Maintaining your spare parts in store serviceable

Thesis Master of Science in Asset Management Control

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Acknowledgements

Dear reader, I want to start the acknowledgement in my thesis with the Zulu greeting “Sawubona” to you and especially to all the people named below. “Sawubona” means “I see you” and I hope that you and the people named below respond with the Zulu response “Ngikhona”, which means “I am here”.

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Summary

The main objective of Asset Management Control is getting and keeping grip on the logistic processes of capital assets. These logistic processes are needed to uphold the capital assets availability and reliability and one of these processes is to provide parts that are available when required and operate as expected.

Different audits within the company E.ON Benelux and articles in reliability magazines have shown that an unknown asset unavailability risk exists as a result of improper or no preservation and/or maintenance on spare parts while they are stored. Some of the parts bought are preserved and come with excellent storage instructions, but not all of them. There are spare parts even without preservation and instructions.

The question that arises is about how to determine the actions for maintaining the serviceable condition of spare parts during their storage period?

The objective of this research is the development of a process to determine the safeguarding actions required to maintain spare parts in a serviceable condition during their storage period by analyzing the different deterioration factors and the different processes to determine maintenance tasks.

The research is split into three parts:
- part 1 – the research into the deterioration criteria;
- part 2 – the analysis of the maintenance defining methodologies;
- part 3 – the development of the new Safeguard Determination Procedure.

The objective of the first analysis was to provide the deterioration criteria by analysing the theories of deterioration and preservation. The literature study and internet search revealed that little information with regards to active safeguarding exists. Most of the literature is on the subject of protecting components against the different types of corrosion (passive safeguarding).

The three types of deterioration found in the literature did not provide enough information to accomplish the objective of the research. The definition of deterioration, “The continuous process of getting worse in condition and quality”, gave a good starting point that led to the three changing component characteristics which depict the condition and quality of a component. The changing characteristics led to their inducing factors that can be used in the Safeguard Determination Procedure.

The analysis of the preservation theory provided the substantiation that equipment at the construction site of an asset, installed or not installed, need to be safeguarded until they are commissioned. It also provided a good insight into the difference between passive and active safeguarding.

The research into the process criteria was done by analysing the current maintenance defining methodologies and by analysing the procedures of the OEM’s. This part starts by explaining the connection and reason for serviceable spare parts by looking into the theory of Asset Management Control. The availability of spare parts plays a significant role in the availability of the asset, by shortening the corrective maintenance. The quality of spare parts on stock (available serviceable spare parts) has a direct relation with the asset reliability.

The theoretical analysis of the current maintenance defining methodologies indicated that these methodologies could not be used for the spare parts. The approach is based on the basic of functional failure which does not differentiate between different spare parts. The analysis provided, on the other hand, several ideas, requirements and constraints that can be used in the new Safeguard Determination Procedure.

The research into the procedures of the OEM’s showed that their storage instructions are not determined with a proactive procedure, but are based on experienced functional failures. During the research a commonality in the origin of the OEM instructions was discovered which led to two tables with perishable items that indicate active safeguarding actions.
The development of the Safeguard Determination Procedure is constructed out of the findings of the research into deterioration and the analysis of the maintenance defining methodologies. The Safeguard Determination Procedure consists of four parts: preparation, determination, calculation and implementation.

Preparation – Creating an initial Recommended Spare Parts List (RSPL) through the METRIC method of Sherbrooke and by listing the storage condition areas at your disposal.

Determination – The core of the Safeguard Determination Procedure in which the required safeguards are determined.

Calculation – The amendment of the initial RSPL by using the Net Present Value, calculated on the basis of purchase price and costs of the safeguards, instead of purchase price solely.

Implementation – The buy of the new calculated RSPL, the implementation of the spare parts data and their safeguard data into the Warehouse Management System and the actual execution of the safeguard tasks.

The determination part of the Safeguard Determination Procedure together with the calculation of the Net Present Value has been tested on four different spare parts currently available in the E.ON Benelux storage.

The conclusion is that the research objective has been reached with the construction of the Safeguard Determination Procedure based on the two tangible outcomes:

- a package of safeguarding actions required for maintaining the serviceability of the reviewed spare part;
- a Net Present Value input for the METRIC method with regards to determining the Recommended Spare Parts List.

A less tangible out of the procedure is the education on deterioration and safeguarding of the people that are using the Safeguard Determination Procedure.
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1 Problem introduction

The research topic is about the asset unavailability risk created by the introduction of premature failures of equipment as a result of using unserviceable spare parts from stock. It is not about the quantity or availability of spare parts but about having the right amount of serviceable spare parts available.

Important elements for ensuring an efficient and effective execution of the functions of capital assets are the logistic processes (Blanchard, 2004). Getting and keeping grip of these logistic processes of capital assets is the main objective of asset management control (Stavenuiter, 2002).

1.1 Initial problem indication

In 2009 an analysis (Lugthart, 2009) was performed on the management of spare parts within E.ON Benelux as a result of the program "Performance to win". The required preservation & maintenance plans for the spare parts were not available, resulting in an unknown condition.

Initiated by the recommendation of the 2009 analysis, an audit on the condition of the spare parts was performed in 2010. In the audit 159 randomly selected spare parts were inspected for technical condition, available label information, storage conditions and preservation. The audit revealed that 42% of the audited items were not in a serviceable condition and these unserviceable equipments represented a total value of €220,483,-, which is 50% of the total value of the audited spare parts (Urlings and Uffelen, 2010).

1.2 Reliability magazine indications

An article 'Care for your spares' (Wilson, 2010) in the reliability magazine "Uptime", presents two different cases (Figure 1 and Figure 2) in which a component was stored for a long time in a dusty and not environmentally controlled facility without maintenance. This resulted in a failure of both components within hours after installation.

Figure 1. Infrared thermography detected a fault condition after this vertical Mount motor ran for only 30 minutes

Figure 2. Blower unit that was stored for over 10 years in the same environment developed a fault and would fail within hours of being put in service.
Posey and Slater (2010) indicate that environmentally protected spare part still can become unserviceable in time due to the lack of maintenance. They identify gravity as the main enemy of spare parts, causing flat spots on axles, bearings and seals as a result from a constant weight on one section.

### 1.3 Other related problem indications

On May 6, 2009 E.ON Benelux received the PAS-55 certification as the first energy production company in the Netherlands. PAS-55 is a Publicly Available Specification of an asset management system and consists of 21 requirements to achieve the organizational strategic plan. One of the requirements calls for the inspection and preferably testing of equipment like critical spare parts at specified intervals to ensure the continuation of the availability and operability of the asset.

The PAS-55 recertification audit in January 2012 revealed the nonconformity with regards to maintaining spare parts in a serviceable condition (Bezemer, 2012). The auditing authority suggested the development of a maintenance program for the spare parts.

E.ON is currently building two ultra-modern coal fired power stations of 1100 MW (Figure 3). One power station is built in Datteln Germany and the other on the Maasvlakte in the Netherlands. The construction of the Maasvlakte Power Plant 3 (MPP3) started on April 15, 2008 and was planned to end with the beginning of the commercial phase on January 1, 2013. Unfortunate delays were encountered and shifted the beginning of the commercial phase to January 1, 2014. During this 6 year construction period all the systems and their buildings are constructed almost in parallel and a lot of components are temporary stored outdoors (lay down area). The result is that, depending on the time of installation, most of the system components are fully or partially exposed to the local environmental influences of sand, strong winds, salt and high humidity for a certain amount of time.

![Figure 3. Overview construction side MPP3 (2009)](image)

During the construction phase it was noticed that:

- Some components were preserved before being delivered to site and others weren’t;
- Components not always are accompanied by their manuals, resulting in waiting for manuals for several years.

A comparable situation as for the spare parts arises. If the non-preserved and preserved components are not preserved or sustained and maintained during the construction phase an asset unavailability risk is introduced (Figure 4 and Figure 5).
Figure 4. Top view open construction Electrostatic Precipitator covered with snow (2011)

Figure 5. Construction Chemical plant in Houston, Texas (system components already installed)
1.4 New Spare parts
To limit the unavailability of the two new power stations Datteln and Maasvlakte have bought normal and strategic spare parts (respectively approximately 27 & 30 Mln.). Spare parts in the size from small gaskets to complete major equipment, like a 700 MVA oil cooled Machine Transformer. Some of these spares will hopefully never be used during the 40 years of commercial operation. But during these 40 years the spare parts have to remain in a serviceable condition all the time, so that when needed they perform as expected (Posey and Slater, 2010).

The calculations performed by E.ON (Rodewald, 2010) as basis for the decision to stock specific strategic spare parts indicate that unserviceable spare parts can cause high unavailability costs, for instance:

- An unserviceable Fresh Air Ventilator creates an asset unavailability risk of € 27,500,- per hour.
- An unserviceable High Pressure By-pass Base and Spindle creates an asset unavailability risk of € 55,000,- per hour.

