SAVONIA

THESIS - **BACHELOR'S DEGREE PROGRAMME**
TECHNOLOGY, COMMUNICATION AND TRANSPORT

CORROSION CIRCUITS AND PROCESS DESCRIPTION

for Implementing Phosphoric Acid Plant to RBI

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SAVONIA-AMMATTIKORKEAKOULU

OPINNÄYTETYÖ
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Tiivistelmä

Tämä opinnäytetyö oli osa fosforihappotehtaan implementointia riskiperusteisten tarkastusten piiriin. Opinnäytetyön tilaaja oli Yara Suomi Oy:n Siilinjärven toimipaikan Tarkastus- ja luotettavuusosasto. Tämä dokumentti voi tarjota lukijalleen ideoita ja apua implementoidessa tehtaita RBI:hin ja tarkastellessa miksi implementointi voisi olla kannattavaa. Opinnäytetyö käsittää korroosion circuittien, injektiopisteiden ja prosessikuvausten määrittämisen fosforihappotehtaan prosessiputkistoista ja tiedonkeruun prosessilaitteista. Tässä opinnäytetyössä vertaillaan API-standardin mukaista RBI:tä ja Yaran soveltamaa versioita RBI:stä keskenään ja kuvaillaan mahdollisia tietolähteitä tiedonkeruuseen.

Teoriaosuudessa käsitellään API RP 580 mukaisen RBI:n peruselementit ja kuinka Yara International ASA on omaksunut ja soveltanut RBI:tä sopimaan yhtiön tarpeisiin. Teoriaosuudessa kuvaillaan myös Siilinjärven toimipaikan ja fosforihappotehtaan tuotantoketjut.

Käytännönosuudessa käsitellään tiedonkeruuta ja korroosio circuittien, injektiopisteiden ja prosessikuvausten määrittämisen tuloksia. Koska tulokset ovat salassa pidettävää materiaalia, ei niitä voida käsitellä yksityiskohtaisesti tässä opinnäytetyössä. Tämän opinnäytetyön tuloksia käytetään tulevassa korroosiontutkimustapaamisessa riskitekijöiden määrittämiseen.

Avainsanat
RBI, Risk-Based Inspection, Inspection, Corrosion circuits, Deterioration, Process description,

SAVONIA UNIVERSITY OF APPLIED SCIENCES	THESIS Abstract

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Abstract

This thesis was part of implementing the phosphoric acid plant to Risk-Based Inspections. The client of the thesis was Yara Suomi Oy, Inspection and Reliability Department of the Siilinjärvi site. This document may provide the user with ideas and assistance on how to implement a specific facility to RBI and why it might be profitable. The scope of the thesis was to determine corrosion circuits, injection points and process descriptions related to the phosphoric acid plant's process pipelines and gather data from the process equipment. This thesis describes the API version of RBI and how Yara's RBI differs from it and possible data sources for gathering data.

In the theory part of the thesis, the key elements of RBI by API RP 580 are covered. It is also explained how Yara International ASA have absorbed and modified API's RBI to fit the company's purposes. Also the production chains of both the Siilinjärvi site and the phosphoric acid plant are described in this section.

In the practical part, the data gathering process and the results of the corrosion circuit, injection point and process description determination are represented. The results cannot be covered in detail due to the confidential information they include. The results of this thesis are used for determining the risk factors in an upcoming corrosion study.

RBI, Risk-Based Inspection, Inspection, Corrosion circuits, Deterioration, Process description,

CONTENTS

ABBREVIATIONS

RBI	Risk-Based Inspection
POF	Probability of failure
COF	Consequence of failure
API	The American Petroleum Institute
ASME	The American Society of Mechanical Engineers
IOW	Integrity Operating Window
MOC	Management of Change
PHA	Process Hazard Analysis
PFD	Process Flow Diagram
P&ID	Piping and Instrumentation Diagram
TA	Turnaround
NDT	Non-Destructive Testing
FFS	Fitness for Service
YIN	Yara Inspection Network

1 INTRODUCTION

1.1 the Scope of the Thesis

The goal of the thesis was to determinate the corrosion circuits and the process description for the implementation of the phosphoric acid plant to the Risk-Based Inspections. The secondary goal was to determinate which process equipment of the phosphoric acid plant are applicable for the Risk-Based Inspections. Fulfilling these goals required detailed data gathering form the process equipment and the pipelines. The scope of this thesis was limited to these aspects and didn't include other partitions of the RBI. The data gathering, determination of the corrosion circuits and the process description determination follows the Yara RBI's procedure and guidelines.

The client of the thesis was Yara Suomi Oy, Inspection and Reliability Department of the Siilinjärvi site. The thesis was supervised by Inspection and Reliability Manager Marko Puhtila. Implementation of the phosphoric acid plant was a part of the Yara wide RBI program where most of the production plants are to be implemented to the RBI.

1.2 Yara International ASA, Yara Suomi Oy and Siilinjärvi Site

Yara International ASA is world's leading fertilizer company and provider of environmental solutions. Yara operates in over 60 countries and have approximately 17 000 employees. The headquarters are located in Oslo, Norway and the current president and CEO of company is Svein Tore Holsether. Yara was originally established as Norsk Hydro in 1905 and demerged as Yara International ASA in 2004. In 2018 Yara International ASA's revenue was 12,9 billion USD, EBITA 1,5 billion USD and total deliveries were 38,6 million tons. Yara international ASA is divided in three operating segments; Sales & Marketing, New Business and Production along with Supply Chain function.
(Yara International ASA, 2020)

Yara Suomi Oy is a subsidiary of Yara International ASA. Yara have three production plants in Finland which are located at Uusikaupunki, Kokkola and Siilinjärvi. Yara Suomi employs approximately 900 employees and 400 of them are working at Siilinjärvi site. Siilinjärvi site is part of the production segment and consist of a phosphate mine, a concentrator, a sulphuric acid plant, a phosphoric acid plant, a nitric acid plant and a fertilizer plant. In addition, Siilinjärvi site have support processes including an administration, technical services, a power plant, a packing unit and a harbor. The main products of Siilinjärvi site are NPK – fertilizers, phosphoric acid, apatite and technical ammonium nitrate. The production chain is represented in figure 1. Siilinjärvi site have production capacity of 500 000 tons of NPK fertilizers, 300 000 tons of phosphoric acid, 1 000 000 tons of apatite and 85 000 tons of technical ammonium nitrate per year.
(Simonen, 2019)

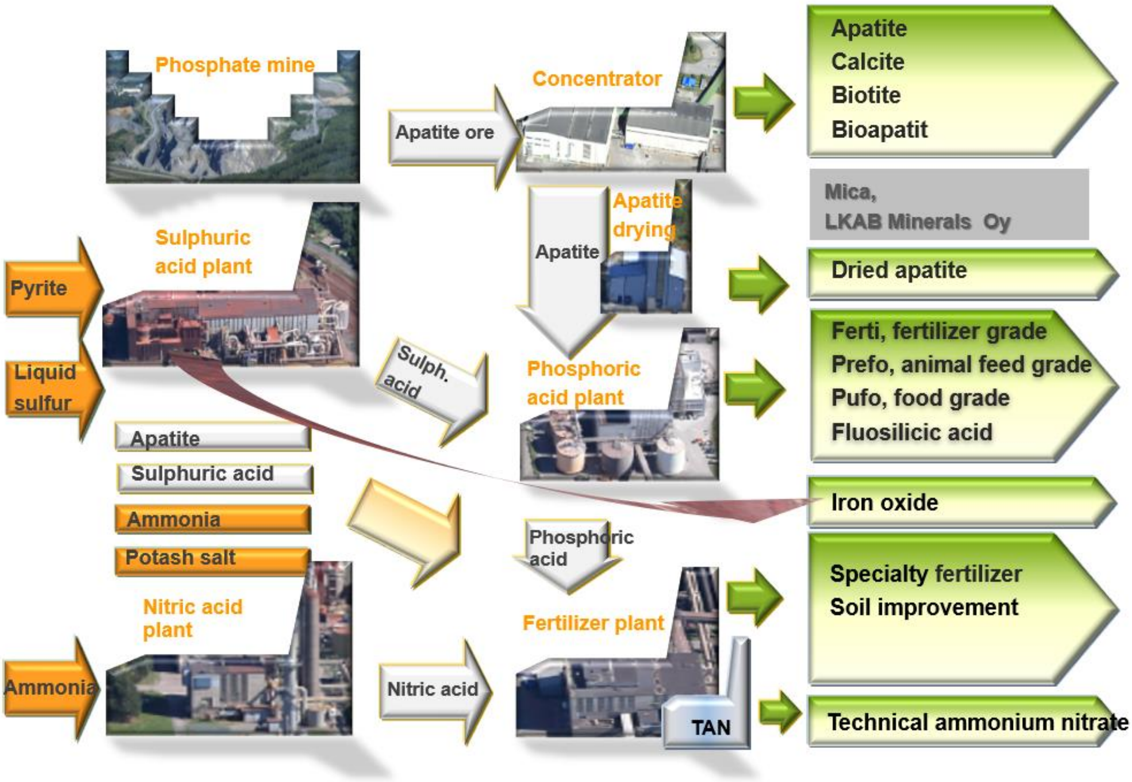

Figure 1 Production chain at Siilinjärvi site (Simonen, 2019)

