Maintenance Optimization of Direct Leaching Reactors

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Preface

This bachelor thesis was a project at the Department of Mechanical and Marine Engineering at Western University of Applied Sciences (WNUAS). The main subject of the thesis is Operations and Maintenance, our internal supervisor is professor Maneesh Singh. The thesis was given to us and written in cooperation with Øystein Espe at Boliden Odda.

We would like to thank Øystein Espe and Svein Moe for the opportunity to write a thesis with them as our supervisors. We would also like to thank the Operating managers, Condition control Technician and the Maintenance Manager at the leaching department for their time and the opportunity to learn from them. This thesis would not be possible without the knowledge we got from them. We would also like to thank professor Knut Øvsthus for his time and the opportunity to learn about Industry 4.0.

Abstract

In this study an RCM analysis is done to prepare one functional and cost-effective preventive maintenance program, based on which failure methods appear to be most critical on the direct leaching reactors at Boliden Odda. By using FMECA and risk assessment the results shows that the transmission is that component that should be prioritized in the preventive maintenance program.

Based on the results of the RCM analysis, a vibration analysis was done to find out what way industry 4.0 could improve the maintenance program on the critical component. Analyses of 10 different points on the transmission with 3 different vibration measurements, velocity, Enveloped Acceleration and high frequencies are analysed to create a RAG rating system.

The results of the analysis of the vibration measurements show that predictive maintenance using conditioning monitoring shows patterns that make it possible to see when the transmission is failing. This means it`s possible to predict shutdowns on direct leaching reactors by using Industry 4.0 in the future by implementing vibration sensors that measures continuously. This can be done on the el-engine and the transmission.

Sammendrag

I denne studien er det utført en RCM-analyse for å utarbeide et funksjonelt og kostnadseffektivt forebyggende vedlikeholdsprogram basert på hvilke feilemetoder som er mest kritiske på direkte lutning reaktorene ved Boliden Odda. Ved å bruke FMECA og risikovurdering viser resultatene at giret er den komponenten som bør prioriteres i det forebyggende vedlikeholdsprogrammet.

Basert på resultatene fra RCM-analysen ble det gjort en vibrasjonsanalyse for å finne ut av hvordan industri 4.0 kunne forbedre vedlikeholdsprogrammet på den kritiske komponenten. Analyser av 10 forskjellige punkter på overføringen med 3 forskjellige vibrasjonsmålinger, hastighet, innkapslet akselerasjon og høyfrekvenser, analyseres for å lage et RAG-vurderingssystem.

Resultatene fra analysen av vibrasjonsmålingene viser at forutsigbart vedlikehold ved hjelp av tilstandsovervåking viser mønstre som gjør det mulig å se når overføringen svikter. Dette betyr at det er mulig å forutsi feil på direkte lutning reaktorene ved å bruke Industry 4.0 i fremtiden, ved å implementere vibrasjonssensorer som måler kontinuerlig.

Table of Contents

Chapter 1 – Introduction

This chapter is the introduction to the project. Where the background, motivation, aim of the project, scope of work and the limitations are explained. It also contains the structure and the abbreviations used in the project.

1.1 Background

Boliden Odda AS was established back in the 1924 and located right next to Sørfjorden in western Norway. They are a major zinc and zinc alloy producer and they also produce sulfuric acid and anhydrite.

They are known for producing the metal in very clean and high quality. The sink plant was modernized in 2003-04 and is considered one of the world's most cost-effective zinc producers. In recent years, Odda has undergone extensive streamlining work with the investments made in new process equipment. The goal is to reach an annual capacity of 200 000 tonnes of zinc, which is now at 172 000 tonnes.

1.2 Need for research

Boliden AS (Odda)has a maintenance strategy which is to sustain the equipment availability, function and status based on the equipments lowest lifetime cost within adopted HSE and quality standards.

Their current maintenance program is based on the program Boliden enterprise introduced when they acquired the plant in 2004. Boliden Odda have after that time improved the program based on experience and recommendations from the equipment suppliers.

There is a need for a systematic study to explore the possibility of improving the maintenance program

1.3 Possible solutions

RCM is a well proven methodology for optimizing a maintenance program.

With the advancement of sensor technology and computation of data it may be possible to develop proactive condition monitoring and management strategy.

A combination of these two may be a good solution for Boliden.

1.4 Aim of the Project

Aim of the project is to develop an optimized maintenance program for Boliden using RCM and Industry 4.0.

Some of the objectives of this thesis are:

- Analysis of the maintenance needs using RCM

- Implementation of Industry 4.0 in the maintenance program

1.5 Scope of Work

1. Literature survey on RCM, sensor technology and Industry 4.0
2. Study of the maintenance strategy and maintenance program currently adopted by Boliden.
3. Study of the data available in Delta V and Maximo.
4. Develop a maintenance program for the direct leaching reactor using RCM and data available in Delta V, Maximo.
    a. Identify potential failures. (Hazard)
    b. Estimate probability of failure as a function of time. (PoF)
    c. Estimate the consequence of failure. (CoF)
    d. Estimate risk by comparing with acceptance criteria (Risk)
    e. Recommend the steps that can be taken to mitigate risk (Risk mitigating steps)
5. Conduct a Vibration Analysis
    a. Compare the vibration data from reactor 1 and 6 before and after the breakdowns
    b. Develop a RAG-system for the different measurement points
6. Study application of Industry 4.0 on this equipment / system.
    a. Selection of industry 4.0 method.
    b. Study of possible data collected
    c. Identification of possible data analysis tools / procedures
    d. Identification of decision support systems
7. Identify if the Vibration data can be used to determine the condition of the equipment

1.6 Limitations

- Not enough vibration measurements on failures to conduct a more comprehensive vibration analysis.
- The vibration analysis is limited to two breakdowns
- Limited data on causes for production stops
- The data available for failure modes and causes for some of the components are limited

1.7 Structure of Report

Chapter 1 - Introduces the project with an introduction to the task's problem, purpose, limitations and abbreviations.

Chapter 2 - Boliden Odda

Chapter 3 - Necessary theory of the RCM concept.

Chapter 4 - The actual use of RCM analysis on the direct leaching reactor. Here Rausand`s twelve steps are used.

Chapter 5 - Presents and summarizes the results of the RCM analysis, as well as submitting a proposal preventive maintenance program.

Chapter 6 – Industry 4.0 and vibration analysis

Chapter 7 - Summary conclusion of the results

1.8 Abbreviations

PoF - Probability of Failure

CoF - Consequence of Failure

RCM - Reliability Centered Maintenance

FFA - Function Failure Analysis

FTA - Fault Tree Analysis

FMECA- Failure Mode, Effects, and Criticality Analysis

RAG - Red Amber Green (Traffic light)

Chapter 2 – Boliden Odda

In this Chapter the production process and maintenance strategy of Boliden Odda will be explained as well as the direct leaching reactor system.

2.1 – What is Boliden Odda

Boliden Odda is a zinc smelter located next to Sorfjorden in western Norway. The smelter was established in 1924 by a French-Belgium mining company. The smelter is known for producing high quality pure metals. Boliden AS acquired the smelter in 2004 and modernized it. Currently the smelter produces around 200 000 tonnes of zinc yearly and an assortment of other products, they include copper cement, sulphuric acid and Cadmium.

2.1.1 – Roasting

In the Roasting department the zinc ore gets refined by processing the ore through a roasting furnace where the Sulphur gets burned of the ore and your left with Zinc oxide, also known as Calcine. The roasting department is also responsible for producing the Sulphuric acid. This is done by using the byproduct that is roasted of the ore Sulphur dioxide and combining it with oxygen and water to create Sulphuric acid.

2.1.2 – Leaching

The leaching stage consist of several different processes. One of them is the direct leaching process, it is an alternative to the roasting process. The direct leaching process is made to handle more difficult ore mixes. Afterwards leaching phase of the process, the zinc gets purified. Here the copper, cadmium and iron are removed from the process liquid.

2.1.3 – Electrolysis

Under the Electrolysis phase the zinc gets removed from the process liquid by electrolysis. This is done by using and anode and cathode and driving a current through them, when this happens the zinc in the process liquid gets collected on the anode. At this stage the zinc that is collected is almost 100% pure.

2.1.4 – Casting

Under the casting stage the customers requested alloy gets created. The pure zinc from the electrolysis halls is mixed with other metals to create the alloy requested. Afterwards the zinc alloy is cast into ingots. Thereafter the ingots are moved into storage and shipped off to the customer by boat.

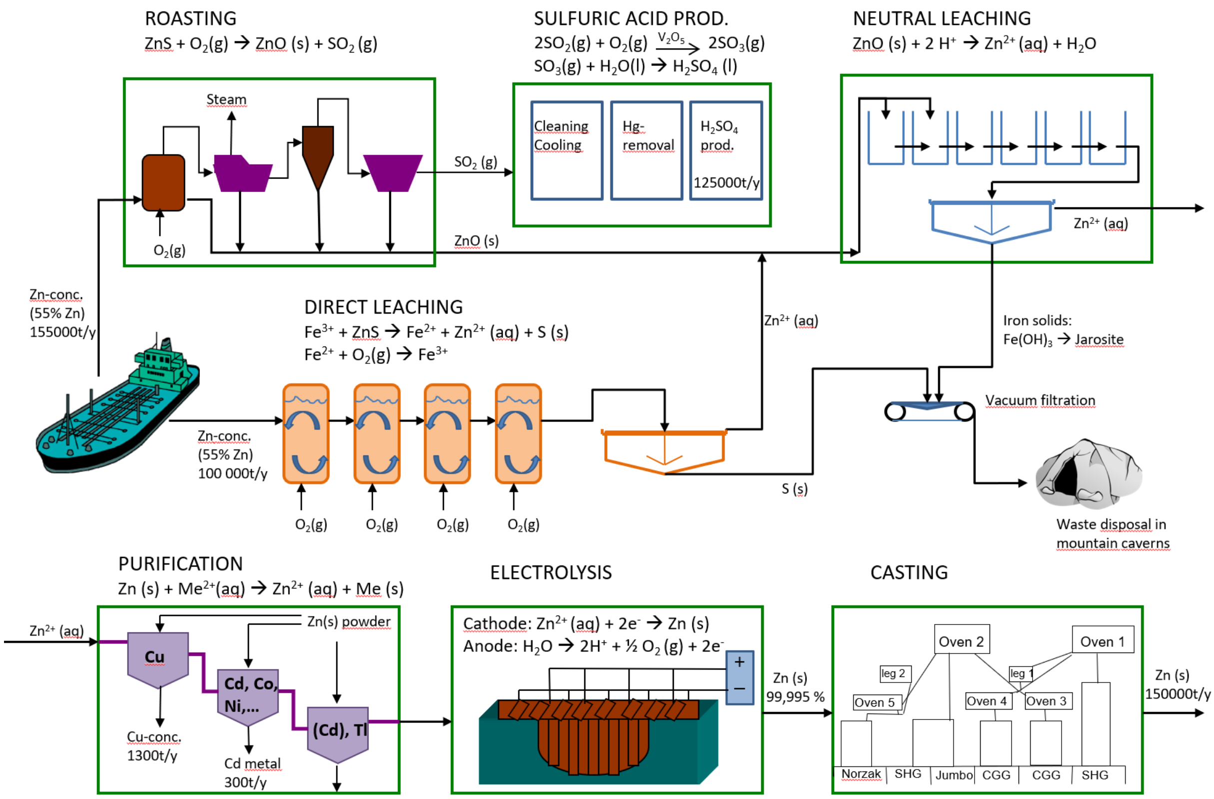

FIGURE 1 BOLIDEN ODDA PRODUCTION FLOW

2.2 – Direct leaching reactors

The direct leaching reactors consist of an agitator unit and a tank unit. At this stage in the production process the mixed ore is pumped from the docks into the tanks where it is mixed with acid and oxygen. In the tanks the ore reacts with oxygen, sulfur and other impurities precipitate out of the zinc solution. This solution gets separated later in the production process.

2.2.1 – Agitator unit

The agitator unit consist of an el-engine, transmission unit, agitator shaft, impellers and mechanical seal. Its function is to agitate the process liquid to speed up the precipitation of impurities.

The el-engine creates torque and power and sends it to the transmission unit. The el-engine is equipped with a frequency converter that is used to regulate the amount of power and torque sent to the transmission unit at startup and shutdown. The transmission unit ensures that the agitator is rotated at the desired speed and torque. It is lubricated by an external lubricator. The lubricator circulates and cools the gear oil.

The agitator shaft transfers the torque and power from the transmission to the impeller and the impeller transfers the torque and power from the agitator shaft to movement in the process liquid. The mechanical seal seals the agitator shaft from the transmission.

2.2.2 – Tank unit

The tank unit is made of duplex steel and is equipped with panels, nozzles and manholes. The tank unit holds the liquid to be mixed. It is designed to withstand process conditions and provide reliable structural integrity. The tank unit consists of the tank itself, an extraction pipe and panels, an oxygen intake and inlet and outlet nozzles. The tank panels, bottom mold and height-to-width ratio are adjusted to achieve the best possible process result. The panels also prevent the formation of a dangerous vortex at the top of the tank. The extraction pipe and panels control the flow inside the tank, so that the desired mixing pattern is achieved. Oxygen is fed into the reactor through the oxygen intake, which is in the agitator nozzle.

2.3 - Maintenance policy at Boliden

2.3.1 – Introduction

Maintenance is, at all Boliden's production facilities, an important factor for cost-effective and safe quality production.

The main task of the maintenance personnel is to keep the equipment operational in order to ensure safe and cost-effective operation and productivity of the facilities.

This means that the business must concentrate on planned stops instead of acute accidents.

It is a responsibility for everyone in Boliden to act so that absolutely the highest quality production can be achieved at the right cost and on the right time. If an observed error cannot be corrected immediately, it must be reported.

2.3.2 – Strategy

No maintenance tasks can be carried when health, safety, internal or external environment (ISO 14001 and 18001), and product quality (ISO 9001) is at stake, in the endeavor to maintain availability or keep costs down.

The maintenance strategy is to be the productions best partner in maintenance issues. This is done by ensuring the planned operational reliability and status of the equipment, and, by having the right expertise, be a technical advisor in maintenance issues.

By systematically registering all deviations, so that later analysis and improvement can be carried out, the maintenance department's activities can be arranged more on preventive and improving maintenance.

2.3.3 – Objective goal

The overall maintenance goal in Boliden is:

"To maintain planned equipment availability, function and status at the lowest life-time cost within approved limits for HSE and quality".

With the goal of using the same terms in maintenance, the thermology system used in Boliden is based on Swedish and European standards SS EN 13306.

2.3.4 – How they do it nowadays

The maintenance system that is use at Boliden Odda is Maximo. It is mainly used as a library of inspection routines and as storage and delivery of work orders. Work orders are created by personnel that detect the failure. At the leaching and roasting department this work order is the sent to the maintenance leader. The maintenance leader is then responsible to coordinate with internal and external personnel to improve the failure. In addition, Boliden Odda also practice planned preventative maintenance. This is done to prolong the time between failures. An example of this is to run water through a pipe weekly to decrease the amount of sediment buildup. Due to the design of the plant there are always alternative routes the process liquid can take and backup equipment. This creates a situation where the production process is modular and does not include much critical equipment, therefore preventative and condition-based maintenance are not in focus.

Chapter 3 – The concept of RCM

In this chapter the RCM methodology will be explained, as well as Rausand's eleven steps of RCM analysis. [1]

3.1 - What is RCM?

Reliability centered maintenance is a methodology used to determine what type of maintenance or maintenance strategy that is best suited for the current equipment or system. The method provides a structured framework to analyze the various functions or errors that may occur with the intention to maintain the system functions, rather than the equipment itself. [2]

The purpose of the methodology is to get the lowest possible operating cost on an equipment by identifying components that are critical to safety, the environment or the economy and to provide for preventive maintenance on these components. At the same time, "uncritical" components are reduced priority and maintenance in so-called corrective maintenance. It is suggested that this process be implemented as a group process that should involve operators, maintenance executives, maintenance planners, suppliers, and so on. This is necessary to document all aspects of the equipment in question, while at the same time the process also has learning and attitudinal change as a purpose.

To be considered as an RCM process, according to the SAE JA1011 standard, the following minimum questions must be answered and documented for the equipment:

- What should the equipment do, what function does it have?
- In what ways, the functions fail to complete their assigned function?
- What causes can cause each cause of error?
- What happens to each malfunction?
- What are the consequences of each malfunction?
- What systematic and proactive measures can be taken to prevent or minimize the likelihood of errors and what measures can reduce the consequences of a possible error.
- What can be done if appropriate preventive measures cannot be taken?

An important aspect is that the RCM is a continuous process in the life of the system for the purpose of providing the highest possible uptime to the lowest possible service life. This requires a proactive attitude from the organization for harvesting and analysis of operational data, error analysis and ongoing updating of maintenance programs, work instructions, procedures, etc.

- History:
  The RCM is originally originated from the US aircraft industry and was first introduced in 1978 by Stanley Nowland and Howard Heap in the report "Reliability

Centered Maintenance". Before this time has Maintenance and Maintenance Management has been in development since the 1930s. The steady change due to the large increase in the number and variety of resources, more complex constructions, new techniques, shifting views of the maintenance organization and the distribution of responsibilities. Now, there is more focus on being aware of the context the maintenance has with product quality and how equipment failure affects environment and safety.

3.1.2 - Benefits of RCM

A deeper look at the RCM process shows that the overriding goal is to ensure that the system works "Reliable" using an integrated maintenance strategy. The process will thus lead to several benefits that could give positive results in safety, the environment and the economy. Among other things, will RCM help reduce the likelihood of sudden errors on the equipment, by focusing maintenance activities on the main system components. Given that the process generates better understanding of equipment fumes and behavior, one can also easily determine optimal maintenance interval.

Using the RCM method, in addition to establishing maintenance strategies, it could be used as results of such an analysis directly against an LCC analysis. By making a balanced amount maintenance will costly equipment increase service life, while making the process more cost effective. The offshore industry often uses Life cycle cost (LCC) to reduce development, operation and maintenance costs. The purpose of LCC analyzes is that the buyer is forced to look at the costs in the entire life expectancy (useful life) and not only on investment costs.

3.1.3 - RCM main steps of analysis

According to Rausaud (1998), an RCM analysis can be prepared as a sequence of the following 11 main steps:

Step 1 - Study preparation

The first step in an RCM analysis is to establish a project group. The group must be able to define and clarify the actual objective and extent of the analysis. Here the requirements, guidelines and acceptance criteria with consideration of HSE lies. And this is seen as boundary conditions for the RCM analysis. All documentation in the form of drawings, charts, and instrumentation are made available at the same time as the limitations are specified.

Step 2 - System selection and definition

All systems can, in principle, take advantage of an RCM analysis, but with limited resources it will be required to set system boundaries. System boundaries are by identifying a function hierarchy for the system by breaking it down into functions and sub functions, often through system and subsystem level, to equipment level. By establishing one function hierarchy, it is possible to map out all the features of the system and show its logical context (Rausand, 1998).

Step 3 - Functional failure analysis (FFA)

Objectives:

- Identify and describe the system's required functions and performance criteria
- Describe input interfaces required for the system to operate
- Identify the ways in which the system might fail to function

- **Fault Tree Analysis**

The fault tree analysis is a relatively simple and versatile method used for the following:

- Reliability analysis in design phase
- Reliability analysis in operational phase
- Risk Analysis
- decision Analysis
- Error finding on existing system

The tree consists of a top event with initial events below it. These are tied together by logical ports consisting of «and» gates and «or» gates. The first step is to define the top event. The top event is the undesirable event that is the goal of the analysis. The top event can also be called initiating event. The next step is to add entry events, which represent the reasons needed to enable the top event.

This creates a good overview of the mechanisms that lead to the top event and ensures a structured approach that helps to override important things. Error analysis is also very visual and relatively uncomplicated. It is an advantage that allows others who are not otherwise specialized in this kind of analysis, yet to be able to contribute or learn from a misinterpretation. In many cases, maintenance personnel and operators with experience in operating the chosen system will be able to contribute.

The focus and gravity of a misinterpretation are mostly on systems and equipment. But the point of the analysis is to illuminate the relationships that relate to the top event, and it may be wrong to confine itself to equipment and systems. Incorrectly executed or missing maintenance, operator errors, etc. may be examples of initial events that may also be important to bring.

Below is an example of a Fail Tree Analysis.

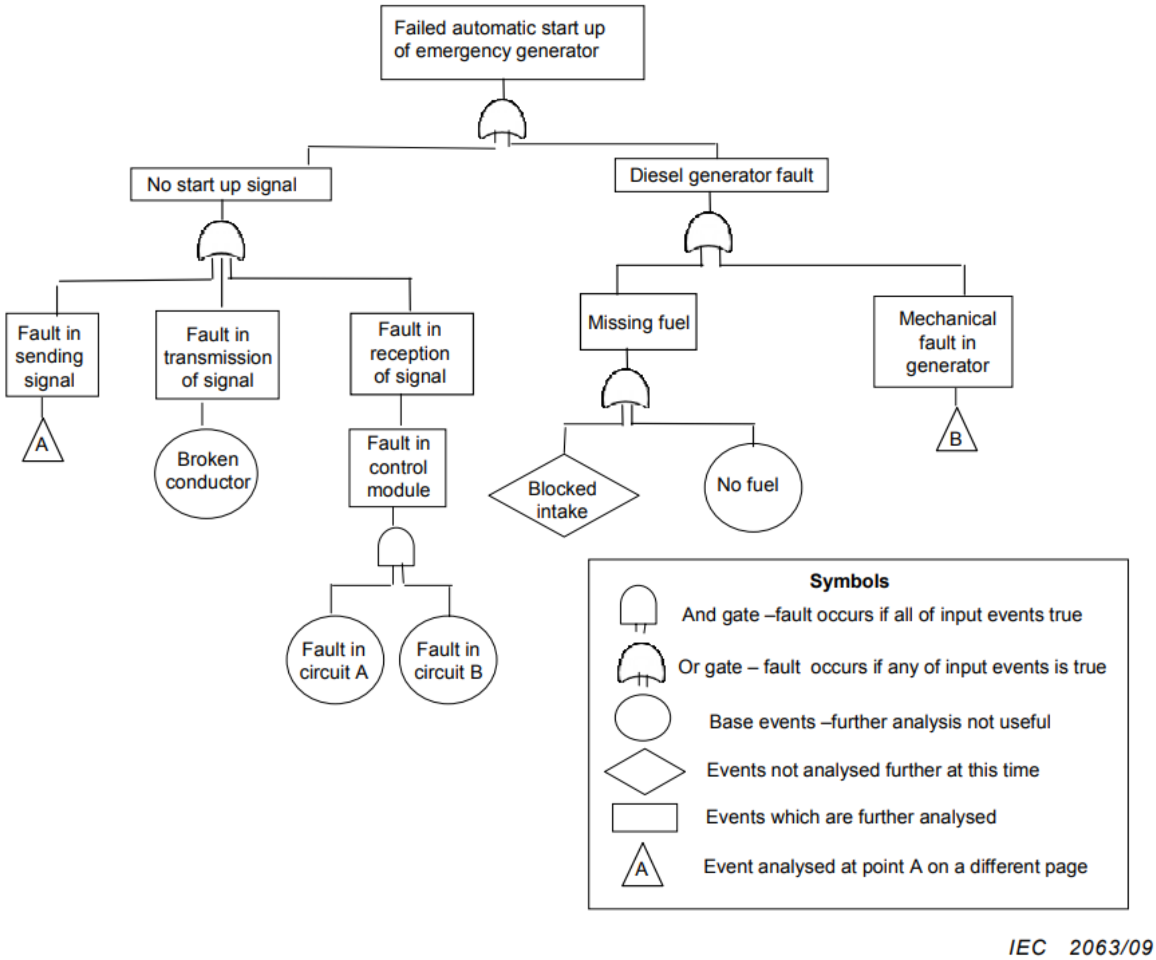

FIGURE 2 - FTA EXAMPLE FROM MS IEC/ISO 31010:2011

The events are linked by logical ports, which are either "AND" ports or "OR" ports. "AND ports" are used if all the identified reasons are necessary for the TOP event shall occur. If only one of the direct causes is necessary, use "OR porter" (Gjellestad, 2012).

Step 4 - Critical item selection

The purpose of step four is to identify and evaluate the system / equipment that is potentially critical to the functional failures is identified in step three.

Criticality is a measure of the risk that an equipment failure, which in turn causes a malfunction, occurs. The purpose of assessing the criticality is to map which parts are critical to the function itself of the system, and if preventive maintenance is recommended. The criticality analysis is considered the consequence of failure (CoF), as well as (PoF) the probability of failure.

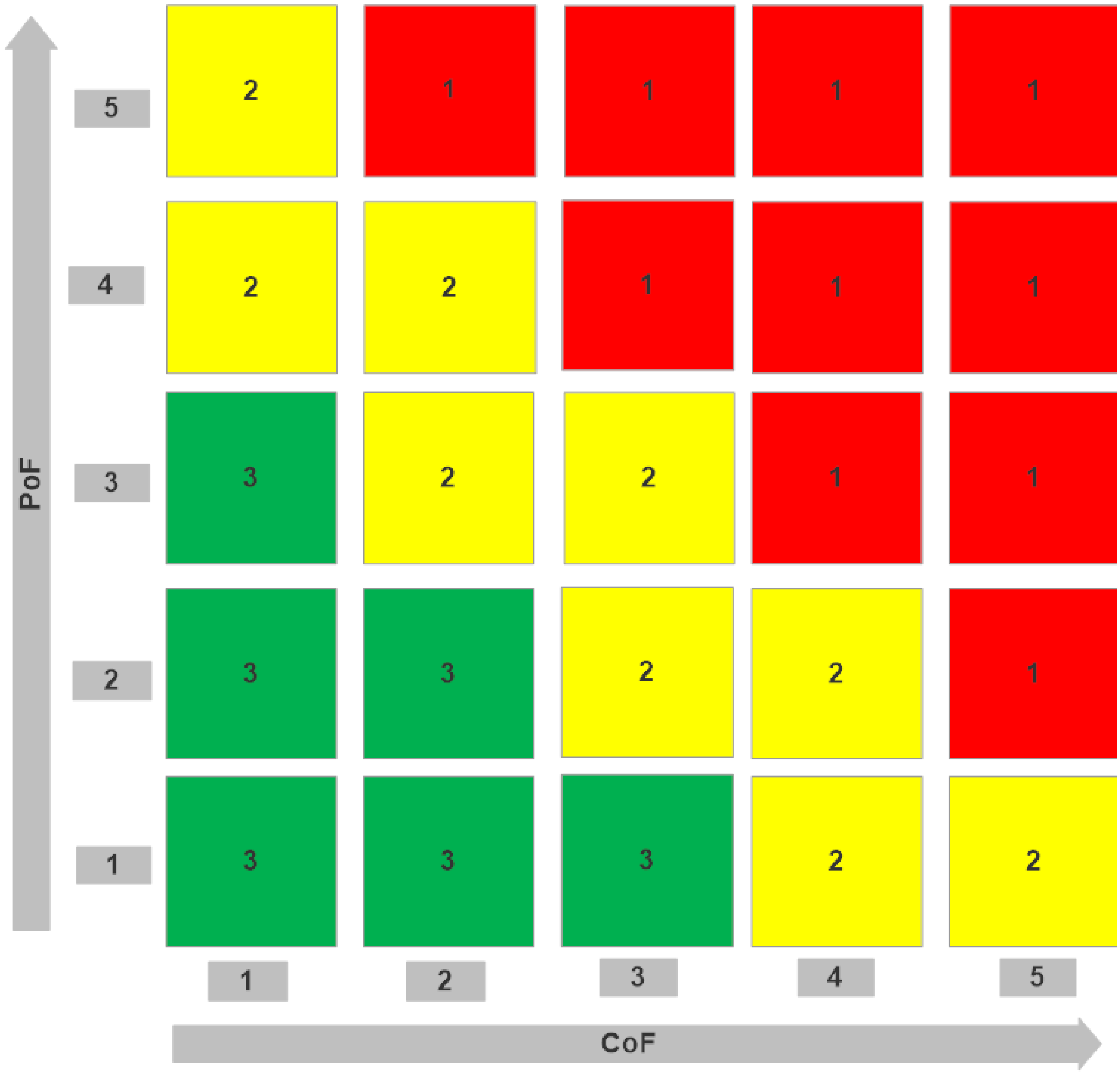

FIGURE 3 – EXAMPLE RISK MATRIX

Criticality (risk) can be presented as an array, which makes it possible to see the relative contribution from both factors (CoF and PoF). Here the probability and consequences of failure can be estimated as qualitative or quantitative way, or by combining the two methods.

An example of a qualitative assessment of the matrix is shown in the figure above. On the vertical axis the PoF goes from 1 (low frequency) to 5 (high frequency) while on the horizontal plane the CoF is ranked from 1 (small consequence) to 5 (high consistency). Based on consistency and frequency rate of the two factors, the criticality (risk) is set according to the matrix.

Step 5 - FMECA

Failure Modes, Effects and Criticality Analysis (FMECA) is a methodology designed to identify potential failure modes for a product or process, to assess the risk associated with those failure modes, to rank the issues in terms of importance and to identify and carry out corrective actions to address the most serious concerns.

FMECA requires the identification of the following basic information:

- Item(s)
- Function(s)
- Failure(s)
- Effect(s) of Failure
- Cause(s) of Failure
- Current Control(s)
- Recommended Action(s)
- Other relevant details (for example: Risk Priority Numbers (RPNs))

FMEA

End item: Operating period:			Item: Revision:					Prepared by: Date:			
Item ref.	**Item description and function**	**Failure mode**	**Failure mode code**	**Possible failure causes**	**Local effect**	**Final effect**	**Detection method**	**Compensating provision against failure**	**Severity class**	**Frequency or probability of occurrence**	**Remarks**

FIGURE *4 - EXAMPLE OF FMECA TABLE FROM IEC 60812*

Step 6 - Selection of maintenance actions

There are three main reasons for doing a PM task:

- 1. To prevent a failure
- 2. To detect the onset of a failure
- 3. To discover a hidden failure

The following basic maintenance tasks are considered:

- 1. Scheduled on-condition task
- 2. Scheduled overhaul
- 3. Scheduled replacement
- 4. Scheduled function test
- 5. Run to failure

Decision tree:

To ensure a strategic approach and to find the most appropriate maintenance strategy in one RCM analysis can be used by a decision-maker. Selection of "path" is documented by register "Yes" (Y) or "No" (N) for the question where to end will end with the desired maintenance strategy.

Maintenance strategy		Explanation
Planned corrective maintenance	PCM	Aware strategy that equipment is repaired / replaced only after failure
Condition-based maintenance	CM-I (Periodic Inspection) CM-F (Periodic function tests) CM-O (off-line measurements) CM-C (continuous measurements)	The first step is to perform a condition monitoring of the components to identify potential failures without repairing. It distinguishes between inspection, function testing, off-line measurement and continuous measurements. When acceptable state limit is exceeded, a state-controlled repercussion is initiated (corrective action)
Periodic overhaul / replacement	PO	The purpose is to put the component in

		acceptable mode or "as good as new" mode
Modification / redesign	M	The purpose is to reduce the criticality to an acceptable level where no other maintenance strategies are expedient

TABLE 1 - DESCRIPTION OF VARIOUS MAINTENANCE STRATEGIES (THORSTENSEN, 2001)

Step 7 - Determination of maintenance intervals

Some of the PM tasks are to be performed at regular intervals. To determine the optimal interval is a very difficult task that has to be based on information about the failure rate function, the likely consequences and costs of the failure the PM task is supposed to prevent, the cost and risk of the PM task, and so on.

In practice the various maintenance tasks have to be grouped into maintenance packages that are carried out at the same time, or in a specific sequence. The maintenance intervals can therefore not be optimized for each single item. The whole maintenance package has, at least to some degree, to be treated as an entity

Step 8 - Preventive maintenance comparison analysis

For preventive maintenance activities to be advantageous, the following criteria must be fulfilled:

1. It must be relevant in relation to reliability knowledge and the consequences of errors. An PM (Preventive maintenance) task will be relevant if it can eliminate or reduce the error, as well as reduce likelihood of the error occurring.

2. It must be effective. The maintenance task should not cost more than the error(s) must prevent.

Step 9 - Treatment of noncritical items

In step 4, the critical elements of the system were chosen for further analysis. The remaining question will be what to do with the uncritical elements. For facilities that do not already have one maintenance program, a short cost evaluation should be carried out.

Step 10 - Implementation

In step 4, the critical elements of the system were chosen for further analysis. The remaining question will Thus be what to do with the uncritical elements. For facilities that do not already have one maintenance program, a short cost evaluation should be carried out.

Step 11 - In-service data collection and updating

Available reliability data at the start of an analysis phase will in many cases be scarce. One of the main advantages of RCM is that it systematically analyzes and documents the basis for the initial decisions. In this way, one can better exploit the operating experience to customize the program as operation experience data becomes available. The full utilization of RCM will only be achieved when operational and maintenance experience is reverted to the analysis processes.

3.2 - Maintenance Strategies

There are two main groups of maintenance:

Preventive maintenance (before failure) to keep things in good working order. Generally, this form of maintenance is planned and happens periodically in accordance with the manufacturer's instructions.

Corrective maintenance (after failure) involves, for example, repair or replacement of defective parts. It also includes "just-needed" actions, the acute events that are done to correct something in the machine. Corrective maintenance is tasks that are not planned and are usually associated with greater risk and risk than preventive maintenance.

3.2.1 - Preventive maintenance

Preventative maintenance is performed before a malfunction and are usually planned activities in accordance with the manufacturer's instructions. The goal of preventive maintenance is to perform regular maintenance to prevent failure and damage to human and environment, as well as reduce the need for corrective maintenance.

A preventive maintenance strategy is suitable for systems or equipment that has:

- A critical operating function
- Malfunction that can be prevented with regular maintenance
- A probability of errors that will increase with time or use

Preventive maintenance can be divided into categories based on whether the maintenance is fixed or state-based. Condition-based preventive maintenance is about to implement continuous, periodic or need-based state controls. If the check shows that the condition which is not satisfactory, activities are initiated so that the equipment can maintain its demand function. If the failure mechanisms to be prevented are time-dependent, the time will be fixed preventive maintenance be effective. This maintenance type is based on intervals which is either based on operating time or the calendar.

3.2.2 - Corrective Maintenance

Corrective maintenance can either be planned (foreseen) or unplanned (unexpected). Planned corrective maintenance is when the failure is foreseen to occur, and the maintenance is planned for after the failure has happened. Unplanned corrective maintenance on the other hand, is when the maintenance is required after an unexpected failure. The unexpected failure could be on vital systems that threaten function and safety.

In addition, corrective maintenance can be divided into delayed and acute corrective maintenance. Exposed Corrective maintenance is actions taken to correct low criticality failure. Maintenance is not implemented immediately after errors are identified. Acute corrective maintenance, on the other hand, immediately following errors are identified, as the device is of high criticality.

Chapter 4 - RCM-analysis

In this Chapter an RCM-analysis will be performed after Rausand's eleven steps on the direct leaching reactors at Boliden Odda.

4.1 - Study preparation

A first visit to Boliden Odda was made on November 1, 2018 for a review of the facility and their Maintenance strategy and to determine in which direction the task could be taken. On a revisit in January 2019, it was decided which part of the facility was to be carried out by a maintenance analysis.

In order to complete the task, this data was collected:

- Description of equipment [2] [3] [4] [5] [6] [7] [8] [9]
- Equipment drawings [10]
- Failure dates [11] [12]
- Vibration measurements [11] [10](Appendix 3,4 and 5)

4.2 - System selection and definition

The following drawing is a simplified representation of how the direct leaching reactor is connected. Reactors are always specific to each delivery, therefor size of the reactor and the individual components may vary. This figure illustrates the main elements of the OKTOP direct leaching reactor, from Boliden's supplier, Outotec.

