be improved, to emphasise the criticality of data validation in RBI process. Examples of consequences that might result from incorrect data validation maybe shown to create awareness.		Training does not emphasis enough the data validation importance, and its impact to the RBI process output.			Unexpected failures	Perform incident investigations and provide the prevention recommendations based on the on the investigation outcome. This could be repair or replace, etc.
	All documents should be sourced from the document centre.		The usage of incorrect/ outdated data sources			Probability of human injuries / fatalities increases	Barricading the affected area to limit human presence could be one of the recommended mitigations.
			Documentation management system failure.				
	All document update should be performed through document centre. System engineers must scan the final signed inspection reports and submit scanned and original documents to document centre.		The document custodian failure to submit the latest/ updated document to document centre.				

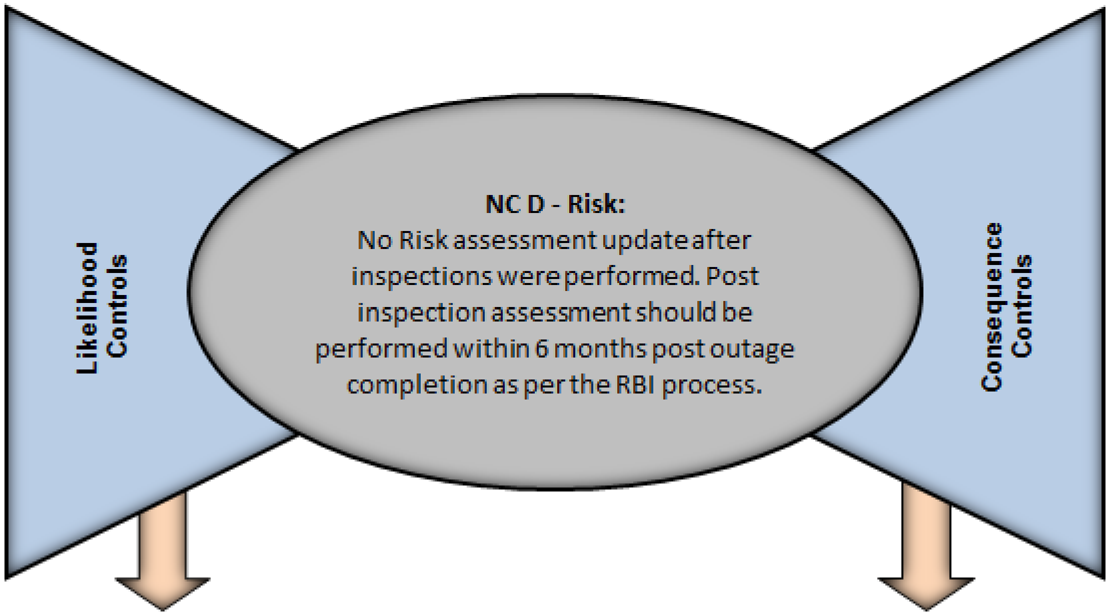


NC C - Risk:
Credits taken for poor NDT techniques or unperformed inspections during the RBI assessments, leading to inaccurate recommendations for inspection scope.

	Mitigations	Causes			Consequences		Mitigations
Process		1	Lack of NDT techniques understanding, inspection grids, etc.		1	Incorrect probability of failure, leading to inaccurate inspection recommendations.	Re-evaluate the inspection report, and review the risk assessment.
	Provide NDT techniques training to all RBI team to improve NDT reports analysis.		Lack of NDT techniques training, e.g. which NDT technique is best for a particular damage mechanism.			Unexpected plant failures	
		2	Poor inspection report analysis		2	Probability of human injuries / fatalities increases	Barricading the affected area to limit human presence

	Provide supervision to the newly appointed Metallurgists		Inexperienced Metallurgists during the RBI assessments. Reports only shows results without any analysis, this only leaves the analysis to be performed by the metallurgist in a short period (on the spot during the assessment).		
	Take breaks during assessments		Lack of concentration, due to fatigue.		
			Extensive assessment duration without adequate breaks.		
	Accept the delays due to unforeseen events, without compromising work done quality.		Pressure to complete risk assessments leading to poor plan execution due to unforeseen events.		
		3	Members not validating each other's work during the RBI assessments		
	Ensure to validate all work done by the team members		Having confidence on an individual member of the team, due to competency levels.		
		4	Not having the inspection report studied by all members during the assessment, but relying on the summary of the inspection populated by an individual.		
	Comply with all validation processes.		Failure to comply with the validation process for inspection reports summaries.		