1.3 Phosphoric Acid Plant

The phosphoric acid plant is one of the first plants established in Siilinjärvi site at 1969. The main products of the phosphoric acid plant are Prefo, Ferti, Bio and Pufo grade phosphoric acids and by-products are fluorosilicic acid and gypsum. The phosphoric acid plant have capacity to produce 300 000 tons of phosphoric acid, 170 000 tons of Ferti grade acid, 130 000 tons of Prefo grade acid and 500 tons of Bio grade acid per year. 170 000 tons of fluorosilicic acid and 1700 000 tons of gypsum are produced per year. 170 000 tons of gypsum is sold to various applications per year.

Fluorosilicic acid is separated from the off-gases and used in the AIF_3-production. The remaining off-gases are treaded in 3-stege washing process. The contaminated wash water is steered back to the process to be used in reactors and condensers. Also the rain water falling over the gypsum stack is collected to be used in the acid production. The water balance is kept in control by neutralizing the excess water in the neutralization vessels.

Apatite and sulphuric acid are used as raw materials to produce weak phosphoric acid. Gypsum is separated from weak phosphoric acid in acid filtration and transported to gypsum stack while product acid is steered to acid concentration. When desired potency is reached, strong phosphoric acid is steered through acid clarification to Ferti or Prefo process. The final products are stored in storage vessels and transferred to fertilizer plant or loaded in trains and tank trucks to be delivered for customers. (Yara International ASA, 2020)

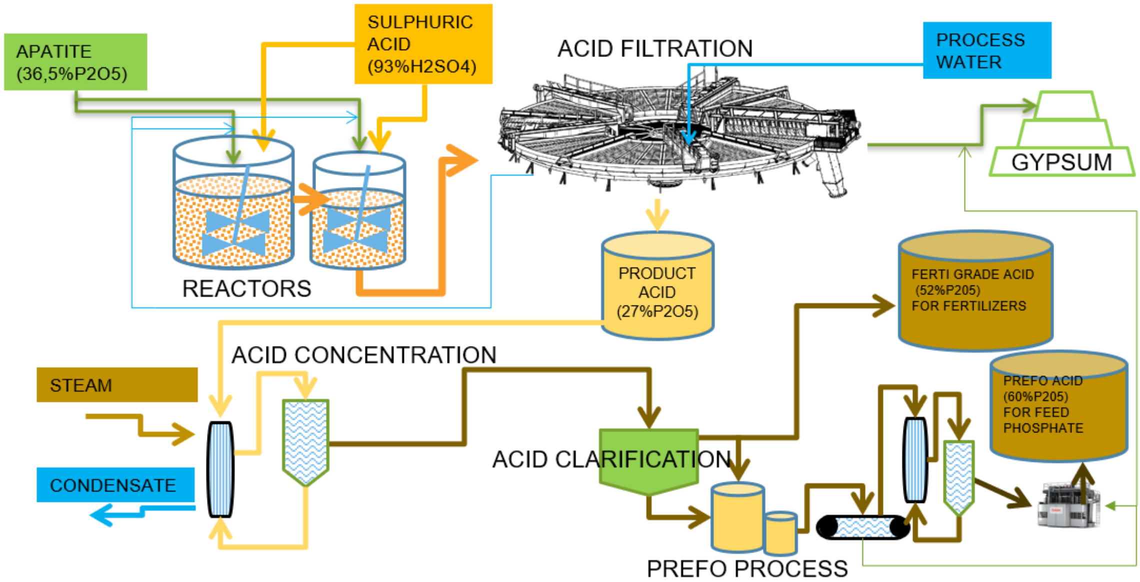

Figure 2 Phosphoric acid plant's process of production (Yara International ASA, 2020)

1.4 RBI at Yara International

The decision to use RBI as basis for inspection was made at 2004. The primary objectives were to improve safety and reliability of plants, avoid unscheduled stops and increase exchange of knowledge between the production sites. The secondary objective was to reduce maintenance and inspection costs by optimizing inspection resources. The first plants were implemented to RBI between 2005 - 2007 and the full RBI implementation process started at 2009. At Siilinjärvi site, RBI started at 2011 and most of the plants at Siilinjärvi site are already implemented past 9 years. Good results of using RBI are already achieved in form of increased reliability of different plants and declined inspection expenses.
(Yara International ASA, 2017) (Ahonen, 2018)

1.5 the Short History of Risk-Based Inspection

The development of RBI started when the American Petroleum Institute decided to develop RBI methodology in 1994. The first API standard was released in 2000 as API PULB 581, Base Resource Document – Risk-Based Inspection. API PULB 581 was replaced by API RP 581, Risk-Based Inspection Technology in 2008 and was widely accepted as a recommended practice especially in oil and gas industry. In 2016 released third edition of API RP 581 changed Risk-Based Technology to Risk-Based Methodology. RBI wasn't considered mere technology for calculate risks anymore, rather a practical and systematic set of methods to develop inspection plans on equipment. Today RBI has proven to be effective tool for optimizing inspections strategies.
(Borges, 2017) (Alvarado, RBI: A short history and justification, 2013) (Kaley, 2017)

1.6 Standards Related to RBI

The most widely used standards for RBI are API RP 580, API PR 581 and ASME PCC-3. ASME PCC-3 is based on API RP 580 therefore the key elements of API RP 580 and ASME PCC-3 are same. While API RP 580 specifies minimum requirements for RBI, ASME PCC-3 includes means for assessing an inspection program. API RP 581 supplements API RP 581 with procedures and methods of RBI and offers tools how to plan and execute inspection programs.

2 RISK-BASED INSPECTIONS BASED ON API RP 580

2.1 the Basic Theory of RBI

RBI is a tool used to managing risks of equipment failures in refining and petrochemical process industry. Risk management is done by increasing confidence on what is believed to be the true damage state of equipment by decreasing probability of failure due inspections focused on equipment with high risk factor. In short, RBI can be described by a question: "How much confidence do I need to have in what I believe to be the true damage state of the equipment?".

Commissioning of optimized inspection programs after successful RBI program is essential for reducing an overall risk level of equipment. Solely increasing inspection activity can reduce the risk level only to a certain point. After reaching this point, increasing inspection activity may add only minimal risk reduction. This scenario is represented in figure 3 as the upper curve. If number on inspections is increased even more, the risk level may also start increasing. This is due to possibility cause deteriorations on protective coatings of vessels to be inspected. This is represented by the dotted line at the end of the upper curve of figure 3.

When RBI program is completed and optimized inspection program is developed and in use, the overall risk level can be reduced further with same amount of inspection activity. This reduction is made possible by focusing inspection activities to higher risk equipment and decreasing number of inspections done to equipment with the lower risk level. The lower curve in figure 3 represents the overall risk level when both RBI and optimized inspection programs are in use.