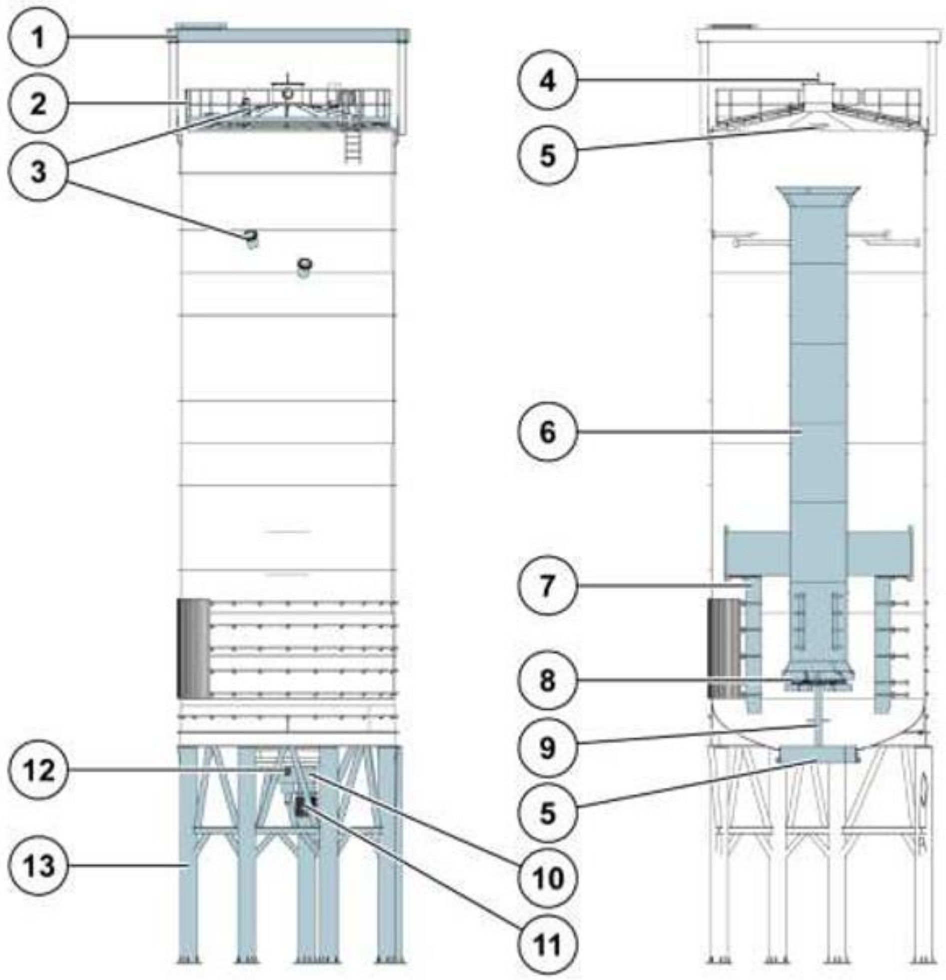

FIGURE 5 - DIRECT LEACHING REACTOR

1. Lift beam for agitator
2. Railings
3. Process flow and instrumentation nozzles
4. Manhole M2
5. Manhole M1
6. Extraction pipe
7. Panels
8. Impeller
9. Agitator shaft
10. Transmission unit
11. El-engine
12. Oxygen intake
13. The tank's supporting structure

4.2.1 – Function Hierarchy

To map all the features and show the logical context of the direct leaching reactor, the function hierarchy is used. The lower level of the function hierarchy links the maintenance objects against the current function, which clearly shows which features are taken out of operation if a device fails.

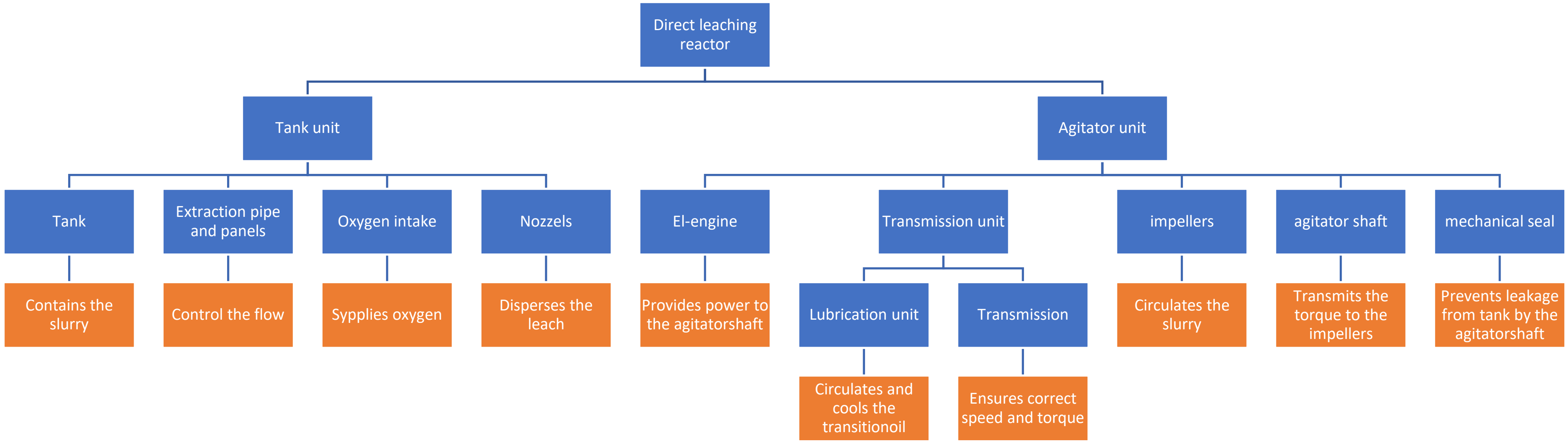

FIGURE 6 - FUNCTION HIERARCHY

4.3 - Functional failure analysis (FFA)

4.3.1 - Fault Tree Analysis (FTA)

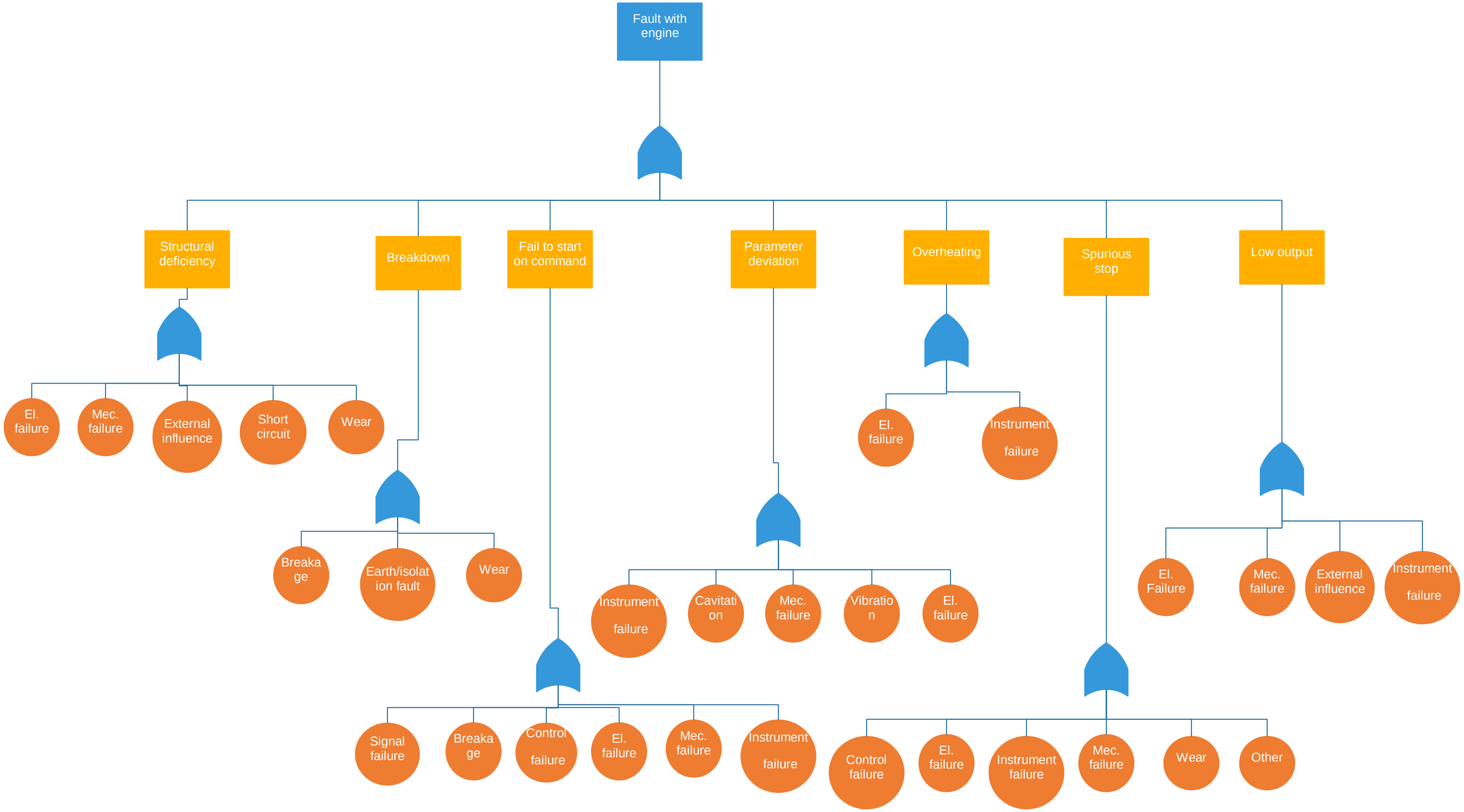

Figure 7 FTA Engine

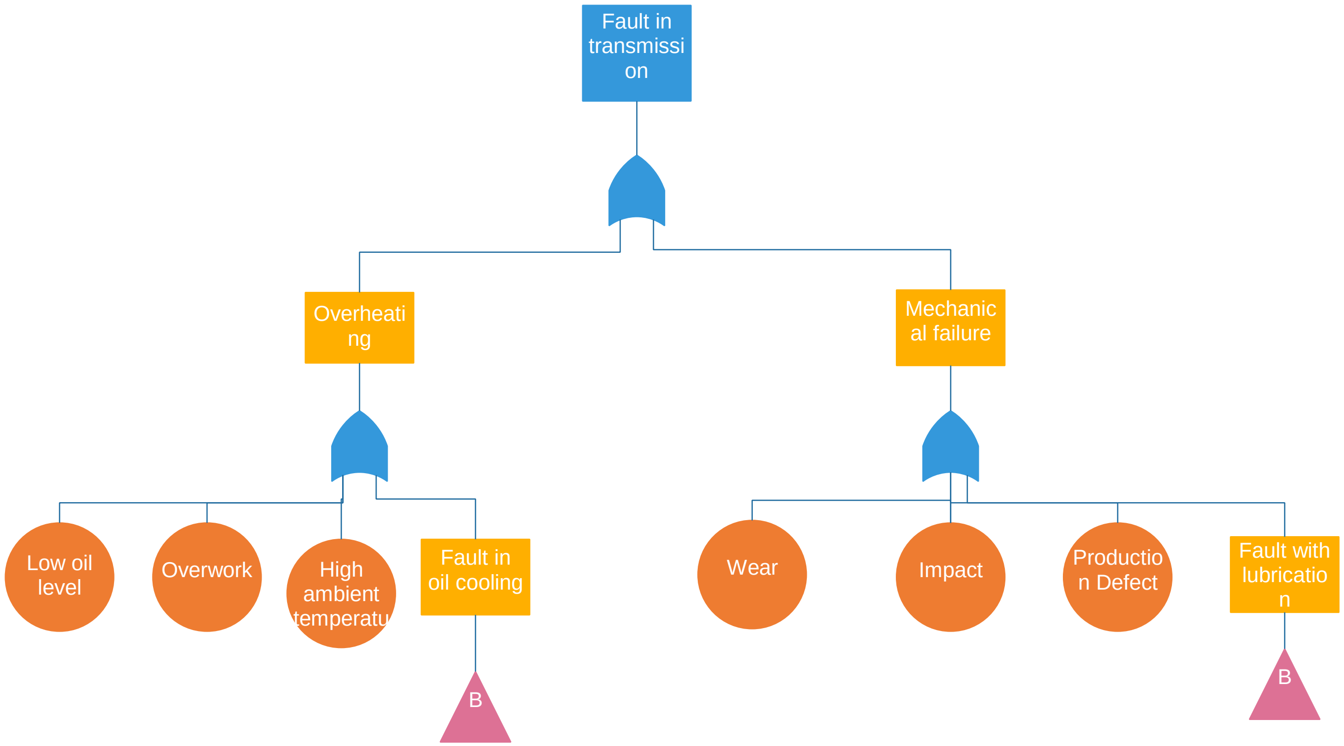

FIGURE 8 FTA TRANSMISSION

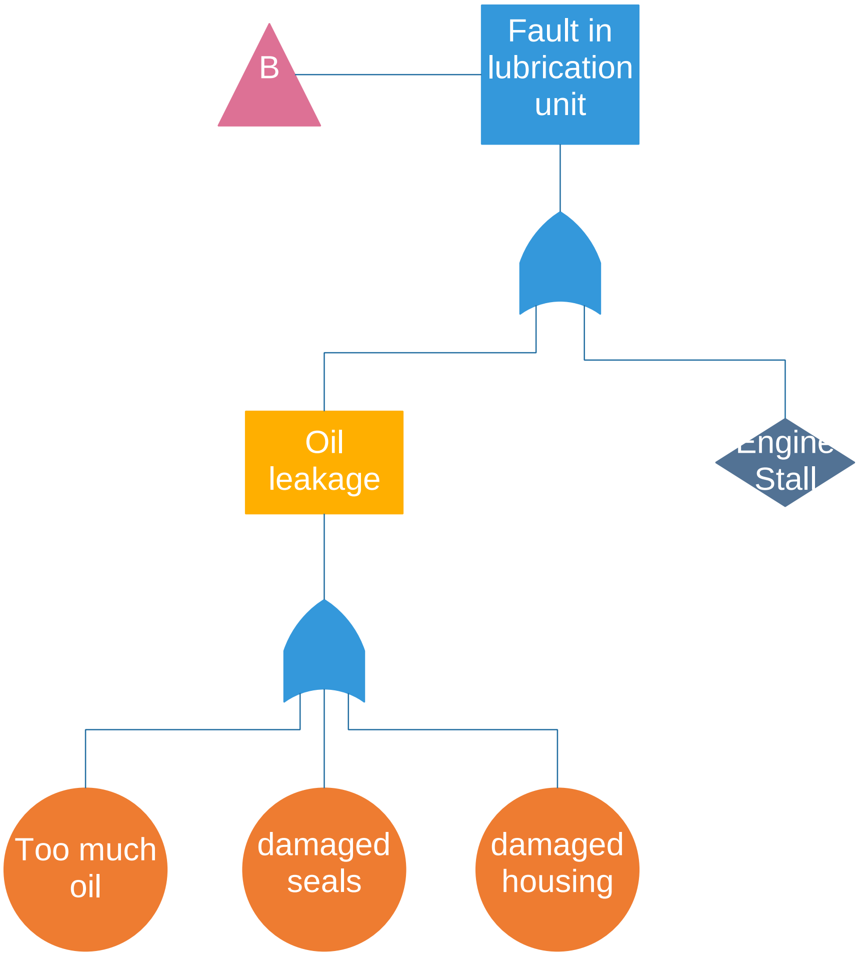

FIGURE 9 FTA LUBRICATION UNIT

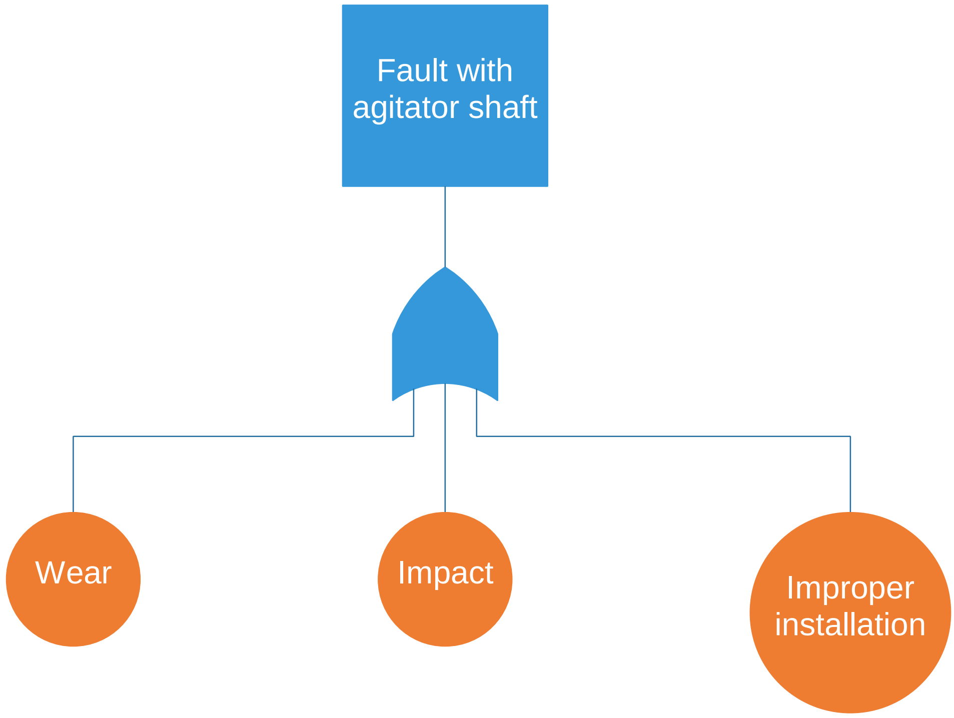

FIGURE 10 FTA AGITATOR SHAFT

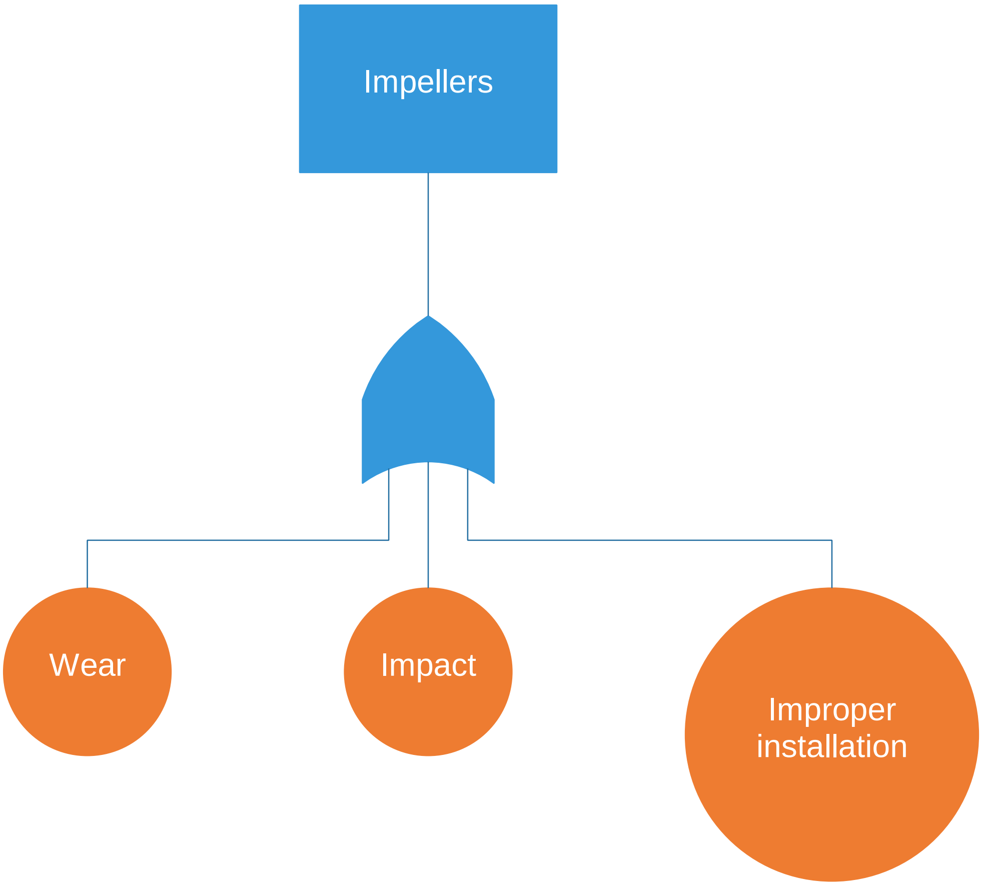

FIGURE 11 FTA IMPELLER

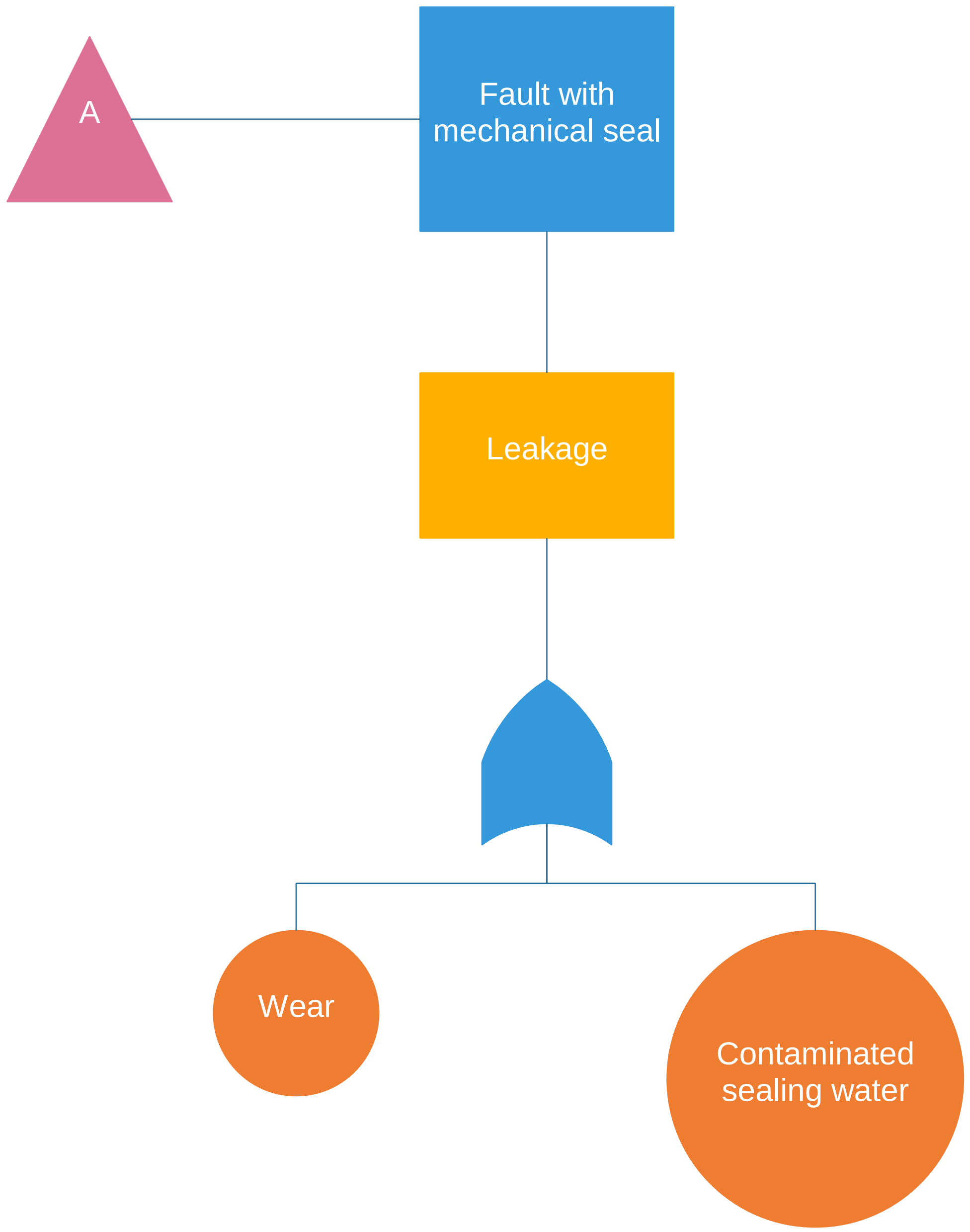

FIGURE 12 FTA MECHANICAL SEAL

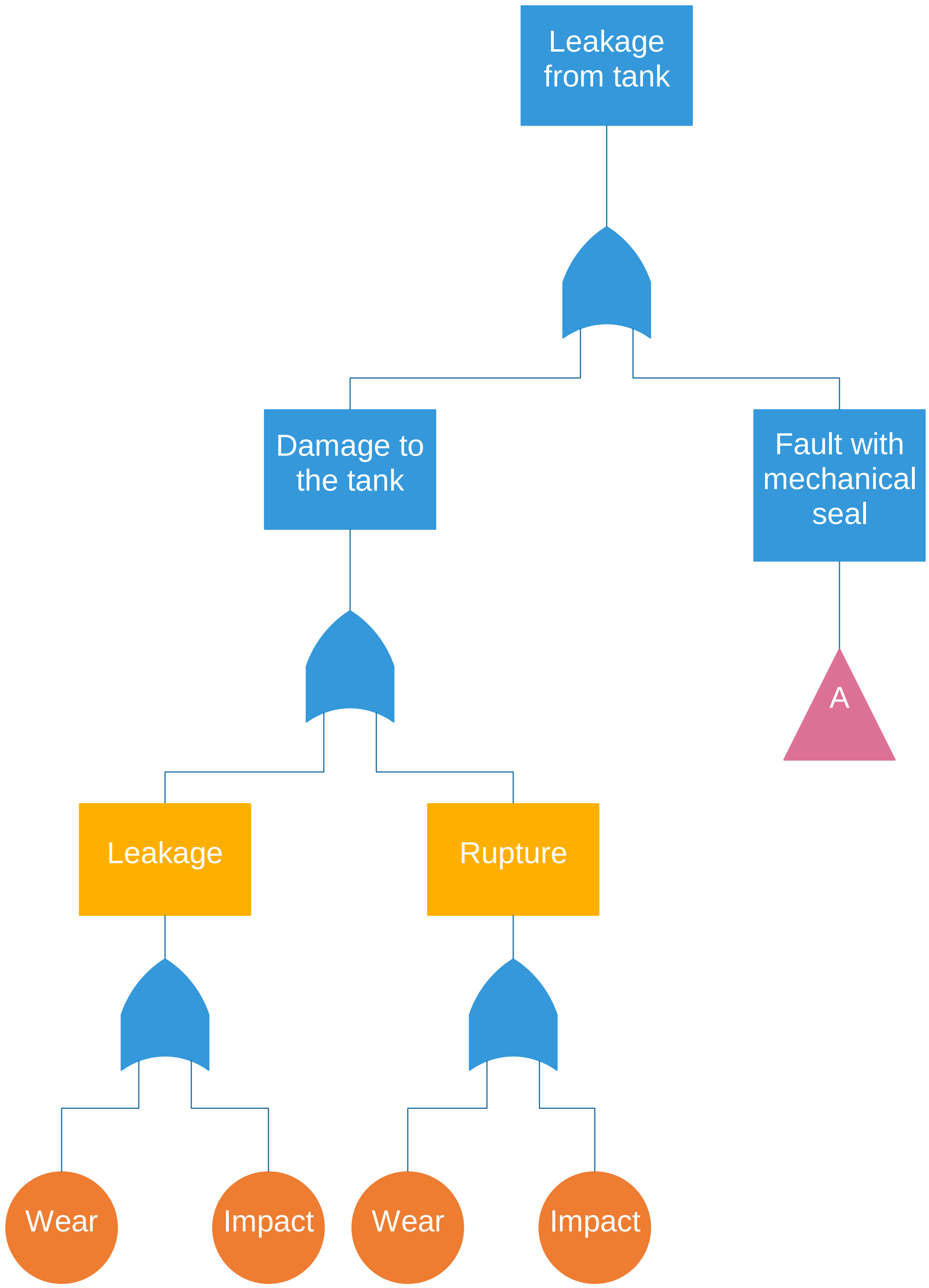

FIGURE 13 FTA TANK

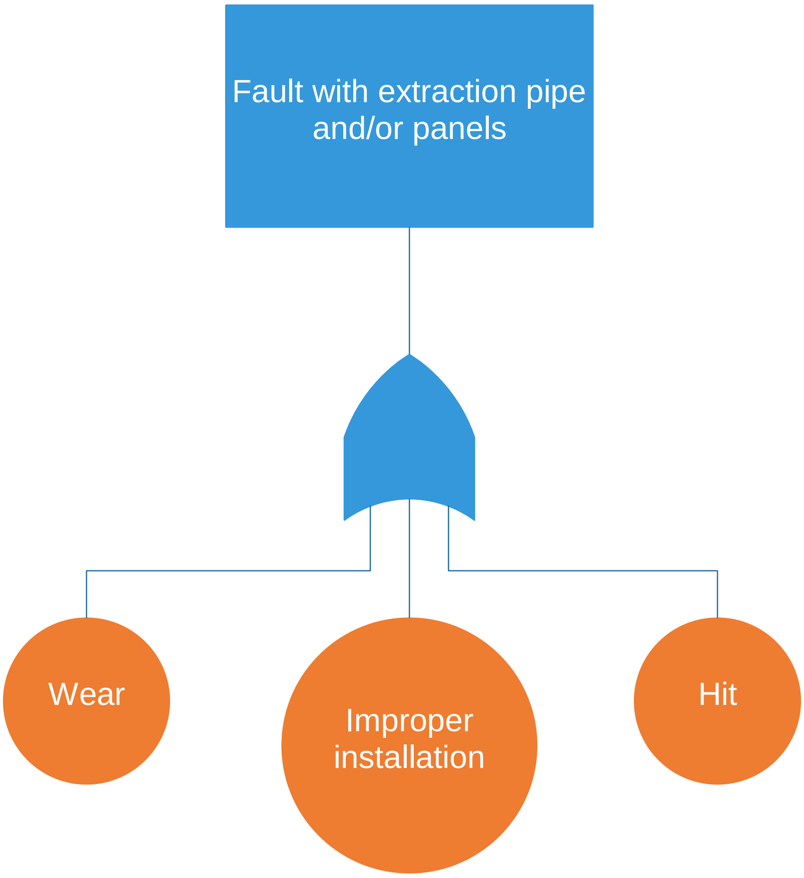

FIGURE 14 FTA EXTRACTION PIPE AND PANELS

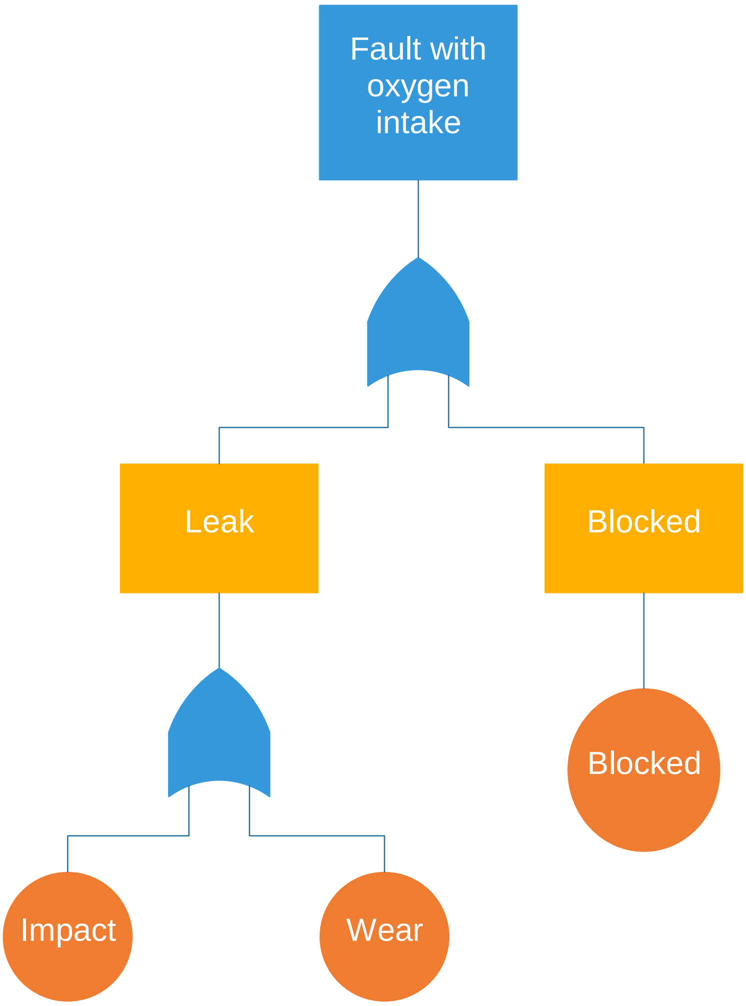

FIGURE 15 FTA OXYGEN INTAKE

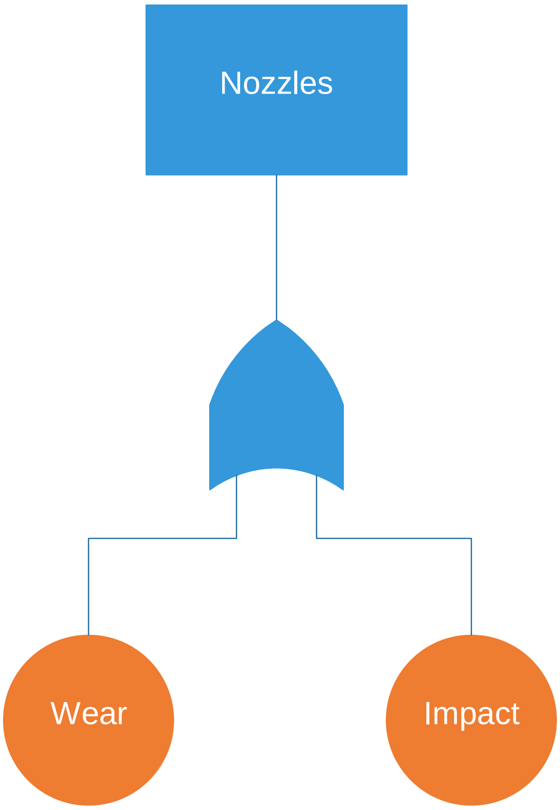

FIGURE 16 FTA NOZZLES

4.3.2 – FFA (Functional Failure Analysis)

Unit	Function	Failure mode	Failure causes	Local effect	Global effect
Nr.1 El-engine	Provides power to the agitator shaft	Overheatin g	El. failure, instrument failure	El-engine stops	Production shuts down

		Structural deficiency	Electrical failure, mechanical failure, external influence, short circuit, wear	Agitator unit stops.	Production shuts down
		Breakdown	Breakage, earth/isolation fault, wear	El-engine stops	Production shuts down
		Fail to start on command	Signal failure, breakage, control failure, el. failure, mechanical failure, instrument failure	El-engine won't start	Production shuts down
		Parameter deviation	Instrument failure, cavitation, mechanical failure, vibration, electrical failure	El-engine parameters deviate	Production slows down
		Spurious stop	Control failure, electrical failure, instrument failure, mechanical failure, wear, other	El-engine almost stops and continues working again	Production slows down

		Low output	Electrical failure, mechanical failure, external influence, instrument failure	El-engine functions below expectations	Production slows down
Nr 2 Transmission	The transmission insures correct speed and torque to the agitator shaft	Overheating	low oil level, wrong type of oil, the ambient temperature is too high, the oil cooler is improperly installed or does not work properly.	Causes wear to transmission unit Shuts down	Production shuts down temporarily
		Mechanical Failure	Wear, impact, product defect	Transmission shuts down and needs replacement	Production shuts down
Nr.3 The lubrication unit	Circulates and cools down the transmission oil	Oil leakage	Seals on outgoing / incoming shafts are worn or improperly installed, too much oil, Clogged oil air plug, the gear housing is damaged, leakage in the oil cooler.	Transmission unit gets overheated	Production shuts down
		Engine stall	Wear, production defect, impact	Transmission unit gets overheated	Production shuts down

Nr.4 Agitator shaft	Transmits the torque to the impellers	Damage	Impact, wear and improperly installed	Internal damage to the tank	Production shuts down. New tank required. Possible leakage from tank
Nr.5 Impellers	Circulates the slurry	Damage	Impact, wear, fault in installation	Suboptimal flow	Possible minor decrease in production
Nr.6 Mechanical seal	Seals the agitator shaft from the transmissio n	Leakage	The sealing water can get contaminated and let the process slurry leak into the transmission	Damage to transmission unit	Production shuts down Transmissio n unit might need replacement
Nr.7 Tank	Contains the slurry	Leakage	Corrosion Internal/Externa l forces or events	Leak	Production shuts down. Tank is emptied for inspection. Followed by repair.
		Rupture	Corrosion Internal/Externa l forces or events	Large leak	Possible danger to workers. Production shuts down until repair or replacement
Nr.8 Extraction pipe and panels	Controls the flow	Damage	Impact, wear, fault in installation	Suboptimal flow	Minor decrease in production efficiency

Nr.9 Oxygen intake	Supplies oxygen	Blocked	Blocked	Process reaction will no longer occur	Momentary stop in production
		Leak	Impact, wear	Process reaction will slow	Momentary stop in production
Nr.10 Nozzles (inlet and outlet)	Disperses the process liquid	Wrong pressure	Impact, wear	Can start overfilling	Stop in production

TABLE *2* - FUNCTION FAILURE ANALYSIS

4.4 - Criticality assessment (risk assessment)

Boliden uses this risk matrix and therefor the risk assessment will be based on these values.

Likelihood (L)

Consequence (C)	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Risk class (R)

Risk class 3 Red – High (15-25)
High to Extreme (intolerable) risk
– Immediate action
– Detailed action plan required

Risk class 2 Yellow – Medium (5-14)
Medium risk
– Need to be managed
– Actions can be executed, for example in connection to a maintenance stop

Risk class 1 Green – Low (1-4)
Low risk
– Managed by existing routine procedures

TABLE 3 - RISK MATRIX BOLIDEN

Boliden uses these tables for PoF and CoF and therefore the risk assessment will be based on these values. All areas of consequences are considered in this risk assessment, but the most commonly used to calculate the risk class are safety, health and quality.