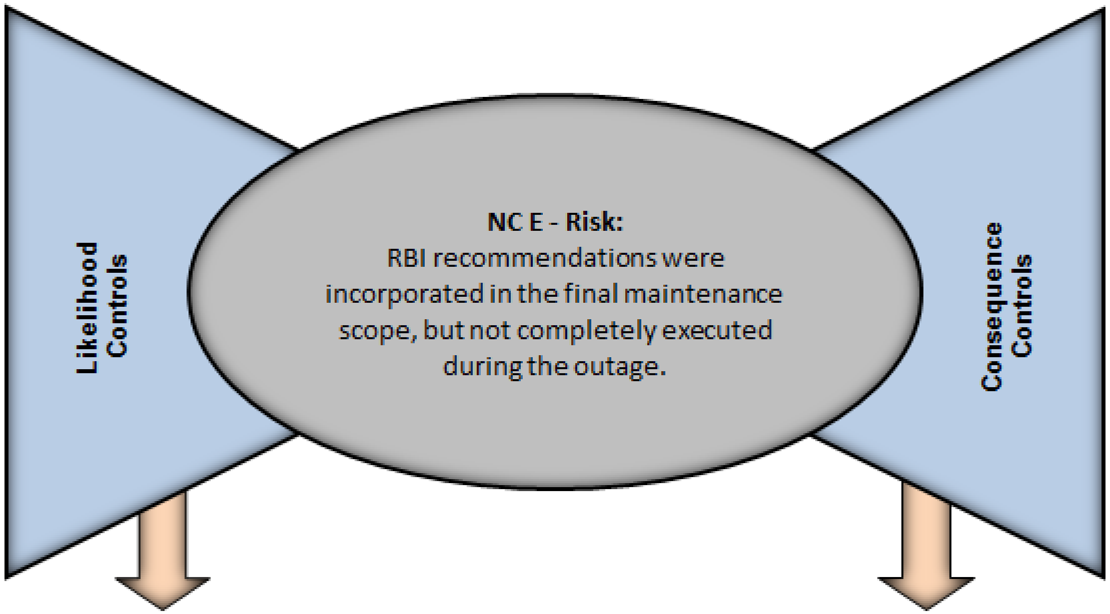
		5	Poorly written inspection reports, trying to make sense of a poorly written inspection report makes the Metallurgists work difficult.		
	Develop a standard inspection reporting templates to be provided to all AIA's.		No standard inspection reporting template available, different AIA's compile reports on their own developed templates. This is sometimes not good enough as some critical parameters are not reported.		



NC D - Risk:
No Risk assessment update after inspections were performed. Post inspection assessment should be performed within 6 months post outage completion as per the RBI process.

Process	Mitigations		Causes			Consequences	Mitigations
		1	Late or no concluded inspection reports. Incompletely signed reports.		1	Un-updated risk profile	Perform the overdue post outage risk assessment.
	Costs implications needs to be implemented, only pay the contractor upon fully signed inspection reports.		Poorly performed inspections, e.g. unrequired additional inspections performed.			Misleading risk ranking	
			Inspections performed without System Engineer's presence, which is an inspection process violation.			Unexpected failures	
		2	No tracking tool to notify the RBI team of the overdue risk assessment updates. SAP is available but not used yet.			Over-scoping, leading to unnecessarily high maintenance costs.	