1.5 Component manuals
Products bought in the European Economic Area (EEA) bearing the CE-mark have to be accompanied with a user-manual in which, among other things, instructions for the operation and maintenance are written (Themag – CE-marking & working safely, 2011). Sometimes these user manuals provide instructions regarding the handling and storage of the product. Like in the operating manual for the Multitec RO pump (KSB Aktiengesellschaft, 2011). The question arises on how the OEM determines if maintenance tasks have to be executed during the storage period and what kind of maintenance actions.

Besides the OEMs that deliver manuals with instructions, there are still spare parts in stock without maintenance instructions for the storage period or even without manuals.

1.6 Downtime costs
An asset unavailability risk consists of a probability (indicated in the previous sub-chapters) and a consequence. An analysis of the historical data of Tennet, the premier electricity transmission operator of the Dutch national high voltage grid, indicated a reasonable linear relationship with a positive slope (0,4 – 0,8) between the shortage of MW and the imbalance price per MWh. The analysis also indicated that the first hours of a failure in a power plant are giving the highest costs (consequence) (Appendix A). It is for a Dutch power plant, more problematic in terms of cost, to have for example 20 failures of 4 hours than 2 long failures of 40 hours.

This clearly indicates that reliability also an important factor is with regards to components.

1.7 Conclusion
The E.ON Benelux spare parts audit, PAS-55 audit and both reliability magazine articles reveal an asset unavailability risk resulting from unknowingly introducing the probability of premature failures into the asset by installing unserviceable equipment. Unserviceable equipment originated as a result of improper or no preservation and/or maintenance in stores. This means that E.ON Benelux is not in control (asset management control) in the area of storing and providing serviceable spare parts.

Another phase were an asset unavailability risk can be introduced is in the construction phase. Again experience has shown that equipment installed during the construction phase needs to be preserved and maintained until it is commissioned.

The topic that arises is about getting and keeping control on the logistic processes to maintain parts in a serviceable condition during storage. This topic and the experienced unserviceable condition of equipment have led to the research question which is written in the next chapter.
2 Research question and objectives

2.1 Research question
How to determine the actions for maintaining the serviceable condition of spare parts during their storage period?

2.2 Objective
The objective of the research is to develop a process for determining maintenance actions to keep spare parts serviceable during their storage period by analyzing the different processes to determine maintenance tasks and the different deterioration factors between installed and spare parts.

2.3 Research Method
Verschuren and Doorewaard (2004) define 7 types of researches with different perspectives, namely: the theoretical development, theoretical testing, problem signalling, diagnose, design, intervention and evaluation perspective. Based on the discovered asset unavailability risk initiated by the lack of care for the spare parts in the analysis on the management of spare parts (Lughart, 2009) and the diagnosis in the form of an audit (Urlings and Uffelen, 2010), has the proposed research a design perspective.

2.3.1 Model

Figure 6. The research model.
The research model consists of three parts (Figure 6): On the top the analysis regarding the deterioration criteria and on the bottom the analysis for the process criteria, both providing the information for designing the spare part serviceability process (part 3). An inquiry into the material deterioration and preservation theories (A) provide the deterioration factors (B). At the same time a comparison of the exposure and deterioration characteristics between installed and spare part is performed, providing (B) the exposure and deterioration similarities and differences. An analysis of the discovered similarities and differences by the deterioration factors provide the deterioration criteria (C) required for the spare part serviceability process (D).

At the same moment the theories of Asset management, Reliability Centred Maintenance, Maintenance, Integrated Logistics Support and Logistics Support Analysis are reviewed (A) providing the theoretical process criteria (B), which is used for analyzing the spare part maintenance processes of the different vendors (B). The outcome of the analysis provides the process criteria (C) which are needed in the draw-up of the spare part serviceability process (D) together with the deterioration factors.

2.3.2 Key and sub-questions
To answer the research question, the following key and sub-questions will be addressed [10]:

1. How does material deteriorate?
   a. What is deterioration?
   b. Which types of deteriorations are there?
   c. What is preservation?
   d. Which types of preservation are there?

2. What are the exposure and deterioration similarities & differences between installed and spare part?
   a. What is a spare part?
   b. To which environmental elements is the equipment exposed?
   c. Which differences are there between installed and spare part regarding the exposure to the environmental elements?

3. Which deterioration factors have affect on the serviceable condition of spare part?
   a. What is meant with serviceable condition?
   b. Which types of deterioration affect the spare part?

4. How to determine maintenance tasks?
   a. What is maintenance?
   b. Which theoretical procedures are there to determine maintenance tasks?
   c. What are the basics of the methods?

5. How do Original Equipment Manufacturers (OEM) determine the storage maintenance tasks?
   a. What is an OEM?
   b. What are storage maintenance tasks?
   c. Do they have a procedure to determine maintenance tasks for the storage period?
   d. Which categories of storage locations are there to storage equipment?

6. What are the process criteria for developing a maintenance determination procedure?
   a. What is meant with a maintenance determination procedure?

2.4 Research strategy
According to Verschuren and Doorewaard (2004) are there five research strategies, namely the survey, experiment, case study, grounded theory and a desk research. In the proposed research consist mainly out of desk research complemented with a survey regarding the practical aspects of the research (OEM spare part maintenance process).
2.5 Resources
According to Verschuren and Doorewaard are the following resources available:

- Persons
- Media
- Actuality
- Documents
- Literature

It is expected that all abovementioned resources are needed to answer the research, key and sub-questions, due to the diversity within the questions.

2.6 Supervisors
The research will be under supervision of Drs. J. Donders MTL (docent, AMC Centre) and Ir. H.J. Compter (Station Coordinator MPP3 project, E.ON Benelux N.V.).

2.7 Outline of the thesis
This thesis is composed, like the research model, of three parts, one devoted to the analysis into the deterioration criteria, the other to the analysis of the process criteria and the last part to the construction of the new procedure.

Part 1 consists of chapter 3, in which deterioration is clarified and studied for its types and causes. This chapter also provides the clarification of and analysis into preservation and active & inactive equipment (spare parts). Part 2 consists of chapter 4, in which the theory of Asset Management Control is studied with regards to serviceable spare parts, a theoretical analysis is performed on the principles of defining maintenance tasks and the outcome is provided of a survey on the procedures for defining storage instructions by OEM’s. In part 3 (chapter 5) of this thesis the new Safeguard Determination Procedure is developed and applied, based on the outcome of chapters 3 and 4. The conclusions and recommendations are presented in chapter 6 and starts with the conclusions of the three research parts, the test cases and the overall conclusion with regards to the research objective. After the conclusions the recommendations for E.ON Benelux are presented followed by recommendations for further research.
3 Material deterioration and preservation

The deterioration of items is a common known phenomenon with regards to food and pharmaceuticals, most of them have a “use before” date stamped on their packaging. It is also commonly known that the deterioration process of most of the food can be slowed down by putting the food in the refrigerator. But beside food and pharmaceuticals, there are more products that deteriorate, e.g., chemicals, various drugs, fashion clothes, newspapers, technical components etc. But what exactly is deterioration and preservation in relation to technical components?

The objective of this chapter is to define the deterioration criteria in relation to technical components and depicts part 1 of the research model. The chapter starts with the clarification of and a theoretical analysis into deterioration and its causes (sub-chapter 3.1 through 3.3). The second part of this chapter is a theoretical analysis into preservation and the differences between active and inactive equipment (sub-chapter 3.4 through 3.6). The last part of this chapter is about the different types of safeguarding (preservation) (sub-chapter 3.7). With these subjects the key questions 1 through 3, shown in chapter 2.3.2 “Key and sub-questions”, will be answered.

The analysis into the deterioration and preservation is achieved by conducting a literature study, a search on the internet and by discussing the subject with experienced persons.

3.1 Deterioration

Deterioration as word is used very often in the literature but not always very clearly defined. In this research the literature found with regards to technical components and also clarifying deterioration, is used to come to an unambiguous understanding of deterioration.

Hermans (1995) and Moncmanová (2007) indicate that all components are influenced by several factors which are surrounding the components during their existence. The result of these influences is a gradual and declining change in the characteristics of the component, which in turn leads to the shortening of the component’s useful life (the inability to fulfill the function for which it was intended). This continuous process of getting worse in condition and quality is called deterioration (Covino, 2003; Havermans, 1995; Hermans, 1995; Moncmanová, 2007; Pahl, 2010; Wait, 1976; Wen-Chuan Lee & Jong-Wuu Wu, 2004).

The speed of the deterioration depends on the intensity of the type of deterioration and the sensitivity of the components (Figure 7) (Hermans, 1995). The intensity of the type of deterioration is in turn determined by:

- the influential factors in the surroundings (like sea & industry),
- the accumulation properties of the component (collection of physical, chemical and/or biological),
- the ability to clean (maintain) the component.