Likelihood		Example
5	Almost certain	”Will most certainly occur”, daily- once per week
4	Likely	”Is likely to occur”, once per month – per year
3	Possible	”Might possibly happen”, once per 1-10 years
2	Unlikely	”Unlikely to occur”, once per 10 - 100 years
1	Rare	”Almost impossible”, once per 100 - 1000 years

TABLE 4 - PROBABILITY OF FAILURE

Consequence		Safety	Health	Environment	Quality	Production Property	Reputation	Energy	Legal
5	**Severe**	Death or life threatening injury.	Serious/life threatening illness, several individuals	Major environmental effects with impairment of ecosystem function. Widespread medium-long term impacts. Difficult or impossible to remediate. Exceeding permit level - loss of license.	Operations prevented for over a week / customer changes supplier	>100 MSEK	International media attention, judicial consequences, authorities stop production	Major losses, large quantities of energy is wasted, impact on economic outcome	Serious criminal sanctions. Financial penalty > 100 MSEK. Other liability > 100 MSEK. Loss of right or contract > 100 MSEK.
4	**Major**	Serious injury causing hospitalisation /absence from work more than 2 weeks (not life threatening)	Serious/life threatening illness	Serious environmental effects with some impairment of ecosystem function. Relatively widespread medium-long term impacts. Exceeding permit level- prosecution and/or corporate fine.	Operations prevented for 1 day - week, customer need additional supplier.	>50 MSEK	National media attention, minor judicial consequences, reporting to authority	Recurring failures, or a significant single failure, with the effect that energy is wasted	Criminal sanctions. Financial penalty. Other liability > 50 MSEK. Loss of right or contract > 50 MSEK.
3	**Medium**	Injury causing absence from work more than 4 days but less than 2 weeks, no need for hospitalisation	Sickness/un-health with long-term sick-leave.	Moderate effects on biological or physical environment. Minor short-medium term damage to small area of significance. Uncomplicated remediation. Exceeding permit level –information authorities	Operations prevented for less than a day, customer complaint	>25 MSEK	Local media attention, reporting to group, possibly to authorities	Temporary losses, with significant impact on energy consumption	Order or injunction against us. Liability > 25 MSEK Loss of right or contract > 25 MSEK.
2	**Low**	Minor injury treatment possible with supply from first aid kit or/and nearby clinic	Sickness/un-health with sick-leave.	Minor effects on biological or physical environment. Minor short term damage to small area of limited significance. Exceeding permit level –no action needed.	Momentary problems	>10 MSEK	Attention from own personnel, group reporting	Temporary losses, or lasting unnecessary losses, with minor impact on energy consumption	Inquiry from authorities. Liability > 10 MSEK. Loss of right or contract
1	**Insignificant**	No/minor injury not requiring medical treatment	Discomfort without sick-leave.	Limited damage to minimal area of low significance. No lasting impact. No exceeding permit level.	No interruption	>1 MSEK	No group reporting, internal interest	Limited or no energy losses	Advice from authorities

TABLE 5 - CONSEQUENCE OF FAILURE (RISK ASSESSMENT)

Units	Failure modes	CoF	PoF	Risk Class
Nr.1 El-engine	Overheating	4	1	1
	Structural deficiency	4	2	2
	Breakdown	4	2	2
	Fail to start on command	4	2	2
	Parameter deviation	3	2	2
	Spurious stop	3	2	2
	Low output	3	2	2
Nr.2 Transmission	Overheating	3	2	2
	Mechanical failure	5	3	3
Nr.3 Lubrication unit	Oil-leakage	3	2	2
	Engine stall	3	2	2
Nr.4 Agitator shaft	Damage	3	1	1
Nr.5 Impellers	Damage	2	1	1
Nr.6 Mechanical seal	Leakage	3	4	2
Nr.7 Tank	Leakage	2	1	1
	Rupture	5	1	2
Nr.8 Extraction pipe and panels	Damage	2	1	1
	Collapse	5	1	2
Nr.9 Oxygen intake	Blocked	4	1	1
	Leak	4	1	1
Nr.10 Nozzles	Wrong pressure	2	2	1

TABLE 6 - RISK ASSESSMENT

4.5 – FMECA

The potential mistakes and cause of failure can be identified by studying the system. The Preventative maintenance should prevent potential mistakes from occurring.

Description of Unit			Description of Failure					Risk and Maintenance	
Unit nr.	Unit description	Unit function	Failure mode	Possible failure causes	CoF	Detection method	PoF	Risk Class	Failure reduction measurements
1	El-engine	Provides power to the agitator shaft	Overheating	El. failure, instrument failure	4	Temperature measuring	1	1	Install sensors
			Structural deficiency	Electrical failure, mechanical failure, external influence, short circuit, wear	4	Visual detection	2	2	Inspection

			Breakdown	Breakage, earth/isolation fault, wear	4	Sensor detection	2	2	Install sensors
			Fail to start on command	Signal failure, breakage, control failure, el. failure, mechanical failure, instrument failure	4	Function test	2	2	Inspection and Install sensors
			Parameter deviation	Instrument failure, cavitation, mechanical failure, vibration, electrical failure	3	Vibration measuring	2	2	Install sensors

			Spurious stop	Control failure, electrical failure, instrument failure, mechanical failure, wear, other	3	Visual detection	2	2	Inspection
			Low output	Electrical failure, mechanical failure, external influence, instrument failure	3	Output readings	2	2	Inspection
2	Transmission	The transmission insures correct speed and torque	Overheating	Low oil level, wrong type of oil, the ambient temperature is too high, the oil cooler is improperly installed or does not work properly.	3	Temperature measurements	2	2	Install temperature sensors
			Mechanical Failure	Wear, impact, product defect	5	Vibration measurements and visual detection	3	3	Inspection and Install vibration sensors
3	Lubrication unit	Circulates and cools down the transmission oil	Oil-leakage	Seals on outgoing / incoming shafts are worn or improperly installed, too much oil, Clogged oil air plug, the gear	3	Visual detection	2	2	Inspection

				housing is damaged, leakage in the oil cooler.					
			Engine stall	Wear, production defect, impact	3	Visual detection	2	2	Inspection
4	Agitator shaft	Transmits the torque to the impellers	Damage	Hit, wear and improperly installed	3	Visual inspection	1	1	Inspection
5	Impellers	Circulates the slurry	Damage	Impact, wear, fault in installation	2	Visual inspection	1	1	Inspection
6	Mechanical seal	Seals the agitator shaft from the transmission	Leakage	The sealing water can get contaminated and let the process slurry leak into the transmission	3	Visual inspection	4	2	Inspection
7	Tank	Contains the slurry	Leakage	Corrosion, Internal/external forces or events	2	Visual inspection	1	1	Inspection
			Rupture	Corrosion, Internal/external forces or events	5	Visual inspection	1	2	Inspection
8	Extraction pipe and panels	Controls the flow	Damage	Impact, wear, fault in installation	2	Visual inspection	1	1	Inspection
9	Oxygen intake	Supplies oxygen	Blocked	Blockage	4	Visual detection	1	1	Inspection
			Leak	Impact, wear	4	Visual detection	1	1	Inspection

10	Nozzles	Disperses the leach	Wrong pressure	Impact, wear	2	Visual inspection	2	1	Inspection

TABLE 7 - FMECA

4.6 - Selection of maintenance actions

To ensure a strategic approach and to find the most appropriate maintenance strategy for Boliden's direct leaching reactors, this custom decision tree is used:

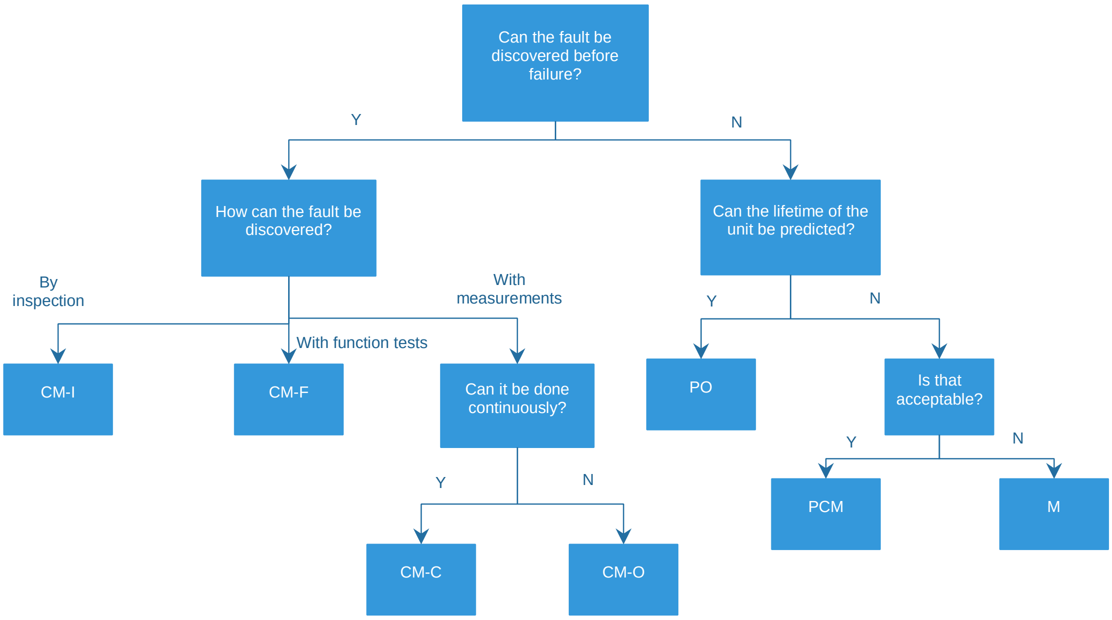

FIGURE 17 - MAINTENANCE STRATEGY DECISION TREE

The following maintenance strategies will be used for the components, based on the decision tree:

Components	Maintenance strategies
El-engine	CM-C
Transmission	CM-C and CM-I
Lubrication unit	CM-C and CM-I
Agitator shaft	PCM
Impellers	PCM
Mechanical seal	CM-I
Tank	CM-I
Extraction pipe and panels	PCM

Oxygen intake	CM-I
Nozzles	PCM

TABLE 8 - MAINTENANCE STRATEGY

4.7 - Determination of maintenance intervals

Selection or determination of maintenance intervals for preventive maintenance activities are often based on qualified assessments, statistics, or warranty requirements and government requirements. The intervals are based on the information about direct leaching reactors from the provider, Outotec (appendix 1 and 2) and the FMECA.

	How often				
Component	**weekly**	**monthly**	**Every 6 months**	**yearly**	**Actions**
El-engine	Every 12 hours				Take new reading with installed sensors
	Weekly				Inspect output readings
	Monthly				Apply grease to ball bearings
	Yearly				Inspect: engine frame, seals/v-rings, fasteners. Check: airflow, noise and temperature of ball bearings. Clean: engine frame.
Transmission unit	Every 12 hours				Take new reading with installed vibration and temperature sensors
	Weekly				Check: oil level
	Every 6 months				Apply grease to seals
	Yearly				Inspect: fasteners, shaft seal, splicing plate inspect and tighten fasteners between the transmission and the agitator flange.

		inspect fasteners every oil change or a minimum of once a year listen to noise during operation check for: leaks, clogged oil-pump, clogged oil cooler change: oil, oil filter, air plug,
Tank unit	Monthly	Check for: leaks Inspect oxygen supply for wear
	Every 6 months	Inspect bellows
	Yearly	Inspect: level control vents, bridge and assembly frame condition and fasteners, tank interior Check for: bottom settling development, corrosion limit
Agitator unit	See manual	See manual from manufacturer for the maintenance of these units: Mechanical seal, seal liquid system, O-rings, pipes
	Weekly	Listen for abnormal noise Inspect: alignment
	Every 6 months	Inspect lifting tackle Also inspect lifting tackle before each use, see the manufacturers lifting tackle manual.
	Yearly	Check: all fasteners including the support for the agitator,

		Inspect: cladding, impellers for wear and descaling

TABLE 9 MAINTENANCE INTERVALS

4.8 - Preventive maintenance comparison analysis

Will be commented, based on the FMECA, in Chapter 5 – Results from the RCM

4.9 - Treatment of noncritical items

Will be commented, based on the FMECA, in Chapter 5 – Results from the RCM

4.10 – Implementation

Will be commented in chapter 6.

4.11 - In-service data collection and updating

Will be commented in chapter 7

Chapter 5 – Results from RCM analysis

This chapter explains which components that have what risk, component by component. The components are placed in critical-, medium- and non-critical-components and it is explained why they have the risk assessment and which tests and inspection that should be performed in the maintenance work.

5.1 – Critical components

The results of the FMECA analysis

High priority		
Component	**Failure mode**	**Risk Class**
Transmission	Overheating	2
	Mechanical failure	3

TABLE 10 - CRITICAL COMPONENTS – HIGH PRIORITY

FMECA analysis ranks the transmission unit of the components in the direct leaching reactors as the critical component if a mechanical failure happens.

5.1.1 – Transmission

Risk Class: 3

From the risk assessment the transmission is at high risk if a mechanical failure happens. It could also fail by overheating, but the difference is the consequence of the failure. It is likely that overheating occurs, this means at least once per year, but also likely to happen several months a year, while mechanical failure might possible happen which means once per 1-10 years.

The transmission is a part of the transmission unit and every failure on the transmission unit will lead to downtime on the entire agitator unit. The transmission ensures correct speed and torque for the agitator unit in the direct leaching reactors and if it gets overheated it can result in downtime on the transmission unit for less than a day. It will also affect the lifetime of the transmission that can in worse case lead to a mechanical failure. If a mechanical failure happens it will lead to severe consequence with operations prevented for over a week. This is because the transmission must be replaced.

Maintenance strategy for the transmission is to control temperature measurement patterns to prevent overheating and control vibration measurement patterns and do visually inspections to prevent mechanical failure.

5.2 - Medium and non-Critical components

The FMECA was used to figure out that the following components have medium and low risk:

Low priority		
Components	**Failure mode**	**Risk Class**
El Engine	Overheating	1
	Structural deficiency	2
	Breakdown	2
	Fail to start on command	2
	Parameter deviation	2
	Spurious stop	2
	Low output	2
Lubrication unit	Oil-leakage	2
	Engine stall	2
Mechanical seal	Leakage	2
Agitator shaft	Damage	1
Impellers	Damage	1
Tank	Leakage	1
	Rupture	2
Extraction pipe and panels	Damage	1
Oxygen intake	Blocked	1
Nozzles	Wrong pressure	1

TABLE 11 - CRITICAL COMPONENTS - LOW PRIORITY

RCM analysis ranks the el engine, lubrication unit, the mechanical seal and the tank as the components with medium risk and the agitator shaft, impellers, extraction pipe and panels, oxygen intake and nozzles as the components with low risk.

5.2.1 – El engine

Risk Class: 2

From the risk assessment the el-engine is at medium risk and it`s possibilities for failure is overheating, structural deficiency, breakdown, fail to start on command, parameter deviation, spurious stop and low output. Failure is unlikely for all of the failure modes except overheating, which means once per 10 - 100 years. Failure by overheating is almost impossible and happens within each 100-1000 years.

The el-engine is a part of the agitator unit and it provides power to the agitator shaft. The el-engine creates torque and power and sends it to the transmission unit. The el-engine is equipped with a frequency converter that is used to regulate the amount of power and torque sent to the transmission unit at startup and shutdown.

The consequences for the failure modes overheating, structural deficiency, breakdown and fail to start on command is major because operations are prevented for 1 day – week. For the rest of the failure modes the consequences are medium with operations prevented for less than a day.

Maintenance strategies for the el-engine to inspect visually for failures yearly and apply grease to ball bearings weekly, as well as control measurement patterns once every 12 hours.

5.2.2 – Lubrication unit

Risk Class: 2

From the risk assessment the lubrication unit is at medium risk and it can fail with either oil-leakage or by motor stop. It is unlikely that both of these failures occur, which means once per 10 - 100 years.

The lubrication unit is a part of the transmission unit and circulates and cools down the transmission oil. Failure will cause operations prevented on the agitator unit for less than a day. Failure by both oil-leakage and motor stop will lead to loss in lifetime on the transmission, that again can cause major consequences with a mechanical failure on the transmission.

Maintenance strategies for the lubrication unit is to do weekly visual inspections to prevent engine from stalling and oil-leakages.

5.2.3. – Mechanical seal

Risk Class: 2

From the risk assessment the mechanical seal is at medium risk. The mechanical seal is a part of the agitator unit and it seals the agitator shaft from the transmission unit. The failure mode is leakage and it happens when the sealing water get contaminated and lets the process slurry leak into the transmission. Failure is likely to occur once per month to once per year.

The consequences are major considered in quality, with operation prevented for a day to a week. Failure also leads to loss in lifetime on the transmission that can cause mechanical failure.

Maintenance strategies for the mechanical seal is to do weekly visual inspections to prevent leakages.

5.2.4 – Agitator shaft

Risk Class: 1

From the risk assessment the agitator shaft is at low risk. It's a part of the agitator unit and it transmits the torque to the impellers. It can fail by damage as hit, wear or that it`s improperly installed. However, the likelihood of this is almost impossible which means it will only happen once in 100-1000 years.

The consequences are medium considered in quality, with operation prevented for less than a day, but it can damage some parts inside of the tank

Maintenance strategies for the agitator shaft is to do daily visual inspections to prevent failures.

5.2.5 – Impellers

Risk Class: 1

From the risk assessment the impellers are at low risk. It's a part of the tank unit and it circulates the slurry inside the tank. It can fail by damages as impact, wear or fault in installation. However, the likelihood of this is almost impossible which means it will only happen once in 100-1000 years. The consequences from failure are low, it will only result in momentary problems.

Maintenance strategies for the impellers is to do yearly visual inspections to prevent wear and descaling.

5.2.6 – Tank

Risk Class: 2

From the risk assessment the tank is at medium risk. It's a part of the tank unit and the tank contains the slurry. It can fail by leakage and rupture by corrosion or Internal/external forces or events. However, the likelihood of this is almost impossible which means it will only happen once in 100-1000 years.

The consequences from leakages are low, it will only result in momentary problems, but the reason that the tank has a medium risk is because the consequences from rupture are severe. If the slurry runs out of the tank there is a great chance that it encounters several individuals and it can cause a life threating injury or in worse case, death.

Maintenance strategies for the tank is to do daily visual inspections to prevent both leakages and rupture.

5.2.7 – Extraction pipe and panels

Risk Class: 1

From the risk assessment the extraction pipe and panels are at low risk. It's a part of the tank unit and it controls the flow in the slurry inside the tank. It can fail by damages as impact, wear or fault in installation. However, the likelihood of this is almost impossible which means it will only happen once in 100-1000 years. The consequences from failure are low, it will only result in momentary problems.

Maintenance strategies for the extraction pipe and panels is to do daily visual inspections to prevent failures.

5.2.8 – Oxygen intake

Risk Class: 1

From the risk assessment the oxygen intake is at low risk. It's a part of the tank unit and it supplies oxygen to the reactor. The oxygen intake can fail by the tube being blocked, which will cause little to no reaction in the reactor. However, the likelihood of this is almost impossible which means it will only happen once in 100-1000 years. The consequences from blockade are major and prevents operations for a day to a week.

Maintenance strategies for the oxygen intake is to do use sensor detection to prevent failures.

5.2.9 – Nozzles

Risk Class: 1

From the risk assessment the nozzles are at low risk. They are a part of the tank unit and disperses the leach in the reactors. They can fail by having wrong pressure which can happen by wear and impact. Failure is unlikely to occur which means once per 10-100 years. The consequences from failure are low, it will only result in momentary problems.

Maintenance strategies for the nozzles is to do daily visual inspections to prevent failures.

5.3 - Maintenance program

The maintenance program is a 5H + N analysis. The program is based on the RCM analysis.

What	Why		How	Where	By who	When
El engine	Overheating	El. failure, instrument failure	• Temperature sensors - Control measurement patterns	In SKF @ptitude Connect	Maintenance engineer	Every 12 hours
	Structural deficiency	Electrical failure, mechanical failure, external influence, short circuit, wear	• Visual detection - Control for physical damage	On location	Operator	Yearly
	Breakdown	Breakage, earth/isolation fault, wear	• Vibration sensors - Control measurement patterns	In SKF @ptitude Connect	Maintenance engineer	Every 12 hours

	Fail to start on command	Signal failure, breakage, control failure, el. failure, mechanical failure, instrument failure	• Visual inspection - Inspect output readings	In the control room	Operator	Weekly
			• Sensors - Control measurement patterns	In SKF @ptitude Connect	Maintena nce engineer	Every 12 hours
	Parameter deviation	Instrument failure, cavitation, mechanical failure, vibration, electrical failure	• Vibration sensors - Control measurement patterns	In SKF @ptitude Connect	Maintena nce engineer	Every 12 hours
	Spurious stop	Control failure, electrical failure, instrument failure, mechanical failure, wear, other	• Visual inspection - Inspect output readings	In the control room	Operator	Weekly
	Low output	Electrical failure, mechanical failure, external influence, instrument failure	• Visual inspection - Inspect output readings	In the control room	Operator	Weekly
Transmission	Overheatin g	Low oil level, wrong type of oil, the ambient temperature is too high, the oil cooler is improperly installed or does not work properly.	• Temperature sensors • Vibration sensors - Control measurement patterns	In SKF @ptitude Connect	Maintena nce engineer	Every 12 hours
	Mechanical failure	Wear, impact, product defect	• Vibration sensors - Control measurement patterns	In SKF @ptitude Connect	Maintena nce engineer	Every 12 hours

			• Visual inspection - inspect and tighten fasteners between the transmission and the agitator flange.	On location	Operator	Yearly
Lubrication unit	Oil-leakage	Seals on outgoing / incoming shafts are worn or improperly installed, too much oil, Clogged oil air plug, the gear housing is damaged, leakage in the oil cooler.	• Visual inspections - Control oil level and change oil, check for: leaks, clogged oil-pump, clogged oil cooler	On location	Operator	Weekly and yearly
	Engine stall	Wear, production defect, impact	• Visual inspections - Control for physical damage	On location	Operator	Yearly
Agitator shaft	Hit, wear and improperly installed		• Visual inspections - Control for physical damage	On location	Operator	Yearly
Impellers	Impact, wear, fault in installation		• Visual inspections - Control for physical damage	On location	Operator	Yearly
Mechanical seal	The sealing water can get contaminated and let the process slurry leak into the transmission		• Visual inspections - Control for leaks	On location	Operator	Look in manual from manufacturer
Tank	Corrosion, Internal/external forces or events		• Visual inspections Control for leaks, wear and damage	On location	Operator	Monthly, every six months and yearly.
Extraction pipe and panels	Impact, wear, fault in installation		• Visual inspections - Control for physical damage	On location	Operator	Yearly
Oxygen intake	Blocked		• Visual inspections - Control oxygen supply for wear	On location	Operator	Monthly
Nozzles	Impact, wear		• Visual inspections	On location	Operator	Yearly

		- Control for physical damage			

TABLE 12 – MAINTENANCE PROGRAM

Chapter 6 – Implementation

In this chapter, there will be an introduction to industry 4.0 to decide which method that will be performed on the critical component. This is done to find equipment within industry 4.0 that can improve the maintenance of the direct leaching reactors at Boliden in the future.

6.1 Industry and maintenance 4.0

The industry is in the midst of a transformation that started some years ago, which is nicknamed "the 4th industrial revolution". [13] [14] According to Klaus Schwab from the World Economic Forum, this is about 'industrial convergence'. It is the merger between the physical, digital and biological world. This thanks to development as:

- robotics
- nanotechnology
- biotechnology
- 3D-printing
- virtual reality
- Internet of things

When looking at "the 4th industrial revolution" on maintenance, there are nine conditions that update basic knowledge of "maintenance 4.0". [15]

6.1.1 – Preventive maintenance

Preventive maintenance actions are based on the principle of "prevention is better than cure". Instead of waiting for an error to occur, the intelligent software plans a maintenance plan. The goal is to prevent mistakes before they occur. This contrasts with the old approach to the maintenance of "Run to failure" which is reactive.

6.1.2 – Industrial Internet of Things (IIoT)

IIoT is one of the basic of the “fourth industrial revolution”. This enables new analysis and insight by engineers linking more and more components, installations and objects together. The most developed application today is predictive maintenance combining with great data analysis.

6.1.3 – Predictive maintenance

Predictive maintenance goes a step further then replacing a certain part after a fixed number of running hours. The intelligent software looks at the part's health based on condition monitoring. Condition monitoring uses data from:

- Vibration measurements
- Oil Analysis
- Infrared measurements

The intelligent software tracks whether a failure is likely within a certain time frame. Engineers can thus schedule and deliver maintenance better and decrease maintenance costs.

For predictable maintenance to be performed on an industrial asset, the following basic components are required:

- **Sensors**
  Data collection sensors installed in the physical product or machine

- **Data communication**
  The communication system that allows data to flow securely between the monitored asset and the central data store

- **Central data storage**
  The central data name where asset data (from OT systems) and business data (from IT systems) are stored, processed and analyzed; either on the spot or on the cloud

- **Predictive analyzes**
  Predictive analytics algorithms used for aggregated data to recognize patterns and generate dashboard and notification insights

Production data is stretched from the sensors to a central warehouse using industrial communication protocols and gateways. Business data from ERP and MES systems, along with production process streams, is integrated into the central data store to relate to the production data. Then predictive analytics algorithms are used to provide insight to reduce downtime, which is investigated using basic analysis software.

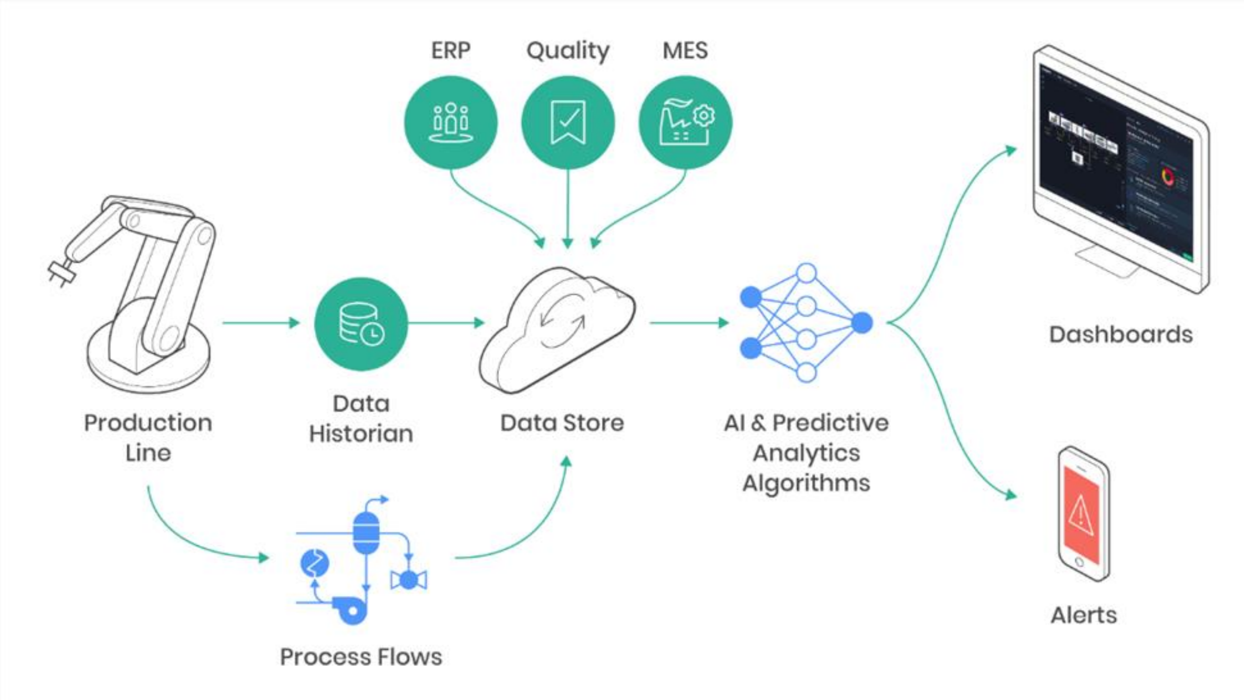

FIGURE 18 PREDICTIVE MAINTENANCE ARCHITECTURE

6.1.4 – Big Data Analytics

Monitoring of important installations provides a large amount of data. This "Big Data" contains massive information. It is possible to predict the "unpredictable" when you connect information streams from the inside and outside of the company.

PwC`s report "Mainnovation" on Predictive Maintenance 4.0 "shows this becomes reality. Top companies provide continuous active monitoring with predictions based on predictive techniques. Regression analysis is one of these techniques.

6.1.5 – Cloud computing versus Edge computing

The development to store more and more data and to perform calculations in the cloud continues, both for individuals and businesses. Nevertheless, there are good reasons in the industry to do Edge Computing because then the data remains close to the source of processing. It is a method of optimizing cloud computing by performing computing near the data source. This is faster, safer and cheaper when sharing between data stored and processed locally and data sent to the cloud.

6.1.6 – Artificial Intelligence

Large Internet companies are pumping billions into artificial intelligence research and development. New breakthroughs follow each other faster and faster. The industry is working on cobots, there are robots that work with and learn from human colleagues. Drones and robots for inspection and cleaning also start to play a role in maintenance.

6.1.7 – Predictive analytics

Predictive analysis includes statistical techniques from predictive modeling, machine learning, and data extraction that analyze current and historical facts to make predictions about future and unknown events.

6.1.8 – Prognostic maintenance

Prognostics is an engineering discipline focused on predicting the time when a system or component will no longer perform its intended function. This form of maintenance is based on predictive analysis and maintenance. It uses machine learning, pattern recognition, and other advanced techniques such as "neural networks" and "neural fuzzy systems".

6.1.9 – Prescriptive maintenance and analytics

The most advanced maintenance option. Prescriptive maintenance tries to answer the question: “What should we do to achieve X?”. It is based on:

- Big Data
- Graph analysis
- Simulations
- Complex event treatment
- Neural networks
- Heuristics
- Machine learning

Prescriptive goes a step further than predictive maintenance because it not only reflects the possible results of a particular approach, but also evaluates which approach is the fastest or most effective.

6.2 – About the vibration analysis

The method used from industry 4.0 is predictive maintenance, focusing condition monitoring with data from vibration measurements. With these data a RAG-rating system [18] is made to determine the correct values on the transmission in the direct leaching reactors. This rating system is used to determine the current state of the equipment and it`s required maintenance. The vibration data is gathered with a hand-held sensor approximately once a month. The data is collected at 10 different points on the transmission. [16] [19] At these points the sensor collects three different types of measurments, RV, LV and HF. RV measurments are velocity measurments [20] in “mm/s”. This is normaly measured to identify problems suck as unbalance, misalignment and looseness. LV measurments are done in “gE” and er done to identify faults in gearboxes and rolling element bearings. HF measurments measure the high frequensy sounds in “g” and give an indication for when damages start to occure.

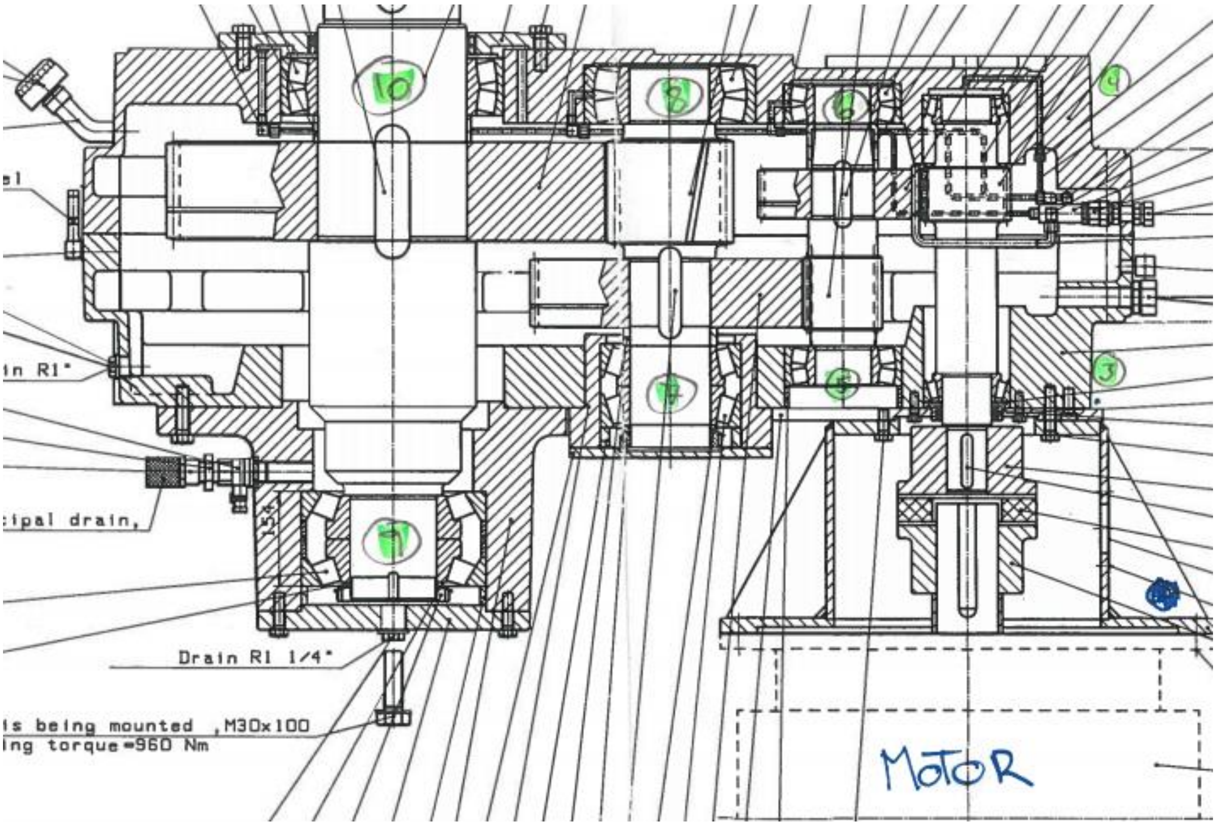

FIGURE 19 VIBRATION MEASUREMENT POINTS

Boliden Odda has provided the vibration data from two transmissions connected to reactor 1 and 6. The transmission from reactor 1 had a breakdown on the 23th of April in 2010. That breakdown happened 9 years ago and is a good example of an early breakdown. Vibration data from the 2010 breakdown is compared with a more resent breakdown of the transmission on reactor 6. That breakdown happened on the 7th of April in 2016. Data from a couple of months before and after the breakdown are compared to determine a base level value, increased values and an extreme value right before the breakdowns. The base level values are set to the green level on the scale. It indicates that the transmission is in good condition and can continue to run as usual, if the vibration values go above the base level it indicates that something is happening in the transmission and it is in need of more thorough inspection and more frequent vibration readings, this is set as the amber level on RAG-system. If the vibration readings go above the amber level it indicates that a breakdown is immanent in the near future and a thorough inspection and disassembly is needed to find the fault before a breakdown occurs.

6.3 – The vibration analysis

The analysis was done by comparing the vibration data before and after the breakdowns. An example of such an analysis of the measurement point and type 02-MH-RV is shown below. The rest of the analysis is shown in appendix 3,4 and 5.

First a base level is set by looking at the data values after the breakdowns and finding a normal operating range, in the case of 02-MH-RV that level is set to 0.7-1.2 mm/s. This is set to the green level in the RAG- system. Then the data from before the breakdowns are analyzed. The breakdowns are marked with a vertical line in the graphs. The extreme data points are found, and the red level of the RAG-system is determined by picking a value that is a below the extreme points before the breakdowns. The data shows that 1.52 and 1.43 were the extreme points before the reactor 1 breakdown. These values were exceeded before the reactor 6 breakdown, that is why 1.4 was chosen as the red threshold value for 02-MH-RV. The range between 1.2 and 1.4 was set to the amber level as these are above the normal operating range yet not high enough to be considered an imminent danger.