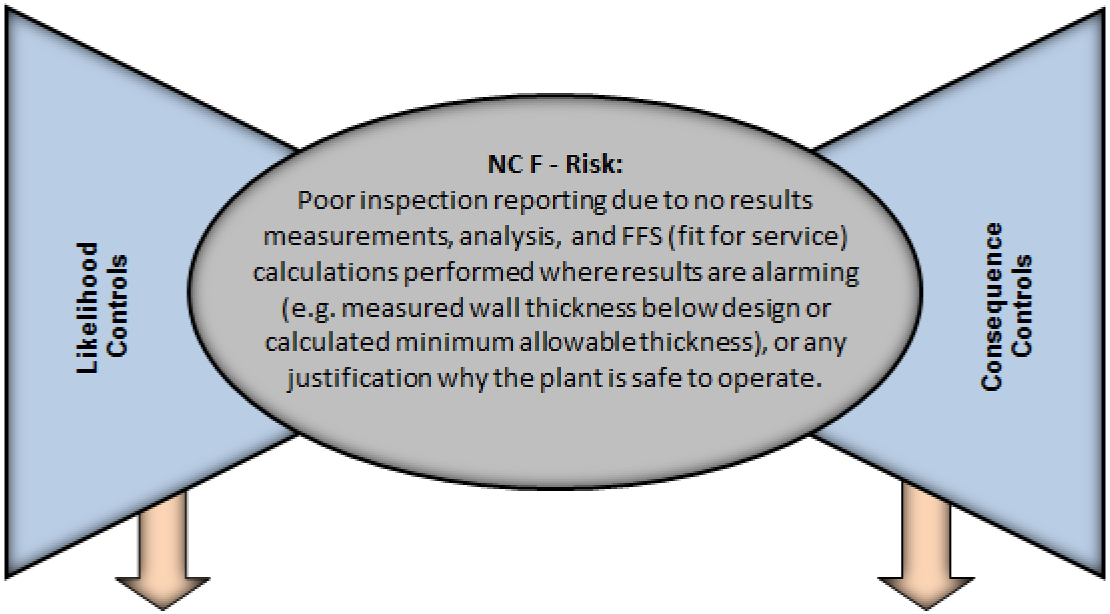
	Develop RBI scope SAP templates, to enable RBI scope uploading to SAP.		RBI scope SAP templates needs to be developed.		2	Probability of human injuries / fatalities increases	Barricading the affected area to limit human presence
	Put the process for tracking the inspections performed at a frequency not exceeding 3 months for all plant areas.	3	No process in place for alerting the Risk Engineers of the inspections performed.				



NC E - Risk:
RBI recommendations were incorporated in the final maintenance scope, but not completely executed during the outage.

	Mitigations		Causes			Consequences	Mitigations
Process		1	No tracking of RBI inspection scope recommendations.		1	Critical scopes not executed	
	Develop RBI scope SAP templates, to enable RBI scope uploading to SAP which will automatically inform all stakeholders when the task is completed.		Lack of communication			The failure risk of the components will increase.	Re-assess the component's risk profile, then mitigate accordingly.
		2	Outage scope execution duration or budget limitation, due to unnecessary over scoping.			Unexpected failures	