The amount of deterioration is determined by the speed of the deterioration process, the amount of time expired and the interim maintenance (repair) performed.
3.2 Types of deterioration

The number of deterioration types mentioned in the various literatures depends on the area of interest in each document. Wait (1976) is mentioning the types of chemical and physical deterioration, due to the focus on deterioration and preservation of metals in Historic Buildings. Hermans (1995) and Moncmanvá (2007) are naming three types of deterioration; Physical, Chemical and Biological. Both are dealing with the basic principles underlying the environmental deterioration of construction materials. Hermans (1995) is also mentioning Mechanical deterioration as a fourth deterioration type based on existing literature on building defects.

This Mechanical deterioration type looks like a part of the Physical deterioration type based on a provided example and the elaboration by Moncmanvá (2007) on Physical deterioration. Hermans (1995) also indicates that most deterioration is a combination of the listed types. This research confines the list of deterioration types to three and sees Mechanical deterioration as part of the Physical deterioration type. This gives the following three deterioration types:

- Physical
- Chemical
- Biological

**Physical deterioration** – mechanical attrition of the material surface, embrittlement, failure of the component due to fatigue or stress or other irreversible changes (Moncmanvá, 2007). Example is the flat spots on tires due to the force of gravity.

**Chemical deterioration** – a process in which one or more substances, the reactants, are converted to one or more different substances, the products, resulting in a regression in the intended condition and quality. Substances are either chemical elements or compounds.

**Biodeterioration** – a decrease in condition and quality of materials by micro- and macro-organisms causing physical and chemical changes. Bacteria, cyanobacteria, algae, fungi, lichens, insects, animals, and plants are a few examples of organisms causing deterioration.

With the identification of the three deterioration types, not enough detail is provided for the object of this research, a process for the determination of the required maintenance necessary to prevent the deterioration of spare parts.
In the previous paragraph deterioration was defined as a *continuous process of getting worse in condition and quality* in which "getting worse" is the effect of the changing component characteristics. Hermans (1995) provides three types of characteristic changes:

- Change of material characteristics;
- Change of shape characteristics;
- Change of locations characteristics.

The change in characteristics can be caused by more than one deterioration type and/or combinations of deterioration types.

Examples:

**Change of material characteristics** (Figure 8) – A rubber O-ring exposed to ozone and other atmospheric contaminants will show tiny cracks (also known as crazing) on the surface. The crazing is the result of the weakening of the compound by attacking unsaturated bonds and breaking apart of the polymer chains. The O-ring does not have the same material characteristics as before.

Storage of O-rings around ozone-generating equipment (such as electric motors), especially in a stretched (installed) condition, will lead to rapid deterioration of the elastomeric compound, often in as little as a few days (Hudson & company, 2012).

![Figure 8. Weather & Ozone cracked O-ring](image)

**Change of shape characteristics** (Figure 9) – A rubber O-ring under a static or dynamic compressive load may permanently flatten on both sides. The O-ring usually hardens and assumes the shape of the gland. The shape characteristics have changed permanently (Hudson & company, 2012).

![Figure 9. Compressed O-ring with flatten sides](image)
Change of location characteristics (Figure 10) – An expanding component (rise in temperature) can push an adjacent component aside. A seal that is unable to adequately hold its intended position within the gland will develop a spiral failure. Spiral failure is the result of spiral surface cuts, which typically recur at regular intervals along the seal’s exterior. The O-ring doesn’t have enough strength to resist the twisting forces that naturally develop during dynamic movement. Part of the O-ring rolls as part of it slides, and this spiralling motion causes the cross-section to be twisted and cuts to develop on the seal’s surface.

![Spiral Failure](image)

Figure 10. O-ring with spiral cut

### 3.3 Inducing factors

After identifying the different deterioration types and the characteristic changes, the next step is the identification of the factors that are inducing the characteristic changes in the materials. These inducing factors are the effect of climatic and meteorological characteristics, biological processes, chemical processes (Moncmanová, 2007) and other production processes and activities which can be found in the surrounding area of the equipment. The pollutants from production processes are of different types and depend upon the nature of the materials used as well as the technology adopted to process them.

The inducing factors of material deterioration identified in the literature include, but are not limited to (Hermans, 1995; Moncmanová, 2007): Moisture, temperature, solar radiation, air movement and pressure, precipitation, chemical and biological attack, intrusion by micro and macro-organisms, stress incorporated within materials or components due to the production process, efflorescence due to substances washing out of a material, causing staining and/or disruption of the material, changes due to the combination of materials, air pollution, loads (originating from use, own weight, wind, etc), water or wind flow containing particles.

The list with inducing factors can be reduced and combined to the following categories:

1. **Temperature** (high and low)
2. **Solar radiation** (Ultraviolet radiation, visible light, infrared light)
3. **Precipitation** (rain, snow, etc.)
4. **Gaseous pollutants** (Carbon monoxide, Carbon dioxide, Sulphur dioxide, Hydrogen sulphide, Hydrogen Cyanide, Ammonia gas, Nitrogen oxides, Ozone)
5. **Dry aerosols** (dust, smoke, salt, ashes, volcanic emissions)
6. **Wet aerosols** (water vapour [steam, mist])
7. **Solid particles** (dirt)
8. **Forces** (use loads, gravity, vibrations)
9. **Fluids** (water, acids, bases, carboxylic compounds, nitrogenous wastes)
10. **Electromagnetic radiation**
11. **Micro organisms** (bacteria, algae, fungi, lichens)
12. **Macro organisms** (insects, animals, plants)
3.4 Preservation

Both the OISD-STD-171 (1998) and the Norsk Standard Z-006 (2001) define preservation as the protection or safeguarding of equipment. The OISD-STD-171 (1998) adds the condition “of unattended and inactive equipment during their down period”. While the Norsk Standard Z-006 (2001) adds the condition “before it is taken into use”. Both conditions comprise the storage phase of the equipment and the phase of construction of the asset. In both the phases the equipment is inactive and not taken into use. But there is a distinct difference between the phrase “before it is taken into use” and “inactive during their down period”. The second phrase also refers to the moments in the life cycle of equipment in which it is taken into use but not working for a certain period of time. This period of inactiveness of the equipment may also require the protection or safeguarding of the equipment against deterioration.

The OISD-STD-171 (1998) also uses the word “unattended” which is the opposite to what I think is intended, namely: paying attention to the inactive equipment.

With regards to the spare part, based on the abovementioned information, it can be concluded that preservation is the safeguarding of inactive equipment against deterioration by protection and preventive maintenance (OISD-STD-171, 1998; Norsk Standard Z-006, 2001).

In the English literature the two words “conserve” and “preserve” are often used, but have both a different meaning. When you conserve something, you ensure that you make use of it wisely. You make sure it is not wasted. When you conserve something, you do not wish to waste or deplete any of the available resources. You attempt not to change anything drastically.

Preserve, on the other hand, suggests that you make attempts to keep something as it is, without making any changes. In other words, when you preserve something you keep it intact. You keep it safe, protecting it from danger. In the context of this thesis, preservation is the correct word, because we want to protect the equipment in such a way that it will operate as expected when required.

3.5 Active and inactive equipment

In the previous paragraph the definition of preservation is provided and starts with “safeguarding of inactive equipment”. The safeguarding of inactive equipment insinuates the distinguishable difference between active, inactive, installed and spare part. Active equipment is installed in the system and operates, while the phrase “installed equipment” does not indicate if the equipment is active or inactive. Spare part on the other hand is seen as inactive and not installed.

Blanchard (1995) indicates that the life cycle of equipment starts with the identification of the customers need followed by the system design and development, production (and/or construction), operational use, maintenance & support and at the end the retirement and phase-out. During the production (and/or construction), operational use and maintenance & support activities of the life cycle the equipment encounters three important and distinct periods with their own or corresponding inducing factors in relation to deterioration, namely (Posey & Slater, 2010; OISD-STD-171, 1998):

- The period of the life cycle in which equipment is placed in storage. [Stored]
- The periods of prolonged inactiveness / downtime of installed equipment. [Inactive]
- The periods of activeness (installed and operating) [Active]
If we look at the inducing factors that are different between the three abovementioned periods, then we can come to the following overview (Posey and Slater, 2010; OISD-STD-171, 1998):
- The kinetic forces during the operation of the system, acting on the active equipment, like wear, heat and vibration.
- The deposits build up during the active time which may turn into inducing factors during the inactive time.
- The environment surrounding the equipment when installed and stored. Sometimes installed equipment is protected with air-conditioning and dust proofing which may not be the case during the storage period.
- The inducing factors who become dominant during the period that the equipment is not installed, like gravity.