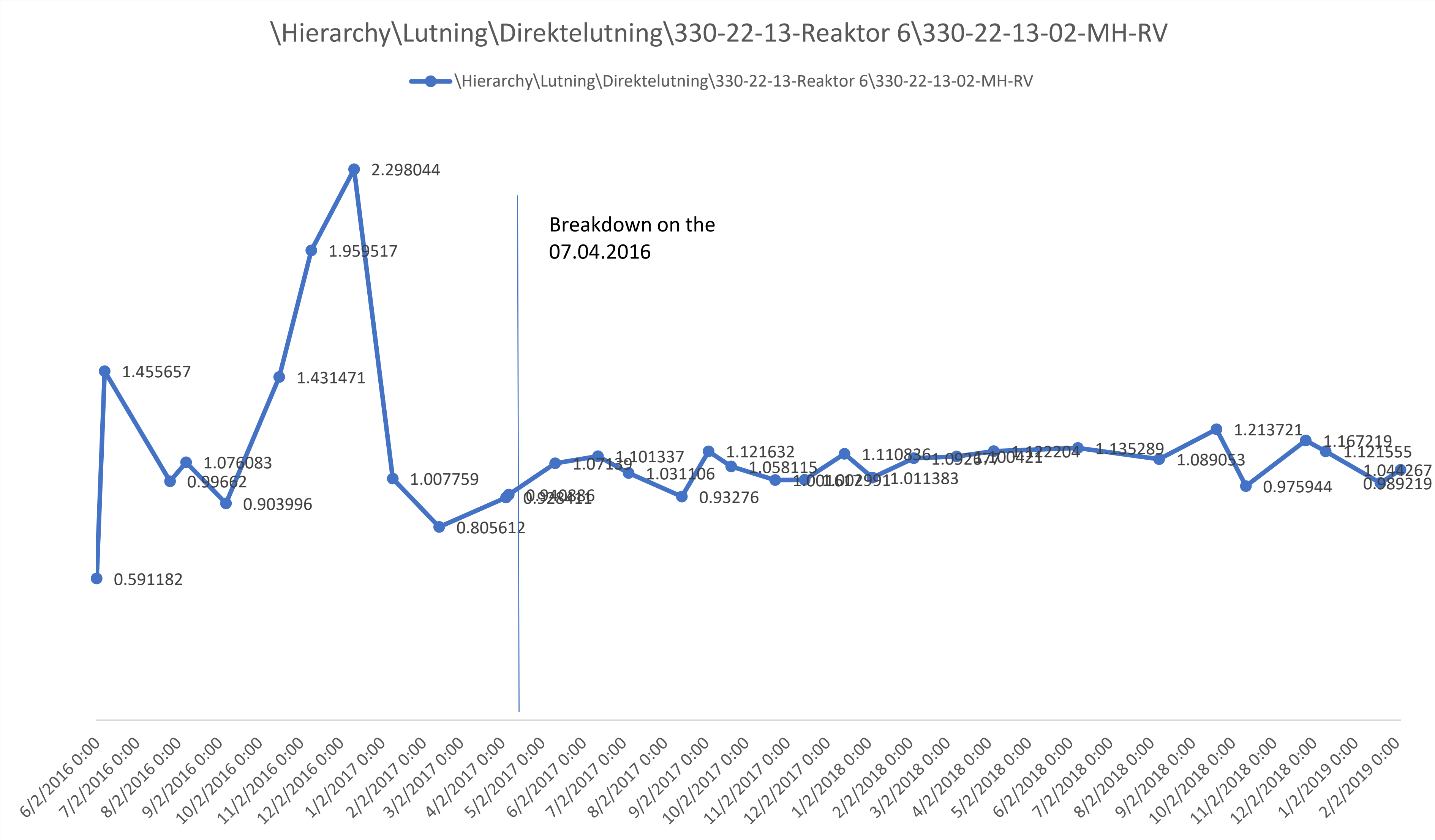

FIGURE 20 VIBRATION DATA POINT 02-MH-RV REACTOR 6

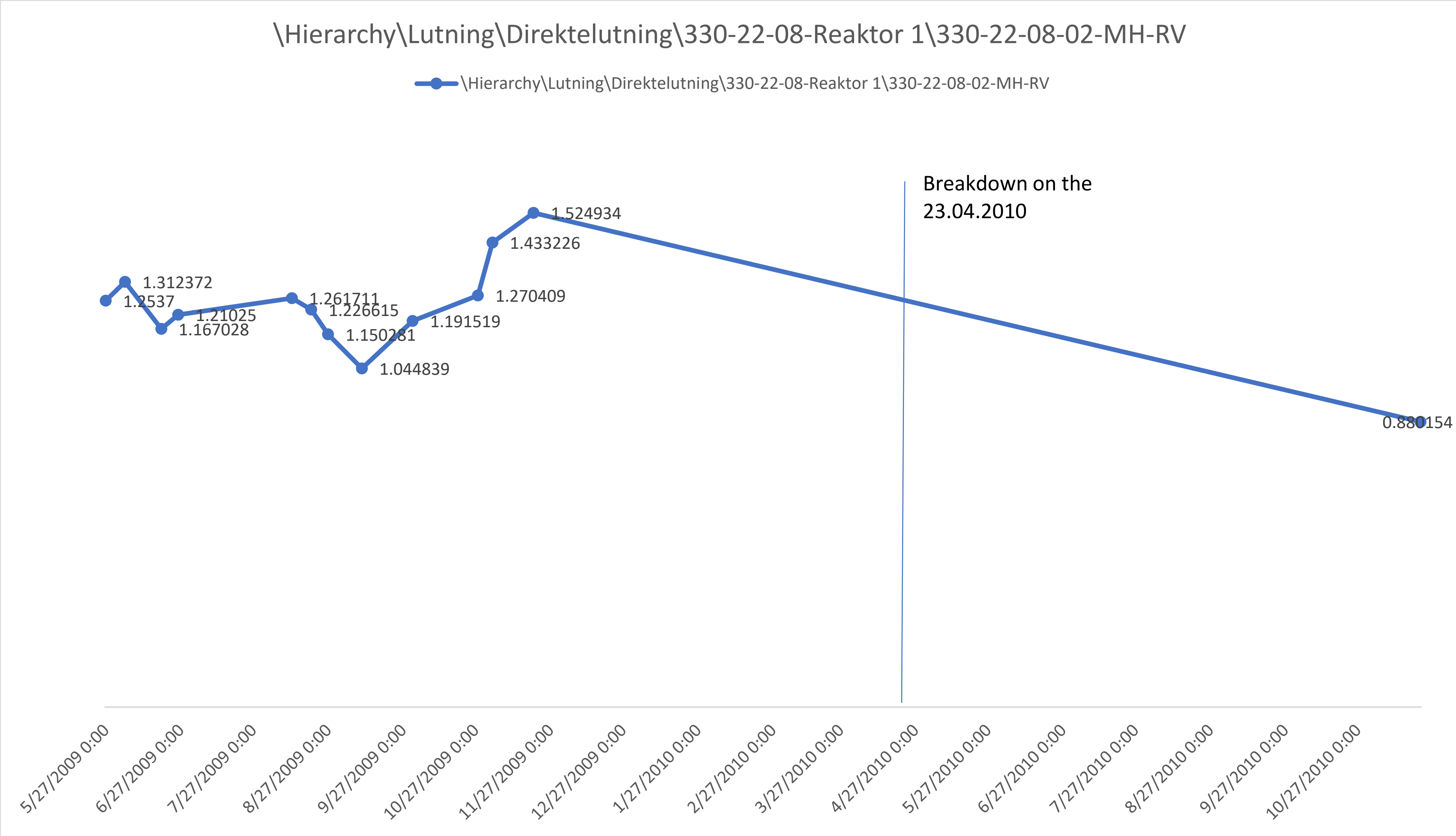

FIGURE 21 VIBRATION DATA POINT 02-MH-RV REACTOR 6

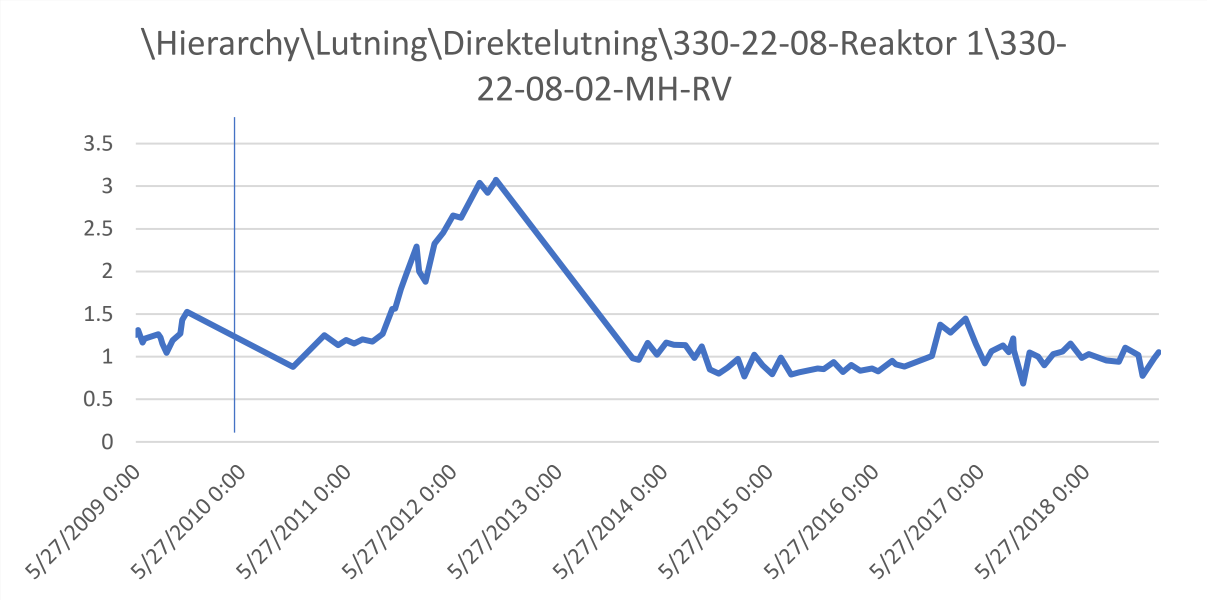

FIGURE 22 VIBRATION DATA POINT 08-MH-RV REACTOR 1

6.4 – Results from the vibration analysis

Below you can see the different vibration read points, types and values that were chosen based on the comparison between the transmission breakdowns. If no patterns or similarities were found between the breakdowns that read point and type is marked out grey.

Read point and type	Green	Amber	Red
01-MH-RV	<2.2	2.2-2.5	>2.5
01-MH-LV			
01-MH-HF			
02-MH-RV	<1.2	1.2-1.4	>1.4
02-MH-LV			
02-MH-HF			
03-GH-RV			
03-GH-LV	<0.3	0.3-0.5	>0.5
03-GH-HF	<0.8	0.8-1	>1
04-GH-RV	<1	1-1.2	>1.2
04-GH-LV			
04-GH-HF	<0.6	0.6-0.8	>0.8
05-GH-RV	<1	1-1.2	>1.2
05-GH-LV			
05-GH-HF	<2	2-2.5	>2.5
06-GH-RV	<0.6	0.6-0.8	>0.8

06-GH-LV	<0.6	0.6-0.8	>0.8
06-GH-HF	<1.5	1.5-2	>2
07-GH-RV	<0.7	0.7-0.8	>0.8
07-GH-LV	<0.2	0.2-0.3	>0.3
07-GH-HF	<0.2	0.2-0.4	>0.4
08-GH-RV			
08-GH-LV	<0.5	0.5-0.8	>0.8
08-GH-HF	<0.4	0.4-0.6	>0.6
09-GH-LV	<0.1	1-1.15	>1.15
09-GH-HF	<0.04	0.04-0.06	>0.06
10-GH-LV	<0.1	0.1-0.14	>0.14
10-GH-HF	<0.01	0.01-0.2	>0.2

TABLE 13 VIBRATION MEASUREMENT RAG-RATING

Chapter 7 - Summary conclusion of the results

This chapter will summaries the results and draw a conclusion based on them.

The results that appear in this report by using FMECA and risk assessment, is that it is 1 component that should be prioritized in the preventive maintenance program, which is the transmission.

The results of the analysis of the vibration measurements show that predictive maintenance using conditioning monitoring shows patterns that make it possible to see when the transmission is failing. This means it`s possible to predict shutdowns on direct leaching reactors by using Industry 4.0 in the future by implementing vibration sensors that measures continuously.

The conclusion is that industry 4.0 can be implemented with condition monitoring from vibration sensors that measures high frequency, acceleration enveloping and velocity on the components el-engine and the transmission.

Further work will be to use other methods within industry 4.0 to analyze the measurements, such as Machine Learning. In addition, by analyzing previous shutdowns from which component failed, one can find out which measurements and measurement points should be looked at for the various failure modes on the different components.

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OKTOP® direktelutningsreaktor

Beskrivelse av utstyret

Dok. nr. DQ150145/090/14/867/09014867311R0, norsk 2015

Sustainable use of
Earth's natural resources

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Status:	Originalstørrelse:
Kunde: Boliden Odda AS.	Prosjektfase: / Anleggsnr.:
Prosjektnavn: P200-prosjekt (Boliden Odda)	
Erstattet av:	Erstatter:
Outotec / Utstyrsnr: / Enhetsnr:	Dokumenttittel: BESKRIVELSE AV UTSTYRET OKTOP® DIREKTELUTNINGSREAKTOR

○ Originalinstruksjoner ◉ Oversettelse av originalinstruksjonene

Språk: NO

Innhold

1 Beskrivelse av utstyret

Navneplatene på OKTOP® direktelutningsreaktor er plassert på siden av tanken og i agitatorenheten.

Figur 1. Navneplate på OKTOP® direktelutningsreaktor

Tankens navneplater har følgende informasjon:

Tabell 1. Navneplate for tank-ID 330-22-12

Kolonneoverskrifter i OT-tabell	Kolonneoverskrifter i OT-tabell
PRODUSERT AV	OUTOTEC (FINLAND) OY RAUHALANPUISTO 9 02230 ESPOO FINLAND
FABRIKERT AV	VIAFIN TERÄSTORNI OY MUUKONKANKAANTIE 113 53400 LAPPEENRANTA FINLAND
KONSTRUKSJONSSTANDARD	EN 13445 / EN 1993
PRODUKSJONSÅR	2016
IDENTIFIKASJONSMERKE FOR TANK	330-22-12

Kolonneoverskrifter i OT-tabell	Kolonneoverskrifter i OT-tabell
SERIENUMMER FOR TANK	N031036369
FYLLINGSGRAD	1. 44 kg/l
INDRE VOLUM	944 m3
HØYESTE TILLATTE TEMPERATUR	105 ºC
LAVESTE TILLATTE TEMPERATUR	- 15 ºC
MAKSIMALT TILLATT TRYKK	20 mbar
EMBALLASJEVEKT	63 000 kg

2 Formål

OKTOP direktelutningsreaktor er en modulær løsning for ekstrahering, utfelling og metallgjenvinning. Reaktorene er alltid en skreddersydd løsning for en bestemt prosess. Du finner mer informasjon i *driftshåndboken for prosess*.

⚠ **FORSIKTIG**

Det er strengt forbudt å bruke reaktoren på en annen måte eller til et annet formål enn det som fremgår av denne instruksjonshåndboken og de tilknyttede vedleggene. Dette inkluderer streng overholdelse av de definerte nominelle verdiene for drift, som ikke skal overstiges.

Reaktorene er ment for automatisk bruk, men du kan også styre dem manuelt eller bruke dem i halvautomatisk modus. Driften kan styres eksternt fra et kontrollrom.

OKTOP direktelutningsreaktor er ment for kontinuerlig drift. Hvis du har et anlegg med flere reaktorer forbundet med vaskere, kan du forbikoble en enkelt reaktor i prosessen for vedlikehold og likevel holde prosessen gående.

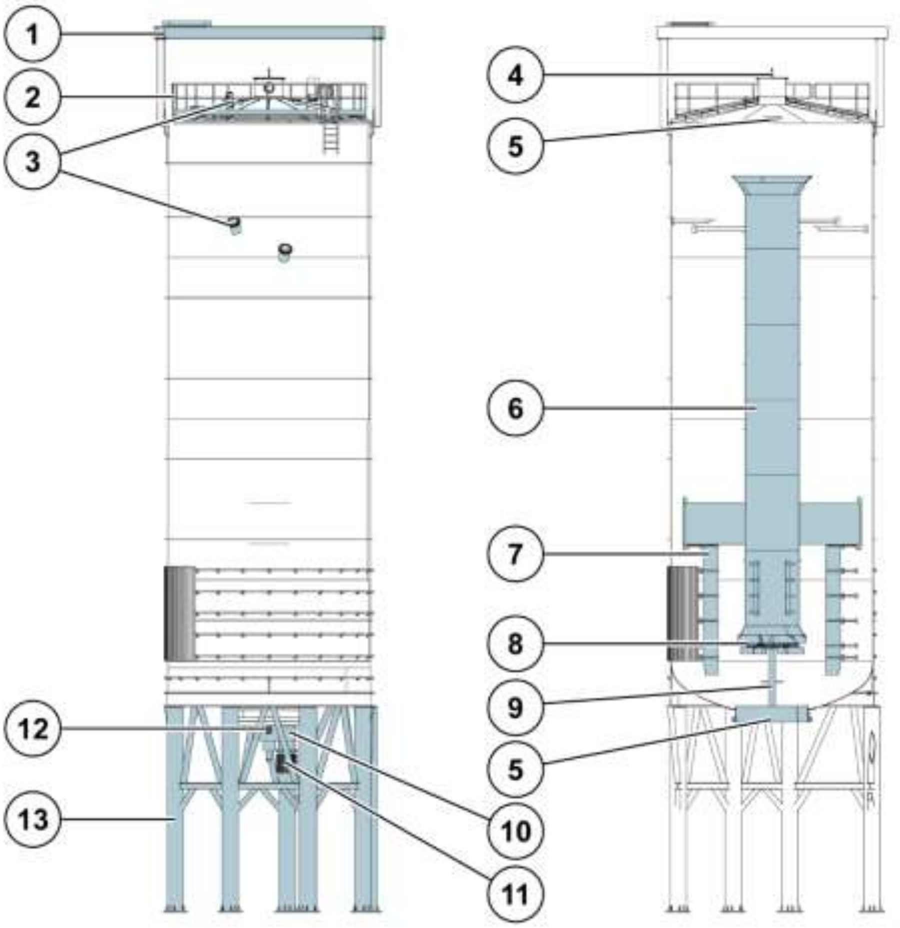
⚠ **FORSIKTIG**

Installering, drift og vedlikehold av OKTOP direktelutningsreaktor skal kun utføres av fagfolk som har relevant opplæring.

3 Hovedkomponenter

Reaktorer er alltid spesifikke for den enkelte leveransen. Størrelsen på reaktoren og de enkelte komponentene kan variere. Dette dokumentet beskriver en typisk reaktorenhet.

Figur 2 illustrerer OKTOP direktelutningsreaktorens hovedelementer.



Figur 2. OKTOP® direktelutningsreaktorens hovedelementer

1. *Løftebjelke for agitator*
2. *Rekkverk*
3. *Dyser for prosessflyt og instrumentering*
4. *Mannhull M2*
5. *Mannhull M1*
6. *Uttrekksrør*
7. *Panel*
8. *Impeller*
9. *Agitatorskaft*
10. *Gir*
11. *Motor*
12. *Oksygeninntak*
13. *Tankens støttestruktur*

Vær oppmerksom på at reaktoren kan avvike fra den som er vist, for å inkludere spesifikke funksjoner og alternativer.

Prosjekt-ID:	Anleggskode:	Anleggsenhetskode:	Dokumenttype:	Kjørenr.:	Revisjon:	Outotecs dokument-ID:
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3.1 Agitatorenhet

En typisk agitatorenhet består av følgende komponenter:

- El-motor
- Gir
- Enhet for smøring av eksternt gir
- Agitatorskaft og impellere
- Mekanisk tetning

3.1.1 El-motor

El-motoren dreier agitatorskaftet gjennom giret.

3.1.2 Gir

Giret sørger for at agitatoren dreies med ønsket hastighet og dreiemoment.

3.1.3 Enhet for smøring av eksternt gir

Giret smøres av en ekstern smøreenhet. Smøreenheten sirkulerer og kjøler ned giroljen.

3.1.4 Agitatorskaft og impellere

Formen på impelleren og bladene er alltid applikasjonsspesifikke. Ulike prosesser krever spesialblandemønstre som oppnås med ulike impellerformer.

Impellerenes materialer og eventuelle belegg skal alltid velges i samsvar med prosesskravene.

3.1.5 Mekanisk tetning

Skaftet på agitatoren tettes med en mekanisk tetning. Du finner mer informasjon i produsentens håndbok.

3.2 Tankenhet

Tanken kan være laget av stål eller av forsterket glassfiberplast (FRP).

Tanken kan være utstyrt platepaneler, dyser, mannhull og et inspeksjonshull.

Tankenheten rommer væsken som skal blandes. Tanken er laget for å motstå prosessforholdene og gi pålitelig strukturell integritet. Tankpanelene, bunnformen og høyde-bredde-forholdet justeres for å oppnå det best mulige prosessresultatet.

3.2.1 Oksygeninntak

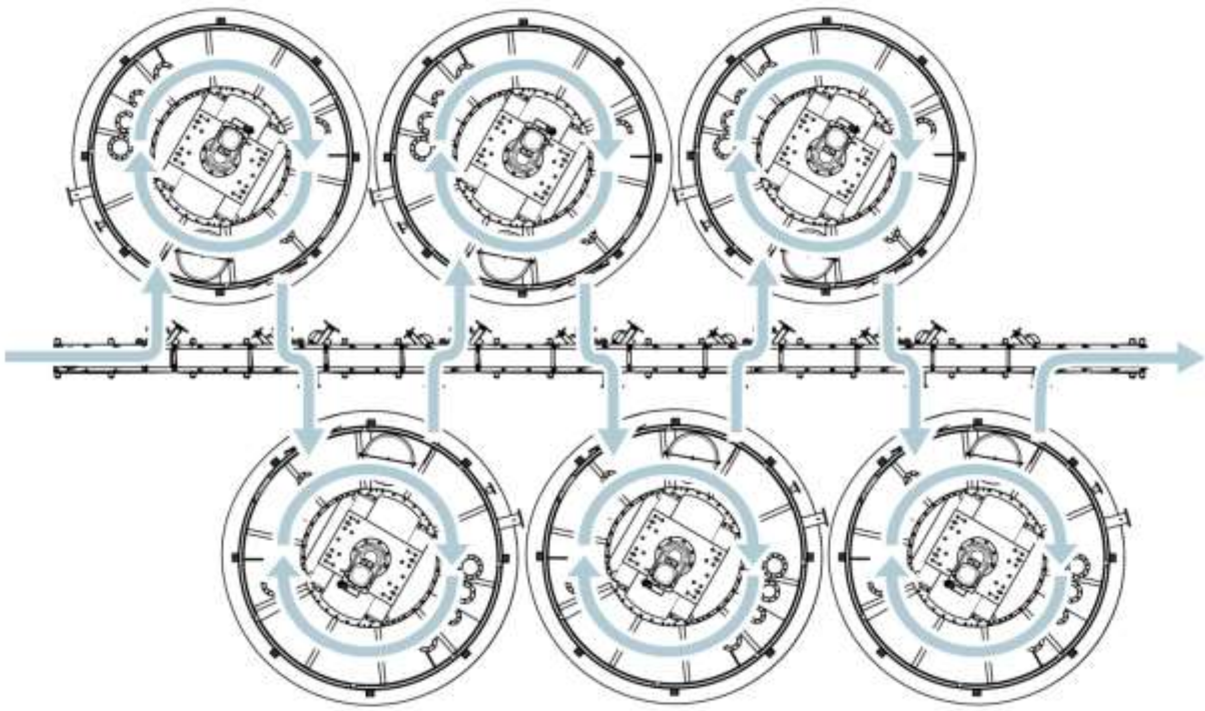
Oksygen mates inn i reaktoren gjennom oksygeninnmatingsrøret. Oksygeninntaket er i agitatordysen.

3.2.2 Paneler

Tanken er alltid utstyrt med paneler. Panelene styrer strømmen inne i tanken, slik at det ønskede blandemønsteret oppnås. Panelene hindrer også at det dannes en farlig virvel øverst i tanken.

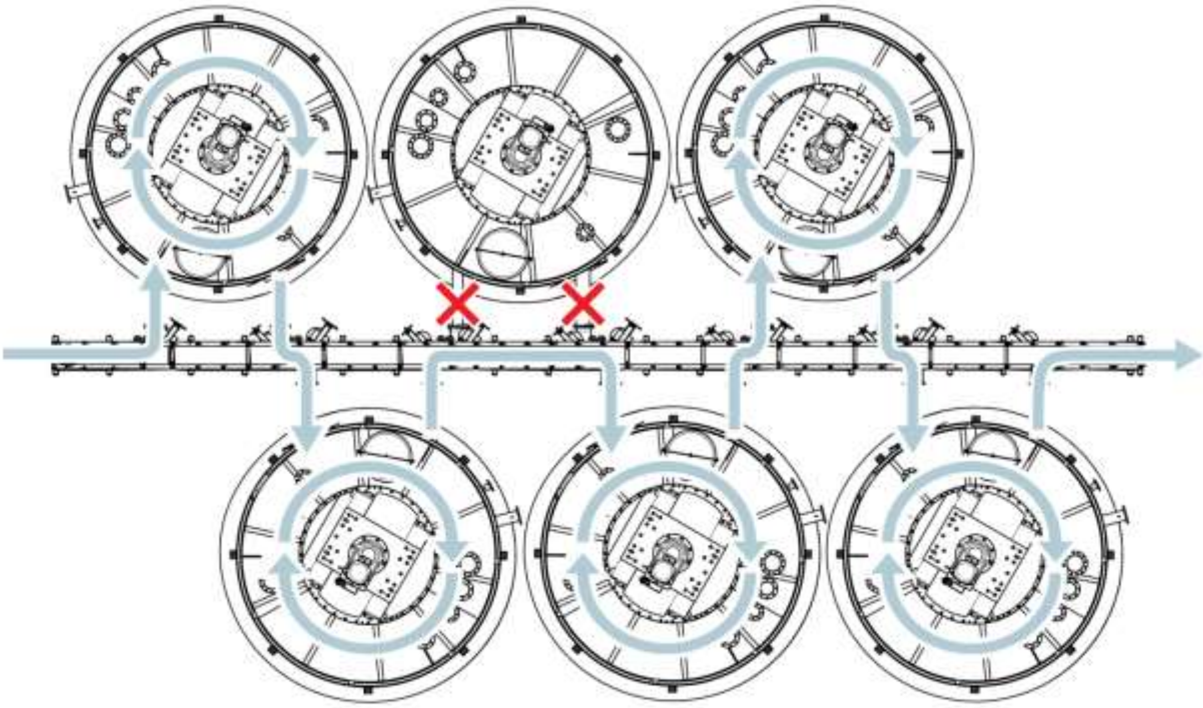
3.3 Vaskere

Vaskerne er en valgfri komponent for anlegg med flere reaktorer. Med vaskerne kan du isolere en reaktor fra prosessen, for eksempel hvis det skal utføres vedlikehold. Figur 3 illustrerer hvordan prosesslurryen strømmer gjennom reaktorene.



Figur 3. Reaktorer og vaskere

Figur 4 illustrerer forbikoblingen av en reaktor. Du finner instruksjoner om forbikobling av en reaktor under *Drift*.



Figur 4. Forbikoble en reaktor

4 Produktendringer

Endringer på OKTOP direktelutningsreaktoren er ikke tillatt uten Outotecs tillatelse under garantiperioden. Alle tillegg eller endringer som utføres uten Outotecs skriftlige tillatelse, vil ugyldiggjøre garantien. Etter at produktgarantien har utløpt, er ikke Outotec juridisk ansvarlig for eventuelle tillegg eller endringer som gjøres på maskinen.

Ethvert system som kobles til OKTOP direktelutningsreaktoren, må avtales med Outotec.

MERK: Outotec forbeholder seg retten til å foreta tekniske forbedringer som kan avvike fra informasjonen i dette dokumentet.

Outotec Sustainable use of Earth's natural resources

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OKTOP® direktelutningsreaktor

Vedlikehold

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Sustainable use of
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Kunde: Boliden Odda AS.	Prosjektfase: / Anleggsnr.:
Prosjektnavn: P200-prosjekt (Boliden Odda)	
Erstattet av:	Erstatter:
Outotec	Dokumenttittel: VEDLIKEHOLD OKTOP® DIREKTELUTNINGSREAKTOR
Utstyrsnr: / Enhetsnr:	

○ Originalinstruksjoner ◉ Oversettelse av originalinstruksjonene

Språk: NO

Innhold

1 Sikkerhet under vedlikehold

Kunnskap om grunnleggende sikkerhetsinstruksjoner er en forutsetning for sikker håndtering og vedlikehold av OKTOP® direktelutningsreaktoren. Hvis du ignorerer sikkerhetsinstruksjonene, kan det føre til alvorlige eller til og med dødelige skader. Dette dokumentet inneholder viktig informasjon for sikker utføring av vedlikeholdsarbeid på tankutstyret.

- Du må lese og gjøre deg forstått med alle sikkerhetsinstruksjoner før du setter i gang med vedlikeholdsarbeid.
- Vedlikehold av reaktorutstyret må bare utføres av opplært og kvalifisert personell.
- Følg sikkerhetsforskriftene angående lukkede rom ved arbeid inne i reaktoren.
- Sørg for at utstyret er isolert fra prosessen, før du starter vedlikeholdsarbeidet.
- Legg merke til at det nasjonale lovverket kan kreve at en *navngitt bruker* med overordnet ansvar må oppgis for reaktoren. Den *navngitte brukeren* av reaktoren må utnevnes, og Outotec må få melding om navnet på personen før tanken kan tas i bruk. Denne personen er ansvarlig for alt arbeid som utføres på OKTOP direktelutningsreaktoren, for eksempel sørge for at tankdrift, vedlikehold og opplæring av personell utføres på riktig måte. Den *navngitte brukeren* må være klar over ansvarsområdene som kreves av det nasjonale lovverket og de lokale myndighetene.
- Under vedlikehold må en generell inspeksjon angående sikkerhet utføres etter regelmessige intervaller.
- Når det gjelder stillaser, må du skaffe til veie en gyldig tillatelse før de kan tas i bruk. Tillatelsen må indikere oppførselsdato for stillaset, kontroller, mål, bærekapasitet og ansvarlig autoritet.
- Alt løfteutstyr, som for eksempel kraner, stropper, kjeder, vaiere og kroker, må være godkjent, overholde forskrifter og sikkerhetsfaktorer, ha tilstrekkelig løftekapasitet og være i god tilstand.
- Ved arbeide inne i reaktoren er pneumatiske anordninger å foretrekke. Elektriske anordninger kan også brukes, så lenge de er jordet forskriftsmessig.
- Les gjennom dokumentet *Sikkerhet* før du setter i gang med vedlikeholdsarbeidet.

⚠ ADVARSEL

Før du tømmer en lukket reaktortank, må du forsikre deg om at dette ikke vil føre til undertrykk i tanken, siden dette igjen kan føre til bulker på tanken. Du kan for eksempel åpne inspeksjonsluken på reaktortaket for å sørge for tilstrekkelig ventilasjon under tømming.

FARE

Du må ikke åpne mannhullet eller inspeksjonsluken på reaktoren før nødvendige sikkerhetsforholdsregler er på plass, siden gasskammeret i reaktoren kan inneholde giftige gasser. Du finner forskriftsmessige sikkerhetsprosedyrer i sikkerhetsdokumentasjonen for anlegget.

FARE

Ikke bruk midlertidige deksler eller annen uekte beskyttelse i luker eller mannhull. Alle åpninger må lukkes med det aktuelle dekselet. Hvis de må være åpne, må de beskyttes.

FARE

Du må ikke gå inn i reaktoren før den er tømt totalt og har samme temperatur som omgivelsene.

Før alt vedlikeholdsarbeid må reaktoren luftes godt ut, og gassmengdene i reaktoren må måles for å kontrollere at det er sikkert å gå inn i den. I mange tilfeller kan det være påkrevde med spesielt sikkerhetsutstyr. Se i sikkerhetsdokumentasjonen for anlegget og være oppmerksom på alle faremomenter før **du fortsetter.**

Vask tanken før alt vedlikeholdsarbeid.

Det er strengt forbudt å utføre vedlikeholdsarbeid alene inne i reaktoren.

FARE

Sikkerhetsbryteren må stå i åpen posisjon og være låst med en hengelås før du begynner med vedlikeholdsarbeidet.

FARE

Det er fare for elektrisk støt når du kobler fra en strømførende motor under vedlikehold. Slå av sikkerhestsbryteren på den elektriske motoren og lås den med en hengelås, før du kobler fra den elektriske motoren. Du finner sikkerhetsbryteren for motoren i MCC.

⚠ FORSIKTIG

Vær oppmerksom på glatte flater når du utfører vedlikeholdsarbeid. Alle flater må rengjøres før vedlikeholdsoperasjoner kan utføres.

⚠ ADVARSEL

Marker impelleren med advarselsteip når du arbeider inne i tanken.

⚠ FARE

Operatørene må være varslet om detaljene om og varigheten av vedlikeholdsoperasjonen. Før driften gjenopptas, må operatørene gis en skriftlig melding om at vedlikeholdsarbeidet er utført.

⚠ FARE

Elektrisk fare. Kun autorisert personell har tillatelse til å betjene strømskapet. Isolasjonen må måles før vedlikeholdsoperasjoner kan utføres.

1.1 Personlig verneutstyr

Alle lokale helse- og sikkerhetsforskrifter angående personellets verneutstyr må overholdes. Dette kapitlet beskriver bare anbefalinger for personlig verneutstyr for reaktorområdet. Følg anleggets anbefalinger for personlig verneutstyr for andre prosessområder i anlegget.

Ved arbeid inne i reaktorens utstyrsområde, må du som et minimum bruke beskyttende verneklær som tåler syre, sikkerhetshansker, hjelm, hørselvern, vernebriller og vernesko med ståltupp. Du må kanskje også bruke en beskyttende hodemaske (sjekk filtertypen fra utstyrsleverandøren), et sikkerhetsvisir som vern mot sprut, og ha på deg gassmaske i reaktorområdet.

⚠ FARE

Bruk alltid egnet personlig verneutstyr under arbeid inne i anleggsområdet.

Tabell 1. Personlig verneutstyr

Symbol	Forklaring
	Bruk hodebeskyttelse med eget lys.
	Bruk vernehansker.
	Bruk vernesko.
	Bruk beskyttende klær: hele, tettsittende overaller som tåler flammer og syre.
	Bruk hørselsvern.
	Bruk vernebriller.
	Bruk åndedrettsvern i henhold til prosesskravene.
	Bruk sikkerhetssele.
	Bruk en lett synlig vest.

Symbol	Forklaring
	Bær med deg en gassdetektor, i henhold til prosesskravene.
	Sørg for at det er et førstehjelpssett i nærheten.
	Ta med deg en kommunikasjonsenhet.
	Ha med deg en nødoksygentank i henhold til prosesskravene.

For miljøer som er definert som farlige på forhånd, og/eller omgivelser med lite oksygen, kan det være nødvendig å bruke en hel vernedress med en nødoksygentank.

Bruk sikkerhetssele når du arbeider på steder der det er fare for å falle ned. Tankene kan ha åpne flenser eller andre åpninger under vedlikehold.

MERK: Sluttbrukeren er ansvarlig for å stille nødvendig personlig verneutstyr til disposisjon for de ansatte. Outotec sørger ikke for det personlige verneutstyret.

2 Før vedlikehold

2.1 Forberedelser

Forhold på stedet:

- En forskriftsmessig arbeidsplan må ha blitt laget og tilstrekkelig opplæring sørget for, før vedlikeholdet kan starte.
- Kontroller at det er nok ventilasjon og belysning i vedlikeholdsområdet.
- Lag til sikre og tydelig markerte tilkomstruter til vedlikeholdsområdet, slik at de ikke går under en løftet last. Annet materiale må være fjernet fra disse rutene.
- Marker vedlikeholdsområdet godt.
- Sørg for at du har nødvendig og godkjent løfteutstyr og verktøy tilgjengelig.
  - Legg merke til at elektrisk verktøy som brukes i tanken, må være jordet.

⚠ FORSIKTIG

Bruk bare egnet verktøy for deler i titanium og rustfritt stål, for å unngå forurensning.

- Vedlikeholdsoppgaver må ikke utføres i ekstreme temperaturer eller under tøffe værforhold. Vær nøye med sikkerhetsutstyret.
- Legg merke til at tanken kan inneholde syreholdige stoffer.
- Legg merke til at tanken kan inneholde farlige gasser.

Ansvarlig person for vedlikeholdet:

- Kontroller at personellet har riktige arbeidstillatelser, for eksempel tillatelse til å utføre varmearbeid.
- Følg anleggets egne vedlikeholdsprosedyrer for sikkert vedlikeholdsarbeid.
- Legg merke til at vedlikeholdet må utføres med team på minst to personer. Personene må hele tiden ha øyekontakt med hverandre eller holde kontakten over en radio med hodetelefoner.
- Ved løfting for hånd må lokale spesifikasjoner og instruksjoner overholdes.
- Klargjør og planlegg en vedlikeholdsplan.
- Informer operatørene om følgende:
  - Ulike arbeidsfaser
  - Adgang til og utgang av vedlikeholdsområdet
  - Midlertidige rør eller elektriske linjer

Myndigheter:

Sjekk alle lokale krav som kan virke inn på planlegging og utførelse av vedlikeholdsarbeid.

MERK: Kontakt Outotec for mer informasjon om både vedlikehold og reservedeler. Se også avsnittet Tjenester og reservedeler.

2.2 Handlinger før oppstart av vedlikeholdsarbeidet

Legg merke til følgende før start av alt vedlikeholdsarbeid:

- Identifiser alle fareområder som skal kontrolleres.
- Følg anleggets og andre lokale forskrifter for isoleringsmetoder og -nivåer.
- Se utformingen av rør og instrumenter for informasjon om hvordan du isolerer tanken fra den spesifikke prosessen.
- Klargjør en isoleringsplan som inkluderer identifikasjon og klargjøring av utstyret som er involvert i oppgaven, og andre områder av anlegget som kan være aktuelle. Virkningene av isoleringen må være tydelig forstått og formidlet videre.
- Isoler motoren og instrumentene fra det elektriske nettet. Det elektriske utstyret må være låst og merket.
- Prøv å starte opp utstyret for å teste ut integriteten og effektiviteten til isoleringene.
- Isoler vedlikeholdsområdet, og informer alt personell i området om vedlikeholdsarbeidet.
- Gjør følgende før du går inn i reaktortanken:
  - Tøm, kjøl ned, spyl og ventiler reaktoren på forskriftsmessig måte.
  - Spyl ut de farlige substansene fra systemet.
  - Sørg for at det er tilstrekkelig ventilasjon under arbeidet.
  - Alt personell må være enige om felles prinsipper ved en nødsituasjon.
  - Sørg for at sikkerhetsutgangene er åpne og fri for hindringer hele tiden så lenge arbeidet pågår.
  - Kontroller at sprinkleranlegget fungerer til enhver tid, og at sprinklene ikke er for langt unna.
  - Kontroller at det er sikkert å gå inn i maskinen, for eksempel med en oksygenmåler og en flergassmåler.
  - Ha alltid på deg en nødmaske når du arbeider i reaktorområdet.
- Ikke gå inn i reaktoren alene. En sikkerhetskontrollør er alltid påkrevet.
  - Sikkerhetskontrollør er en person som er til stede utenfor tanken og som kan utløse en alarm i en eventuell nødssituasjon.
  - Kommunikasjonsprinsipper og nødsituasjoner må være gjennomgått med sikkerhetskontrolløren før du går inn i tanken.
- Anleggets egen veiledning for vedlikeholdsarbeid må gjennomgås før du går inn i tanken. Dette kan for eksempel være handlinger ved et nødsfall, plassering av røykdykkerutstyr og fluktruter.