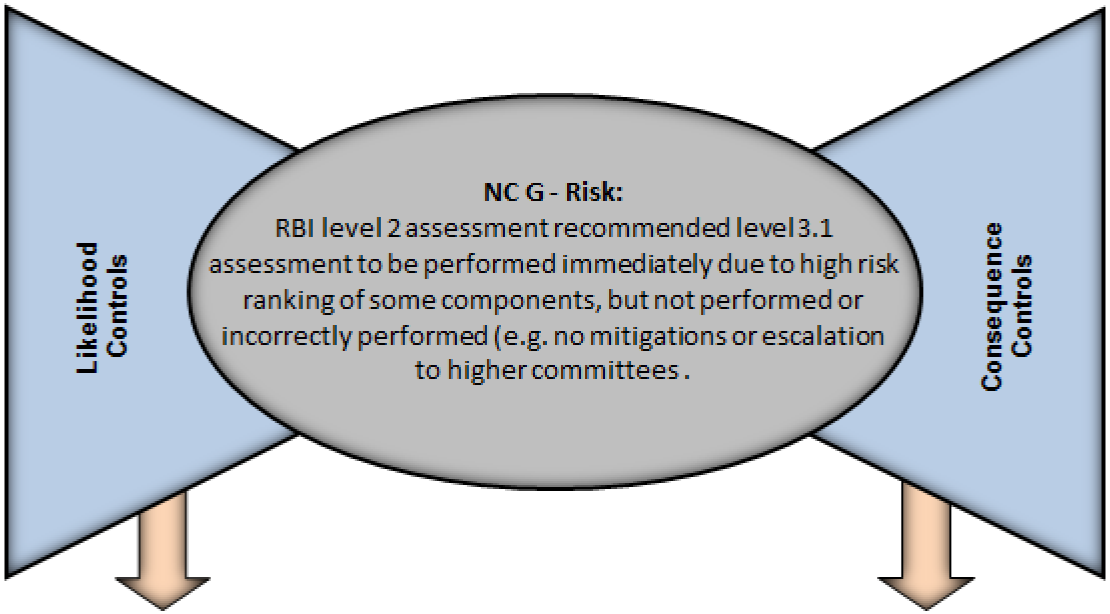
	High risks components inspections should be prioritised, if the time and funds are still available then the Medium High components should be added to fit as much scope as reasonably possible.		No inspection scope optimisation (scope challenge) sessions performed.		2	Probability of human injuries / fatalities increases	Barricading the affected area to limit human presence
	Communicate in advance to the outage department that there will be scopes to be submitted late.	3	Scopes submitted late without alerting the outage department to expect delayed submission.				
	Educate the management on the criticality of safety on operating the plant.	4	Management pressure to bring back the unit, due to production prioritisation.				



NC F - Risk:
Poor inspection reporting due to no results measurements, analysis, and FFS (fit for service) calculations performed where results are alarming (e.g. measured wall thickness below design or calculated minimum allowable thickness), or any justification why the plant is safe to operate.

	Mitigations	Causes			Consequences		Mitigations
Process		1	No proper checking of the inspection reports, responsible personnel just sign reports without verification (Inspection reports review process failure).		1	Forced shutdown of the plant due to components recently inspected but not fit for service.	
	Reviews and Signing of inspection reports should be performed on a daily basis, to allow enough time for properly checking the quality of the inspection reports.		Responsible personnel do not perform inspection reports reviews until they pile-up, and sign at the end of the outage under pressure.		2	Inconclusive report, resulting in assumptions during the risk assessment sessions, leading to inaccurate probability of failure.	
	Perform results analysis and fit for service calculations before the plant is returned to service after the outage.		Results analysis not performed immediately upon receiving the inspection results, this should always be part of the inspection report.		3	Incorrect risk profile	Review the risk assessment and re-rate the risk ranking correctly.