This overview (Figure 11) is far from complete but the mentioned inducing factors clearly show that the Stored and Active status of the equipment with regards to deterioration strongly influences the type of safeguarding required. Because even if the equipment is stored in a suitable environment the equipment may exhibit failure modes from exposure, such as (Posey and Slater, 2010):
- Rust
- Hardening, cracking, softening of rubber components (seals, belts, etc.)
- Build up of dust
- Oxidation of lubricants
- Vibration from the operating asset nearby.
- Bended axles and shafts
3.6 Serviceable spare parts

In the previous chapter spare parts are described as equipment that is inactive and not installed. During the period of inactiveness and not being installed the equipment is placed in storage and is referred to as spare parts (Posey and Slater, 2010). Spare parts are items required for the support of scheduled and unscheduled maintenance actions (Blanchard, 2004; Jones, 2006; Öner, 2010). They shorten the corrective maintenance time, and with it the system and/or asset down time.

The term spare part sometimes refers to the following items (Jansen, 1991; Jones, 2006; Schouten-Niëns, 1991):

- Exchange / repairable parts – parts that are repaired after replacement
- Wear parts – parts that are not repaired after replacement but discarded
- Consumables – parts that are consumed when used, like oil and gaskets
- Strategic parts – major or important assemblies for the assets availability and existence, which are in principle the same as exchange parts, but with a high criticality factor

Strategic parts are parts that, with regards to their very low usage during the lifecycle of the asset, would not qualify for stocking, were it not that they are very essential for the functioning of the asset and have a very long delivery/lead time and/or lead to very high expenses when required (Jansen, 1991).

In chapter 1 was written that it is not about the quantity or availability of spare parts but about having the right amount of serviceable spare parts available. The major dictionaries (Oxford, Cambridge & Merriam Webster) define serviceable as being capable to fulfil its function (fit for use). Posey and Slater (2010) define serviceable spare parts as parts in the storage facility that are available when required and operate as expected.

If the spare part is not fully serviceable but slightly deteriorated as a result of poor preservation and/or lack of preventive maintenance, then it will not operate as expected. The result is a premature failure of the component which has to be replaced again with corrective maintenance, creating extra downtime. But this decrease in reliability also increases the amount of spare parts in stock and with it the costs of investment and storage (Blanchard, 2004).

3.7 Type of safeguarding

It is easily to assume that by placing spare part in a temperature and humidity controlled building it is protected enough and it will be operating as expected when required. Unfortunately this is not always the case, because the biggest enemy of stationary equipment is gravity (Posey and Slater, 2010).

Gravity belongs to the inducing factor of Forces and is always there. The constant weight on one section of seals, axles and bearings results in flat spots, it causes relative long axles to bend and let lubricants flow to one side, leaving the other side unprotected. Equipment can not be protected against gravity, the effects therefore have to be managed (Posey and Slater, 2010).

The result is that two types of safeguarding are required to ensure that equipment will be operating as expected when needed, passive and active safeguarding. The passive safeguarding is for instance the protection against environmental elements like dust, temperature, humidity, UV-light, etc. The active safeguarding is for instance the management (preventive maintenance) of the deteriorations caused by gravity. In the case of axles and bearings in assemblies the preventive maintenance consists for instance out of the rotation of the axle each month for 1¼ turn each time (Posey and Slater, 2010; OISD-STD-171, 1998).
3.7.1 Passive Safeguarding

The company Alstom (2001) has written a storage instruction document for their customers in which they provide the minimum requirements for storing their equipment. It starts with the classification of the equipment into 4 categories of material classes based on their sensitivity to atmospheric and physical influences. The second part describes the requirements regarding the storage area and conditions and has 4 storage categories. The components leave the factory with preservation and packaging valid for 12 months when the provided instructions and inspections are fully complied with. For storage periods longer than 12 months after leaving the factory, special technical instructions shall be ordered. The first storage instructions are unfortunately not complete because it only provides safeguarding of the passive kind (protection). The provided storage instructions do not include the active safeguarding like the axle turning of pumps or electro motors. Still the document provides a good starting point with regards to safeguarding spare part.

Storage area A
- Closed Building
- Ventilation system with filters and air-conditioning – ensuring an atmosphere free of dust and harmful vapours
- Heating to ensure a constant temperature between 20° - 25°C
- Relative humidity of max. 40%

Storage area B
- Closed building
- Ventilated
- Heating to ensure a constant temperature between 5° - 50°C
- Relative humidity of max 60%

Storage area C
- Closed building that protects against direct weather influences like rain, snow, etc.

Storage area D
- Outdoors
- Protection against precipitation

3.7.2 Active Safeguarding

For a reasonable amount of equipment, the protection (passive safeguarding) against the deterioration factors is enough, but not for all equipment. As previously indicated, there is no protection measure against the forces of gravity it is only possible to manage these deterioration effects.

Rubber is a material that is susceptible to several inducing factors like UV-light, humidity, oxygen, ozone, heat, bacteria and stress (EPM, 2012; Hudson & company, 2012; SAE ARP5316 rev B, 2002). The protection against these inducing factors is possible by creating the correct storage environment and by using the correct packaging materials like an airtight opaque container for rubber o-rings (EPM, 2012).

Lubricants (oils & greases) degrade due to several inducing factors like temperature and temperature variations, humidity and contact with metals. Oxidation occurs in all oils that are in contact with air, including stored lubricants. An increase in storage temperature with 10°C doubles the oxidation rate and cuts the usable life of the oil in half.

The recommended maximum storage time, depending on the lubricant composition, ranges from 3 to 12 months. Protecting the lubricants against the inducing factors ensures that the maximum storage time can be reached.
But is safeguarding of the rubber components and lubricants still possible when they are used in assembled but not active equipment like pumps, fans and electro motors? O-rings fitted in pumps are exposed to air present in the pump and are in most cases in contact with metals, which have a deleterious effect on rubbers (EPM, 2012; Hudson & company, 2012; SAE ARP5316 rev B, 2002). Most pumps, fans and electro motors have a grease or oil in their bearings and other components for the lubrication. Most of these components are made from some kind of metal which increases the rate of oxidation and shortens the useful life (Troyer, 2001). Passive safeguarding of this equipment is not enough to ensure that equipment will be operating as expected when needed, also active safeguarding is needed. The active safeguarding is the management of the effects of deterioration and is with regards to the abovementioned materials/components:

- Replacement of the rubber o-rings at predetermined intervals
- Removal, cleaning, re-greasing and installation of bearings.

Examples of active safeguarding instructions by OEM’s:

**Siemens low voltage motors**

Turn the shafts 1x every year to avoid bearing brinelling. Prolonged storage periods reduce the useful life of the bearing grease (aging).

- **Open bearings**
  - For open bearings e.g. 1Z, check the state of the bearing grease over 12 months.
  - Replace the grease if it can be identified that the grease has lost oil content or has become dirty (ingress of condensation leads to consistency changes of the grease).

- **Closed bearings**
  - For closed bearings, replace the DE and NDE bearings after a storage time of 48 months.

For rotors there is also a combination of active and passive safeguarding possible by removing the rotors from the equipment (pumps, fans and turbines) and hang them vertically in a protective environment. The downside of the safeguarding is the extra downtime of the assets at the moment of need due to the assembly of the rotor into the equipment.

### 3.7.3 Determining a safeguard

Finalising a safeguarding for a piece of equipment requires a carefully performed study in which the following issues should be taken into account (OISD-STD-171, 1998):

- The type of equipment
- Current condition of the equipment
- Period of safeguarding
- The applicable inducing factors
- Allowable deterioration and rate of deterioration
- The cost of repair/replacement (including missing revenue)
- The possibility of failure of the equipment with and without safeguard
- The consequence of failure of the equipment
- Probability of reuse
- Type of environment in which the equipment are to be stored
- Criticality of the services
- Type of safeguarding (various alternatives)
- The cost of the safeguard

For inactive equipment it is preferable to remove it out of the system and into the storage facility. Of course taken into account the aforementioned issues, especially the required period of safeguarding compared to the amount of effort needed to place the equipment in the storage.
Safeguarding of equipment will not be necessary if;
   a) It has become obsolete and will not be put to service again.
   b) It has deteriorated beyond economical repair and requires to be condemned.
   c) The estimated value of the equipment is not worth the expenditure to be made for
      preservation, if it is not in critical service.

3.8 Conclusion

The objective of this chapter was to define the deterioration criteria needed for the
development of the safeguarding determination procedure. The research into the
deterioration criteria started with the clarification of deterioration which was defined as a
continuous process of getting worse in condition and quality. This definition led to the three
changing component characteristics:
   • Change of material characteristics;
   • Change of shape characteristics;
   • Change of locations characteristics.

The next step was the listing of the factors that are inducing the changing component
characteristics, which could be grouped into 12 categories. These three changing component
characteristics and list of inducing factors provide together the needed deterioration criteria.
The second part of the chapter started with the clarification of what preservation is and was
followed by an analysis into the active and inactive equipment differences with regards to the
inducing factors. In the last part of chapter 3 the differences between passive and active
safeguarding were explained. And at the end of the chapter a list was provided with items
that should be taken into account during the determination of a safeguard.