⚠ FARE

Når du skal tømme en lukket tank, må du kontrollere at luftelinjen er helt åpen før du starter uttappingen. Undertrykk kan få tanken til å presses sammen.

3 Adgang til reaktoren for vedlikehold

Løft tunge objekter gjennom toppen, ved å bruke takinngangen. Dermed kan en lokal, overhengende kran brukes, noe som minimerer løftingen fra personellets side. Tilgang gjennom mannhullet passer for lettere objekter, for eksempel belysning og lette stillasdeler. Ved løfting av tunge objekter må sikkerheten være i fokus. Når du lager løfteplaner, må du legge merke til at den innvendige diameteren i mannhullet ikke nøyaktig den samme som standardstørrelsen det er referert til i tegningen. For DN700-mannhullet, som åpnes fra innsiden av tanken, er den maksimale bredden på objekter som kan sendes gjennom, på 618 mm.

⚠ FORSIKTIG

Når du løfter materiale inn i tanken, må personellet inne i tanken være oppmerksomme på det innkommende materialet. Avgrens løfteområdene, slik at det ikke er fare for at objekter faller ned på personellet.

⚠ FORSIKTIG

Når du løfter materiale inn i tanken, må du være forsiktig så du ikke treffer veggene i tanken, panelene eller agitatoren. FRP-tanker, malte tanker og tanker med gummikledning er spesielt ømfintlige for slag fra skarpe objekter, for eksempel endene på stillasbjelker.

Objekter må ikke støttes på gassinnløpsrøret inne i reaktoren, hvis et slikt før finnes.

⚠ FARE

Risiko for å falle. Hvis inspeksjonsluken, slepeluken eller agitatorflensen er åpen, må den markeres tydelig og utstyres med et vern eller rekkverk, for å unngå at personellet faller ned. La ikke inspeksjonsluken eller slepeluken stå åpen ubevoktet og uten at de er i bruk.

Når du løfter materiale inn i tanken, må du beskytte bunnen fra slag under arbeidet:

- I en flatbunnet tank må du legge et beskyttende teppe eller lignende for å beskytte materialet fra skader.
- For en kuppeltank må du oppføre et stillas for å få en jevn arbeidsflate.

3.1 Tilgang til en lukket reaktor

Hvis vedlikeholdet av reaktoren krever at du må ha stillas eller stiger inne i reaktoren, kan følgende inngangspunkter brukes:

- Mannhullet på taket av tanken.
- Inspeksjonsluken på taket av tanken

4 Planlagt vedlikehold

Hvor ofte hver oppgave må utføres, avhenger av stedet og prosessbetingelsene, men utstyret må uansett inspiseres visuelt daglig. Operatørene må utføre ytterligere inspeksjoner under sine regelmessige runder i anlegget. Etter inspeksjonene må feil eller potensielt uvanlige virkemåter ved maskinen rapporteres.

Det anbefales å inspisere utstyret etter en forhåndsdefinert plan, minst én gang i uken. Denne inspeksjonen utføres uten å stoppe maskinen, og kan blant annet inkludere følgende:

- Se etter spor på feiljustering, overoppheting og unormale lyder.
- Måling av vibrasjoner i lagre og giret med en egnet, håndholdt vibrasjonsmåler.

Maskinen må stanses og tømmes for en mer komplett inspeksjon etter en forhåndsdefinert plan, omtrent hvert halvår.

Vær spesielt oppmerksom når du inspiserer tilstanden til følgende elementer, og om de er ordentlig festet:

- Agitatoren og eventuell kledning
- Avsetningsdannelse
- Drivenhet
- Nivåkontrollventiler
- Tank
- Agitatorens støttestruktur
- Mekanisk tetning

Du kan finne standardelementer for planlagt vedlikehold i tabellene nedenfor. Denne informasjonen kan brukes som et utgangspunkt ved planlegging av de faktiske vedlikeholdsplanene på stedet.

MERK: Vedlikeholdsintervallene må tilpasses i henhold til anleggsbetingelsene. Anbefalt maksimalt intervall er tolv måneder.

⚠ FORSIKTIG

Alle manuelle ventiler i innmatingsrørene må være lukket, og rørene må være forseglet med blindskiver før vedlikeholdsarbeid på reaktoren.

Hvis vaskere er koblet til OKTOP direktelutningsreaktorenheten, kan du se *driftshåndboken* for instruksjoner om forbikobling av en reaktor.

MERK: Impelleren er en slitasjedel. Komponentbladene slites ut før det oppstår mekaniske feil på dem. Levetiden avhenger av slurryegenskapene (kjemisk og nedsliping). Vedlikeholdsintervallet må være definert i henhold til prosessen.

MERK: Les nøye gjennom dokumentene fra den opprinnelige utstyrsfabrikanten for instruksjoner om vedlikehold av drivenheten og girkassen.

MERK: Reparasjoner på utstyr av forsterket glassfiberplast (FRP) må bare utføres av en profesjonell laminatarbeider med adekvat kompetanse og kunnskap om materialer, herding og konstruksjonsmetoder. Kompetansen må minst være på nivå med standarden EN 13121-3.

Beskytt FRP-delene hvis det utføres varmearbeid i nærheten.

MERK: Kledningen på agitatorskaftet kan bare repareres av en person som er kjent med alle de nødvendige prosedyrene og med utformingen av agitatoren.

⚠ ADVARSEL

Det er fare for å snuble når du åpner lukene for vedlikehold. Plasser ut sikkerhetsinnretninger, eller marker lukene med advarselsteip når lukene er åpne.

4.1 Første vedlikehold etter installasjon

Utfør det første vedlikeholdet etter 500 timer med drift. Dette er den viktigste vedlikeholdsprosedyren i reaktorens levetid.

Ved det første oljeskiftet, som utføres etter 500 timer med drift, må du utføre følgende vedlikeholdsprosedyrer:

- Sjekk og trekk til boltkoblingene mellom giret og agitatorflensen.
- Trekk til alle bolter i henhold til oppgitt moment.

4.2 Vedlikehold av tank og agitator

Tabell 2. Preventive vedlikeholdskontroller for agitatoren

Agitatorkomponent	Ukentlig	Hver måned	Hvert halvår	Årlig	Handlinger 1 = Sjekk, rengjøring og påfyll 2 = Bytt
Feiljustering	1				Se etter tegn på feiljustering
Unormal støy	1				Se etter tegn på unormal støy
Blader				1	Se etter betydelig avskalling eller slitasje
Kledning				1	
Fester				1	Sjekk alle boltkoblinger, inkludert støtten for agitatoren.
Skaft og skaftbøssinger					Se håndboken til produsenten av originalutstyret.
Mekanisk tetning					Se håndboken til produsenten av originalutstyret.
Tetningsvæskesystem					Se håndboken til produsenten av originalutstyret.
O-ringtetninger på flens					Se håndboken til produsenten av originalutstyret.
Rør for indikering av lekkasje					Se håndboken til produsenten av originalutstyret.
Løfteutstyr for agitatoren			1		Inspiser utstyret før bruk. Se håndboken til produsenten av originalutstyret.

Tabell 3. Preventive vedlikeholdskontroller for girenheten

Komponent i girenhet	Ukentlig	Hver måned	Hvert halvår	Årlig	Handlinger 1 = Sjekk, rengjøring og påfyll 2 = Bytt
Overoppheting	1				Se etter tegn
Vibrasjoner i lager og gir	1				Måling
Temperatur	1				

Komponent i girenhet	Ukentlig	Hver måned	Hvert halvår	Årlig	Handlinger 1 = Sjekk, rengjøring og påfyll 2 = Bytt
Oljenivå	1				
Boltkoblinger				1	
Boltkoblinger mellom giret og agitatorflensen.				1	Sjekk og trekk til boltkoblingene mellom giret og agitatorflensen. Sjekk under hvert oljeskift, eller minst én gang per år.
Lyder i drift				1	
Lekkasjer				1	
Skafttetninger				1	
Skjøteflater				1	
Oljeskift				2	
Bytte av oljefilter				2	
Bytte av luftepropp				2	
Tetninger med smørefett			1		Påfør smørefett
Tetthet i oljepumpen				1	
Tetthet i oljekjøleren				1	

Tabell 4. Preventive vedlikeholdskontroller for tanken

Komponent i tanken	Ukentlig	Hver måned	Hvert halvår	Årlig	Handlinger 1 = Sjekk, rengjøring og påfyll 2 = Bytt
Tegn på utvendige lekkasjer		1			
Avsetningsdannelse				1	
Nivåkontrollventiler				1	
Bro eller montasjestativ				1	Sjekk tilstand og feste

Komponent i tanken	Ukentlig	Hver måned	Hvert halvår	Årlig	Handlinger 1 = Sjekk, rengjøring og påfyll 2 = Bytt
Blåsebelg			1		
Oksygeninnmating		1			Se etter slitasje
Innvendig i tanken				1	Se etter slitasje og integritet.
Korrosjonsgrense (bare i ståltanker)				1	
Korrosjonsbarrierelag (bare i FRP-tanker)				1	

Tabell 5. Preventive vedlikeholdskontroller for motoren

Motorkomponent	Ukentlig	Hver måned	Hvert halvår	Årlig	Handlinger 1 = Sjekk, rengjøring og påfyll 2 = Bytt
Motorramme				1	Sjekk/rengjør
Luftstrøm				1	Sjekk at det er fri luftstrøm
Tetninger/v-ringer				1	
Tilkoblinger				1	Sjekk alle boltkoblinger
Lagre				1	Sjekk for støy og temperatur
Lagre		1			Påfør smørefett

4.3 Vedlikehold av vaskeren

MERK: Bytt alltid til nye tetninger under vedlikehold eller hver gang du åpner en dysekobling. Ikke bruk en gammel tetning.

⚠ **FORSIKTIG**

Bruk alltid forskriftsmessig verneutstyr når du utfører vedlikehold av vaskeren. Se etter lekkasjer, og unngå direkte hudkontakt med prosessløsningen.

Det anbefales å inspisere utstyret regelmessig. Utfør følgende inspeksjoner kontinuerlig mens systemet er i normal drift:

- Se etter lekkasjer.
- Trekk til alle løse bolter og muttere.
- Se etter vibrasjoner eller forskyvninger.
- Sjekk tilstanden til ekspansjonsskjøten visuelt.
- Sjekk at dekslene er brukt på riktig måte, når du sjekker bunnen av vaskeren.
- Hvis du har en FRP-vasker, må du se etter fargevariasjoner på overflaten.

Hvis det oppstår problemer, må du finne årsaken og løse problemet så snart som mulig. Ikke nøl med å kontakte Outotec hvis du har spørsmål eller problemer.

Hver sjette måned, eller hver gang en reaktor forbikobles, må du utføre en mer omfattende, forhåndsplanlagt inspeksjon av koblingslinjen mellom vaskeren og hver reaktor. Du må forbikoble en reaktor i henhold til driftsinstruksjonene for vaskeren, og utføre følgende inspeksjoner:

- Skift ut alle tetninger i koblingsrørlinjen mellom reaktoren og ventilene.
- Fjern all avskalling inne i ekspansjonsskjøten.
- Sjekk tilstanden til ekspansjonsskjøten når du snur blindplaten. Bytt den ut hvis du oppdager sprekker, deformasjoner eller andre skader.

Hvert andre år, eller når systemet er avstengt, eller når vaskeren er tømt ellers, må du utføre en forhåndsplanlagt inspeksjon av hele vaskeren. Blind innløpet til vaskeren, og kontroller at hele vaskeren er tom, og at løsningsnivået i reaktoren er på et sikkert nivå i forhånd til koblingsrøret. Se i *driftshåndboken* for instruksjoner. Denne inspeksjonen omfatter:

- Bytt tetninger mellom vaskerseksjonene.
- Sjekk og rengjør ekspansjonsskjøtene. Bytt den ut hvis du oppdager sprekker, deformasjoner eller andre skader.
- Sjekk at ventilene åpnes og lukkes slik de skal.
- Fest ekspansjonsskjøter, ventiler og vaskerseksjoner.
- Rengjør bunnen i vaskeren hvis det er omfattende avskalling.

5 Etter vedlikehold

Gjør følgende etter vedlikeholdsprosedyrene:

- Varsle operatørene om endringene og reparasjonene i vedlikeholdsområdet.
- Fjern vedlikeholdsområdemarkeringene.
- Fjern midlertidig installerte rør og elektrisitet, om nødvendig.
- Sørg for at rekkverk og tilsvarende utstyr monteres tilbake på plass igjen, hvis dette har vært fjernet under vedlikeholdet.
- Dokumenter strukturelle endringer som er foretatt under vedlikeholdet, hvis aktuelt.
- Test at automatiske sikkerhetsanordninger virker, hvis det utførte vedlikeholdsarbeidet kan ha påvirket det automatiske sikkerhetssystemet.
- Sjekk de lokale forskriftene for godkjenning av vedlikeholdsarbeidet (for eksempel om en trykktest må utføres).
- Varsle operatørene når sikkerhetslåser kan åpnes.
- Se dokumentet *Drift* og en separat *driftshåndbok for prosess* (ikke inkludert i leveringen) for igangsetting av prosessen etter vedlikehold.
- Før prosessen startes, anbefales det at en generell inspeksjon utføres i området.

6 Avhending av avfall

⚠ **FORSIKTIG**

Sørg for deponering av alt avfall i samsvar med lokale bestemmelser.

I tillegg til lokale forskrifter må du følge anleggets instruksjoner for avfallshåndtering.

Avhend alle forurensede deler som giftig avfall. Alle forurensede arbeidsklær, pustemasker og oksygentanker er også giftig avfall.

Giftige materialer, som for eksempel syreholdige væsker, må ikke tømmes ut på bakken eller i kloakken.