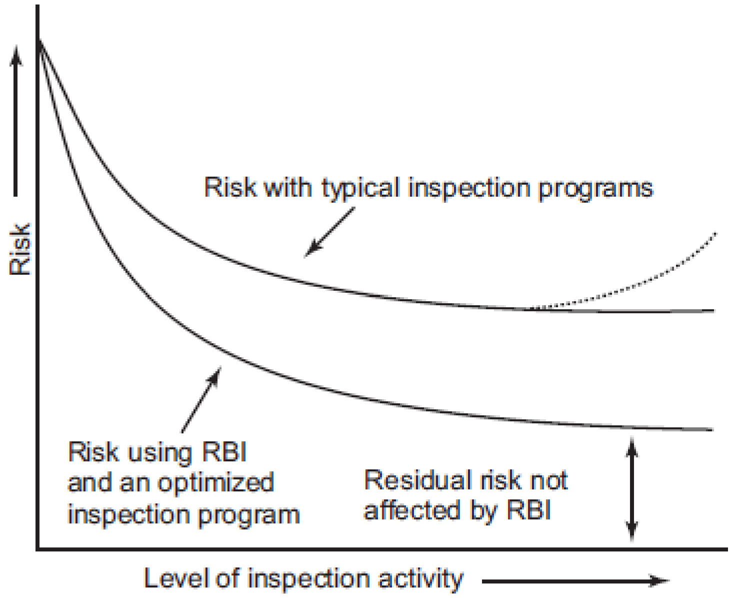

Figure 3 Management of risk using RBI (American Petroleum Institute, 2016)

However, the overall risk level cannot be reduced to zero solely by inspection activities. There will always be residual risk level as a result of unforeseen issues. These issues can be e.g. human errors, natural disasters, design errors or collisions.
(Alvarado, Whiteboard Discussion: Foundational Principles of Risk-Based Inspection, 2017) (American Petroleum Institute, 2016) (Yara International ASA, 2017)

2.2 Concept of a Risk in RBI

Commonly a risk is combination of the consequence and probability of event with negative influence. Typically, organizations have treated consequence and probability of the risk as separate measurements for the risk level. In RBI, the risk is considered as the combining of Consequence of Failure (COF) and Probability of Failure (POF) and from this product, estimation is made if the risk is in acceptable levels.

As for example, both COF and POF of 10 equipment items have been determined and the results have been placed in figure 4. Each number represent an individual equipment with a determined risk level. An ISO-risk line presented in figure 4 represents a constant risk level where all items that fall on or very near the line are equivalent in the same risk level. An acceptable risk level is usually defined on ISO-risk line. When the user-defined acceptable risk level is plotted as an ISO-risk line, the acceptable risk line will separate the unacceptable and the acceptable risk items from each other.

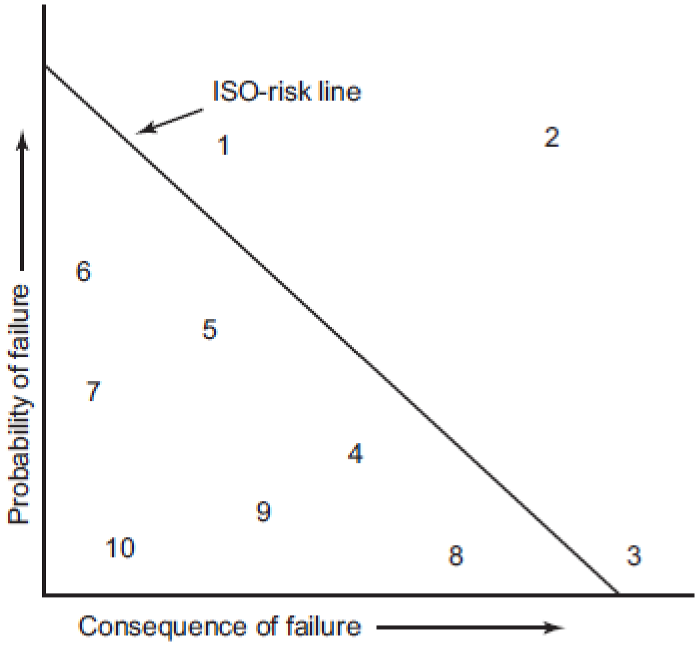

Figure 4 Risk plot (American Petroleum Institute, 2016)

In this example the item numbers 1, 2 and 3 in figure 4 are above the acceptable risk level and the mitigating actions should be executed for these items to lower the risk levels to acceptable levels. To reduce the risk level of these items, inspection activities from low risk items can be transferred to high risk level items. In this example, the low risk items where inspection efforts are to be transferred are the item numbers 7, 9 and 10. If optimizing inspection activities are insufficient to lower the risk level of the items 1, 2 and 3, are alternative risk management activities needed to achieve required risk level.

The high number of factors effecting the risk makes risk calculation a highly complex process. Calculating an absolute risk can be very time-consuming, costly and the results can be too inaccurate to use due to numerous uncertainties. Determination of the absolute risk is often found impossible and too costly to execute. RBI focuses on systematically determining the relative risk and ranks the process equipment based on their relative risk values. The relative risk values can tell when level of uncertainty is acceptable or unacceptable and this way answer the question "How much confidence do I need to have in what I believe to be the true damage state of the equipment?".
(American Petroleum Institute, 2016) (Alvarado, Scalable Accuracy: Inspection Planning and RBI, 2012)

2.3 Types of RBI Assessment

The RBI procedure can be roughly distributed to three manners of approaches; qualitative, quantitative and semi-quantitative. Despite of chosen approach RBI provides a systematic way for screening risk, identifying areas of potential concerns and developing prioritized lists for more elaborate inspections. Usually when an RBI study is executed, some aspects of each qualitative, quantitative and semi-quantitative approaches are used as combined.
(American Petroleum Institute, 2016)

2.3.1 Qualitative Approach

A qualitative approach uses engineering judgment, subject matter expertise and experience as the basis for POF and COF. Inputs are typically data ranges and given in descriptive terms such as high, medium and low. This approach allows completion of the risk assessment even with a limited amount of detailed data. In the qualitative approach, experience of the risk analysts and team members highly affects to the accuracy of the results of analysis. The qualitative approach is suitable for screening out units and equipment with the low risk level. The qualitative approach can be used for any aspect of inspection plan development.
(American Petroleum Institute, 2016)

2.3.2 Quantitative Approach

Compared to the qualitative methods, a quantitative approach is more systematic, consistent and detailly documented. In the quantitative approach numerical values are calculated and used as input data. Use of numerical values makes database easier to keep updated with inspection results. The quantitative approach is data-intensive and therefore use of a software program is generally inevitable to calculate risk and develop inspection program recommendations. The equipment are ranked based on their risk determined from POF and COF. Each individual risk is calculated and reported separately for aiding identification of contributors to the risk drivers. When all risks are identified, the risks are combined to acquire the overall risk level of equipment. According to API RP 580, the quantitative approach has four major advantages:

1. calculates when risk acceptance limit is reached with adequate precision
2. separating of equipment risks allows prioritizing of mitigations activities
3. risk exposure can be trended and monitored over time
4. allows benchmarking of reliability management

To summarize, the quantitative approach is more time consuming and data-intensive but offers more rigor RBI analysis. In the quantitative programs, models are made based on input data which is the most data-intensive phase of the quantitative approach, but use of the models will reduce repetitive, detailed work from the inspection planning process.
(American Petroleum Institute, 2016)

2.3.3 Semi-Quantitative Approach

A semi-quantitative approach is a combination of both the qualitative and the quantitative approaches. The semi-quantitative approach still requires most of the data from the quantitative approach, but in less detail. The results of RBI analysis are acquired faster, but the models may not be as rigorous as would been through the quantitative approach. In the semi-quantitative approach, the results are given in consequence and probability categories or as risk numbers.
(American Petroleum Institute, 2016)

2.4 RBI Planning Process

The RBI process is composed of 6 sections regardless the chosen RBI approach. The essential elements of RBI planning process are shown in figure 5. RBI is not just a single encompassing inspection, rather RBI is a dynamic, constantly ongoing process which database is updated as soon as new confirmed information is available. Succeed of RBI process heavily depends on quality and accuracy of available data and expertise of personnel performing the RBI assessment.
(American Petroleum Institute, 2016)