In the next chapter the process criteria are determined by an analysis of the maintenance
methodologies and the experiences of the OEM's.
4 Process criteria

The objective of this research is the development of a process for determining the maintenance actions required to keep spare parts serviceable during their storage period. The development of the process is split into two subjects, namely the analysis of the deterioration criteria and the analysis of the process criteria. In the previous chapter the different deteriorations, inducing factors and safeguarding have been identified and listed. In this chapter the second subject, the analysis of the process criteria, will be handled, by answering the key questions 4 through 6 of chapter 2.3.2.

In chapter 1 a connection between the asset unavailability risk and unserviceable spare parts was made. This chapter starts by explaining the connection and the reason for serviceable spare parts by looking into the theory of Asset Management Control (sub-chapter 4.1 through 4.3). The second part of this chapter is a theoretical analysis into the principles of defining maintenance tasks through a literature study of the current maintenance defining methodologies (sub-chapter 4.4 and 4.5). The third part of this chapter provides the outcome of a survey with regards to the principles of defining storage instructions by OEM's (subchapter 4.6 through 4.8).

4.1 Asset Management Control

Capital assets are designed and constructed to perform as intended, be available when required, and be cost-effective during the utilization phase (Blanchard, 2004; Stavenuiter, 2002). Important elements in ensuring an efficient and effective execution of these requirements are the logistic processes (Blanchard, 2004). And getting and keeping grip on these important logistic processes is the main objective of the management approach called Asset Management Control System (AMCS) (Figure 12) (Stavenuiter, 2002).

![Figure 12. Asset Management Control System (Stavenuiter, 2002)](image)

4.2 Logistics Process Cycle

A Logistics Process Cycle (LPC) (Figure 13) was constructed by Stavenuiter (2002) based on the principle elements in the system and logistic process breakdown structure to provide qualitative insight into AMCS. The LPC also complies with the general management control system of De Leeuw (Stavenuiter, 2002) and consists of three interrelated system levels, "Operational Environment", "Logistics Process" & "Technical System".
4.3 Availability and Reliability

Availability is the readiness of an item (asset, system and/or component) to successfully perform the intended operational demand when required independent of the actual operation (Blanchard, 2004; Jones, 2006; Stavenuir, 2002; VGB-R 808 e, 1999).

The availability (Figure 14) of an item is determined by the amount of active time and downtime of the item (MIL-HDBK-338B, 1988; Stavenuir, 2002). The down time of an item is influenced by several factors, the amount of trouble shooting required to find the problem, time needed to get the spare part, and time needed to repair the item (Kranenburg, 2006). Spare parts play a significant role in the performance of corrective maintenance and shorten the corrective maintenance time if the required spare part is available (Blanchard, 2004).
Reliability is the probability of an item (asset, system and/or component) to perform its intended function within a given period of time, assuming that the item is used within the conditions for which it was designed. (Staveniuter, 2002; Blanchard, 2004; Jones, 2006)

Note that there are four important elements (see also figure 3):
1. The element “probability” is the percentage signifying the number of times that an event occurs, divided by the total number of trials.
2. The element “within a given period of time” refers to the mission time.
3. The element “assuming that the item is used within the condition for which it was designed” refers to the load experienced by the item.
4. The element “to perform its intended function”, is a key element with regards to spare part and it’s way of storage. This statement refers to the quality of the item which is determined by its design, materials, storage, handling and transportation.

The above written paragraphs clearly indicate that only having spare parts available in the storage facility only upholds the availability of the installation by shortening the downtime (Jones, 2006; Rustenburg, 2000). In order for the installations to have a high availability, reliability and capacity of fulfilling the required functionality, it is necessary to have the correct amount of serviceable spare parts. Maintaining the spare parts serviceable during their storage period is the subject of this thesis. The correct amount of spare parts can be calculated by using the METRIC model of Sherbrooke (1966) (METRIC - Multi-Echelon Technique for Recoverable Item Control).
4.4 Maintenance

What is maintenance? In this research a relevant question because it is the main topic in this research with regards to spare parts. The unambiguous understanding of what is meant with maintenance with regards to spare parts is obtained by analysing the maintenance methodologies that are listed below. The presented list is not pretended to be complete but provides the methodologies that are referenced the most in literature with subjects of asset management, maintenance management and spare part management.

- Reliability Centred Maintenance – (Moubray, 1997)
- Business Centred Maintenance – (Kelly, 2006)
- Integrated Logistic Support – (Jones, 2006)
- Logistic Support Analysis – (Jones, 2006)
- On the maintenance concept for a technical system, a framework for design – (Gits, 1984; 1992)
- Description of a methodology for the design of maintenance concepts – (Reijnen, 1998)
- The EUT maintenance model – (Geraerds, 1988; 1991; 1992)

Gits (1984; 1992), Kelly (2006) and Jones (2006) define maintenance as a set of activities needed to sustain the integrity of the physical assets. In which the set of activities can be divided into repairs, replacements and modifications. Reijen (1998) also indicates that these activities should be based on the technical requirements, properties and user profile. Waeyenbergh & Pintelon (2000; 2002) and Moubray (1997) on the other hand define the main objective of maintenance as “to ensure that assets continue to do what their users want them to do”.

Posey & Slater (2010), writing the article about the spare part management as the missing link on reliability, define maintenance with regards to spare parts as “the actions required to preserve equipment in a suitably operational state such that it operates as expected when required”.

With regards to spare parts, based on the abovementioned answers, it can be concluded that maintenance is the set of activities needed to sustain the integrity of the spare part such that it operates as expected when required (Gits, 1984; 1992; Jones, 2006; Kelly, 2006; Posey and Slater, 2010).

4.5 The basics of the methodologies

The unambiguous understanding of maintenance with regards to spare parts enables further review of the listed methodologies for the basics of the used approaches by which the required maintenance activities are determined. Based on these basics it can be decided if this specific methodology can be used on spare parts or not. If the methodology in total cannot be applied to spare parts, then the basics or parts of the process could contribute in a set of requirements, constraints or ideas for the new procedure.

The first review of the above listed methodologies showed that Kelly (2006) and Jones (2006) both refer to the Reliability Centred Maintenance (RCM) process of Moubray (1998) for defining the required maintenance tasks from scratch. The methodology of Reijnen (1998) on the other hand shows a very close resemblance with the RCM process. The EUT maintenance model of Geraerds (1988; 1991; 1992), illustrating the interrelations of partial and dispersed knowledge and serving as a tool to assess the possibilities to improve maintenance in an enterprise, refers to the framework of Gits (1984; 1992) for the methodical design of the maintenance concept.
The intensive review of the methodologies of Gits (1984; 1992), Moubray (1997), Reijnen (1998) and Waeyenbergh & Pintelon (2000; 2002) made it clear that none of these methods can be used in its totality for the determination of the maintenance tasks required for the spare part due to their underlying basic method.

The basic used in the methodologies Moubray (1997), Reijnen (1998) and Waeyenbergh & Pintelon (2000; 2002) is the one of functional failure. The basic starts with describing the function(s) of the system or component followed by the determination of the way(s) it fails to fulfil this function. Gits (1984; 1992), on the other hand, uses this basic partially and couples a maintenance action directly to a failure without describing the function. In the application of the functional failure basic with regards to the determination of the maintenance tasks for spare part a problem arose in that it does not differentiate between the different spare parts. The objective and function of all the spare parts are the same, namely "to avoid or reduce the consequence of failure" (Moubray, 1997) and that is done by "being fit for use when required" (Posey, 2010). This function changes at the moment the equipment is installed in the asset, then the designed function becomes active. The result is one set of failures for all the different spare part resulting in the same preventive measures or safeguarding.

In chapter 3 three different types of deteriorations were presented and three types of characteristic changes. The different types of characteristic changes are the effect of the different inducing factors and their effect on the specific materials of the spare part, which shows that one preventive measure does not protect against all deteriorations. The subchapter 3.7.3 “Determining a safeguard” also provide a list of issues that should be taken into account in the determination of a safeguard. The first listed issue is “the type of equipment” (OISO-STD-171, 1998). All clearly indicates that a distinction between the spare parts is required to determine the correct safeguard.