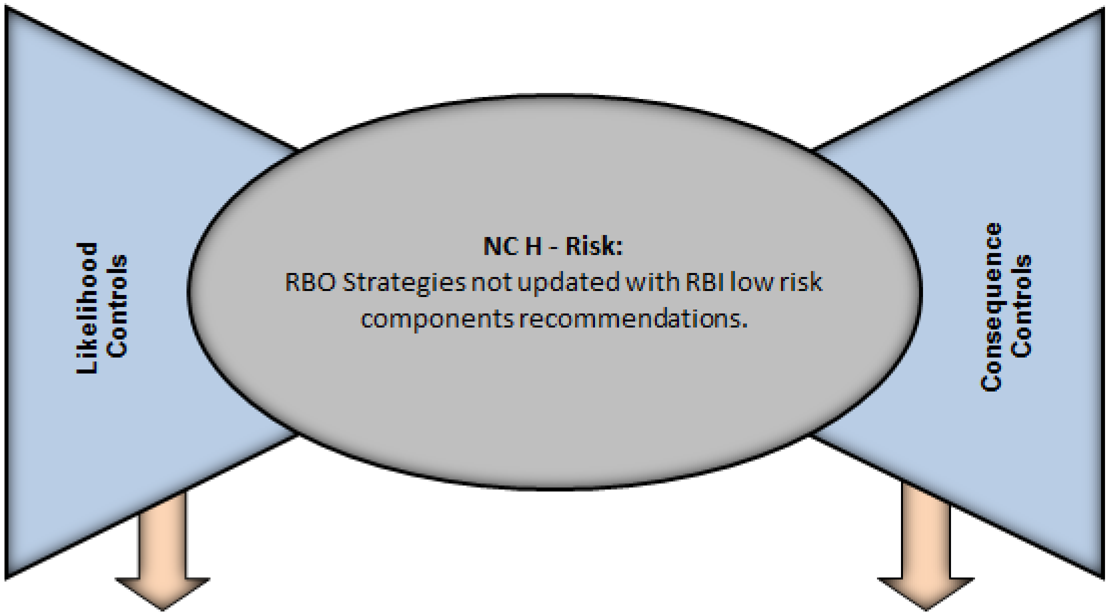
		2	Contractors getting paid not based on the inspection report quality verification.		3	Probability of human injuries / fatalities increases	Barricading the affected area to limit human presence
	Payment of inspection contractors should be done based on the quality of the inspections performed and reporting.		Quality of the inspection report, and work done needs to be properly checked prior to contractor's payment.				
	Perform FFS on all components with alarming results.	3	FFS is performed only on the critical components, thus leaving other components with inconclusive inspection reports.				
	Specify minimum required information for the inspection report to the contractor.	4	There is no document specifying the minimum reporting requirements to the contractors.				



NC G - Risk:
RBI level 2 assessment recommended level 3.1 assessment to be performed immediately due to high risk ranking of some components, but not performed or incorrectly performed (e.g. no mitigations or escalation to higher committees.

	Mitigations	Causes			Consequences		Mitigations
Process	Risk assessment tool should be modified to popup a warning message for a triggered level 3 risk assessment up on completion of level 2 assessment.	1	Risk Engineers not checking the level 2 assessment results or recommendations.		1	High risk of affected components failing within 1 year after the assessment, as there will be no risk recommendations in place.	Perform level 3.1 immediately after picking up this error, and provide mitigations.
	Risk engineers to take breaks when performing the Risk assessment.		Human fatigue due do long hours of working on the RBI assessment tool.		2	Probability of human injuries / fatalities increases, if recommended mitigations are not effective.	Barricading the affected area to limit human presence
	Risk engineers to verify each other’s work at the end of each assessment.		Risk engineers not checking each other’s work.				

	Internal auditors to ensure asking all the questions on the audit check list. Also ensure verification of all the level 2 results to check if level 3 is required (not rely on the Risk Engineers response if level 3 was required or not).		Internal audit process failure, as it was supposed to pick this error.		
		2	Lack of understanding of the level 3 assessment (Bow-tie)		
	Provide the Bow-tie training for level 3 assessment team, at least the chairperson of the assessment should have been trained on the Bow-tie.		Lack of training on the Bow-tie analysis process.		
		3	Level 3 escalation process failure.		
	Provide process training for RBI team.		Lack of level 3 process understanding		



	Mitigations		Causes
Process		1	Misalignment on low risk components scoping.
	Guidance provided to study the existing RBI scope and include the RBI recommendations where necessary.		Lack of guidance/ communication.
	Develop one SAP template that covers all possible inspection recommendations.	2	Having separate scopes, RBO, RBI, FAC, HP pipework, etc.