Outotec

Sustainable use of
Earth's natural resources

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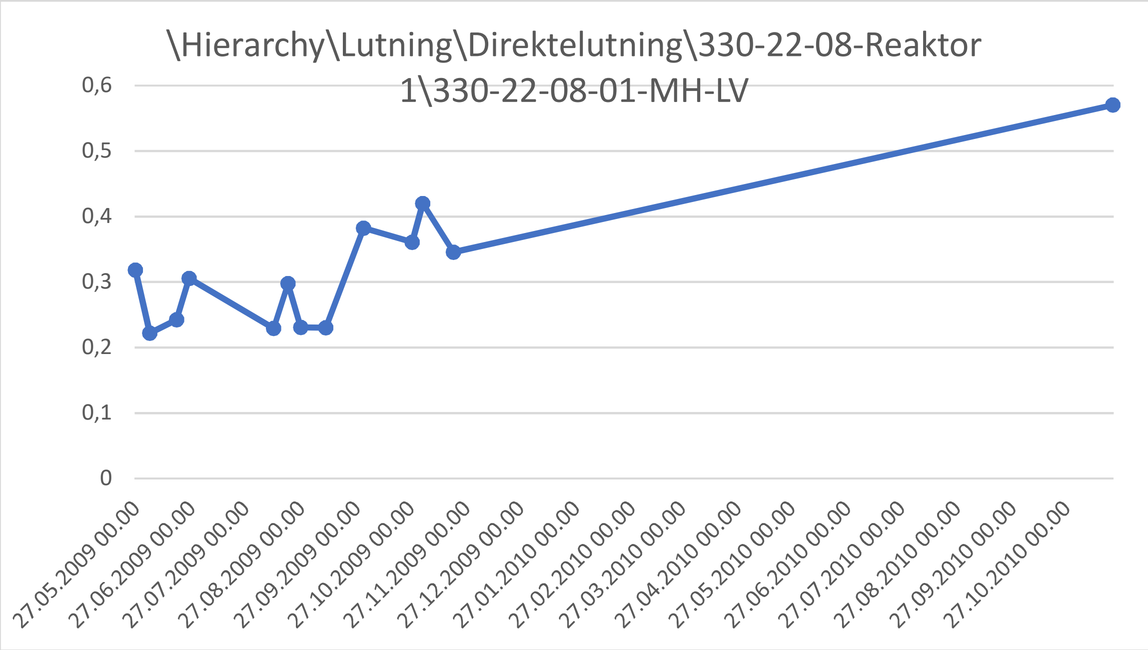
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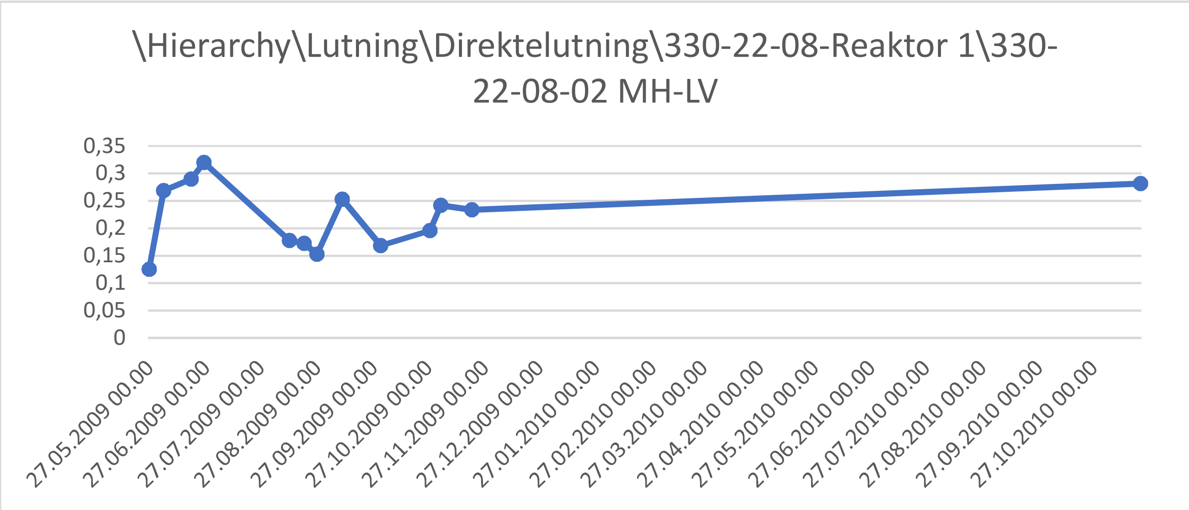
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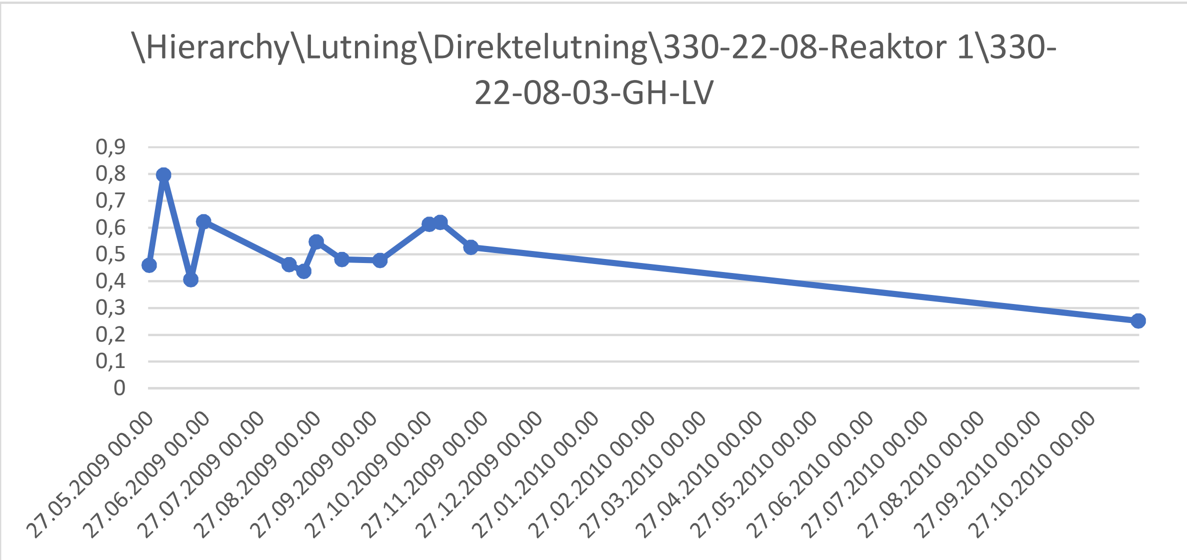
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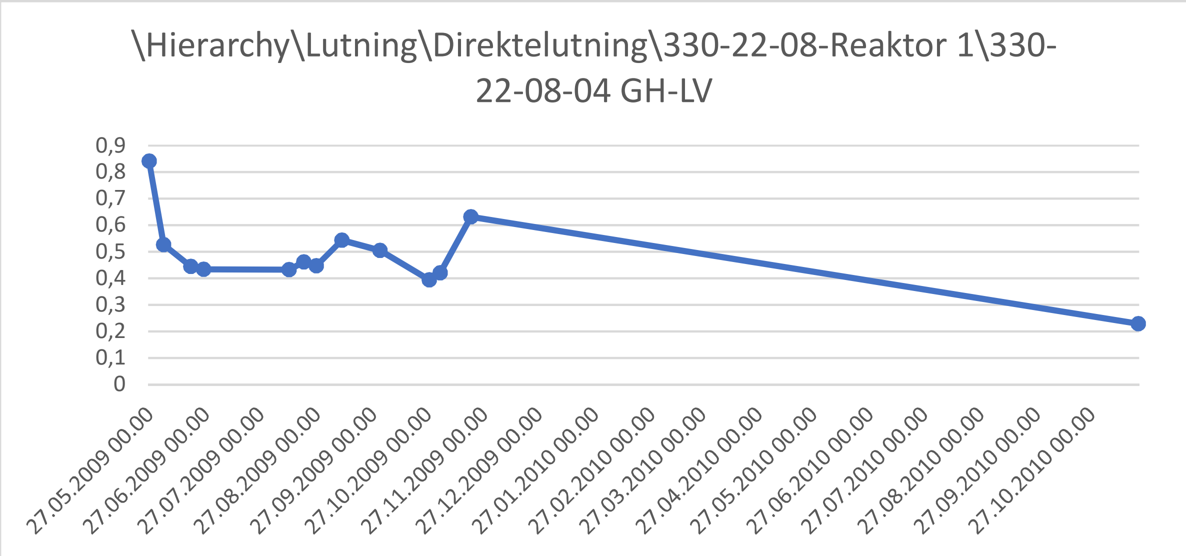
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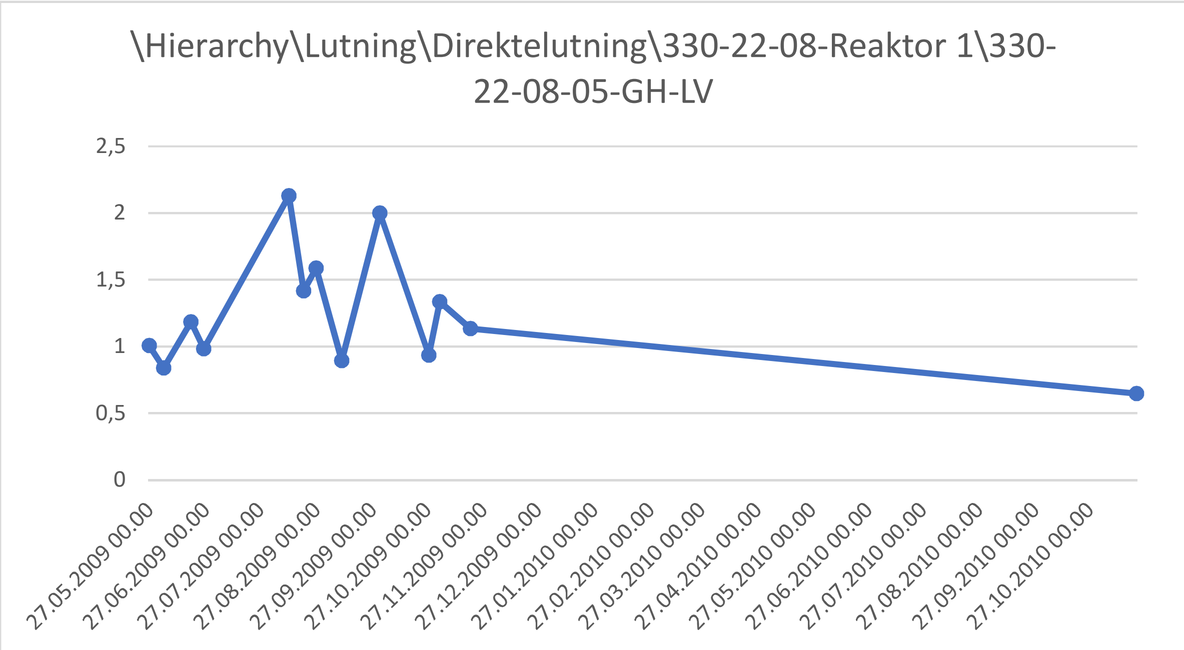
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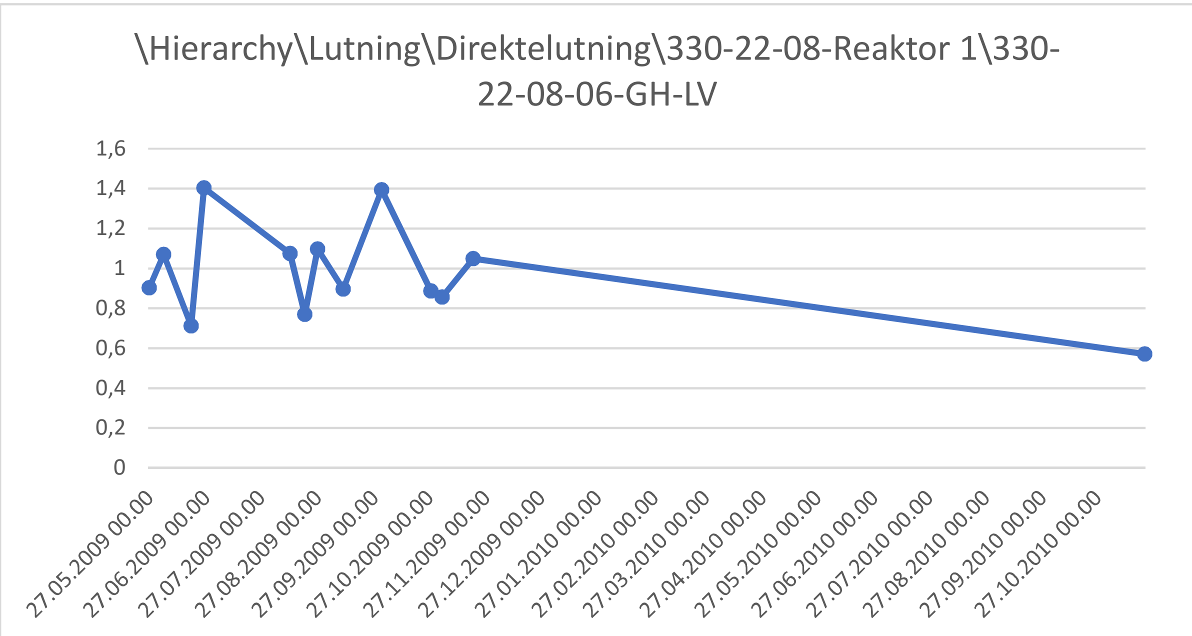
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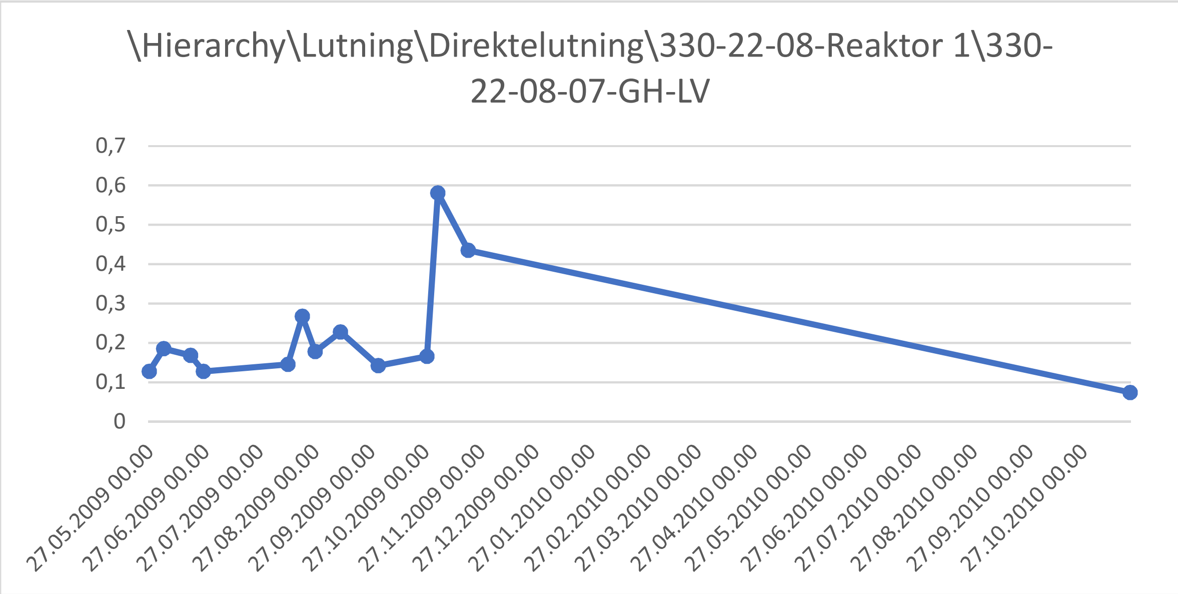
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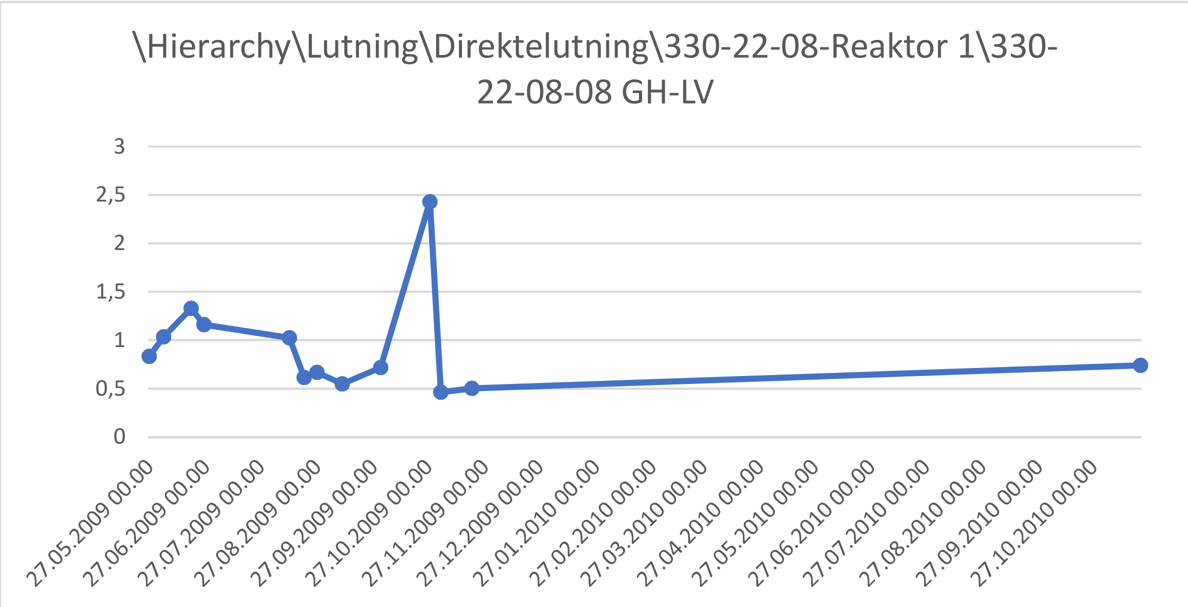
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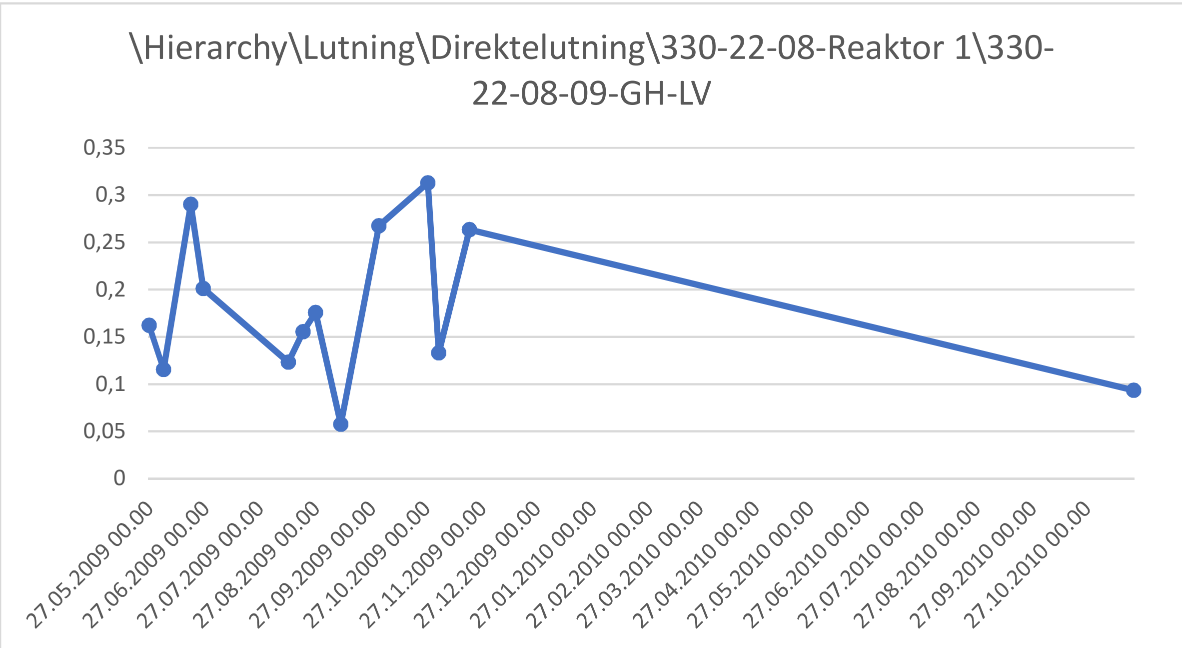
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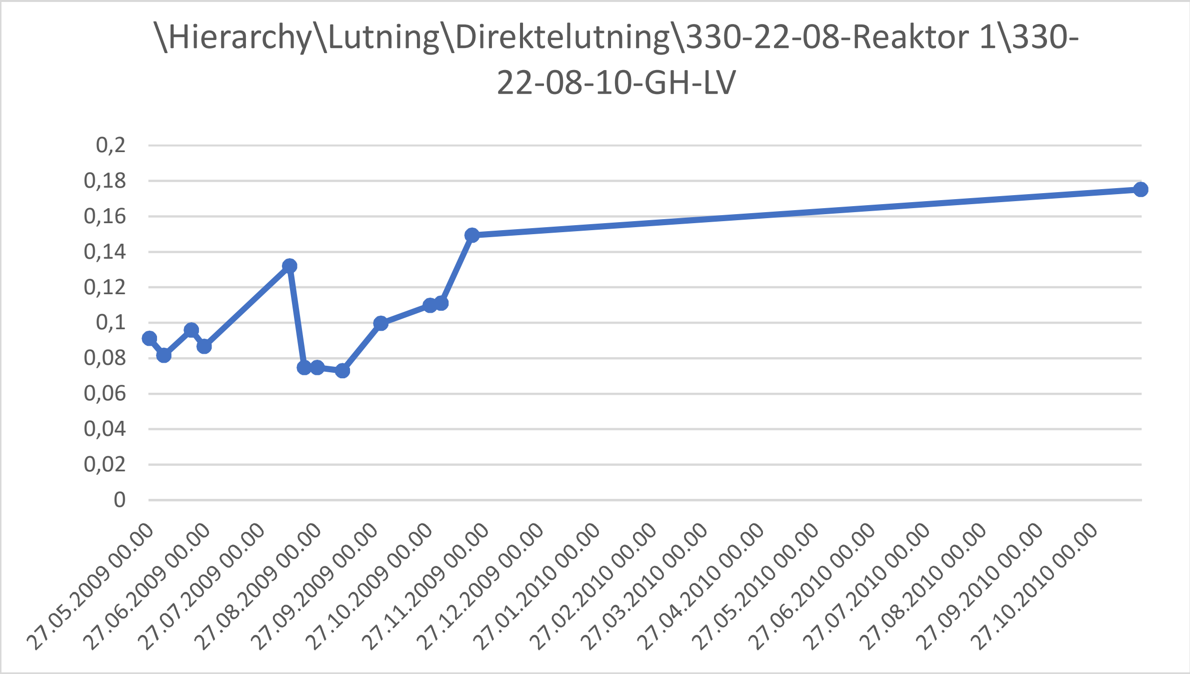
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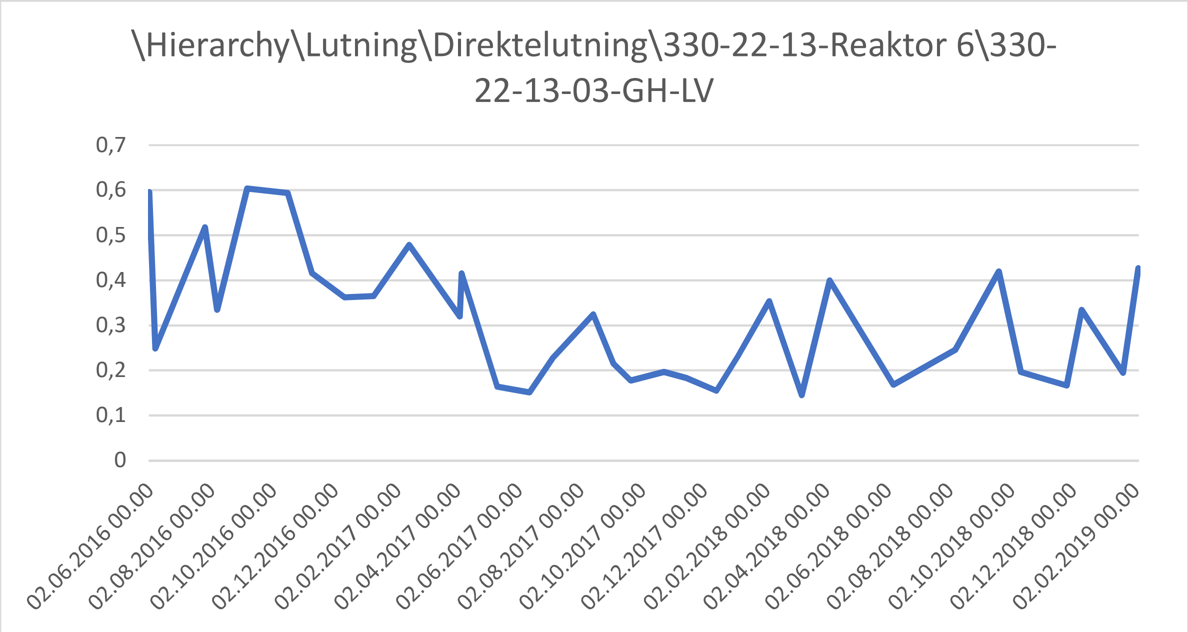
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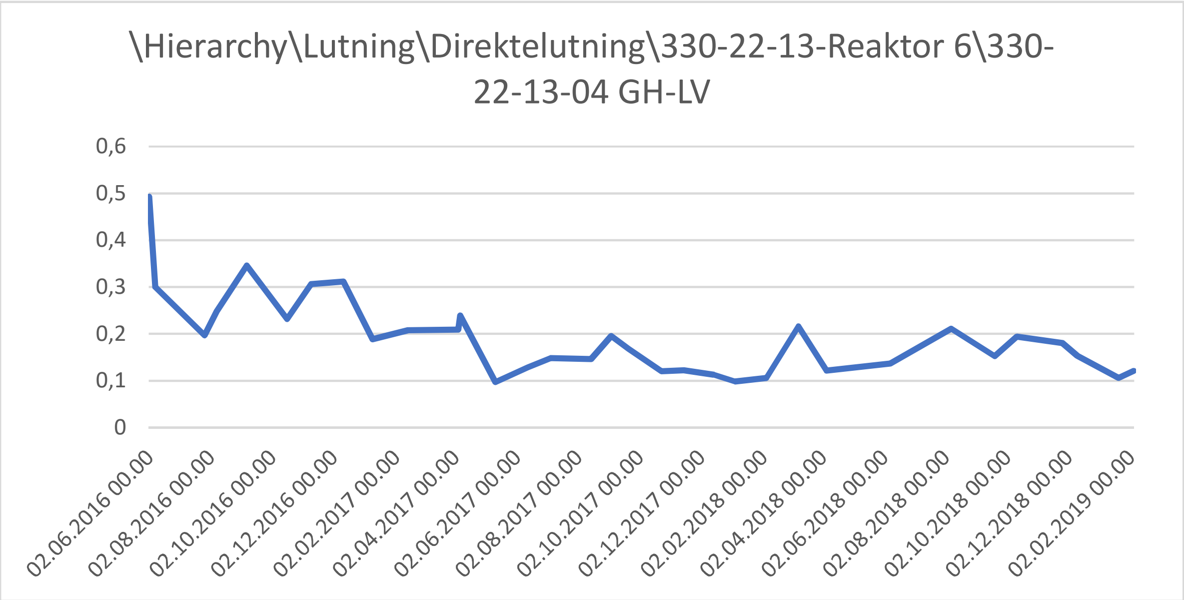
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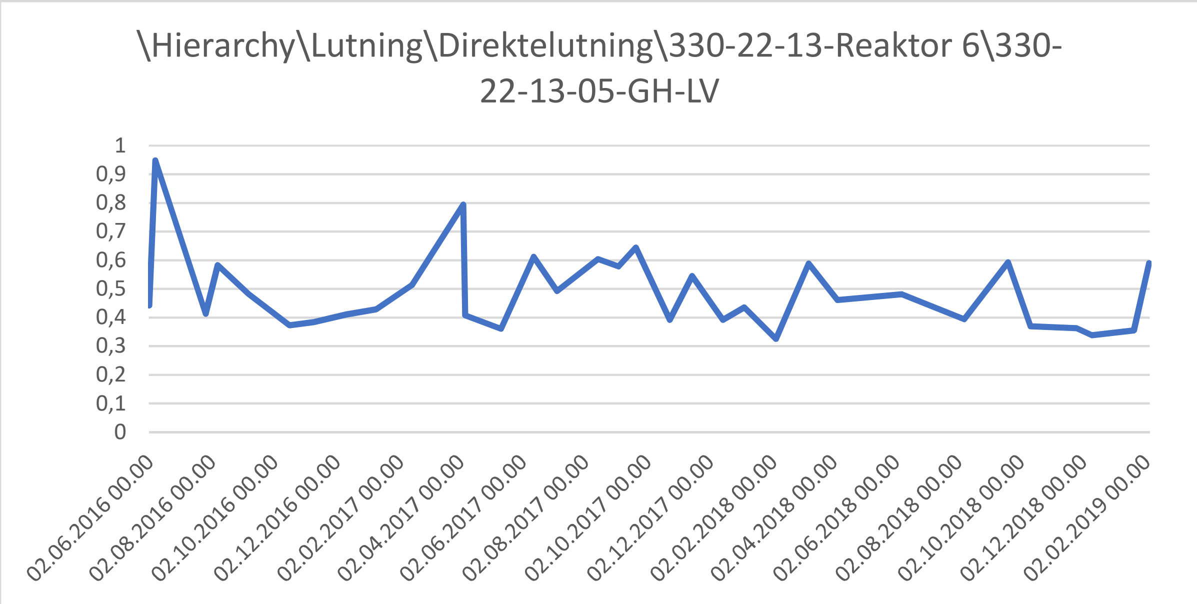
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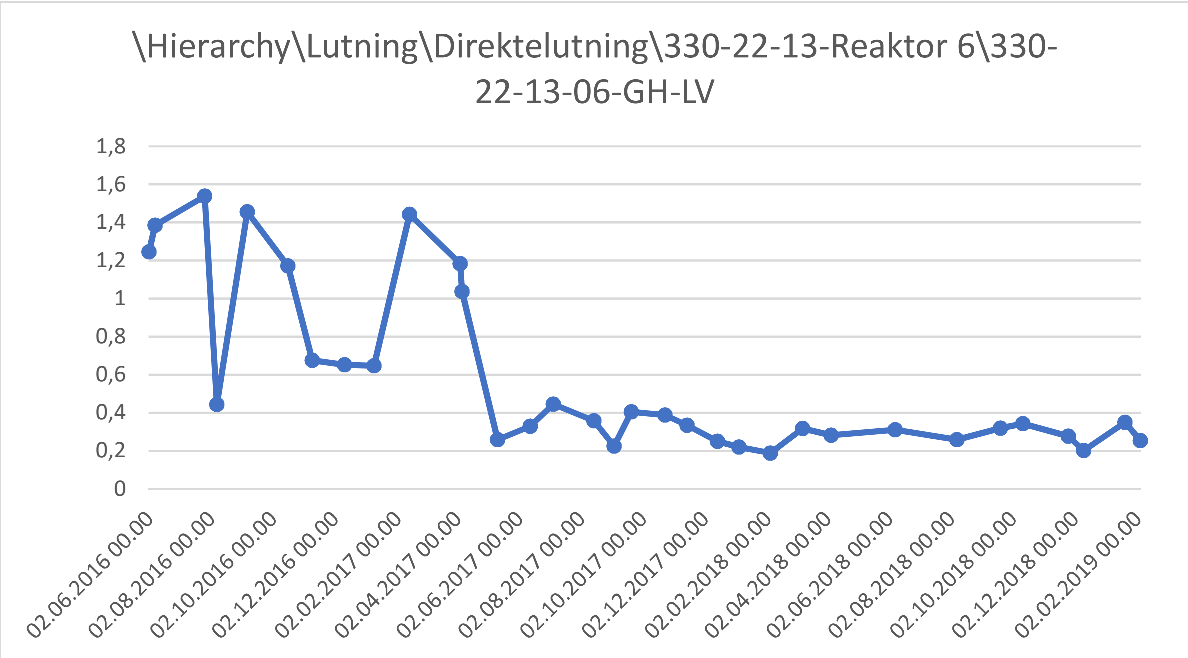
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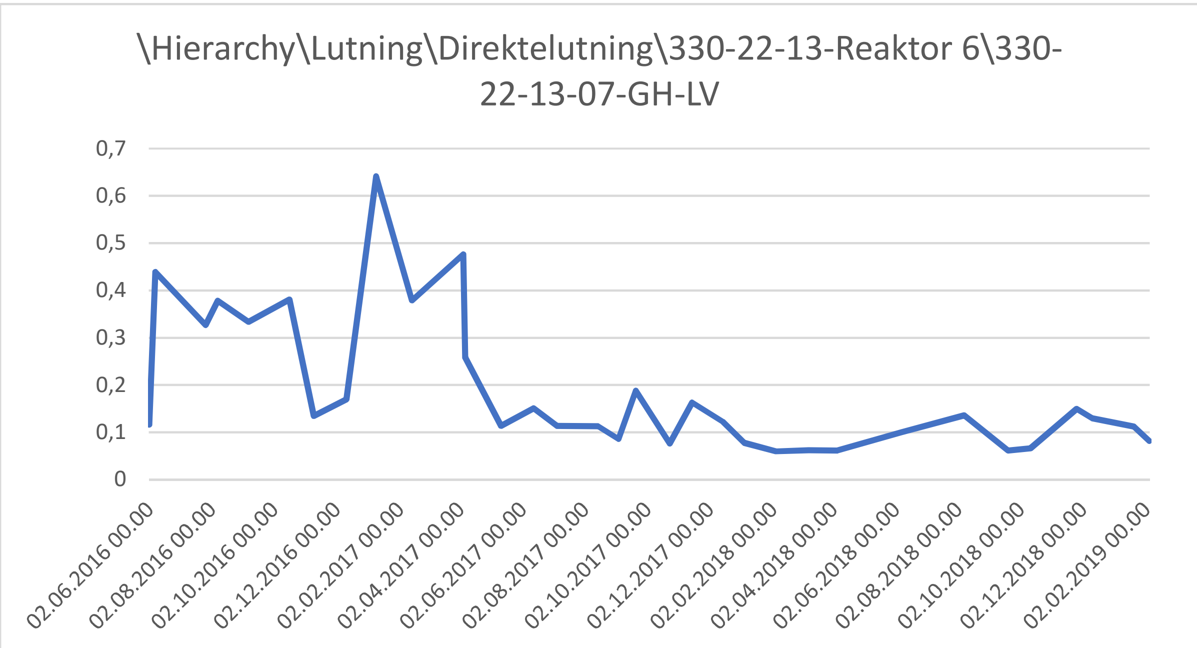
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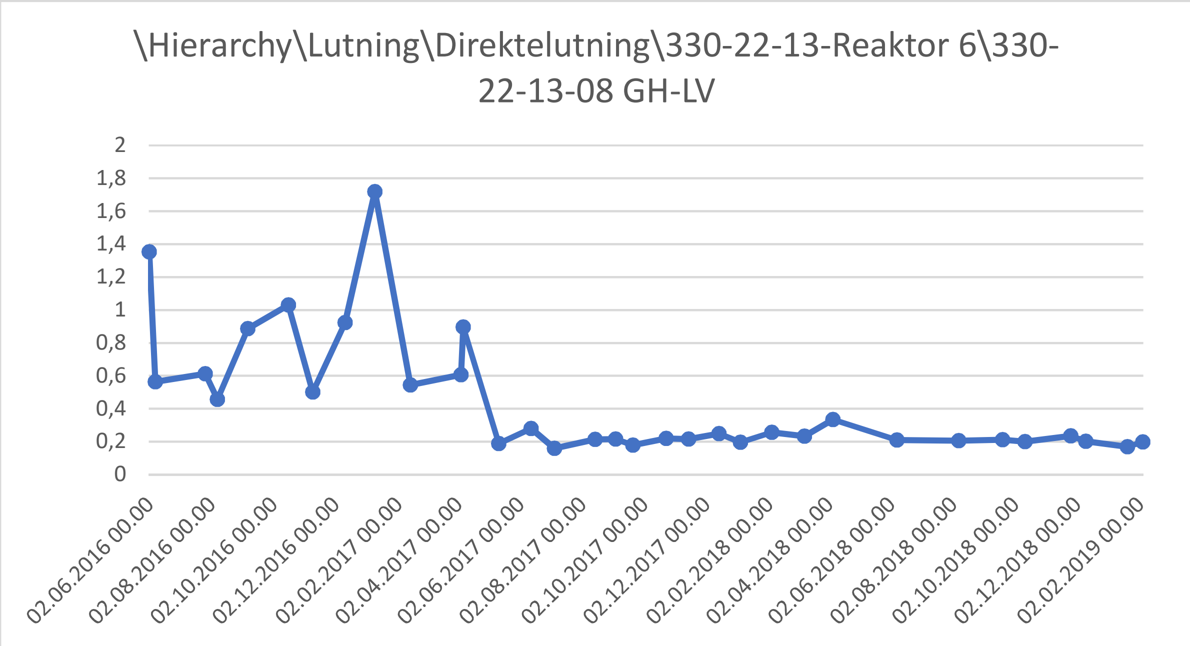
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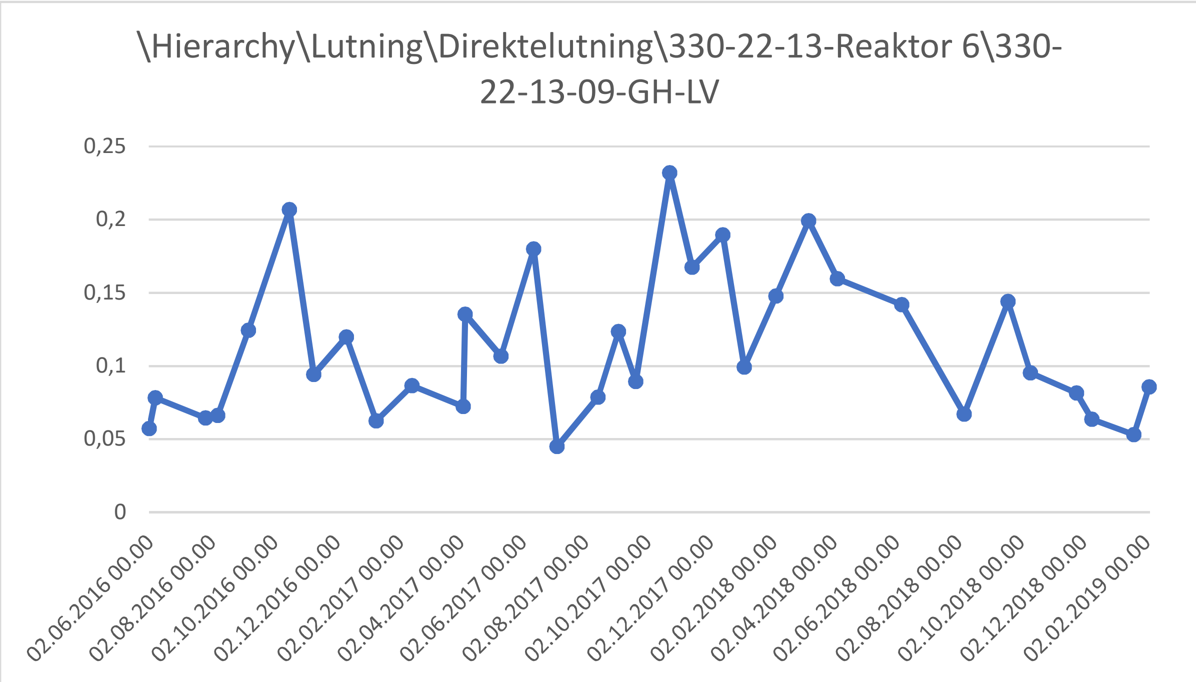
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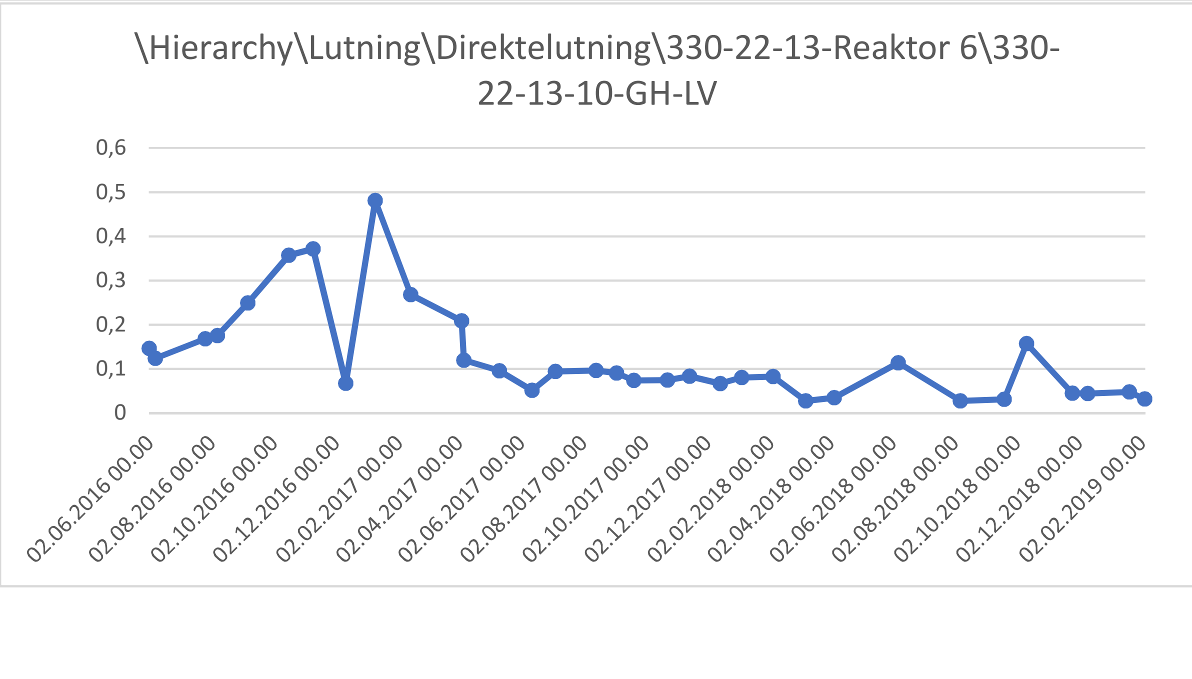
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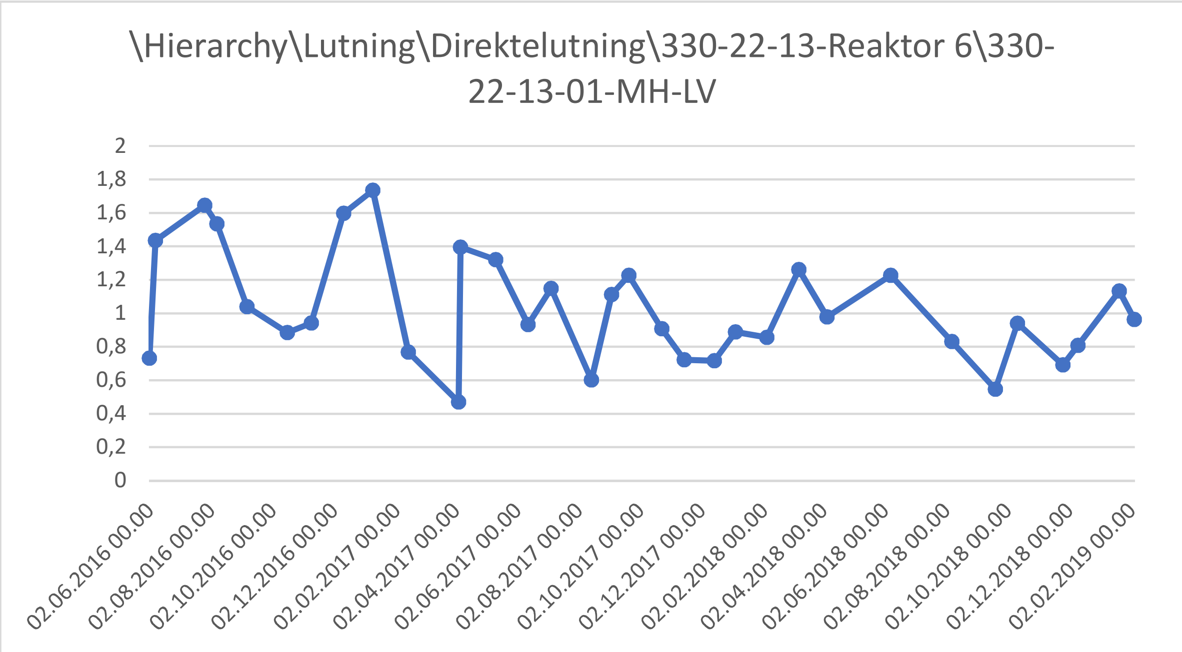
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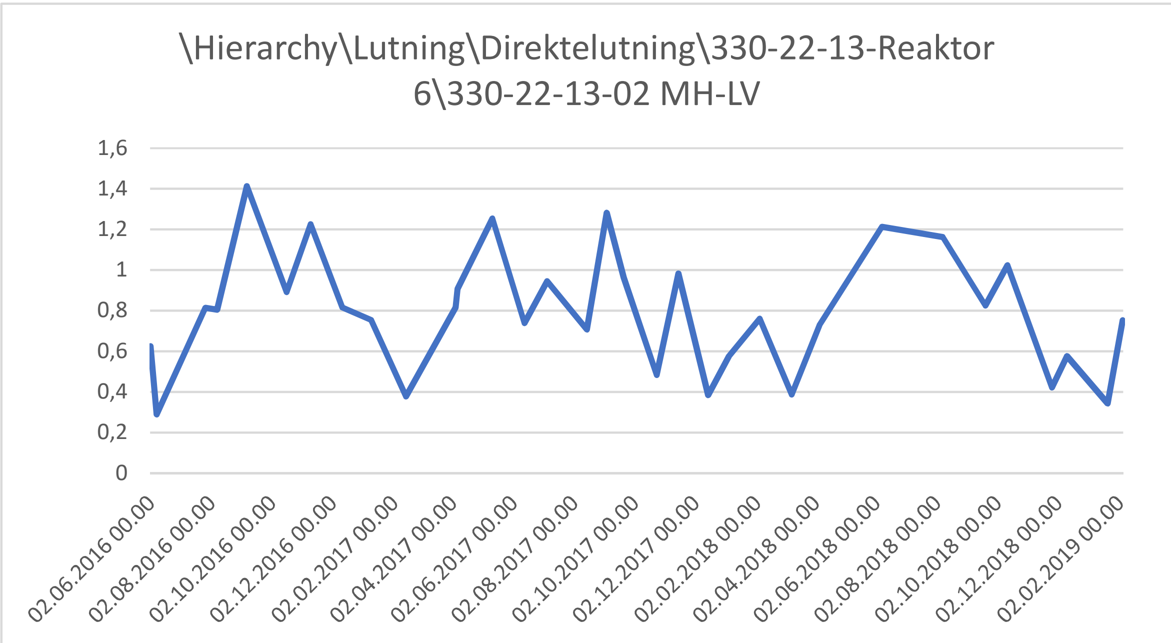
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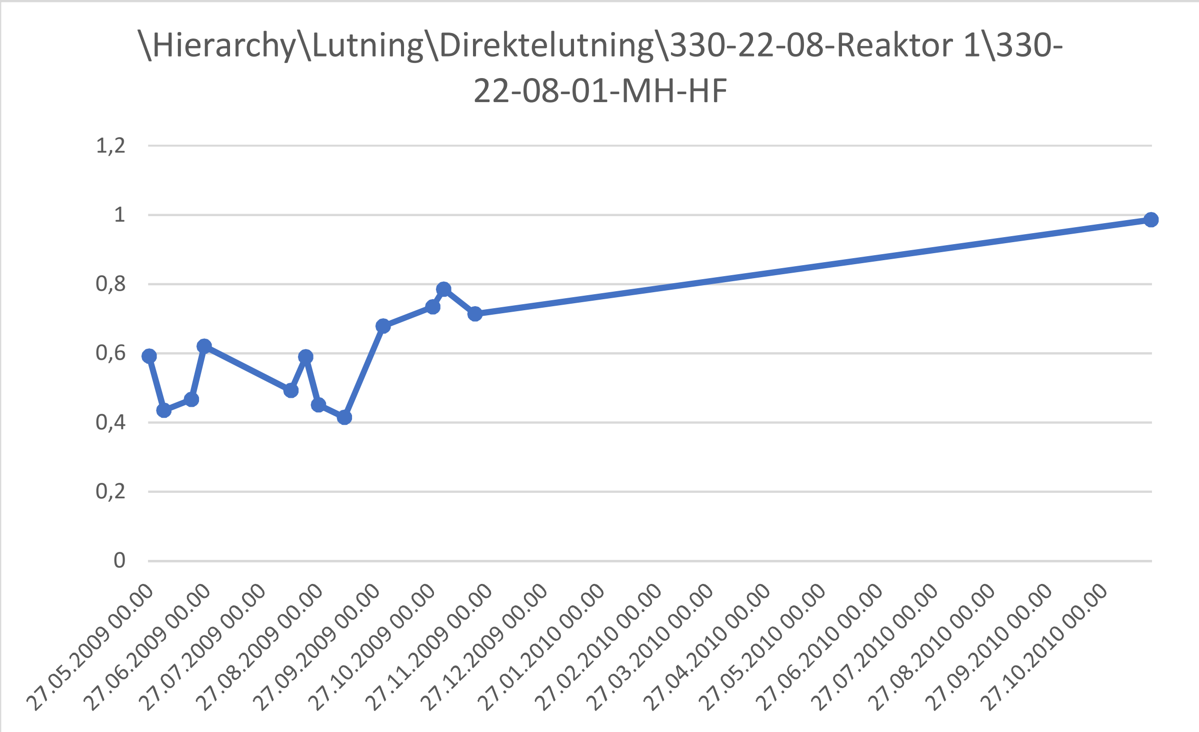
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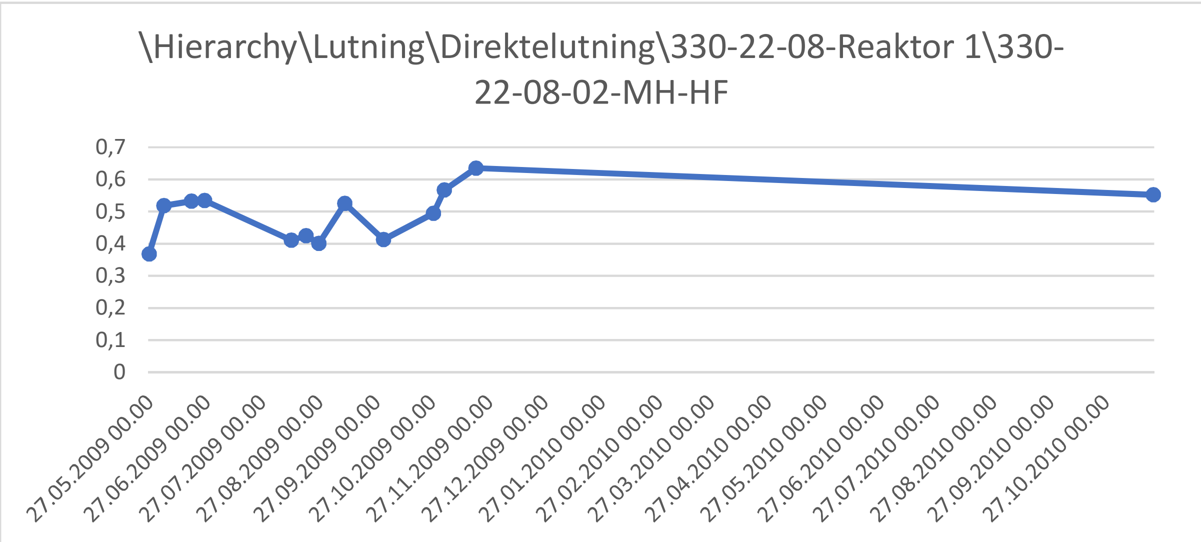
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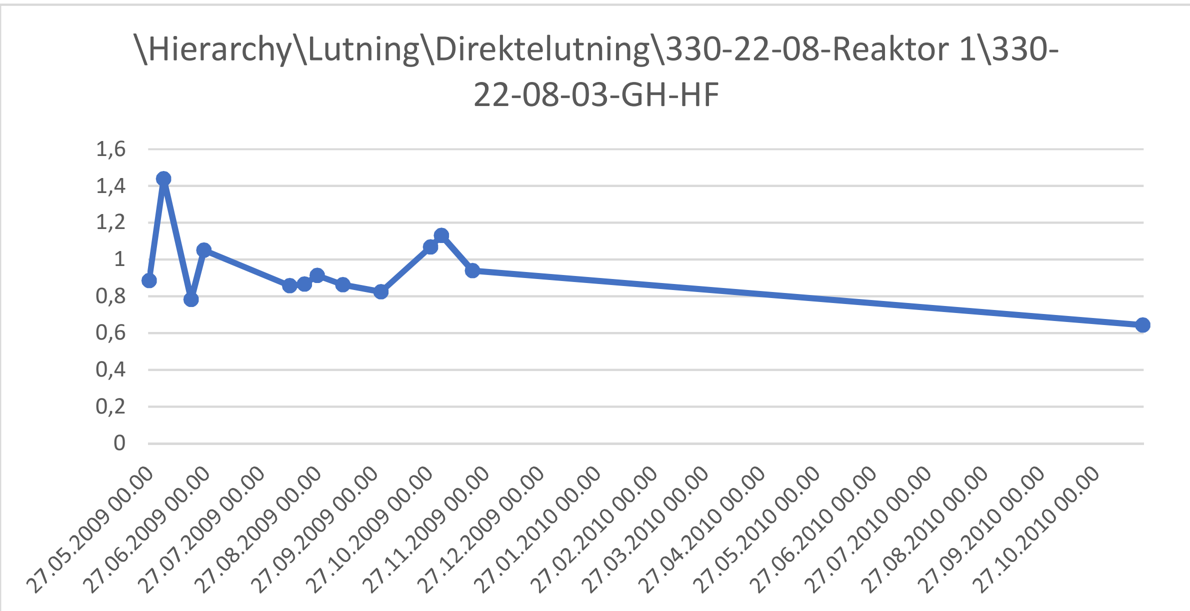
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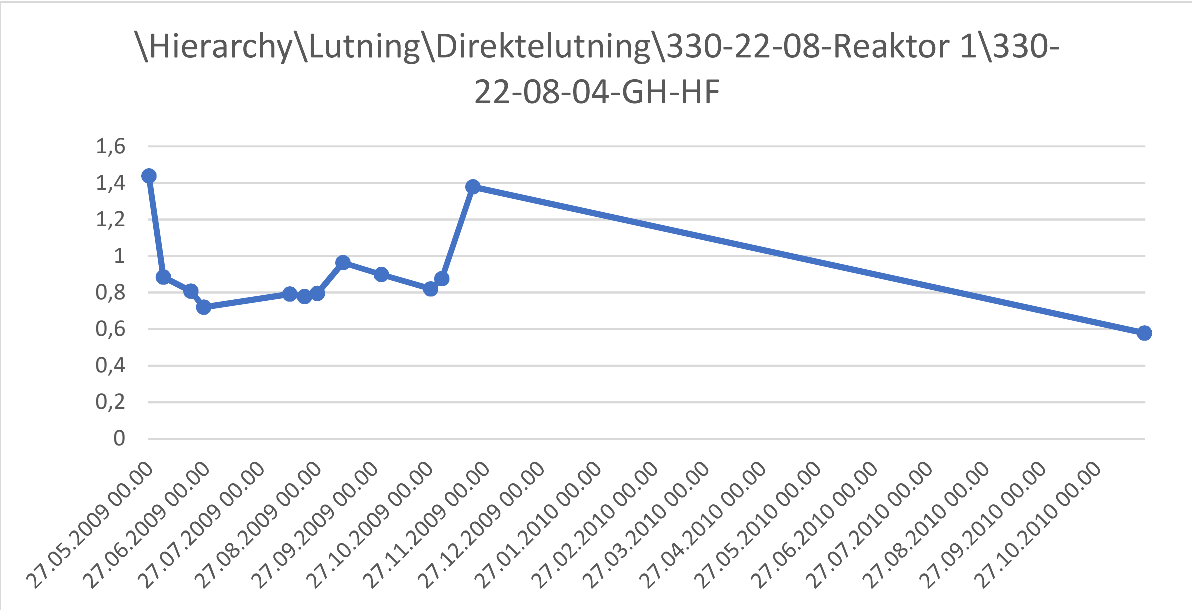
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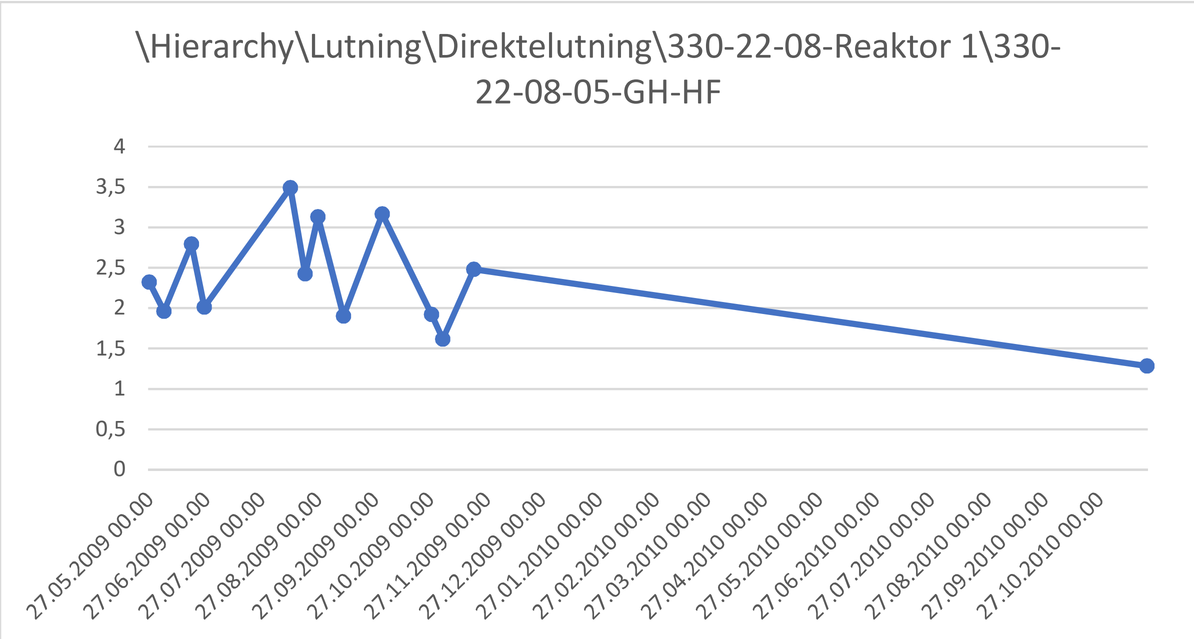
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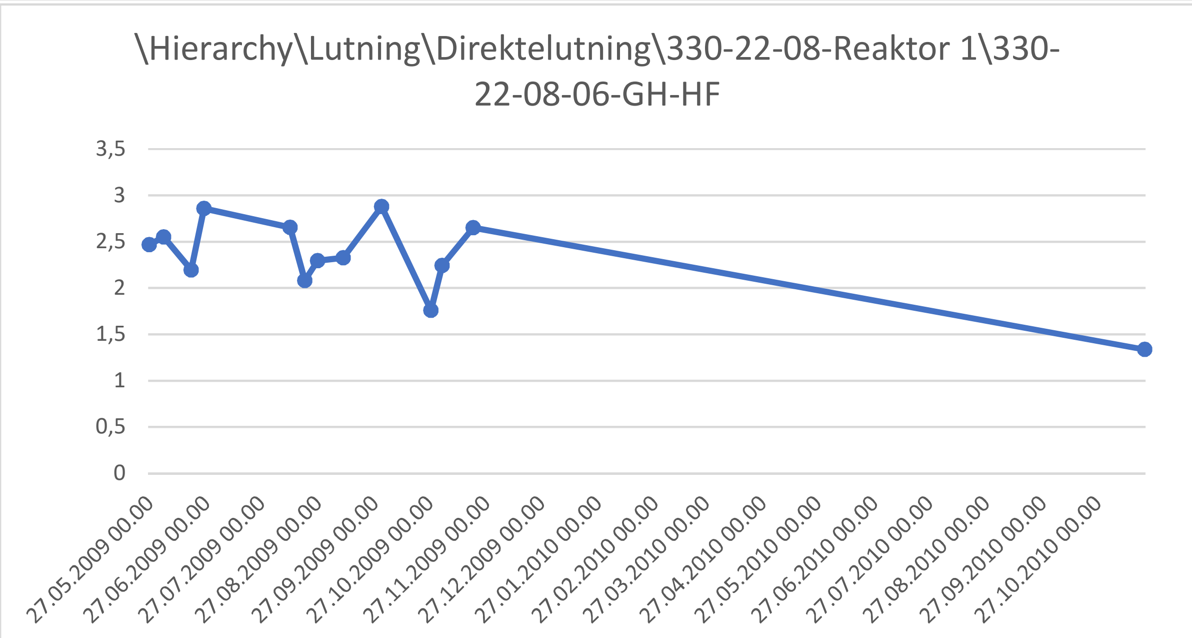
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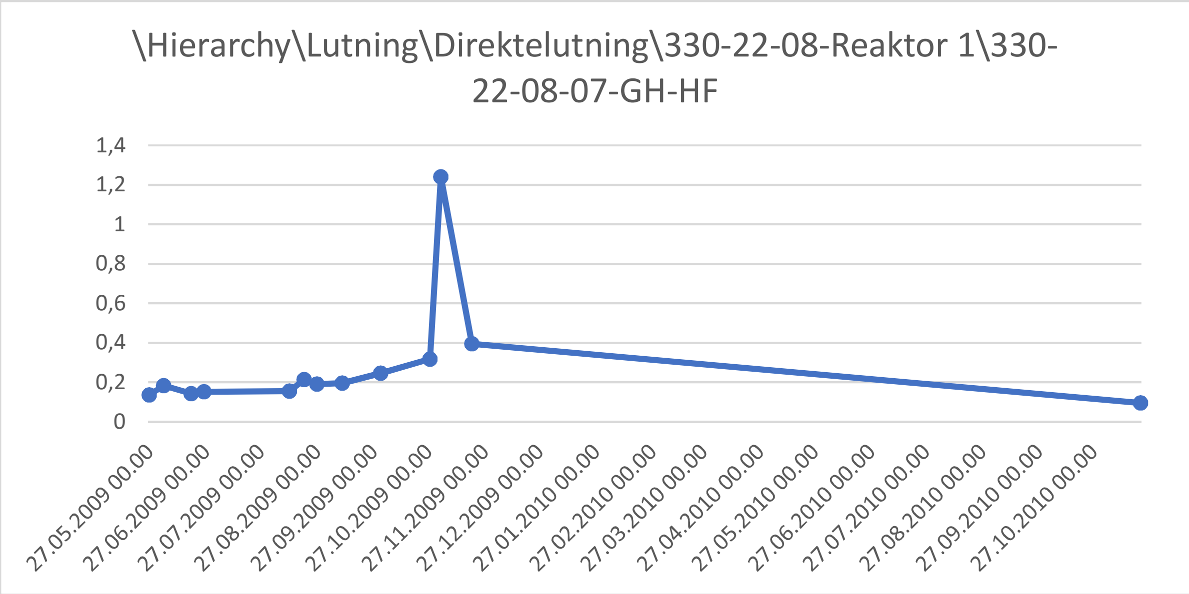
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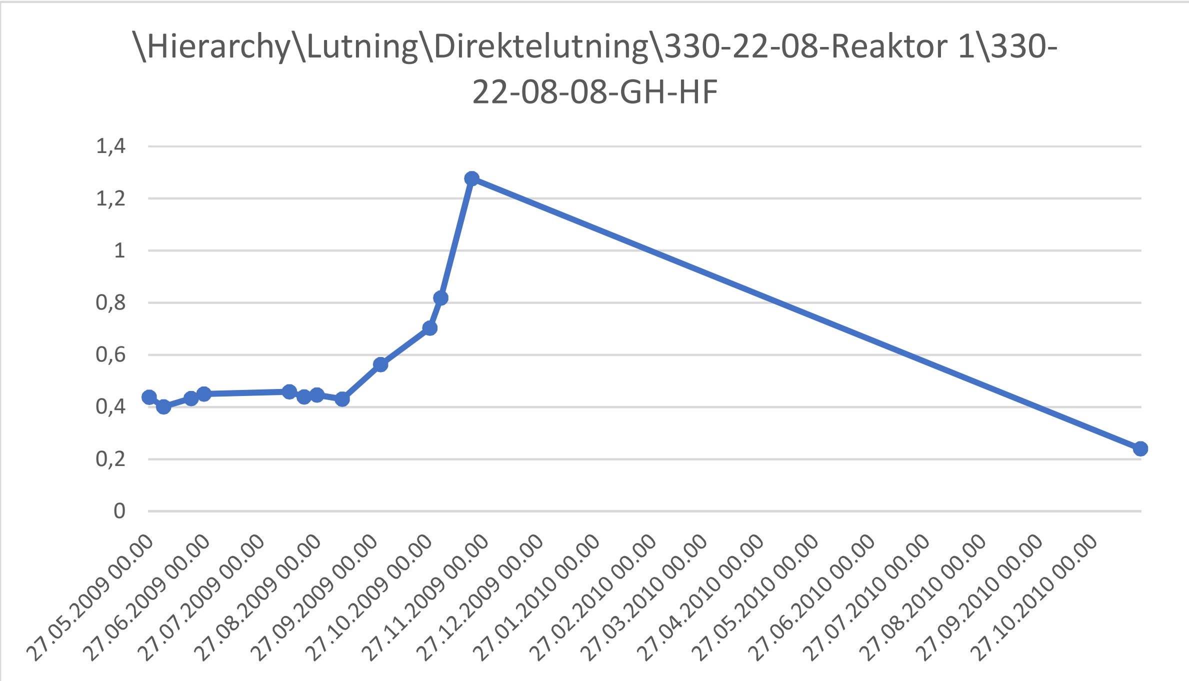
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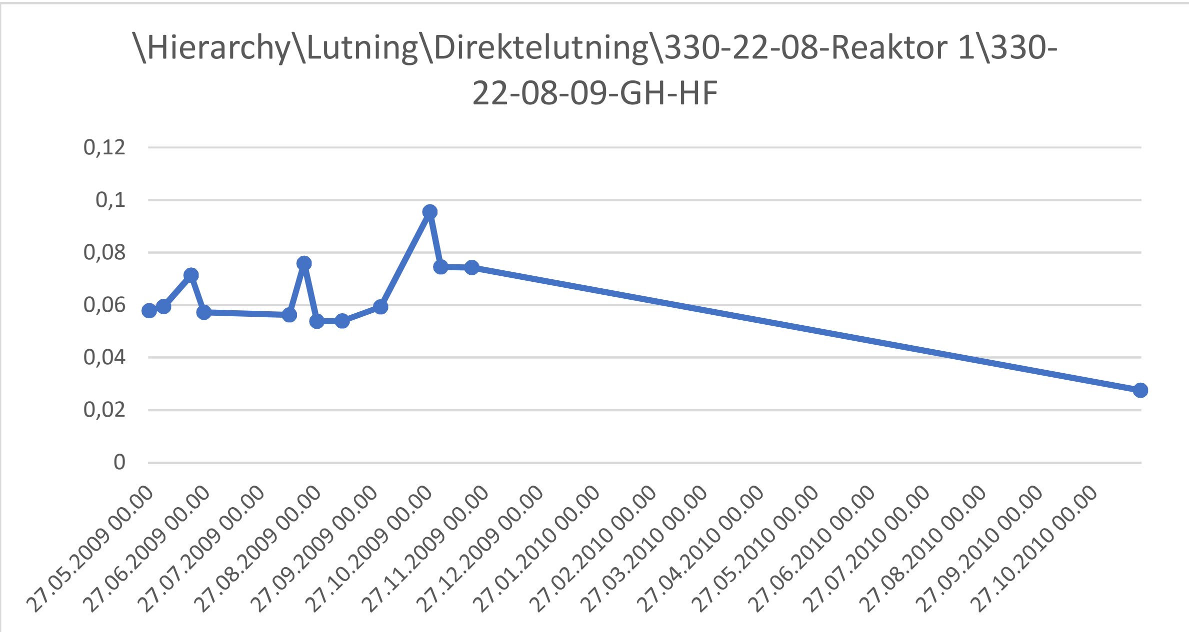
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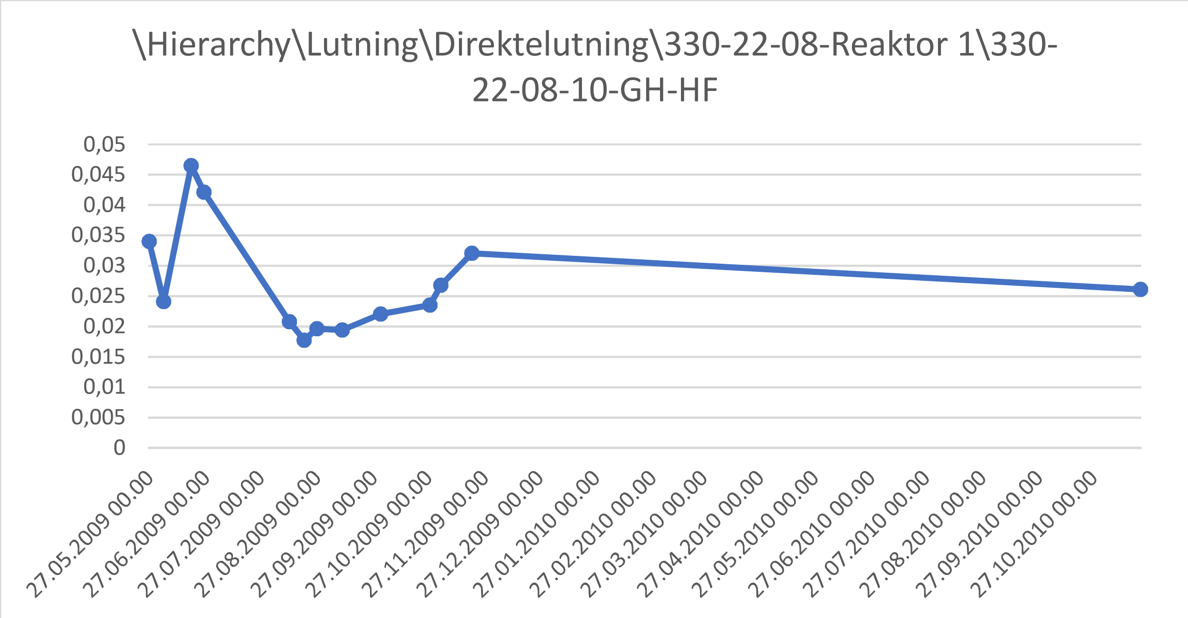
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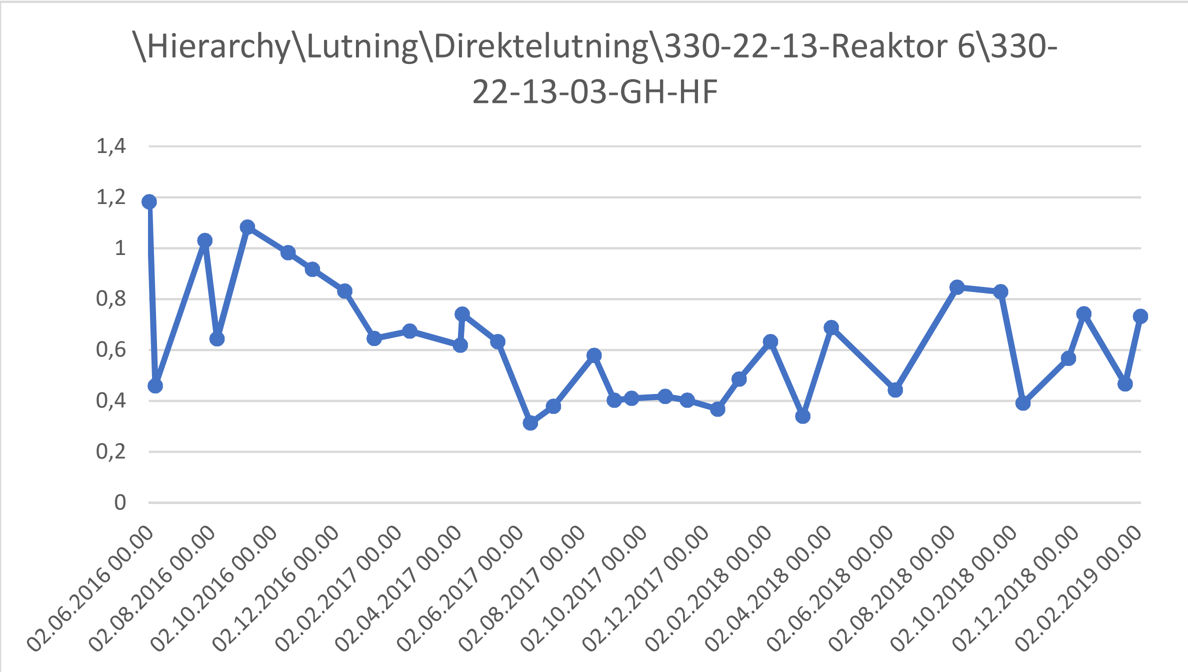
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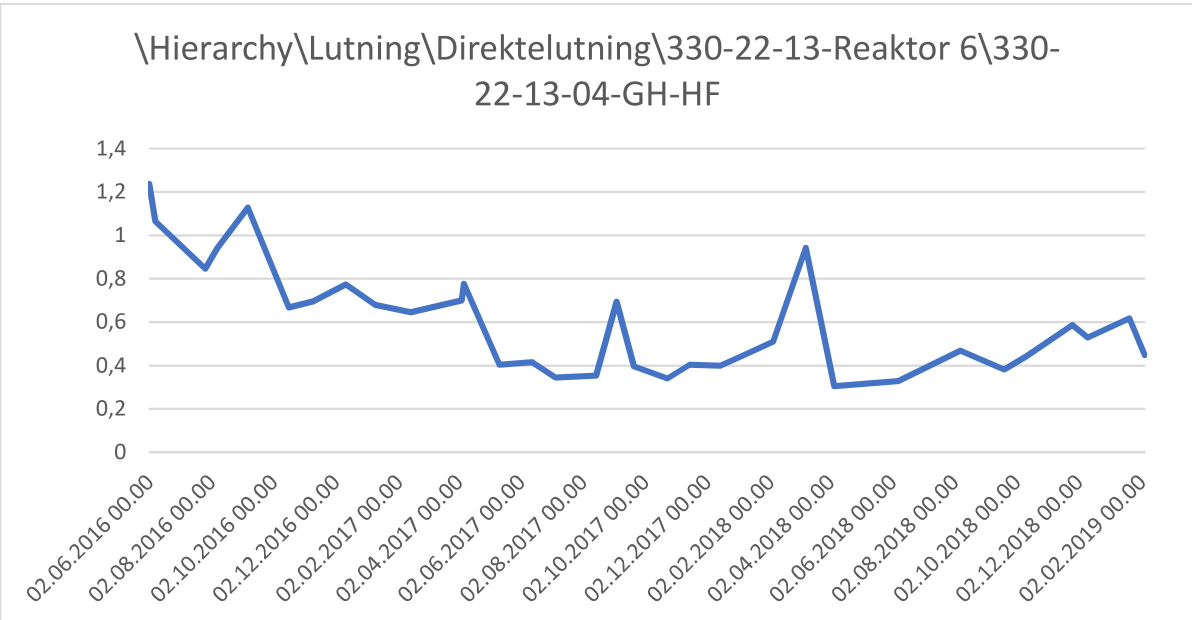
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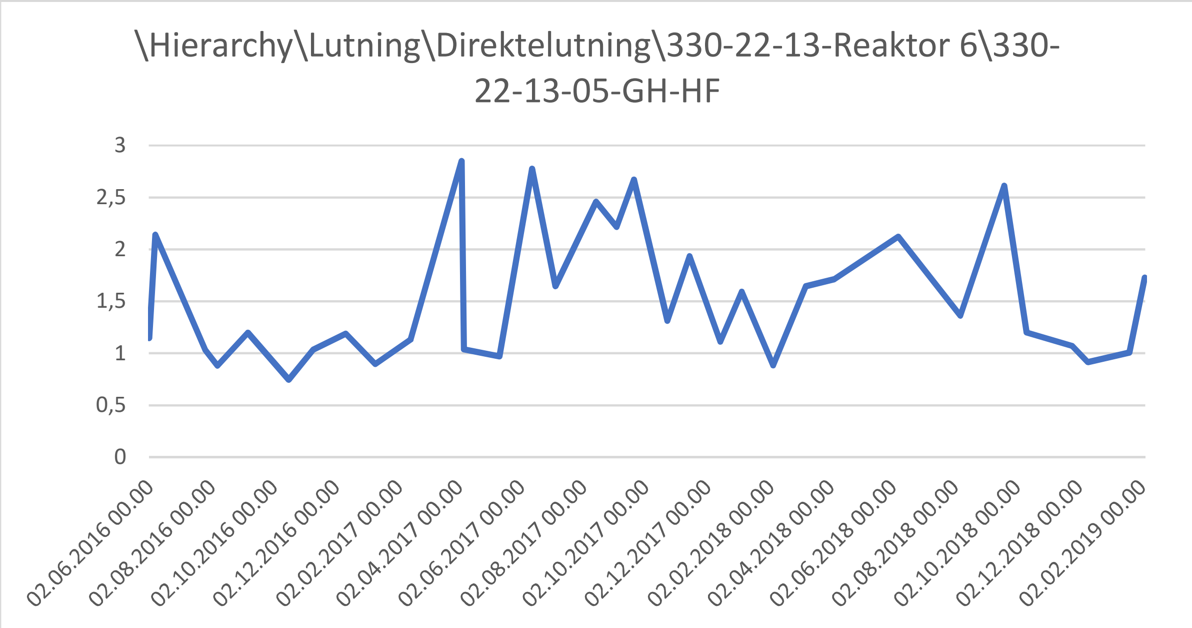
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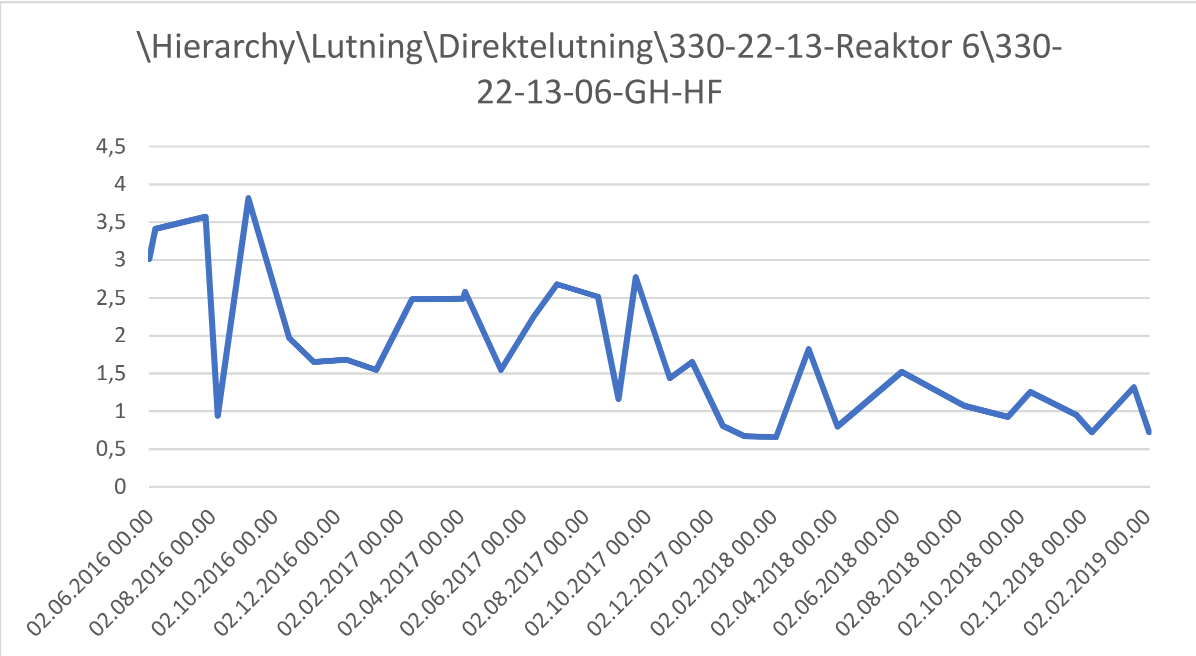
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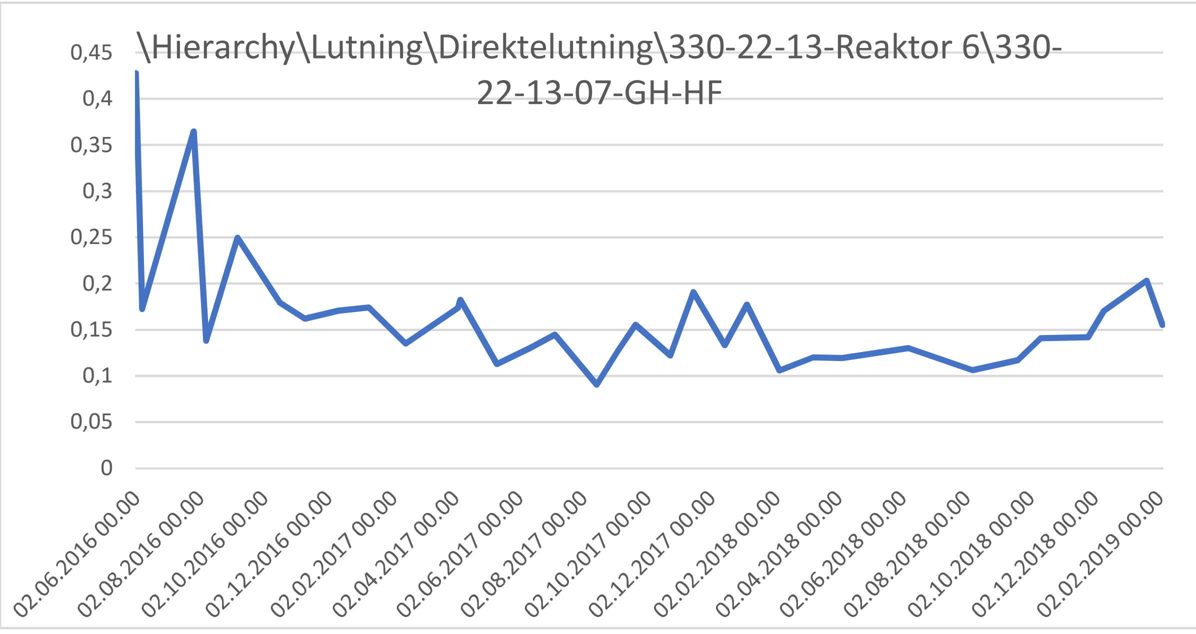
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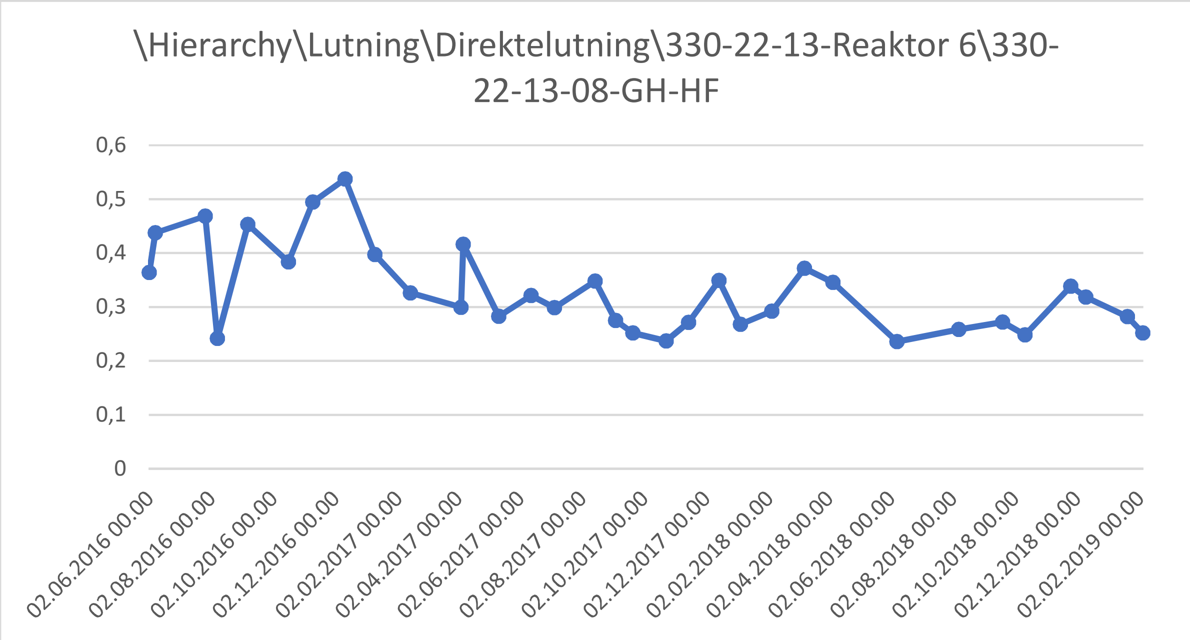