The methodologies can not be used in their totality but still provide some good ideas, requirements and constraints for the draw-up of a new process for spare part. The following list shows the amended version of the encountered ideas, requirements and constraints with regards to the spare part maintenance process in random order:

- Select and determine in the beginning of the process or as preparation the most important spare part. Differentiate in several levels and determine the sequence of analyses. (Moubray, 1997; Reijnen, 1998; Waeyenbergh & Pintelon, 2000; 2002).
- Is the selected safeguard technically feasible and worth doing? (Moubray, 1997; Reijnen, 1998)
- The altered process steps 2 through 6 of the RCM procedure (Moubray, 1997):
  - In which way does it deteriorate?
  - What causes each deterioration? \( \text{(what are the inducing factors?)} \)
  - What happens when each deterioration occurs? \( \text{(what are the characteristic changes?)} \)
  - In what way does each deterioration matter?
  - What can be done to prevent each deterioration? \( \text{(which safeguarding should be applied?)} \)
- Harmonization of the maintenance intervals by consolidating the amount of intervals into a smaller number of intervals and work packages. (Gits, 1984; 1992; Moubray, 1997)
- Clustering of the maintenance actions. (Gits, 1984 & 1992; Moubray, 1997) Example: perform the monthly axle turning all at once (locate all the affected components like electro motors, as much as possible in one area).
4.6 Original Equipment Manufacturer Guidelines

The Original Equipment Manufacture or OEM refers to the company that originally manufactured the product. The KSB group, Sulzer and Siemens are examples of Original Equipment Manufactures. Both the KSB group and Sulzer are leading producers and international suppliers of pumps and other essential related products. Both innovate, design and produce pumps for different areas of application.

The energy sector of Siemens is one of the world’s leading suppliers of a wide range of products, solutions and services in the field of energy technology. Siemens is for example the OEM for different electro motors that can drive the pumps of the KSB group and Sulzer.

All three companies deliver their products in the European Economic Area (EEA) with the CE-mark (Conformité Européenne), which means that their products are conform the European Guidelines (Themag – CE marking & working safely, 2011). Their products bear the CE-mark and have to be accompanied with a user-manual in which they provide instructions for the storage period and long periods of inactiveness of their products. Examples of component storage instructions of these three companies can be found in Appendix D – SDP fill-in sheet.

4.7 OEM process to determine safeguarding instructions

In the appendix C passive and active safeguarding instructions are provided out of the component manuals of the three OEM’s as an example. Unfortunately, this practice of providing passive and active safeguarding instructions is not always the case.

The fine examples of passive and active safeguarding instructions of the three OEM’s give the impression that these OEM’s have probably some kind of procedure for the determination of safeguarding tasks. May be this procedure could be used to determine the safeguarding instructions for other spare parts that are missing these instructions. All this led to the following key-question:
How do Original Equipment Manufactures determine the storage maintenance tasks?

To answer this key-question inquiries were made by the OEM’s Sulzer, the KSB group and Siemens about how they determine the active safeguarding actions. Surprisingly, all three OEM’s answered that they do not have a procedure to determine the active safeguarding (maintenance tasks). Their active safeguarding actions provided in the manuals are based on the many years of experience.

The answers were:

**KSB**
KSB answered that all their active safeguarding instructions are based on the standards of good & correct engineering and their experience of more then 140 years of construction, production and servicing their components.

**Sulzer**
The active safeguarding grew chronologically with the influence and knowledge of their experts. This continuing process means that if new issues arise, they look if they have something in their documentation basis and validate it or create new procedures. New issues are encountered within Sulzer and at their clients and are communicated to the project management and experts, which will find a solution and update or amend the documentation.

**Siemens**
Siemens indicated that they do not have a procedure and that all the active safeguarding actions are based on the many years of experience.
Based on the provided answers it can be concluded that none of these OEM’s has a procedure to proactively determine the storage instructions. All instructions are based on their own experienced functional failures of parts. The result is that an own generic Safeguarding Determination Process has to be developed for the spare parts without storage instructions.

4.8 Commonality in active safeguarding instructions

During the survey and research into the active safeguarding instructions of the different products and between different OEM’s (Sulzer, Siemens, KSB, ABB, Richter) an interesting commonality in the origin of the instructions was discovered. The companies Siemens, Richter and ABB instruct the users to replace the bearings or to clean and repack the bearings with new grease after 4 or 5 years. The reason for this instruction is the change in material characteristics of the grease. The instruction by KSB, Siemens, ABB and Sulzer to monthly rotate the axles is to prevent bending of the axle or to prevent indentations. Both the bending and indentations are deteriorations as a result of changes in the shape characteristics. The requirement to replace the O-rings and seals after 5 years of storage is needed to prevent leakages. The deterioration of the O-rings and seals is the result of a change in material characteristics of the products (See also sub-chapter 3.2).

An internet search on the shelf life of elastomeric and rubber products led to the Aerospace Recommended Practice (ARP) 5316 and the R.J. Hudson & Company internet site. Both provided a table for governing the shelf life of unassembled elastomeric and rubber seal elements, see Table 1 below.

<table>
<thead>
<tr>
<th>Type</th>
<th>ASTM designation</th>
<th>Maximum storage life (years)</th>
<th>Hudson</th>
<th>ARP 5316</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Nitrile (Buna N)</td>
<td>NBR</td>
<td>3 – 5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2 Styrene Butadiene (Buna S)</td>
<td>SBR</td>
<td>3 – 5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3 Polybutadiene</td>
<td>BR</td>
<td>3 – 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Polyisoprene</td>
<td>NR, IR</td>
<td>3 – 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Hypalon</td>
<td>CSM</td>
<td>5 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Ethylene Propylene</td>
<td>EPDM, EPM</td>
<td>5 – 10</td>
<td>Unlimited</td>
<td></td>
</tr>
<tr>
<td>7 Neoprene</td>
<td>CR</td>
<td>5 – 10</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>8 Polyurethane (polyether)</td>
<td>EU</td>
<td>5 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Epichlorohydrin</td>
<td>CO, ECO</td>
<td>5 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Fluorocarbon (Viton)</td>
<td>FKM</td>
<td>Up to 20</td>
<td>Unlimited</td>
<td></td>
</tr>
<tr>
<td>11 Perfluoroelastomer</td>
<td>FFKM</td>
<td>Up to 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Silicone</td>
<td>Q</td>
<td>Up to 20</td>
<td>Unlimited</td>
<td></td>
</tr>
<tr>
<td>13 Fluorosilicone</td>
<td>FVMQ</td>
<td>Up to 20</td>
<td>Unlimited</td>
<td></td>
</tr>
<tr>
<td>14 Poliyacrylate</td>
<td>ACM, ANM</td>
<td>Up to 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Polysulfide</td>
<td>T</td>
<td>Up to 20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Shelf life elastomers and rubbers (R.J. Hudson & Company & ARP5316 RevB)

An internet search on the shelf life of oil and grease provided several internet sites and documents stating the limits of different oils and greases. (Troyer 2001; Imperial Oil Canada 2012; Nationallube, Chevron, Lubricant University and Penrite Oil Company; 2008)
The maximum storage life, showed in the Table 1 and Table 2, represents the maximum period of time, starting at the time of manufacture, that this specific element can be stored under the correct conditions. After the indicated maximum period of time the element is regarded as unserviceable for the purpose for which it was intended (ARP 5316 RevB, 2002). Due to the relative short storage life of the items in Table 1 and Table 2 are these items called perishable items. The items give a quick indication of the required active safeguarding actions and therefore will be used in the new safeguard determination procedure.

Spare parts containing the above listed elements (Table 1 &Table 2) have to be serviceable. This means that, in order for the spare parts to be serviceable, the above listed elements have to be replaced before their storage life is reached.

### 4.9 Conclusion

The objective of this chapter was to define the process criteria needed for the development of the safeguarding determination procedure. The research into the process criteria was done by analysing the current maintenance defining methodologies and by analysing the procedures of the OEM’s.

The theoretical analysis of the current maintenance defining methodologies indicated that these methodologies could not be used for the spare parts. The approach is based on the basic of functional failure which does not differentiate between different spare parts. The analysis provided, on the other hand, several ideas, requirements and constraints that can be used in the new Safeguard Determination Procedure.

The research into the procedures of the OEM’s showed that their storage instructions are not determined with a proactive procedure, but are based on experienced functional failures. During the research a commonality in the origin of the OEM instructions was discovered which led to two tables with perishable items that indicate active safeguarding actions and should be used in the new safeguarding determination procedure.

In the following chapter the new safeguard determination procedure will be constructed based on the findings of:

- The research into the deterioration criteria and (chapter 3);
- The research into the process criteria (chapter 4).
5 Design of Safeguard Determination Procedure

The objective of this research is the development of a process to determine the safeguarding actions required to maintain spare parts in a serviceable condition during their storage period. To enable a constructive development of the Safeguard Determination Process (SDP), the research was split into three parts: an analysis into deterioration & preservation, an analysis of the maintenance defining methodologies and the development of the SDP itself.

In this chapter the findings of the two aforementioned analyses are combined for the development of the SDP (Appendix C – Safeguard Determination Procedure). The SDP has been divided in four parts: Preparation, Determination, Calculation and Implementation.