	Consequences	Mitigations
1	No recommendations provided for low risk components	Low risks remain not mitigated, leading to risk escalation without being tracked, which could result to unexpected failures.
	Probability of human injuries / fatalities increases, if recommended mitigations are not effective.	Barricading the affected area to limit human presence
2	Probability of human injuries / fatalities increases, if recommended mitigations are not effective.	Barricading the affected area to limit human presence

13. APPENDIX E _INTERVIEWS

Station 1				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	Yes	All units on scheduled time.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	Unit 5: Boiler and scope was observed to be reduced by 44% and 5% respectively.
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	No	On average 95% of submitted scopes is executed, in one occasion some high risk components were missed.
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	CoC's always renewed before expire date.
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	No unexpected failures experienced.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	Yes	No actual cost calculations performed, this is purely based on the knowledge that the RBI scope to be submitted to outage is reduced as per criteria B above.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	No	Steercom Chairperson not yet trained, due to frequent management turnover.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	No	Some Steercom meeting did not take place, due to frequent management turnover.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	Documents always reviewed before expire date, and accessible by everyone at any point and time.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Opportunities for improvement helps in enhancing our RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Opportunities for improvement helps in enhancing our RBI process.

Station 2				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	Yes	RBI implementation is not behind the schedule.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	Additional scope reduction, based audit finding closure on pre-outage
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	73% Turbine scope executed during outage, 93% Boiler scope executed during outage
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	Compliance tracking spreadsheet that flags CoC expire dates, mini RBI is used to prevent expiry
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	No unexpected failures experienced.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	No	Additional scope executed during outages, leading to no costs reduction realisation.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	Yes	All RBI involved personnel trained.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Meetings take place as per the ToR, and challenges get resolved.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	All documents are reviewed before expire date, and accessible to all members at any time.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Nonconformities and Opportunities for improvements closed.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Nonconformities and Opportunities for improvements closed.

Station 3				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	Yes	All units as per the plan
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	34.5% Turbine Scope reduction when compared with the pre-outage
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	Submitted RBI scope are fully executed.
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	All renewed before expire date
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	No unexpected failure experienced.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	Yes	Cost reduction expected, due to reduced RBI scopes. There are no actual calculations as there is no unit undergone 2nd post outage.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	Yes	All resources trained as per training requirement.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Meetings take place as per ToR, and matters get resolved.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	All documents reviewed before expire date, and accessible by everyone at any time.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Findings contributes in improving the RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Findings contributes in improving the RBI process.

Station 4				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	No	Behind on Unit 1 completion, due to turbine piping assessment. Data gathering validation delays
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	Observed 83%, 77%, 55% scope reduction on boiler and turbine, Generator & generators (ElecGen) statutory components Unit 5 respectively.
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	No	90% Scope execution, some components still not executed (all high risk components were executed)
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	No components are overdue.
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	No unexpected failure experienced.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	Yes	R2 million costs savings on statutory components for unit5.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	No	One member refused to be trained, matter taken up with the engineer manager.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	No	Challenges sometimes not resolved, actions taken not addressing the matters at hand. It feels like Steercom takes place just to fulfil the ToR.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	Documents up to date and accessible to everyone at all times.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Auditors at times are not aligned (mostly on the quality auditors having different views)
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Contributes in improving our process.

Station 5				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	No	Unit 2 completed slightly later than planned.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	75% scope reduction for the next outage.
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	100% of the submitted to outage was executed
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	CoC's renewed on time, RBI used as a support to defer outage safely.
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	Non unexpected failures experienced.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	Yes	Maintenance cost reduction observed in unit 1.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	No	3 Steercom members not trained yet, due to management turnover.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Meetings take place as per ToR, and matters get resolved.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	All documents reviewed before expire date, and accessible by everyone at any time.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Findings contributes in improving the RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Findings contributes in improving the RBI process.

Station 6				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	Yes	RBI roll-out is executed within the planed dates.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	No	RBI scopes optimisation not observed as the station execute more than requested scope.
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	100% of RBI submitted scope gets executed, and more.
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	RBI is used to defer outages, in the case of CoC's that will expire before the unit goes on outage.
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	No unexpected failures were experienced on RBI assessed components.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	No	Maintenance cost increased due to additional scopes execution during outage.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	Yes	All RBI resources are trained as per training schedule.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Steering committee meetings take place as per the ToR and matters get resolved. Steercom sitting was disturbed during the period where RBI future was unknown.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	All documents are stored in a common place and accessible to everyone at any time.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contribute in improving the RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contribute in improving the RBI process.