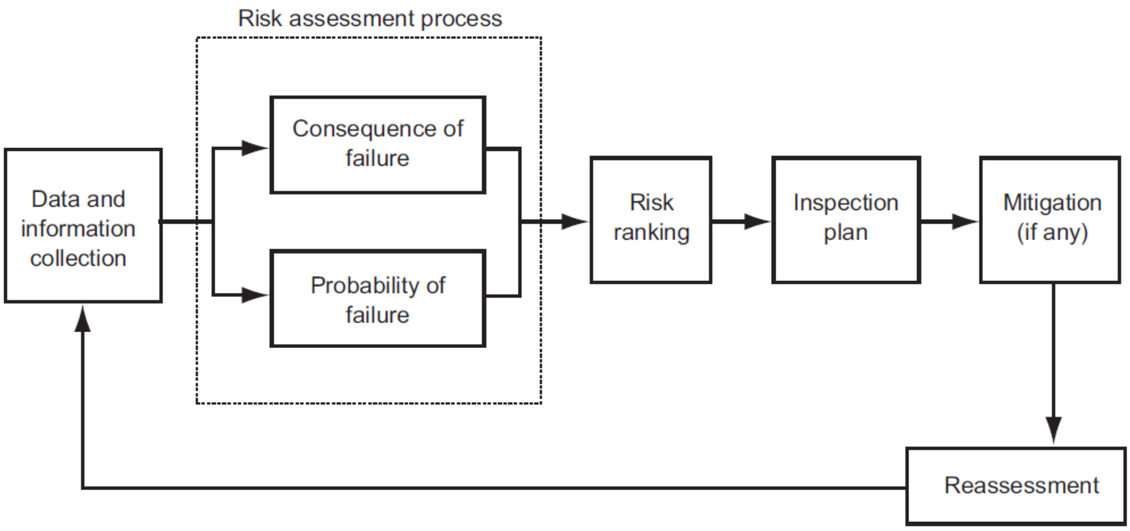

Figure 5 Risk-Based Inspection planning process (American Petroleum Institute, 2016)

2.4.1 Data and Information Collection

The data and information collection -phase is the most time-consuming step of the RBI planning process. In this phase the objective is to provide an overview of data that may be needed for developing the RBI plan. The collected data should provide adequately information to assess potential damage mechanisms, potential failure modes and scenarios of failure. The choice of the RBI approach significantly affects to the amount and detail of data used through the RBI assessment.

The qualitative RBI typically requires only the amount of data needed to categorize equipment into broad ranges or to be classified versus a reference point. The paucity of detailed data makes it essential to have qualified personnel with a high level of judgment and skill to perform the qualitative RBI analysis.

In the quantitative RBI, logic models are created to depict combinations of risk events and physical models to depict the progression of accidents and transportation of hazardous material to the environment. Creating and upkeeping of these models requires higher amount and more detailed information and data.

The semi-quantitative analysis requires the same type of data as the quantitative, but not as detailed and some of the values can be estimations. The precision of the semi-quantitative RBI is a compromise made with speed of the data gathering and detail of analysis. Still, the semi-quantitative analysis won't automatically be less accurate than the other RBI approaches.

Regardless the type of RBI analysis, the quality of import data is on highest importance and therefore data inputs and assumptions should be validated by qualified personnel. Assumptions are one of the major potential error sources in any RBI analyses and may affect negatively on calculated corrosion rates and risk levels. Understanding the potential impact of assumptions on the risk calculation should be clarified with the personnel processing the data.
(American Petroleum Institute, 2016)

2.4.1.1 Focusing time and resources effectively

For utilizing limited time and resources effectively, it is advisable to focus the time-consuming RBI analysis on the most important group of equipment. This can be done by grouping a process unit into systems or circuits. Dividing to groups should be made based on the operating conditions, process chemistry, pressure and temperature. Likewise metallurgy, equipment design and operating history should be used as a criterion while dividing the process unit. Divining the process unit allows different equipment sharing a common corrosion sensitivity to be processed through RBI assessment as a single entity.
(American Petroleum Institute, 2016)

2.4.1.2 Corrosion systems and circuits

A common purpose of corrosion systems and circuits is to facilitate inspection planning and data analysis. When properly developed, both the systems and the circuits offer a practical overview on degradation mechanisms in the process unit. The choose between the systems and the circuits depends on the desired detail-level of outcome.

A corrosion system is an assembly of interconnected pipes that are subjected to the same or similar process fluids and/or operating conditions. The systems are used for defining the potential corrosion issues and to determine the general location of damage mechanisms within the process unit. The corrosion systems are typically defined at PFD level and contain multiple piping/corrosion circuits. Defined systems may contain or pass through several process equipment sharing common characteristics covered before.

The corrosion circuits are subsection of the corrosion systems and represents section of the process unit sharing common process conditions, material selection and deterioration mechanisms. The type and rate of damage must be reasonably be expected to be same or very similar between items defined to the same circuit. The corrosion circuits are typically defined and marked at P&ID level instead of PFD. In RBI, the corrosion circuits may be subdivided based on risk level if corrosion characteristics are same, but risk of equipment failure is greater. The common characteristics for the corrosion circuits are defined in API RP 970 as following:

- common materials and construction
- common design conditions
- common operating conditions
- common set of one or more damage mechanisms
- common expected corrosion rate
- common expected damage locations/morphology

(American Petroleum Institute, 2017) (Yara International ASA, 2017)

2.4.2 Risk Assessment Process

At the risk assessment process, POF and COF are determined based on the information collected at the data collection phase. The risk assessment process begins with identifying credible damage mechanisms and failure modes. For providing a confident damage mechanism and failure mode identification, it is essential to have a qualified corrosion specialist in the RBI team during the risk assessment.

The damage mechanisms discoursed during the risk assessment process are corrosion, cracking, mechanical damage and metallurgical damage. To identify these damage mechanisms, solid understanding of equipment operation, process environment and mechanical environment is required. Understanding of damage mechanisms is important for the POF analysis, coordinating inspections and for decision-making ability that can reduce the probability of damage mechanisms to occur.

Once the damage mechanisms are identified, the failure modes associating for each individual damage mechanism should be identified as well. It is possible for each damage mechanism to have more than one failure mode. The failure modes specify how the inspected item/equipment/component will fail and comprehension of these modes is needed for the COF analysis, run-or-repair decision-making and for selection of repair techniques.
(American Petroleum Institute, 2016)

2.4.2.1 Probability of Failure

POF expresses the likelihood of failure for certain equipment or item on given timeframe. The POF analysis covers all damage mechanisms identified at start of the risk assessment process. Furthermore, the POF analysis reveals if the equipment is susceptible for several damage mechanisms and address the situation where these may occur. An outcome of the POF analysis is estimation of probability for specific negative consequences. The consequences are caused by equipment failures that occur due to damage mechanisms. The results are typically given in frequency expressing a quantity of events occurring during certain timeframe.

POF is determined by equipment's construction material's damage mechanisms and rates at its current operating environment and by the effectiveness of inspection program identifying and monitoring the damage mechanisms involved to the equipment. When the POF is calculated by deterioration type, are following variables combined:

- damage mechanism
- damage rate or susceptibility
- process monitoring
- inspection data
- effectiveness of inspections

Using these variables, the POF can be calculated for current operating conditions as well as for future time periods and conditions.
(American Petroleum Institute, 2016)

2.4.2.2 Consequence of failure

COF provides discrimination between equipment based on the significance of potential failure. Determination of the COF is made by estimating and ranking the potential consequences for safety, health, environment and economics in the event of equipment failure. The measurement units vary depending on the nature of the hazard measured and the appropriate units to use are selected by the RBI analyst. The resultant consequences should be comparable for risk prioritization and inspection planning phases. The measurement units that can be used include, but are not limited to, such units as safety, cost, affected area and environmental damage.

Determination of COF is six step process. Each step should be performed by using the assumptions of specific scenarios and be repeatable for each scenario of equipment failure. API RP 580 specifies steps for determination of COF as follows:

1. estimate the release rate
2. estimate total volume of fluid that will be released
3. determine if the fluid is dispersed in rapid manner (instantaneous) or slowly (continuous)
4. determine if the fluid disperses in the atmosphere as a liquid or a gas
5. estimate the impacts of any existing mitigation system
6. estimate the consequences

To gain more rigorous results from RBI, it is recommended to develop POF and COF interactively. After developing the scenarios and estimating potential consequences, the consequences are listed by one of the following ways:

a) Consequences are classified to three or more categories. Categories might be e.g. low, moderate and high.

b) Consequences are ranked by a scale. A scale might be from 1 to 10.
c) Ranking is based on measure. For example, estimated quantity of fatalities or economic loses can be used as a measure.

(American Petroleum Institute, 2016)

2.4.3 Risk Ranking

At the risk ranking section, outcome of POF and COF are combined to determinate the risk and to provide a risk priority list. The risk determination also provides guidelines to prioritize and assess the acceptability of the risk based on the risk criteria. Determination of the risk is executed by using the general form of the risk equation:

$$\text{Risk} = \text{Probability} \cdot \text{Consequence} \tag{1}$$

The probability and severity of consequence are linked together and may considerably differ from the probability of equipment failure. Commonly the severity of incident increases when probability for that event decreases. Unqualified personnel in the risk assessment may often combine the POF with the most severe consequences to be envisioned. Incorrect combining of POF and COF may result in the overly conservative risk assessment and negatively effect to the results of RBI assessment.