5.1 SDP - Preparation part 1

One of the issues of asset management is the decision about whether or not to put a part on stock and in which quantity. The METRIC-method of Sherbrooke (1966) enables the determination of the optimal inventory on the basis of the probability of failure of each part and the purchase price (Sherbrooke, 2004; Rustenburg et al., 2001). The outcome of the METRIC-method is a Recommended Spare Parts List (RSPL) which forms the start of the SDP preparation. The METRIC-method itself is outside the scope of this thesis and therefore not further elaborated.

The SDP can also be used on spare parts already in the storage facility without proper safeguards, by performing the SDP parts "Determination" and "Implementation".

The second step in the preparation is to identify which kind of storage conditions are at your disposal. An example is provided in chapter 3.7.1. The identified storage areas and their conditions should be placed in the yellow box in the SDP flowchart (Appendix C) for easy reference during the process.

5.2 SDP – Determination part 2

Part 2 of the SDP is the main section with regards to determining the required safeguard(s). The safeguard determination part starts by dividing the process in two flows:

- Spare part consisting of a single item;
- Spare part consisting of a collection of items fitted together (assembly).

The reason for the division is that single item spare parts can be preserved with passive safeguards. Assemblies on the other hand may require both passive and active safeguards (see sub-chapter 3.7.2).

5.2.1 Period of safeguarding

The second step in the process is the determination of the duration in years that the equipment is staying in storage, because this is the period during which the safeguard is needed. Later on in the process the period of safeguarding is used to decide on the number of required safeguarding actions.
5.2.2 Inducing factors

In this step the SDP provides a list with 12 categories of various inducing factors. The aim is to identify all the inducing factors that affect the condition and quality of the equipment under review. These inducing factors can be found on the outside as well as on the inside of the equipment under review. For example the category “Fluids” (inducing factor - condensate) and “solid particles” (inducing factor – dirt) can be found on the outside as well on the inside of the equipment.

5.2.3 Characteristic changes

The previous step entailed the listing of the inducing factors, this step requires the identification of the characteristic changes induced by these listed factors. There are three different characteristic changes:
- Change of Material characteristics;
- Change of Shape characteristics;
- Change of Location characteristics.

5.2.4 Perishable items

In perishable items step the subject is the same but the question is different between single item spare parts and assemblies. The questions are:
- Single item spare part - "Is the single item spare part under review a perishable item?".
- Assemblies – "Are there perishable items present on the outside or inside of the assembly?".

With regards to the single item spare part: this spare part is most likely supplied in a safeguarding with a use-before-date printed on the package. This means that this single item spare part has to be destroyed at the moment the use-before-date is reached and the spare part should not be used.

Assemblies on the other hand may contain one or more perishable items, but without a safeguard and use-before-date. These perishable items have to be replaced with new perishable items on a regular interval depending on the shelf life of the perishable item. Please keep in mind that the perishable items are not placed in the most optimal surrounding conditions with regards to their shelf life (see chapter 3.7.2).

5.2.5 Safeguarding actions

After the characteristic changes and perishable items have been identified, the safeguards have to be determined. For single item spare parts the safeguard will consist of a passive safeguard. For assemblies the preservation will exist of a combination of passive and active safeguards or only passive safeguards.

5.2.6 Amount of activities

Now that the kind of active safeguard(s) are identified for the assembly is it necessary to determine the amount of active safeguard(s) actions needed during the safeguarding period. This step is only applicable for the active safeguards of assemblies. Examples:
1) An assembly contains a rubber (NBR) O-ring and needs to be safeguarded for a period of 20 years. The SDP shows that the shelf life of rubber (NBR) is 5 years. This means that the O-ring has to be replaced at least 4 times during the safeguarding period.
2) An assembly contains an axle and needs to be rotate each time 1¼ turn with an interval of approximately 3 months. This means that for a safeguard period of 10 years the 1¼ rotation is performed 40 times.
With regards to the interval of corresponding active safeguards, not determined by perishable items, they should be harmonized as much as possible by consolidation. This provides the possibility to perform the same kind of active safeguards (like rotating axles) all at once (see chapter 4.5).

5.2.7 Total costs

The next step is the determination of all the costs of the chosen safeguard(s) for the spare part under review. For each year of the safeguarding period the total costs of the selected passive and active safeguards have to be determined. These costs should be used for:
- determining the required budget to safeguard the spare parts in the storage facility
- the calculation of an update RSPL in combination with the purchase price.

5.3 SDP – Calculation part 3

As indicated in sub-chapter 5.1 is the initial RSPL determined on the basis of the probability of failure of each part and the purchase price. These two parameters do not include the total safeguarding costs, required to ensure the serviceability of the spare part throughout its storage period.

The first step of the SDP calculation part requires therefore the calculation of the Net Present Value (NPV) on the basis of the purchasing price and all the safeguarding costs for each part on the initial RSPL. The second step in the process is a verification to see if for all the parts on the initial RSPL the NPV is calculated.

The third step is the recalculation of the RSPL with the METRIC-method on the basis of the probability of failure of each part and the calculated NPV of each part, instead of the purchase price. In this way all the part specific costs are included in the determination whether or not to stock the part. The result may be that the recalculated RSPL differs from the initial RSPL, due to the difference in value between the purchase price and the NPV. For this reason step four is incorporated to verify if for all listed parts on the recalculated RSPL the safeguards and costs are determined. The process of determining the safeguards and calculating the NPVs & the new RSPL will be repeated until for all parts on the RSPL the safeguards are determined.

Figure 16. SDP part 3 - Calculation
5.4 SDP – Implementation part 4

The last part of the SDP starts with buying the spare parts listed on the recalculated RSPL. This is the beginning of implementing the determined safeguards, by informing the spare part suppliers during the buy of the required safeguards. If the determined safeguards cannot be applied at the supplier then they need to be applied when the spare parts are received at the storage facility. When the spare parts are stored in the storage facility then the spare parts with approximately the same active safeguards should be placed together as much as possible (see chapter 4.5). This cluster of the spare parts enables the clustering of the active safeguarding tasks and minimizes the required time and with it the costs to perform the tasks.

The last step of the implementation is to record the RSPL and safeguarding data into the Warehouse Management System (WMS). In this way the announcements of the recurring active safeguard tasks can be automated.

5.5 Testing of the Safeguard Determination Procedure

Before the start of the testing a fill-in sheet was created to facilitate the process and the recordings of the decisions during the process (Appendix D). The new developed SDP has been applied to four spare parts currently stored within E.ON:

- A Düchting pump ROWA MCC 400-500
- Siemens 1LG4183-2AA60 B02+C23 Three phase motor
- O-ring EPDM 80 SH ID 658,88 x 5,33
- O-ring NBR 70 SH ID 430,66 x 5,33

The results of the four test cases are provided in respectively Appendix E, Appendix F, Appendix G and Appendix H.

During test case 1 and 2 it became clear that the cross-section drawing or exploded view with part description the minimum required documents are to identify the parts of the assembly and to be able to perform the SDP.

- After test case 1 the determined safeguards were compared with the storage instructions of the supplier the following points were encountered: The OEM documentation does not mention any storage instruction with regards to the limited storage life of O-rings.
- The OEM instructed to turn the axle ¼ turn each time. During the SDP it was determined that the rotation should be 1¼ turn each time, this with regards to the bearings.
- The OEM instructions did not provide the cost of the safeguarding actions.

To correctly determine the safeguard of the installed perishable parts requires information about the material. Absence of material information may be substituted by expert knowledge for the time being. After the review session the required material specification should be requested from the supplier.

The test cases indicated that the people attending the reviews gained more understanding on deterioration and safeguards. The attendees also indicated that the procedure part for determining the safeguards was clear and easy to use.
6 Conclusions and Recommendations

This chapter starts with the conclusions of the two analyses, the analysis into the deterioration criteria and into the process criteria, and is respectively followed with the conclusion of the test case and the conclusion with respect to the research objective. The chapter ends with the recommendations for E.ON Benelux and for further research.

6.1 Deterioration criteria conclusions

The objective of the first analysis was to determine the deterioration criteria by analysing the theories of deterioration and preservation.

Deterioration is defined as the continuous process of getting worse in condition and quality. There are three types of deterioration: Physical, Chemical and Biological. Preservation is the safeguarding of inactive equipment against deterioration by protection and preventive maintenance. The passive safeguarding is the protection against environmental elements like dust, temperature, humidity, UV-light, etc. The active safeguarding is the management (preventive maintenance) of the deteriorations caused by elements for which protection does not work (like gravity).

Material deteriorates as result of factors that are inducing characteristic changes in components. The three characteristic changes are:

- Change of **material** characteristics;
- Change of **shape** characteristics;
- Change of **locations** characteristics.