Station 7				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	Yes	Roll-out implementation is within the schedule.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	No	Scope increase was observed due to baselining the RBI risks.
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	100% of RBI submitted scope executed.
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	RBI contributes in preventing CoC's expiring during outages deferral.
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	Yes	No RBI assessed component failed unexpectedly.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	No	Maintenance costs increased due to scope increase in an effort of baselining RBI risks.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	Yes	All RBI resourced trained as per the training schedule.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Steercom meetings take place as per the ToR, and matters get resolved.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	All documents are up to date and stored in Hyperwave and SharePoint for better accessibility.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contribute in improving the RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contribute in improving the RBI process.

Station 8				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	No	Boiler inspection reports causing the delays
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	Scope prioritisation is done on RBI scope
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	100% of RBI scope executed.
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	Mini RBI performed on Reheater to defer Unit 4 outage.
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting) - has there been any unexpected RBI assessed component failures.	No	The pipe cracked vertically, tests are normally done horizontally. Unit 2 cold reheat line.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	Yes	Maintenance costs reduction observed, but could improve with time.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	Yes	All RBI resources trained as per the training guideline.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Steering committee meetings take place in time, and matters get resolved.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	Documents stored on G-drive and accessible to all members at all times
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contribute in improving the RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contribute in improving the RBI process.

Station 9				
RBI IMPLEMENTATION EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
1	RBI process roll-out implemented as planned.	Schedule: Compare the Actual tasks completion dates vs Target completion dates.	No	The roll-out is currently behind the schedule.
2	RBI Scope optimisation - RBI Scope reduction, due to process improvement and better process understanding.	Compare the Pre-outage vs Post-outage scopes of work submitted to outage for execution (observation if there is scope reduction).	Yes	Scopes are optimised on the newly RBI implemented units. Only unit 2 had a scope without optimisation for baselining purposes.
3	RBI Scope execution during the outage.	Inspection reports: Compare the percentage of RBI recommendations submitted to outage vs executed recommendations with inspection reports.	Yes	100% RBI scope executed in unit 2
4	Certificates of Compliance (CoC's) validity.	SAP / List of CoC's Validity from the AIA / Statutory Compliance list: assesses if there are (how many) CoC's that have been maintained due to RBI/ Mini-RBI implementation.	Yes	Mini RBI was performed on Unit 8
5	Unexpected/ undetected pressurised component failure (RBI Assessed Components).	Issue Classification and Occurrence Management Meeting/ Production Risk Management Meeting: Minutes (Risk Engineer to attend the meeting)	Yes	No unexpected failures were experienced.
6	Maintenance Cost reduction realisation	RBI maintenance scope execution quotations/ payment invoices: Assesses if there is cost reduction.	No	Scope increase was observed on the first RBI unit (U2) due to RBI scope baselining, resulting in cost increase.
RBI COMPLIANCE EFFECTIVENESS				
	Criteria	Measurement	Effective	Comments
7	Resource Training	Training plan: Compare the required training planned vs actual executed.	No	Training is already planned for untrained resources.
8	Steering committee	Terms of Reference (ToR): assess if Meetings take place as planned, and provides resolutions to the escalated challenges.	Yes	Steering committee meetings take place as per the ToR, and matters get resolved.
9	RBI Process Documentation	Expiry date and accessibility: Assess if all documents are still valid and are stored in a common place and accessible to all RBI members.	Yes	Documents renewed before expiry date, stored in Hyperwave and accessible to all RBI members at all times.
10	RBI Internal Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contributes in improving the RBI process.
11	RBI External Audits	Audit Findings: Evaluate if all Nonconformities and Opportunities for improvements are closed/ addressed.	Yes	Audit findings contributes in improving the RBI process.