The risk for each specific consequence is calculated by equation 1. The total risk of equipment is the sum of each individual risks and is given in numerical values. Often the total risk can be approximated by the dominant risk standing out of calculated risks. If probability and consequence are expressed in non-numerical values, a risk matrix can be used to determinate the risk. The probability used in the risk matrix is not POF, rather it is the probability of the associated consequence. When using the risk matrix, the overall risk includes the probability of loss of containment.

After the risks are calculated and compared to the risk acceptable levels defined by the corporate, a sensitivity analysis is required to determinate the overall influence of input variables on the resultant risk value. Outcome of this analysis is identification of input variables significantly increasing the resultant risk value. When such input values are identified, additional attention and information gathering is recommended. The information gathering performed after sensitivity analysis should provide a re-evaluation of the key input variables and thereby improve the quality and accuracy of the risk analysis. The re-evaluation of the key input values is important part of the data validation phase of the risk assessment.

The developed risk values should be processed to a format that a variety of people can easily understand. Use of the risk matrix or plots are effective way to transmit the result of the analysis to decision-makers and inspection planers.

The risk matrix is an effective method for representing the distribution of risk without numerical values. If numerical values are used, it is desirable to associate them with the categories to provide guidance to the personnel performing the assessment. The size of the risk matrix can change to match the number of categories. The risk categories can be assigned to the risk matrix on symmetrical or asymmetrical fashion. In figure 6 is an example of the symmetrical risk matrix. The asymmetrical risk matrix can be used if either probability or consequence is wanted to be weighted.

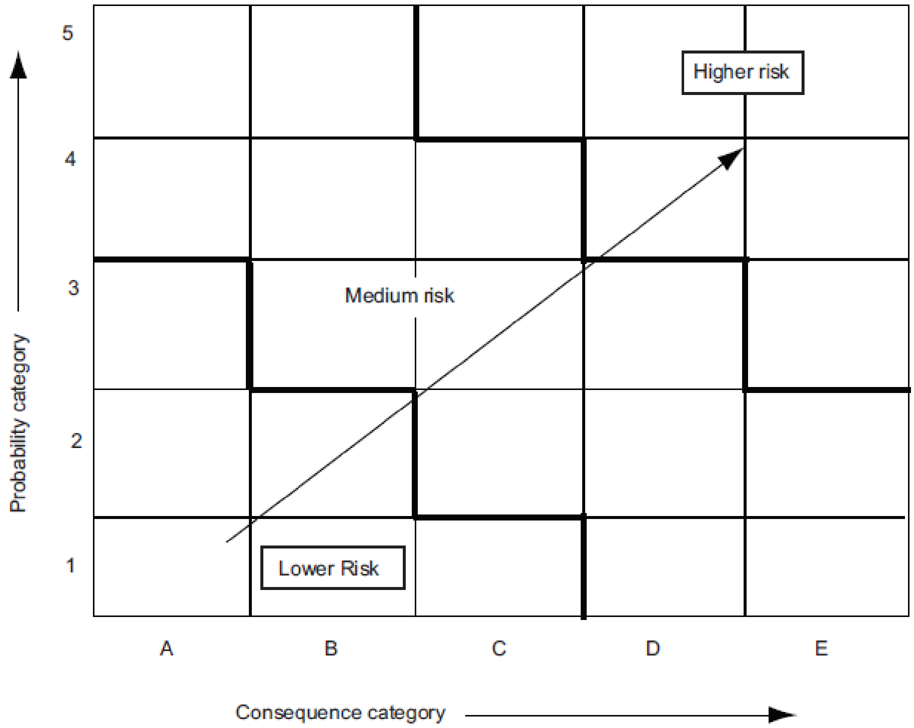

Figure 6 Example of qualitative risk matrix (American Petroleum Institute, 2016)

In more quantitative approaches of RBI and when numerical risk values are more meaningful, the risk plot is a recommended practice to represent the risk values. The basic structure of the risk plot is similar to the risk matrix, the highest risk is located towards the upper right corner and the POF and COF are aligned with x- and y-axis. Typically risk plots are drawn using log-log scales and the acceptable risk level is often assigned to or near the ISO-risk line. Determination of ISO-risk line is typically based on the corporates safety and financial policies or on the risk criteria. In figure 7 is an example of risk plot, where 10 pieces of equipment are plotted based on their risk values. If the acceptance risk level is assigned along the ISO-risk line, equipment number 1, 2 and 3 require risk mitigation actions in this example.

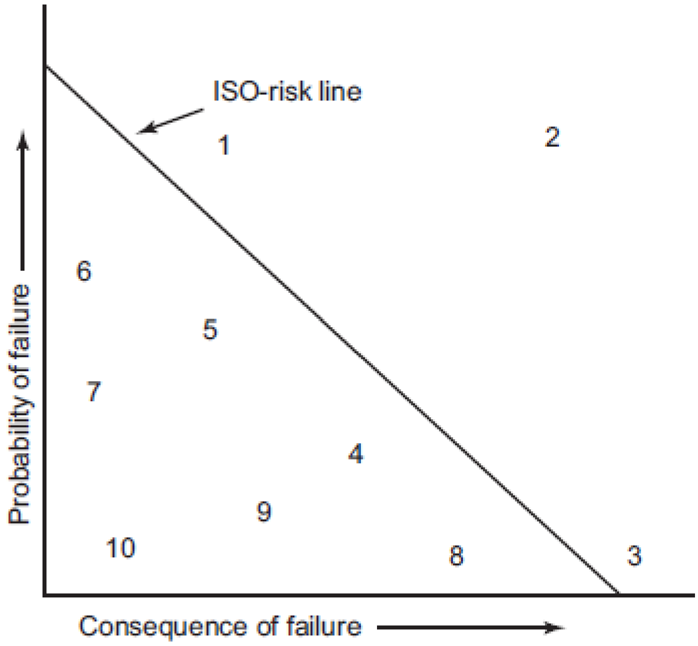

Figure 7 Example of risk plot (American Petroleum Institute, 2016)

In both risk matrix and plot, equipment located towards the upper right corner will have the highest risk and therefore they need to be prioritized in inspection planning. The completed risk matrixes and plots can be used as a screening tool at the inspection planning phase.
(American Petroleum Institute, 2016)

2.4.4 Inspection Planning

Even though the risk can be managed through the inspection activities, inspections themselves does not mitigate the damage mechanisms and reduce the risk. The risk reduction and mitigating the damage mechanisms are achieved by the information gained through effective inspections. This information is used to remove uncertainties and improve predictability of the damage mechanisms. With better predictability of the damage mechanisms, mitigation actions including repair, replacement, changes, etc., can be planned more accurate. In order to the risk mitigation be successful, the corporation is required to act on the inspection results on time. Also, the quality of input data, reliability of analysis and proper inspection methods are critical for the successful risk mitigation.

At the inspection planning phase, the risk priority list acquired from the risk ranking is used for inspection planning considering the driving risk factor. All items with the unacceptable risk level should be included in the risk management process. Also, items with the high risk level are potential for need of the risk management actions and should be evaluated if the risk management is necessary. Outcome of the inspection planning phase should be an inspection strategy that, with other mitigation plans, decreases the resultant risk of all items to the acceptable risk level.
(American Petroleum Institute, 2016)

2.4.5 Mitigation

Means of the risk management depends on the driving risk factor. If the driving risk factor is POF, inspections are usually potential mean for the risk management. Effect of the risk management through inspections depends on the reminding life of the equipment and type of the damage mechanisms. If inspections are estimated to be ineffective for the risk management, alternative forms of mitigation actions should be considered.

After determination of the present risk, RBI can be used to influence and monitor the future risk through inspection activities and to define when, what and how inspections should be executed to keep the resultant risk at the acceptable level. The future risk can be influenced with coverage and frequency of inspections as well as tools, techniques, procedures and practices used.

If successful risk mitigation is not provided through inspections or is not cost-effective enough, other risk mitigation activities should be executed. Some possible mitigation activities are:

- Replacement or repair of equipment in cases where risk of failure cannot be reduced to acceptable levels.
- Performing Fitness-for-Service assessment.
- Modification, redesign and rerating of equipment and utilizing MOC process.
- Providing remote operational emergency isolation capability e.g. by isolation valves.
- Providing capability to depressurizing or deinventorying vessels or containers.
- Modifying process toward less hazardous conditions.
- Establishing IOWs.
- Reducing inventory capacity.
- Establishing water curtains, water sprays or capability to deluge a vessel.
- Providing blast-resistant constructions for personnel, critical equipment, instruments and lines.