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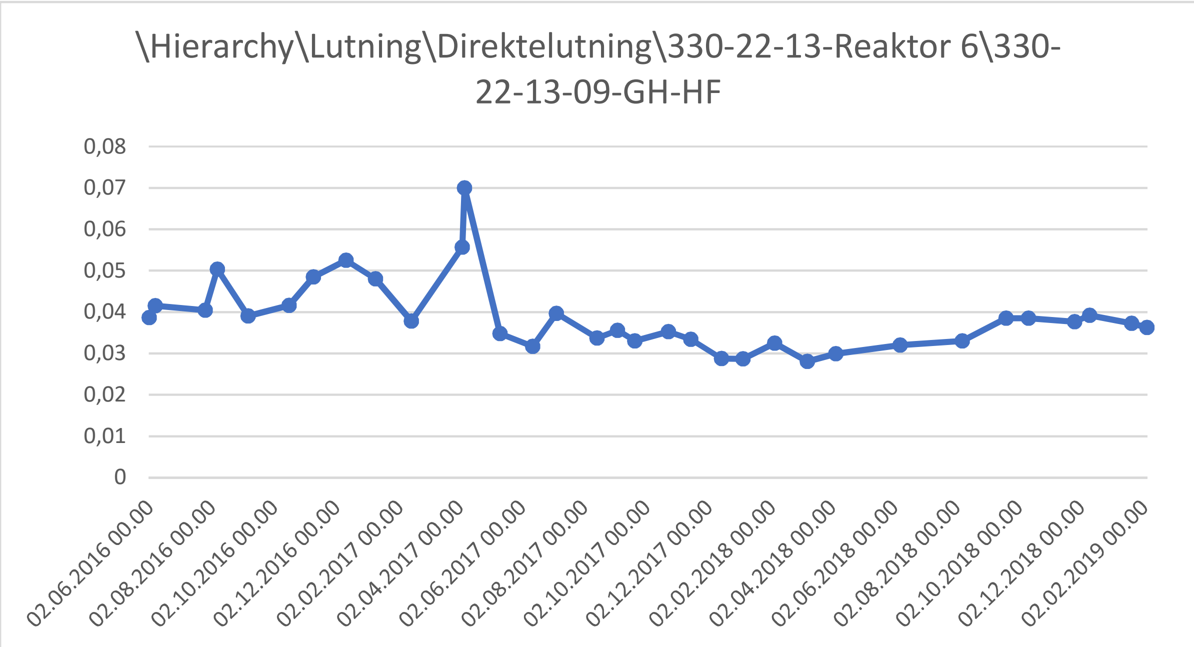

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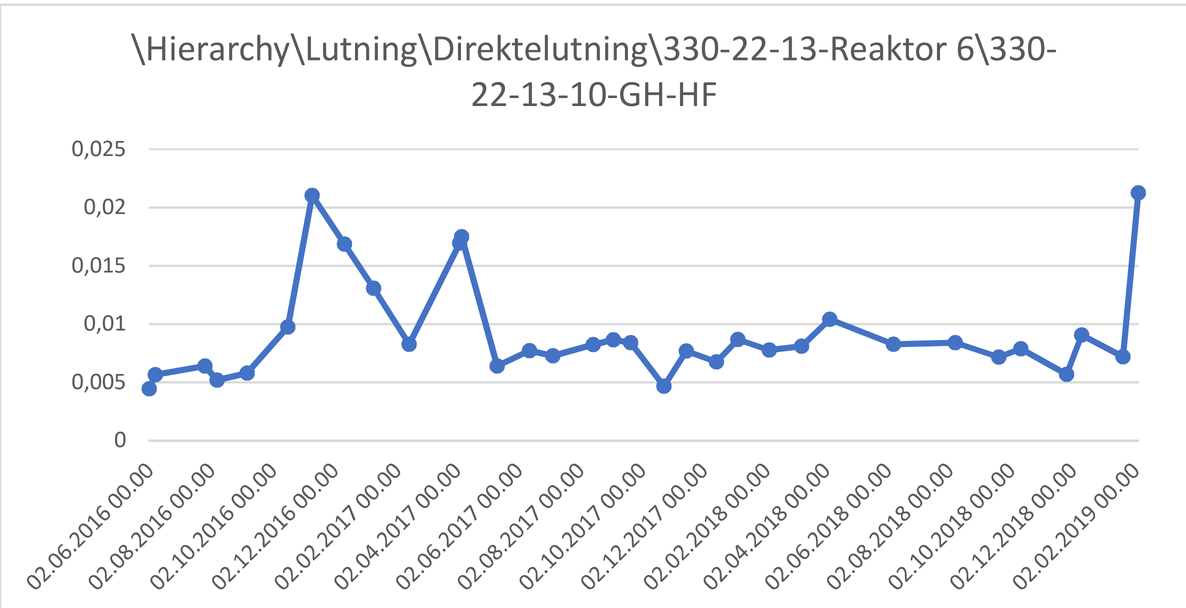