After development of the inspection strategies and deployment of other mitigation activities, the resultant risks of all items should be in the acceptable levels.
(American Petroleum Institute, 2016)

2.4.6 Reassessment

RBI provides evaluations of current and future risks based on the data and information collected at the time of the RBI assessment. Changes at the process equipment and environment are inevitable as time goes by and therefore updates of the RBI database is essential to retain the resultant risk at the acceptable level. The most resent inspection, process and maintenance information should always be updated to the RBI database.

All causes that have significant effect on the risk may trigger need for reassessment of RBI. These trigger events include but are not limited to inspections results, changes in process conditions and implementation of maintenance practices. Also, RBI reassessment should always be performed if one or more of the following events occur:

- Significant changes in process conditions, damage mechanisms, rates or severities in RBI premises.
- Preset time period for reassessment expires.
- Risk mitigation strategies are implemented.
- Before and after maintenance turnarounds.

(American Petroleum Institute, 2016)

2.5 Inspection Cost Management

With RBI, inspection costs can be managed by directing limited inspection resources to the identified high risk items. Shifting resources from the low risk items to where they are needed most, increases cost-effectiveness of inspections without sacrificing the overall reliability of process equipment. Although the savings are possible with RBI, the user should recognize that the main purpose of RBI is to increase equipment integrity and safety while optimizing inspection costs.

Inspection costs may also be managed by identifying opportunities to do inspections non-intrusively on-stream. This decreases downtime of the item and provides savings by eliminating need for blinding, opening and cleaning of inspected equipment. The potential non-intrusive inspections may also increase uptime of the specific equipment if the inspected item is required to keep the considered equipment operational.

RBI can also be used to lower the overall life cycle cost of equipment. The lower life cycle cost is achieved with various cost benefit assessment. Some examples of these are:

- longer cycle time of equipment through increased predictability of potential failures
- allows development of upgrading plans for equipment
- more efficient preplanning of maintenance and repairs

(American Petroleum Institute, 2016)

2.6 Documentation of RBI Assessment

For sustaining information gathered through the RBI program, an effective document management system should be developed. Preferred way to store the information is a digital database where information can be updated during reassessment. Aspects of the RBI assessment to be documented are:

- the overall RBI methodology used
- personnel performing the RBI assessment

- definition of timeframe when the RBI analysis was performed
- inputs used for risk assignment
- assumptions made during the risk assessment process
- The results of the risk assessment
- decided mitigation activities and follow-up of the RBI assessment
- relevant codes, standards and regulations

Additionally, use of any specific software program to perform the RBI assessment shall be documented. The documentation of RBI assessment should be sufficient enough so that the assessment can be recreated and updated by personnel not involved to the original RBI assessment.
(American Petroleum Institute, 2016)

3 PRE-RBI SITUATION OF INSPECTIONS AT PHOSPHORIC ACID PLANT

Before implementation to RBI, inspections made at the phosphoric acid plant are planned and executed following traditional procedure. Inspections for the pressure vessels follow 1144/2016 Pressure Equipment Act and inspections for the other equipment are planned in cooperation with the maintenance and repair department. For the other than pressure vessels, decision of inspection targets, methods and frequency is based on knowledge of the personnel and the equipment's history. Some critical process equipment are inspected once per TA and inspections are typically executed during planned shutdowns.
(Puhtila, 2020)

4 THE SCOPE OF IMPLEMENTING PLANT TO YARA RBI

By implementing specific plant to RBI, the aim is at reducing static equipment failures due to in service degradation mechanisms and to maintain the mechanical integrity of pressure equipment. The main deliverables expected of RBI to provide are inspection plans to address ways to manage risks, understanding of the risk that can be managed by inspection activities, and a tool for economical evaluating of cost effectiveness of inspection and maintenance resources.

RBI methodology changes traditional procedure of inspections. Traditionally inspections were mostly driven by the authority requirements, but RBI instead offers possibility to look forward and plan future inspections based on the possible risks to be realized. RBI methodology predicts what could happen by considering all possible degradation mechanisms, safety and economical losses, equipment history and national authority requirements. Benefits gained with the better predictability of failures are such as improvement of workplace safety, increased uptime of equipment and optimized inspection costs.

Other identified benefits of using RBI are:

- the involvement of all disciplines in the integrity study of static equipment of the plant gives a better and deeper knowledge of the real condition of the equipment

- increases exchange of knowledge between sites
- the corrosion study as basis for type of inspection increases the confidence level of the inspection itself
- an improved understanding of current risk gives the opportunity to focus the resources on the high-risk items
- an overall reduction in risk for equipment assessed
- a tool for continuous improvement: ever-greening the RBI process gives a continuous risk reduction
- common argument towards authorities

(Yara International ASA, 2017)

5 STEPS OF IMPLEMENTING PLANT TO YARA RBI

At Yara international ASA, RBI program have minor differences when compared to the API version of RBI. The most significant difference is number of steps in RBI process which is 8 in Yara's RBI and 6 in API's RBI, however this includes preliminary activities and introduction to RBI which are preparatory actions and not technically part of the standard Yara RBI program. Preliminary activities and introduction are only executed once per production site and when a plant is going to be implemented, process starts from "Data collection 1st step". All required and essential content introduced in API RP 580 are included in Yara's RBI program but divining to the steps is made differently. RBI process by Yara is presented at figure 8.
(Yara International ASA, 2017)

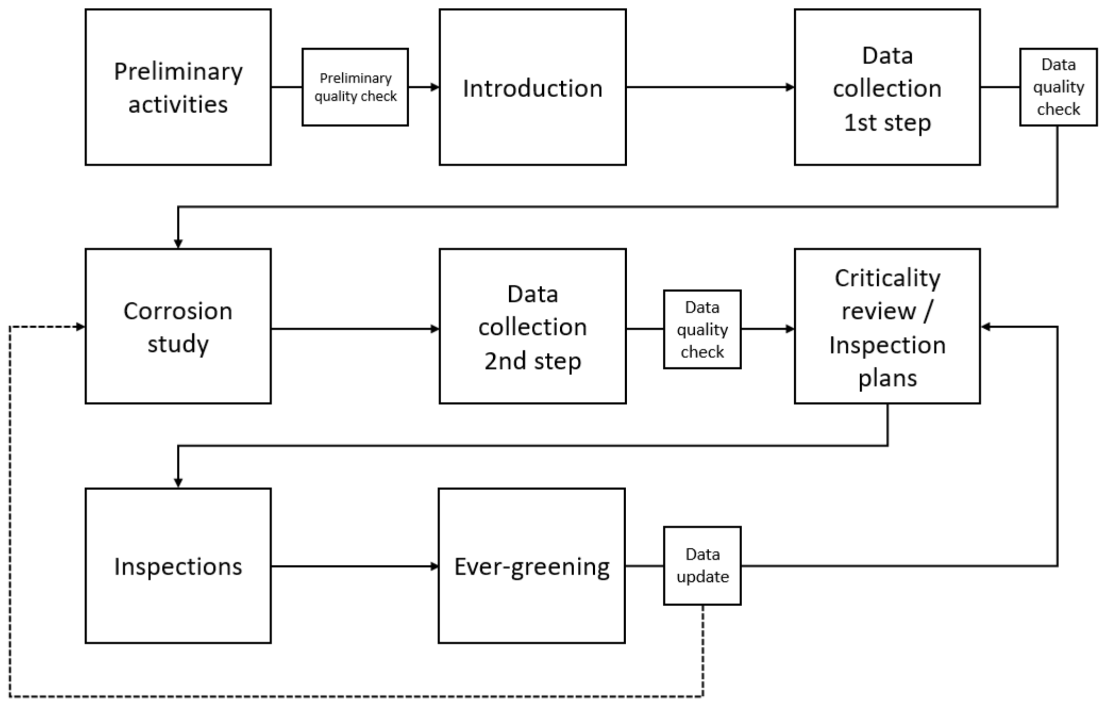

Figure 8 Phases of RBI process by Yara International ASA

5.1 Data Collection 1st Step

When a specific plant is about to be implemented to RBI, the process starts from Data collection 1st step. At this step, all necessary data and information considering the process equipment and pipelines are collected and the corrosion circuits and the process description are defined. For the reason of data quality being crucial for successful RBI, the data quality check is executed after data collections. Purpose of the data quality check is to verify the data input and to provide a list of verifications and corrections as an outcome to guarantee a consistent RBI analysis and consequently a good quality of inspection plan.
(Yara International ASA, 2017)(Yara International ASA, 2017) (Yara International ASA, 2019)

5.1.1 Process Description as a Part of RBI

The process descriptions are one of key elements needed for the corrosion study. The process descriptions are used alongside with the corrosion circuits and they provides additional information about the process environment. The process descriptions are defined on corrosion circuit level and they identifies from where the circuit starts, which equipment and pipelines are included, operating temperature and pressure existing in the circuit and where the circuit ends. Required information for the process descriptions are pipeline identifications, flowing substance and PFD or P&ID. The process descriptions are included in the corrosion study report. The process descriptions are recommended to be defined with aid of personnel with knowledge of the process environment.

5.1.2 Identification of Injection Points and Effect to Degradation Rates

When medians with differing composition are injected to the process stream, accelerated internal degradation can occur in form of corrosion or thermal fatigue. The degradation rates near and downstream these injection points may differ from degradation rates determined for rest of the pipeline. This may result in loss of containment, impact on reliability, and/or being potential safety hazard. Therefore, injection points should always be included to data gathering when implementing plant to RBI.

Injection points are locations where relatively small quantities of medians are injected to process streams. Typically, medians injected are wash water or process chemicals. Examples of injection points are listed but not limited to list below.

A. Streams injected with:
   - utilities
   - acids
   - oxygen
   - chemical additives
   - alkaline chemicals such caustic or ammonia
   - catalyst
B. wet process gas mixed with dry process gas
C. vapor mixed to liquid

D. hotter streams mixed to cooler streams when ΔT is more than 150 °C

Any identified injection points shall be listed to excel table with following information:

1. Injection point number
2. Description of what is injected to where
3. Corrosion circuit where point is located
4. Number of pipeline where point is located
5. Material of pipeline

Reassessment of injection point identification shall be executed as part of RBI ever-greening process. Standards related to injection points are API 570 "API Piping inspection code" and NACE SP0114-2014 "Standard Practice, Refinery Injection and Process Mix Points".
(Rijksen, 2016)

5.2 Corrosion Study

After the quality of data has been checked, the corrosion study is executed. The corrosion study is a team session where failure modes for each equipment are defined starting at component level. The failure modes are assigned, corrosion rates/POF are applied and this information is used in the RBI software to define the risk. The RBI software used by Yara International ASA is LR AllAssets by Lloyd's Register Group. The failure modes are defined in the normal operating conditions. Within the corrosion study, the IOW are defined to assure that operating conditions do not deviate as much that they effect on the failure modes. The deviations of the IOW are taken in consideration at the next evergreening step. The outcome of the corrosion study is a corrosion study report. The corrosion study report forms a basis for criticality review and inspection planning. Typical content of the corrosion study report is following:

- introduction
- corrosion circuit definition on PFD level
- process description
- material selection, failure modes, possible damage mechanisms
- measure of corrosion prevention
- predictable or potential locations for corrosion
- corrosion circuit on P&ID level and piping circuit

(Yara International ASA, 2017) (Yara International ASA, 2017)

5.3 Data Collection 2nd Step

The 2nd step of data collection is executed if need for more data was appeared in the corrosion study. The data collected at the data collection 2nd step is verified at the data quality check. The results of the data collection are updated to the corrosion study report without reassignment of the corrosion study.
(Yara International ASA, 2017)

5.4 Criticality Review / Inspection Plans

Determination of POF and COF is done at risk ranking session which is part of "Criticality review / Inspection plans" phase and it is done with aid of RBI software. Process of POF and COF determination follows guidelines of API RP 581 and the outcome is processed to a risk matrix. After defining the risk matrix, all portions of Yara RBI are interpreted and "what if" analysis is executed. Outcome of this process should provide all necessary information for inspection planning including inspection priority categories.

At inspection planning, an inspection plan with inspection strategies is developed for the every equipment included to RBI program based on equipment type, degradation mechanisms and inspection priority index. Both the inspection plans and strategies are developed by used RBI software and therefore the inspection planning phase is not very time consuming. The RBI software generates an inspections priority index with 25 inspection priorities for every defined damage mechanism. These priorities are divided in following manner: inspection priority from 1 to 6 are strongly recommended, priority from 7 to 12 are recommended and priority 13 to 25 are not recommended. All the inspection tasks with inspection priority index from 1 to 12 should be executed. The inspections tasks and strategies developed by the RBI software are recommendations and can be customized by the user if needed.

The outcome of the inspection planning is a draft inspection plan which must be manually worked up to obtain the final inspection plan. This includes verifying the corrosion study and RBI risk result reports, "what if"-analysis, major findings and repairs executed during last TA. Also, the local authority requirements, production requests and maintenance feasibility should be included in the inspection scope. After these activities are completed, the final inspection plan can be accepted.
(Yara International ASA, 2019) (Yara International ASA, 2019) (Yara International ASA, 2019)

5.5 Inspections

The accepted final inspection plan should be executed as it is in order to the risk mitigation be successful. If the final inspection plan is not followed, the required confidence level of the true damage state of equipment is not achieved and belief on equipment safety may be faulty. This may eventually cause serious consequences on process safety, environment and economics.

After a specific plant has been implemented to RBI, all inspections should be carefully documented in order ensure continuum of the RBI program. After each inspection task, a "Recommended Inspections Review Summary" should be written including the following information:

- Deviation from the final inspection plan
- Inspection date
- Used inspection technique
- Inspection location description
- Inspection coverage
- Inspection priority index according to RBI
- Description of inspection findings
- Number of inspection report
- Evaluation of NDT contractor's quality
- Evaluation of the selected NDT technique's quality
- Evaluation of overall quality of inspection
- Resultant summary of executed FFS assessments
- Description of executed repairs
- Equipment replacement
- Review of the plant modifications affecting the equipment

(American Petroleum Institute, 2016) (Yara International ASA, 2019)

5.6 Ever-Greening

Ever-greening is a term used to describe the RBI reassessment at Yara International ASA and it have a same goal than the RBI reassessment by API PR 580; ensure effectiveness of risk mitigation by inspection activities. Because of risk is a dynamic, constantly changing concept, the RBI ever-greening process is essential for achieving the required overall risk level. The ever-greening process should not be considered as a single event, but rather a chain of events overlapping some parts of the Yara RBI process. Triggers for ever-greening process are following:

- New inspection results are available
- Modifications to equipment or process which can affect COF or POF
- IOW follow-up
- if ever-greening is not executed in past 5 years

The complete RBI ever-greening process include following steps:

1. Preparation of "Recommended Inspections Review Summary"
2. Preparation of "IOW Deviations Review Summary"
3. Re-evaluation of damage mechanisms
4. Corrosion study update

5. Information input into the RBI software
6. New risk ranking
7. New draft inspection planning
8. Inspection planning
9. Inspection cost-Benefit evaluation
10. Repairs recommendations
11. Replacement recommendations for next two TAs
12. Contractor management consideration for next TA
13. Resources evaluation for next TA

Re-executing the corrosion study may be necessary depending on the quality and amount of data gained from the last inspection. Re-execution of the corrosion study is presented in figure 8 with dashed line. The RBI ever-greening process is required to be documented carefully for the successful RBI reassessment and enabling of YIN Bulletin.
(Yara International ASA, 2019) (Yara International ASA, 2018)

6 EQUIPMENT OF PHOSPHORIC ACID PLANT APPLICABLE FOR RBI

In RBI, the risk is measured by loss of containment. This limits equipment suitable for RBI to those containing fluids or gases. The equipment suitable for RBI are following:

- Pressure vessels – all pressure-containing components
- Process piping – pipe and piping components
- Storage tanks – atmospheric and pressured
- Rotating equipment – only the pressure-containing components
- Boilers and heaters – pressurized components
- Heat exchangers – shells, floating heads, channels and bundles
- Pressure-relief devices

The following equipment are not covered by RBI:

- Instrumental and control systems
- Electrical systems
- Structural systems
- Machinery components

(American Petroleum Institute, 2016)

It is not beneficial to include every possible process equipment to RBI due to high amount of required data. Therefore pumps are not included to Yara RBI program. Pumps typically have low risk factors and therefore possible risk mitigation through RBI is considered to be minor. The phosphoric acid plant has roughly 350 different process equipment and 700 individual pipelines. Approximately 26 % of the phosphoric acid plant's equipment are RBI applicable.