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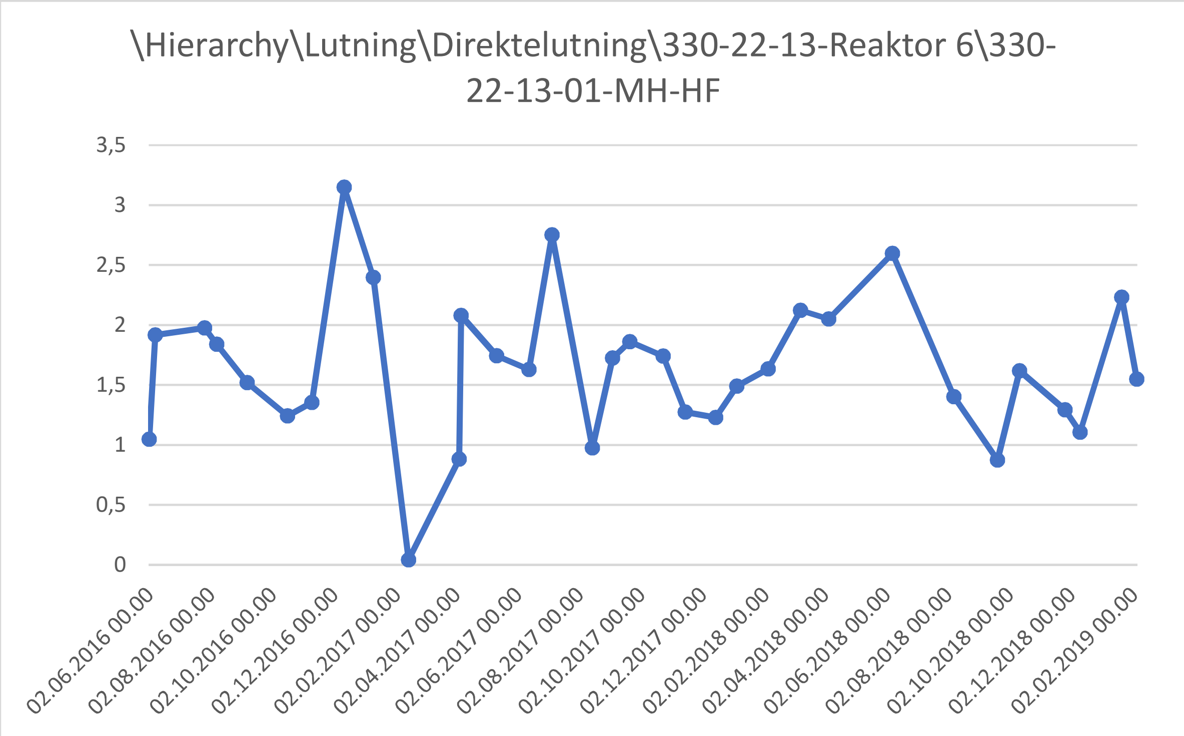
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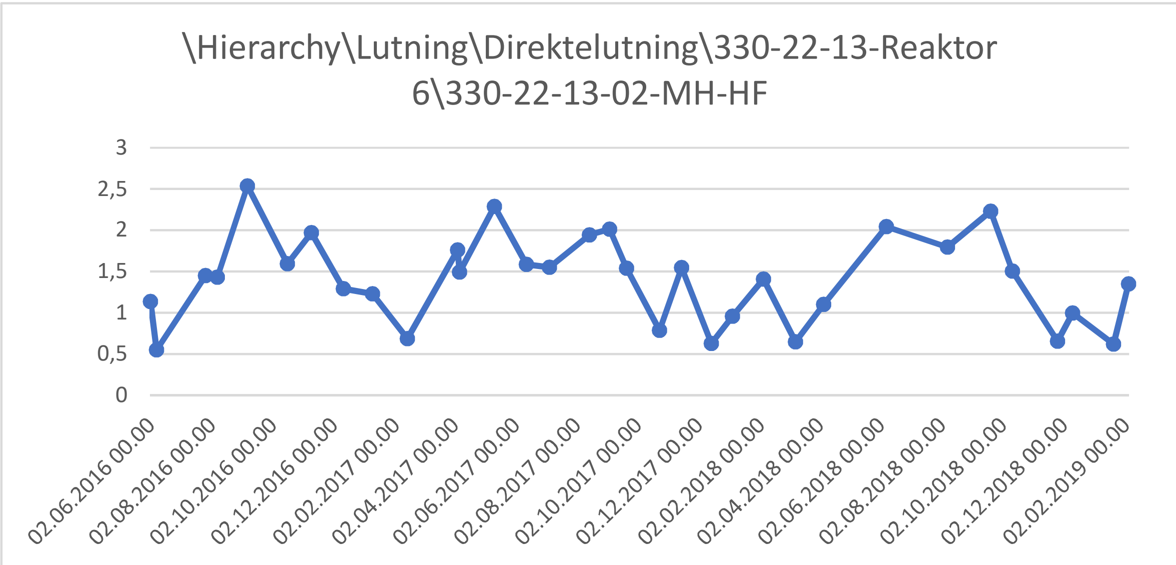
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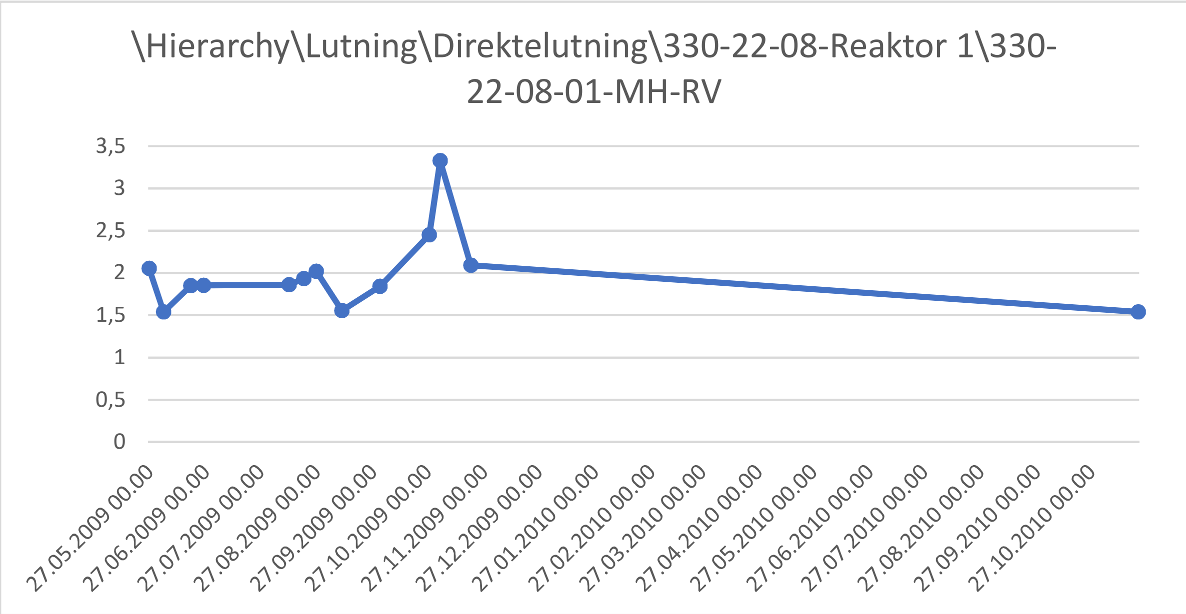
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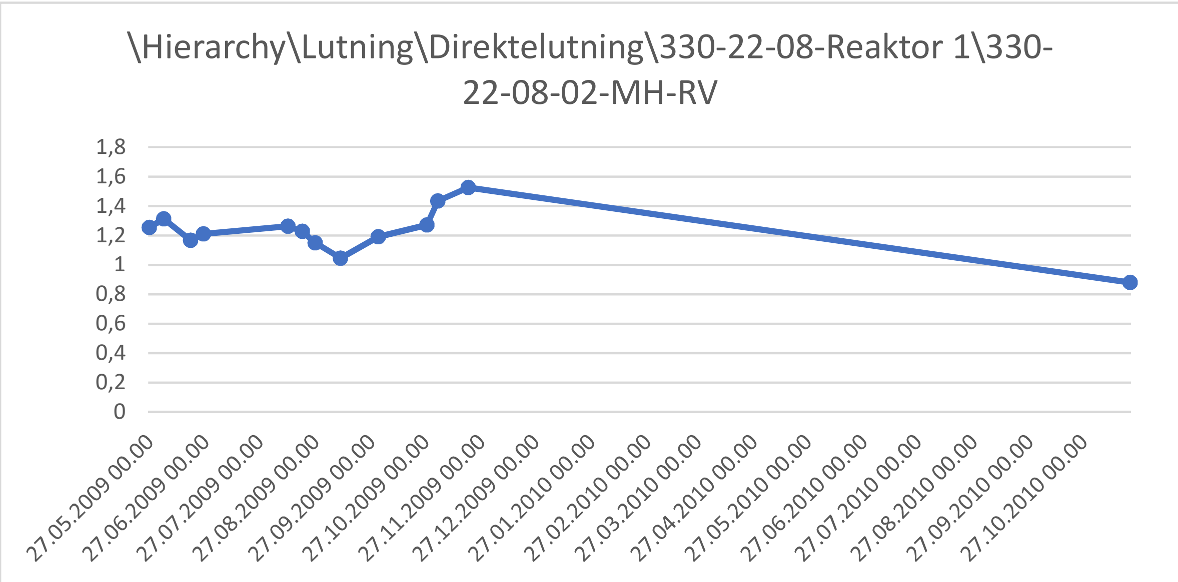
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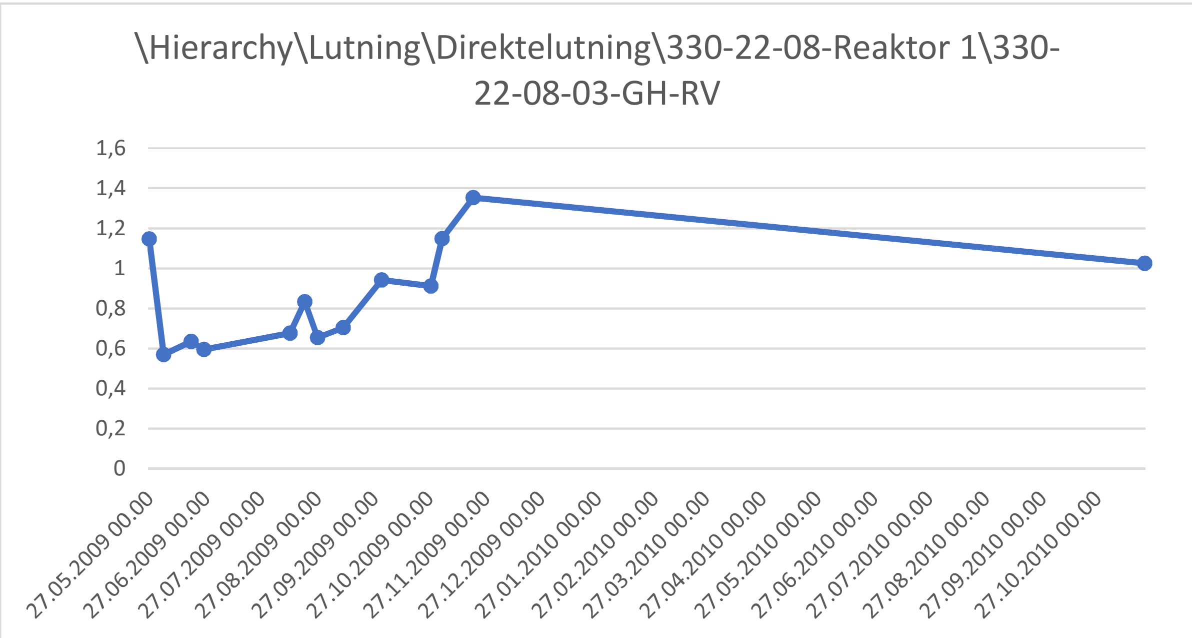
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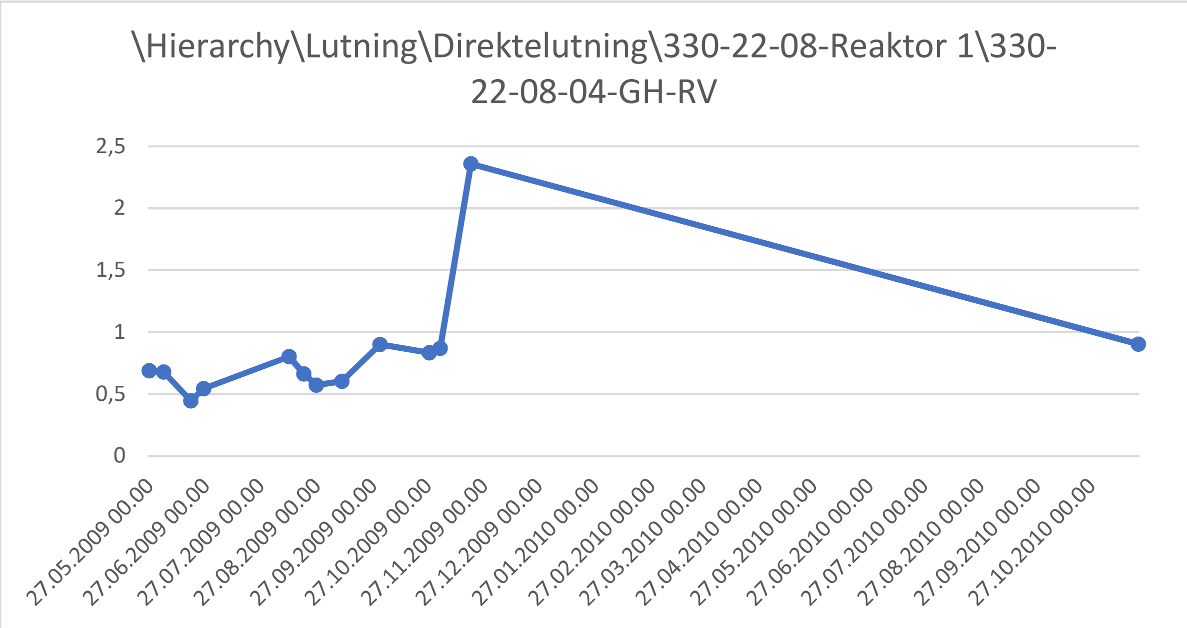
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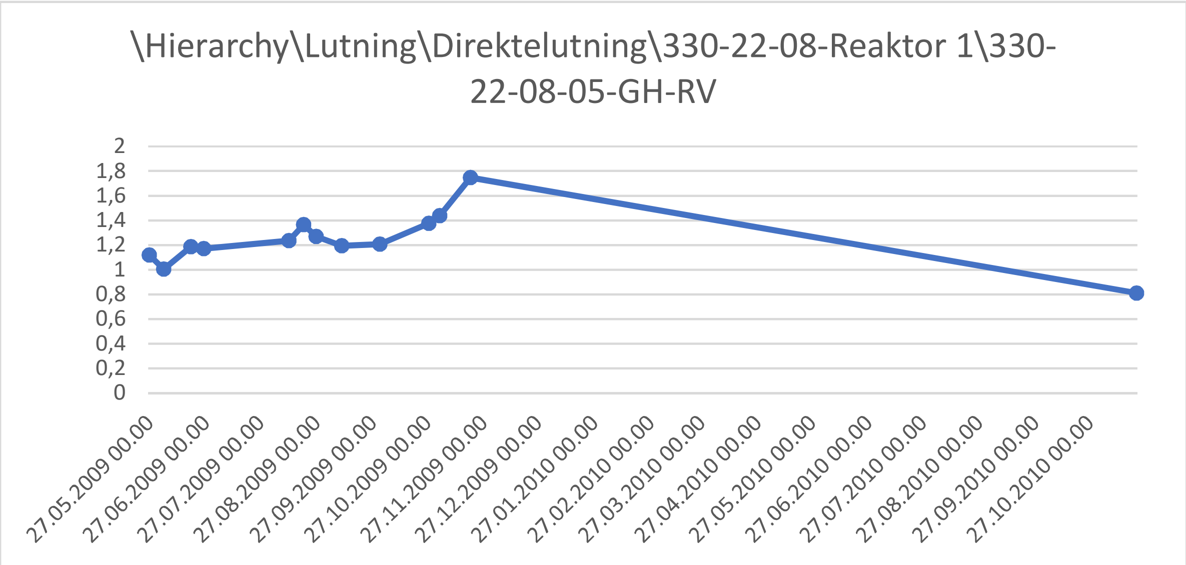
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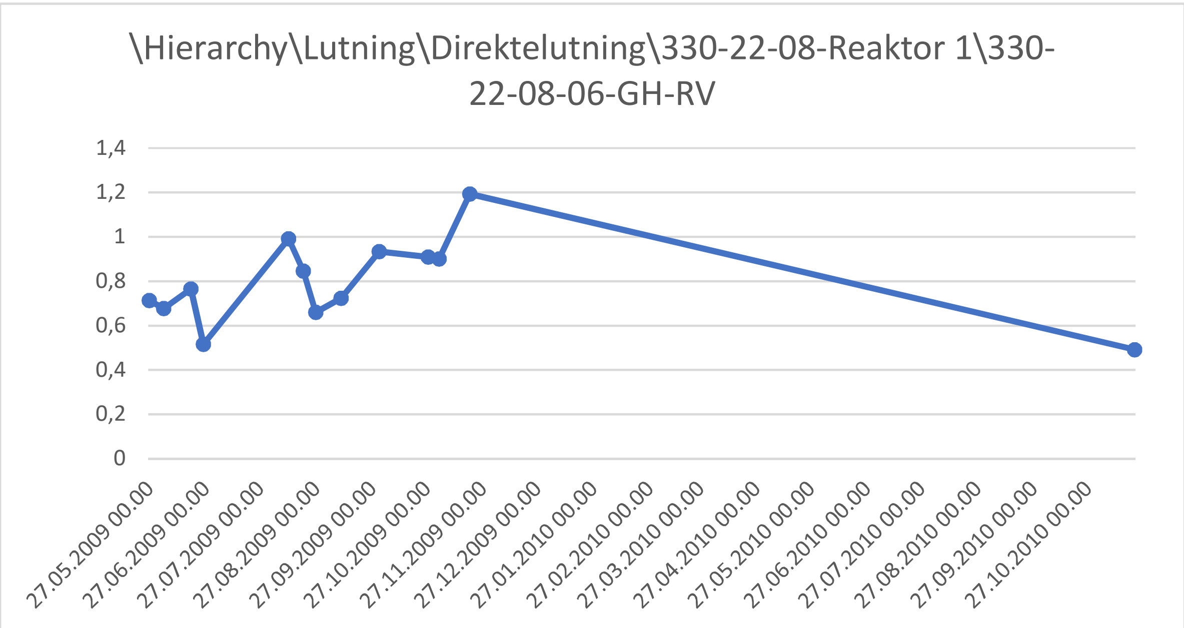
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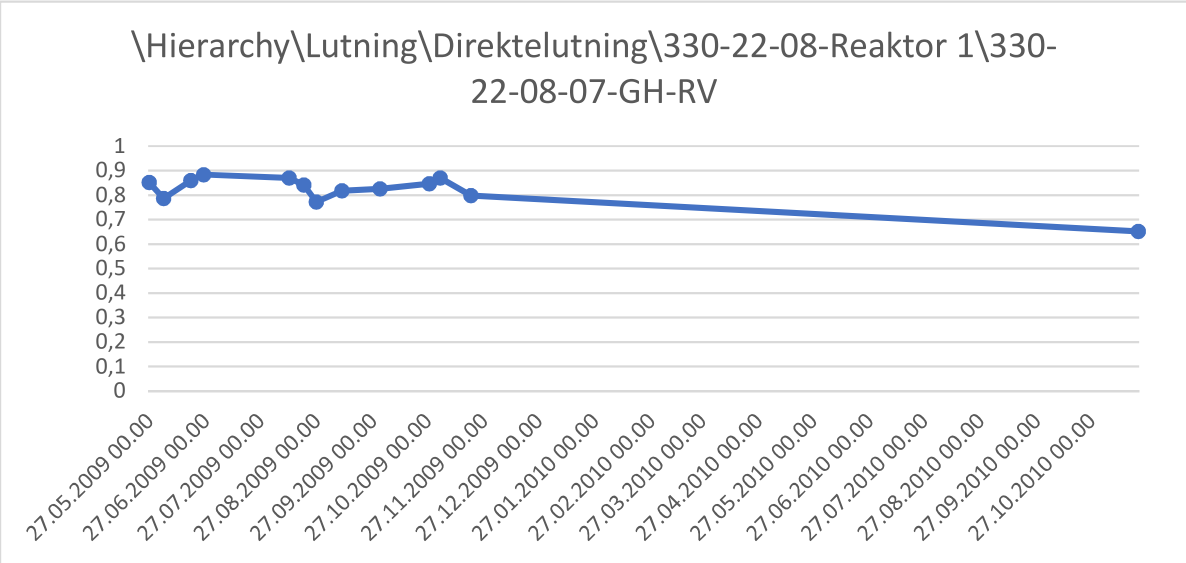
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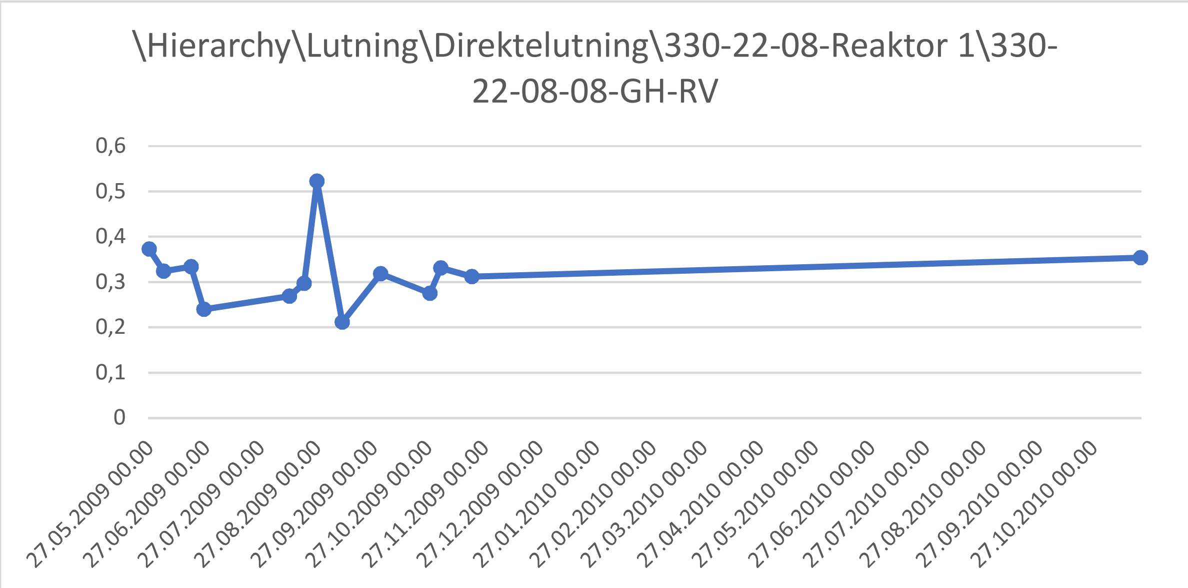
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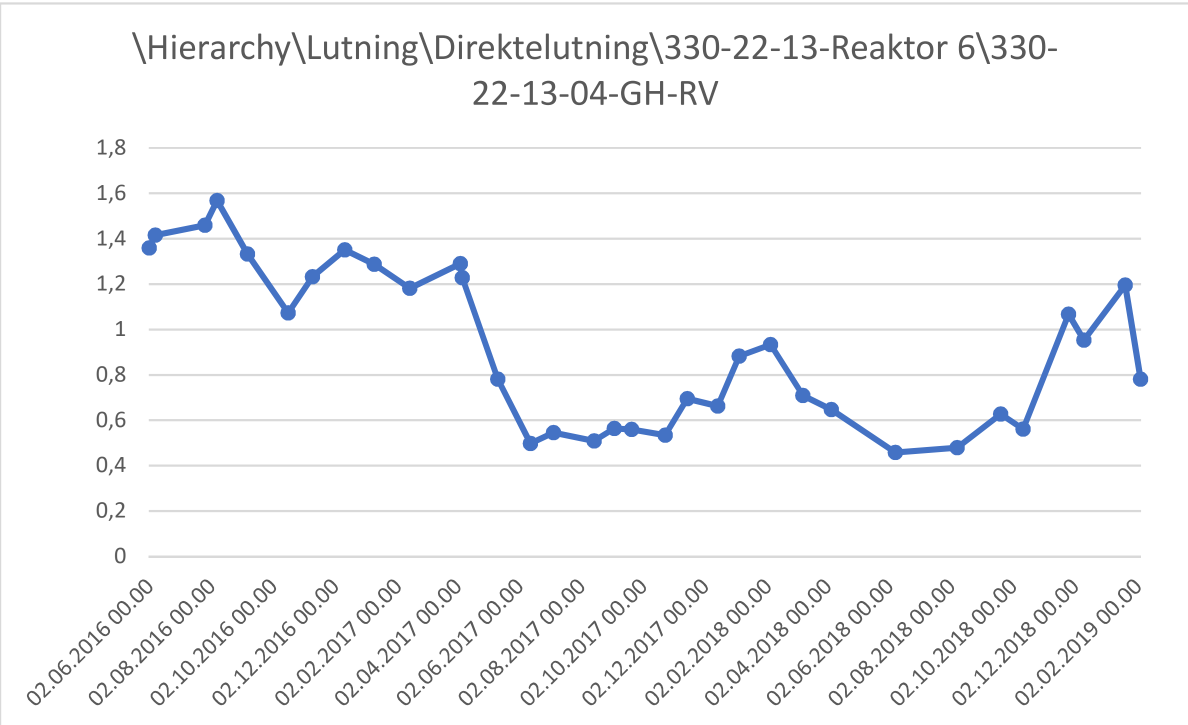
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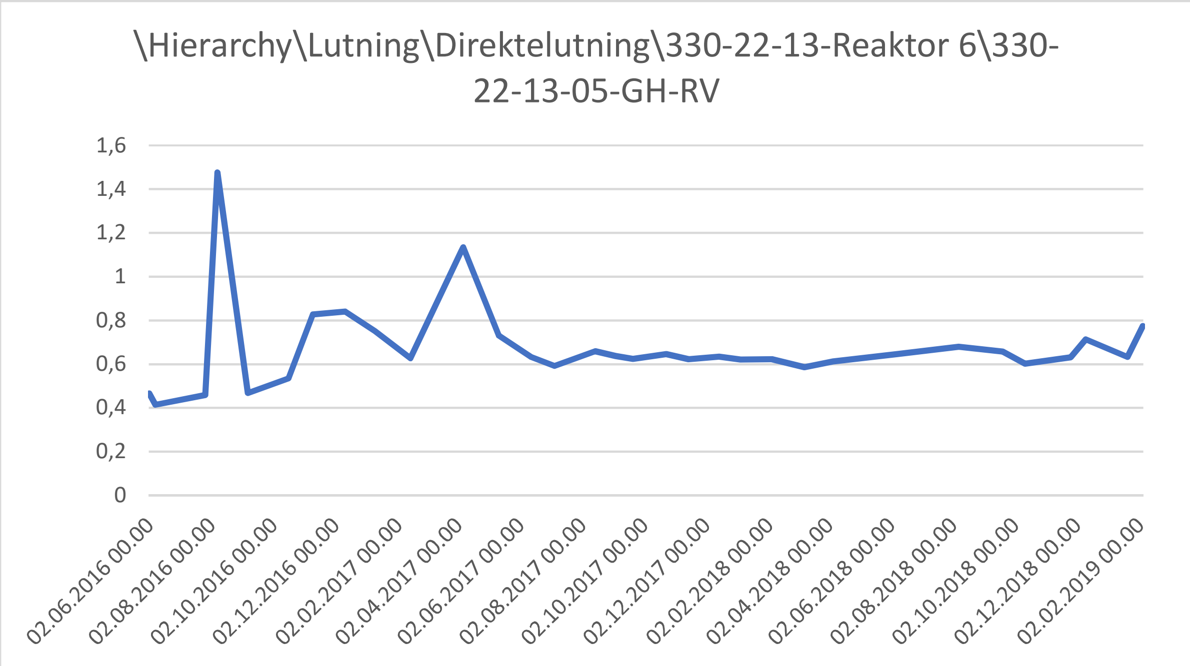
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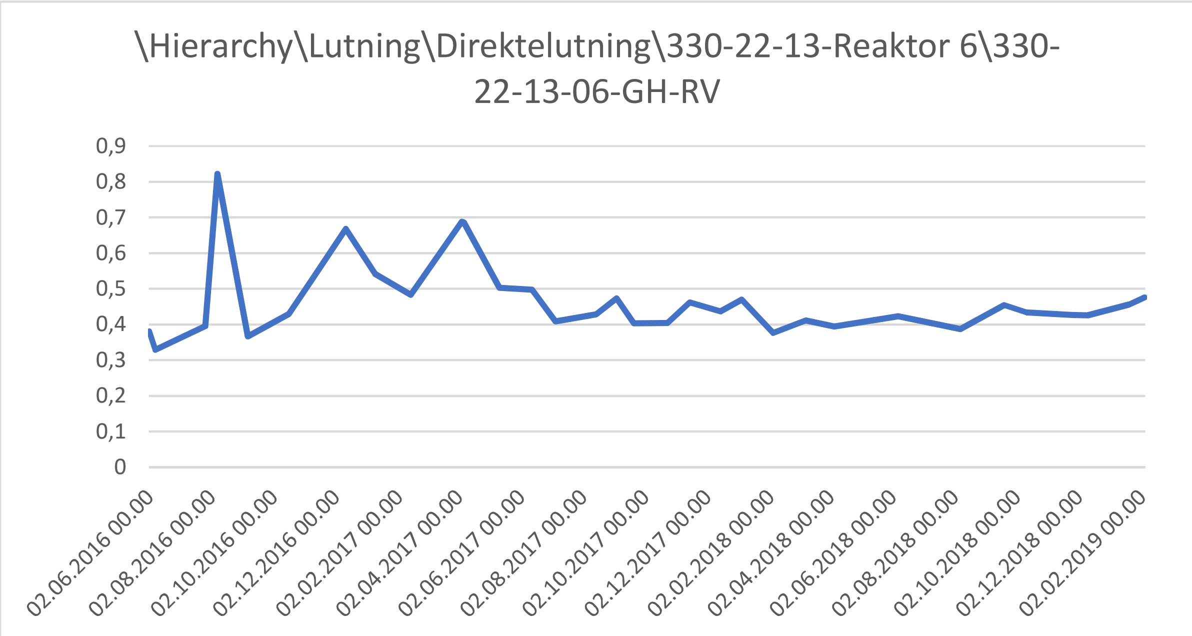
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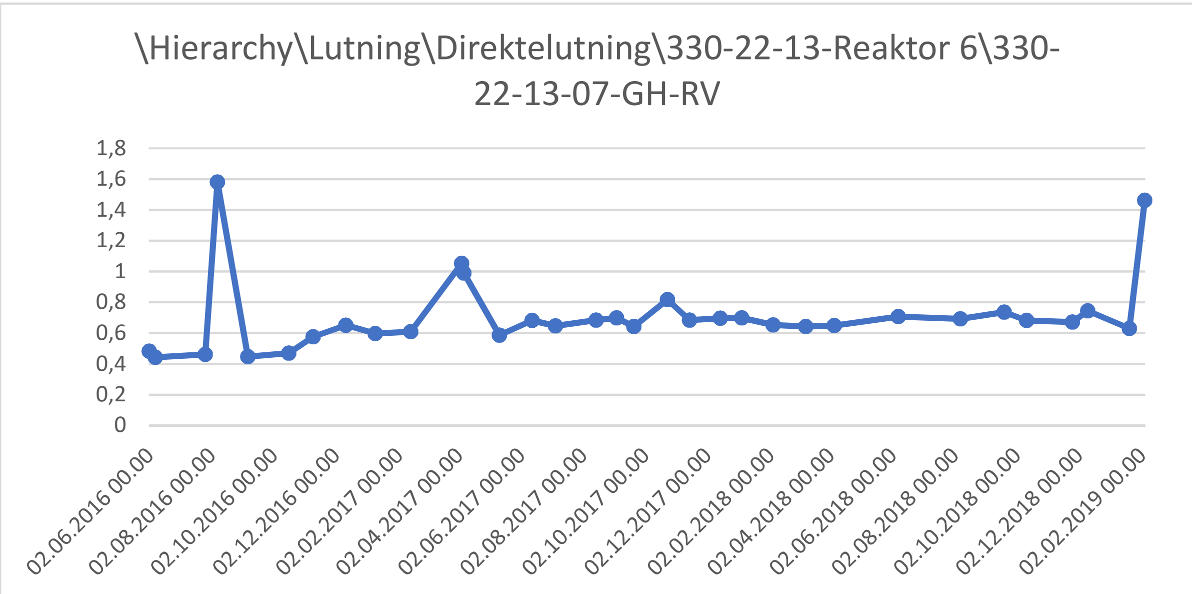
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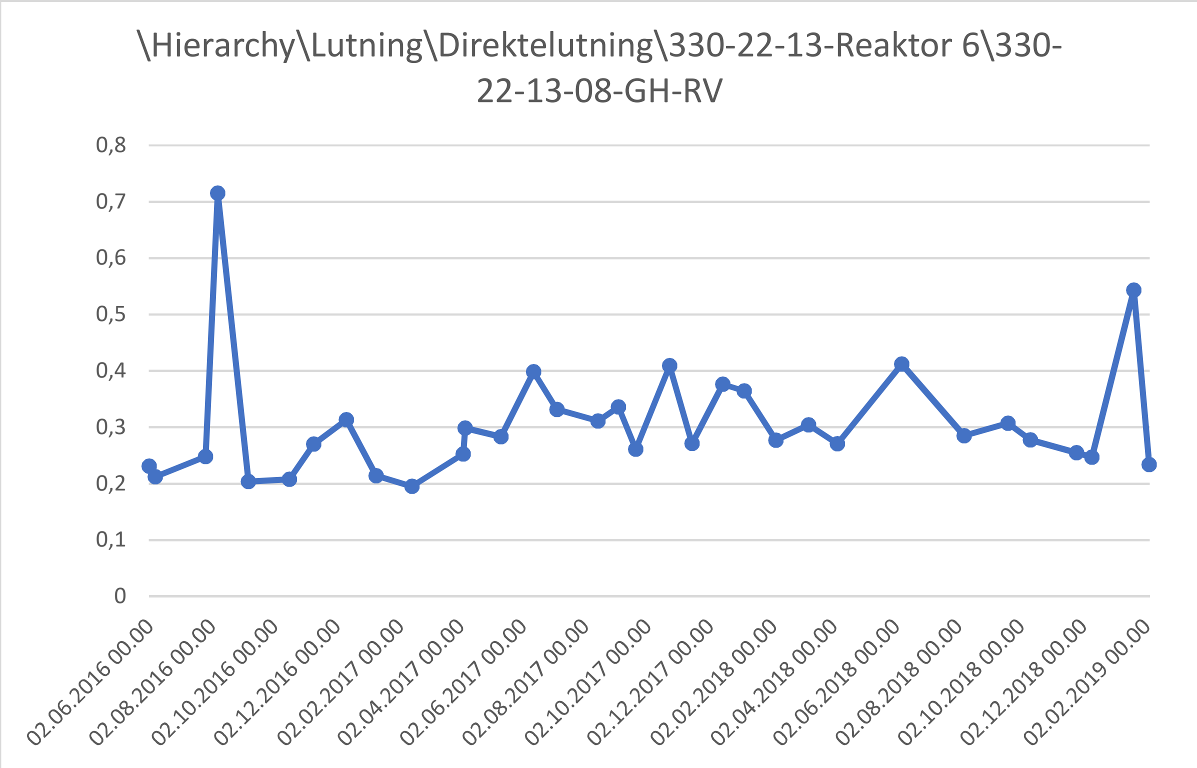

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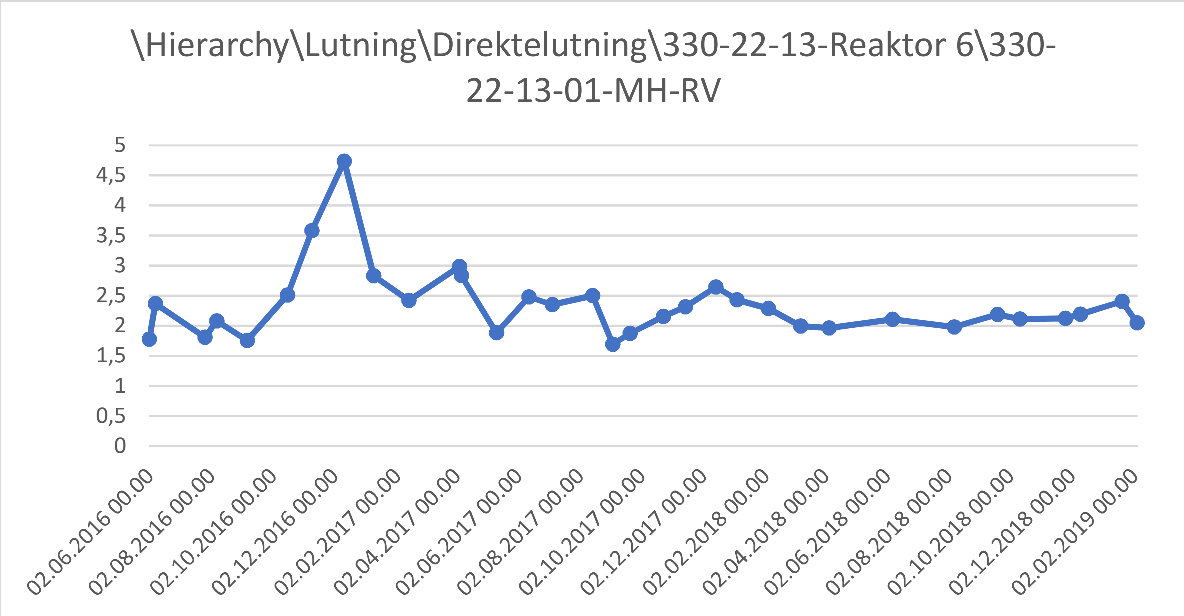
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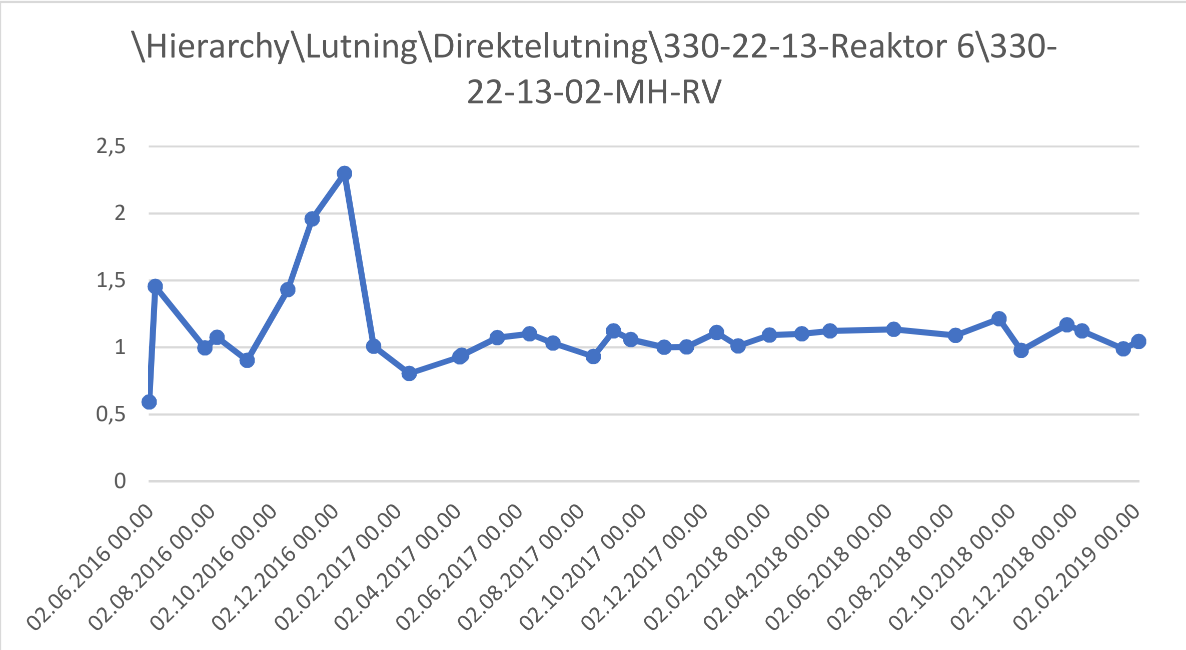
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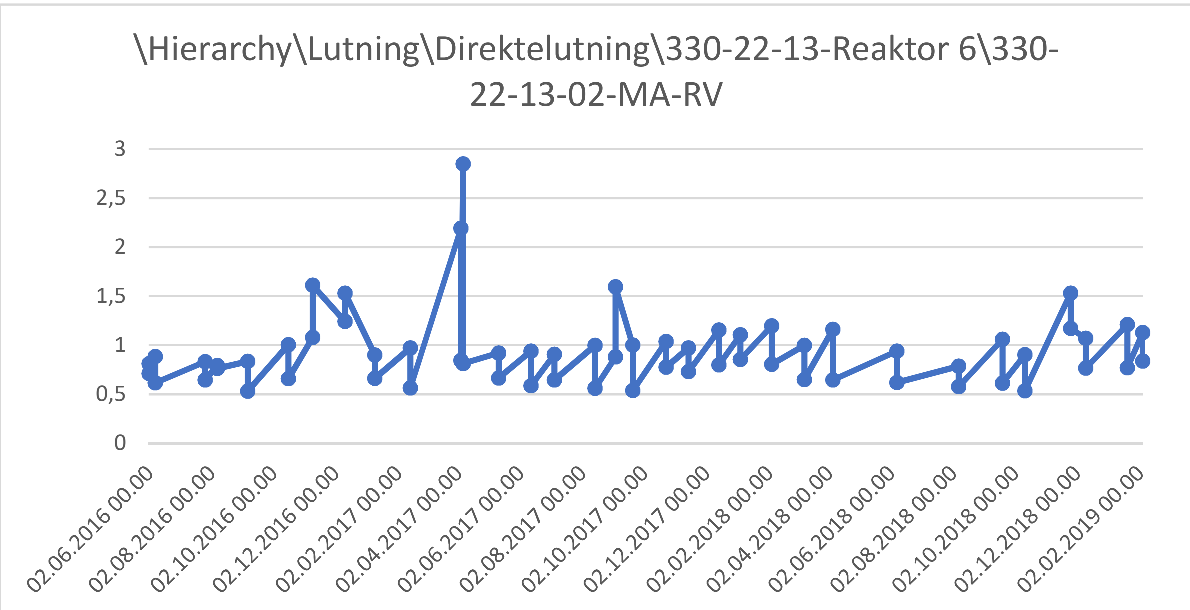
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