7 DATA SOURCES FOR DATA GATHERING

Due to the fact that Siilinjärvi site's phosphoric acid plant is 50 years old facility, the data needed for determinizing the corrosion loops and the process descriptions were scattered on various sources. Major data sources used for the corrosion loop determination were P&IDs, drawings of process equipment and pipe isometrics. For the process descriptions, work instructions and personnel interviews aside with P&IDs were used as the data sources. Some of the gathered data was dated a few decades back or was otherwise uncertain and therefore this uncertain information was needed to be verified at site.

8 RESULTS AND CONCLUTIONS

The results of data gathering, determination of the corrosion circuits and the process descriptions are all confidential material and therefore cannot be reviled with this document. However, the results are covered in general point of view in this thesis. The gathered data, the corrosion circuits and the process descriptions will be covered in detail by personnel of Yara International ASA in the upcoming corrosion study session.

8.1 Data Gathering

Data gathering done during this thesis was part of data collection 1st step. As result the quantity of pipeline data is adequate for completion of step. For vessels, heat exchangers and pressure equipment, quantity of data is not adequate to gain desired confidence of equipment's true damage state. Data gathering for these process equipment classes is required to continue before corrosion study is beneficial to be executed. The data gathering from process equipment was halted because of COVID-19 pandemic occurring during the thesis process. The postponement of the data gathering was agreed with the client of thesis and therefore the amount of gathered data is acceptable for the situation.

102 pieces of phosphoric acid plant's process equipment was identified to be RBI applicable. Data gathering was performed for 49 pieces of these equipment and for 8 applicable equipment pieces there was not enough data to include them to RBI.

8.2 Corrosion Circuits

At the end of the project, 17 corrosion circuits were identified. Three of these circuits were joint circuits where priority for inspections was estimated to be low and the medians in pipes were similar. The identified corrosion circuits are represented in table 1. The identified circuits were colored in phosphoric acid plant's P&IDs. Reading these corrosion circuit P&IDs requires the process descriptions as a support to descript the process conditions and environment. Latest updates to phosphoric acid plant's P&IDs were made at 2017 and due to non-up-to-date diagrams and numerous aberrations at them, circuit drawing process was slower than expected and consumed more time than was scheduled for it. The details about the corrosion circuits and the circuit P&IDs cannot be represented in this thesis due to the confidential nature of information in these documents.

Table 1 Corrosion Circuits

Circuit no.	Flow medium
1	phosphoric acid
2	ferti grade phosphoric acid
3	weak PreFo acid
4	strong PreFo acid
5	arsenic sulfide dregs
6	gypsum sludge
7	steam and condence
8	exhaust vapor
9	additive
10	sulphuric acid
11	fluorosilicic acid
12	sodium sulphide
13	circulation water
14	air
15	contamined waters
16	non-critical waters
17	process condensate

8.3 Injection Points

Total of 17 injection points were identified from P&IDs. These injection points include acids, additives, steam and water to be injected to process streams. The details of the injection points cannot be represented in this thesis due to the confidential nature of this information.

8.4 Process Description

The process descriptions for all 17 corrosion circuits were determined. The detailed process descriptions were determined for the circuits 1 – 13 and 17, including operating temperature, pressure, composition and pH of the material in the circuit and the description of where circuit starts, which equipment it passes and where it ends. Due to the lower criticality of the joint circuits 14 – 16, the process descriptions were shorted for these and they only covered on common level circuit's purposes on process. The limiting process conditions were determined for the circuits 14 – 16 on same detail as for the circuits 1 – 13 and 17. The process descriptions are confidential material and cannot be represented in this thesis.

9 ACTIONS NEEDED TO COMPLETE THE IMPLEMENTATION

The first task to complete the implementation is to gather all the absent data being related to the process equipment. After that, the data quality check can be finished and the next step of Yara RBI process will be started. At the time of this thesis was finished, the collected data of pipelines, corrosion circuits and process descriptions were in the data quality check. When the data from process equipment is added to the data quality check and is confirmed and required corrections and additions completed, the corrosion study will be executed. The corrosion study session produces the corrosion study report, which forms a basis for criticality review and inspection planning. During data collection 1st step, no matters requiring changes to Yara RBI process was discovered, and therefore the RBI process will proceed as covered at the chapter 5.

REFERENCES

Ahonen, K. (10. Jan 2018). *Ovatko tarkastukset pakollinen kuluerä vai sijoitus tulevaisuuteen?* Noudettu osoitteesta Kiwa Inspecta: https://www.kiwa.com/fi/fi/Tiedotus/uutiset/ovatko-tarkastukset-pakollinen-kuluera-vai-sijoitus-tulevaisuuteen/

Alvarado, G. (2012). Scalable Accuracy: Inspection Planning and RBI. *17*(4). Noudettu osoitteesta Inspectioneering.

Alvarado, G. (20. May 2013). *RBI: A short history and justification*. (Inspectioneering) Haettu 24. Jan 2020 osoitteesta Inspectioneering: https://inspectioneering.com/blog/2013-05-20/3326/rbi-a-short-history-and-justif

Alvarado, G. (17. Feb 2017). *Whiteboard Discussion: Foundational Principles of Risk-Based Inspection*. (Inspectioneering) Haettu 28. Jan 2020 osoitteesta Inspectioneering: https://inspectioneering.com/videos/2017-02-17/6155/whiteboard-discussion-foundational-principles-of-risk-based-insp

American Petroleum Institute. (2016). API RP 580. *Risk-based Inspection(Third edition)*. American Petroleum Institute.

American Petroleum Institute. (2017). API RP 970. *Corrosion Control Documents(First edition)*. American Petroleum Institute.

Borges, V. (23. Feb 2017). *Terminology Explained: What is Risk-Based Inspection (RBI)?* (DNV GL) Haettu 21. Jan 2020 osoitteesta DNV GL Digitalization and software solutions: https://blogs.dnvgl.com/software/2017/02/terminology-explained-what-is-risk-based-inspection/

Kaley, L. (29. Mar 2017). *API RP 581 Risk-Based Inspection Methodology Revisions.* Haettu 23. Jan 2020 osoitteesta Trinity Bridge - Knowledge Center: https://www.trinity-bridge.com/?q=knowledge-center/presentations/api-rp-581-risk-based-inspection-methodology-revisions

Puhtila, M. (27. Feb 2020). Inspections before RBI. (T. Ilkko, Haastattelija)

Rijksen, C. (2016). *Management of Injection points and mixing points (add on BP 62).* Yara International ASA.

Simonen, A. (2019). Siilinjärvi site presentation UK. *Yara Suomi, Siilinjärvi site*. Siilinjärvi: Yara Suomi Oy.

Yara International ASA. (6. Sep 2017). E211, Internal Training Material. *Risk Based Inspection (RBI) Introduction, E21(E211)*. Yara Inspection Academy.

Yara International ASA. (6. Sep 2017). E212, Internal Training Material. *Data Collection and Corrosion Study, E21(E212)*. Yara Inspection Academy.

Yara International ASA. (1. Dec 2018). TS 2_06_06 Inspection Information Update. *Inspection Information Update And Feedback For Improvement*.

Yara International ASA. (19. Nov 2019). E213, Internal Training Material. *RBI Risk Ranking*. Yara Inspection Academy.

Yara International ASA. (19. Nov 2019). E214, Internal Training Material. *RBI Risk Results*. Yara Inspection Academy.

Yara International ASA. (19. Nov 2019). E215, Internal Training Material. *RBI Inspection Planning*. Yara Inspection Academy.

Yara International ASA. (19. Nov 2019). E216, Internal Training Material. *RBI Ever-greening*. Yara Inspection Academy.

Yara International ASA. (19. Nov 2019). E217, Internal Training Material. *RBI Data Quality Check*. Yara Inspection Academy.

Yara International ASA. (18. Feb 2020). Phosphoric acid production External. *Phosphoric acid production*. Phosphoric acid plant.

Yara International ASA. (1. Jan 2020). *This is Yara*. (Yara International ASA) Haettu 28. Jan 2020 osoitteesta Yara: https://www.yara.com/this-is-yara/yara-at-a-glance/