Serviceable spare parts are defined as spare parts in the storage facility that are available when required and operate as expected (fit for use). The spare parts can be classified into the following categories: exchange / repairable parts, Wear parts, Consumables, Strategic parts. The components are exposed to a list of environmental elements that are clustered into 12 categories: Temperature, Solar radiation, Precipitation, Gaseous pollutants, Dry aerosols, Wet aerosols, Solid particles, Forces, Fluids, Electromagnetic radiation, Micro organisms, Macro organisms.

Components encounter during their life cycle the three distinct periods of stored, inactive and active with the following differences with regards to inducing factors:

- The kinetic forces during the operation of the system.
- Deposit build up during the active time turning into inducing factors during the inactive time.
- The environment surrounding the equipment when installed and stored.
- The inducing factors who become dominant during a different period, like gravity.

6.2 Process criteria conclusions

The objective of the second analysis was to define the process criteria needed for the development of the safeguarding determination procedure.

With regards to spare parts is maintenance defined as the set of activities needed to sustain the integrity of the spare part such that it operates as expected when required. The following maintenance methodologies were used to define maintenance with regards to spare parts:

- A framework for maintenance concept development
- Reliability Centred Maintenance
- Business Centred Maintenance
- Integrated Logistic Support
- Logistic Support Analysis
- On the maintenance concept for a technical system, a framework for design
- Description of a methodology for the design of maintenance concepts
- The EUT maintenance model
The research showed that the quality of the spare parts on stock has a direct relation with the availability and reliability of the asset.

The basic of the listed methodologies is the one of functional failure, which starts with the description of the function(s) followed by the determination of the way(s) it fails to fulfil this function. The application of this basic, with regards to the determination of the safeguarding tasks for spare parts, provided a problem in that this basic does not differentiate between the different spare parts. The result would be an improper set of safeguarding activities that would not prevent all the characteristic changes.

An OEM refers to the company that originally manufactured the product. Inquiries, with regards to the procedures of the OEM’s, showed that their storage instructions are not determined with a proactive procedure, but are based on experienced functional failures. An OEM provided a storage instruction with requirements regarding the different condition of the storage areas.

The following process criteria’s were found for the development of a (active) Safeguard Determination Procedure:

- Determine at the beginning the most important spare parts.
- Is the selected safeguard technically feasible and worth doing?
- The process steps 2 through 6 of the RCM procedure.
- Harmonization of the intervals by consolidation into smaller numbers and packages.
- Clustering of the actions.

6.3 Test case conclusion

The tests have shown that cross-section or exploded view drawings are the bare minimum to enable the execution of the SDP on assemblies. For executing the SDP on a single item it may be required to know the material specification. Omission of this information can be substituted for expert knowledge.

A comparison between the SDP data and the storage instructions of the OEM showed that the SDP may provide more safeguards, but definitely provides more background and understanding of deterioration and safeguards.

The test cases showed that the procedure part for determining the safeguards was clear and easy to use.

6.4 Research objective conclusions

The research objective was the development of a process for the determination of active safeguards required to maintain the spare parts serviceable during their storage period by analysing the deterioration criteria’s and the process criteria for determining maintenance actions.

The outcome of the research is a Safeguard Determination Procedure developed on the findings of the two analyses. The conclusion is that the research objective has been reached with the Safeguard Determination Procedure based on the two tangible outcomes:
- a package of safeguarding actions required for maintain the serviceability of the reviewed spare part;
- a Net Present Value input for the METRIC method with regards to determining the Recommended Spare Parts List.

A less tangible out of the procedure is the education on deterioration and safeguarding of the people that are using the Safeguard Determination Procedure.
6.5 Recommendations

Recommendations for E.ON Benelux (EBX) and E.ON AG:

- The first recommendation for EBX is to implement the new Safeguard Determination Process into the EBX quality system. The implementation will resolve the nonconformity found during the recertification audit of January 2012.

- The second recommendation for EBX is to implement a warehouse management system which allows the passive and active safeguarding actions to be recorded and uses the intervals to notify its users for upcoming safeguarding actions.

- Along the implementation of the warehouse management system should the new SDP be applied to all the current and future spare parts in the storage facilities, starting with the oldest spare parts. This will greatly reduce the asset unavailability risk as result of installing unserviceable spare parts.

- To implement the new SDP in all the project handbooks such that it will be used in future new build projects. First, for applying the SDP and METRIC method during the selection of the spare parts. Second, to apply the SDP on the all components of the project during the phases of construction and commissioning, to preserve the condition and quality of the new components.

Recommendations for further research:

- The categories of inducing factors provide several examples for each category. Further research into all the existing inducing factors would increase the awareness of the safeguarding and simplifies the identification of the applicable inducing factors during the process. The result would be a better safeguarding.

- The list with perishable items simplifies the identification of the required active safeguarding. Further research into all the existing (technical) perishable items would increase the identification.

- In chapter 4.8 is a list of perishable items provided with a storage life limit. It is recommended to discard all parts of which the storage life limit is passed. A research is recommended into the effects of installing assemblies with parts of which the storage life limit has passed.

- In the calculation part of the SDP are the safeguarding costs added to the purchase price of the components through the Net Present Value calculation. This is done to incorporate all the spare part specific costs into the decision. A research into the effects on the outcome (the RSPL) of the METRIC method is outside the scope of this research and is therefore presented as recommendation.

- In the METRIC method are the NPV (based on purchase price and safeguarding costs) and probability of failure of each part used as input. In this research it is shown that the probability of failure will decrease if the spare part is deteriorated. A research into the effects of the METRIC method outcome based on the decreased probability of failure as result of deterioration is recommended.
7 References

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Thesis
Maintaining your spare parts in store serviceable


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Wilson, W (2010), *‘Care for your spares’*, Uptime-magazine, August/September 2010, page 42.
Appendix A – Downtime costs

An asset unavailability risk consists out of a probability and a consequence. The existence of the unavailability probability has been indicated in the sub-chapters 1.1 through 1.5. This Appendix A will elaborate on the possible cost consequences with regards to an asset unavailability of an 1100 MW power station in the Netherlands.

Tenet, the premier electricity transmission operator of the Dutch national high-voltage grid, is responsible for maintaining the balance between demand and supply of electricity in the transmission system. In order to enforce and maintain this balancing Tenet makes use of (Godfried, 2004):

- Program-Responsibility
- Control, Reserve and Emergency Power
- the Imbalance-price-system

Program Responsibility is the obligation under the Electricity Act 1998 that all parties connected to the national grid should adhere to their own pre-issued volume delivery and withdrawal of energy.

The control, reserve and emergency power are various types of capabilities among producers which can be used to eliminate any imbalance in the transmission system.

The Imbalance-price-system is a method to reduce the costs for eliminating the imbalance in the high-voltage grid by charging the costs of the imbalance to the party that is causing the imbalance.

This imbalance-price-system makes the reliability of a power plant very important. Unexpected power plant failures create an imbalance in the high-voltage grid and costs for the power plant causing the imbalance, because the pre-issued volume of energy was not produced.

An analysis of the historical imbalance data of Tenet regarding the deficits with corresponding imbalance price of the years 2002 t/m 2011 indicates that a reasonable linear relationship between the shortage of MW and the imbalance price per MWh. The analysis also shows that the slope of the linear relationship between 2002 and 2007 fluctuated between 0.4 and 0.8, and since 2007 steadily decreases from 0.5 to 0.3 (see figure 18).

Figure 18. Imbalance costs vs. time
The analysis and the fact that in the event of a failure only for 70MW of energy per hour can be purchased to eliminate the imbalance, indicate that the first hours of a malfunction or failure of a power plant give the highest costs. The imbalance costs show an exponential decline seen since the beginning of the fault / failure to the regular cost for the purchase of energy (see figure 19). It is therefore for a Dutch power plant, more problematic in terms of cost, to have for example 20 total failures of 4 hours than 2 long total failures of 40 hours. This clearly indicates that besides the availability, also the reliability on the correct function without failure important is for the components.

![Estimated total cost of failure](image)

Figure 19. Total estimated cost of failure for a 1100 MW power plant (internal E.ON expert information)

Up till now the cost consequence calculations have been done with the assumption of total loss of power (1100 MW), which is not always the case. The consequence of a premature failure also depends on the importance of the failing component for the production process. Components important for the production process in a non-redundant system will give a higher consequence than that of a failing component in redundant utility system. The consequence of the strategic spare parts, identified for Maasvlakte and Datteln (Rodewald, 2010), are very high with regards to the amount of performance loss and the delivery time of a new component.
Appendix B – Examples of OEM storage instructions

Instructions of the KSB group

Standardised Chemical Pump (CPKN, Bearings UP02 to UP06 and P08s)
The pump (set) needs to be stored in a dry, protected room with a constant atmospheric humidity. The shaft of the pump has to be rotated once a month. New pumps are supplied duly prepared for storage for a maximum of 12 months when properly stored indoors.

For the prolonged inactiveness period of the pump, the pump has to be started up regularly between once a month and once every three months for approximately five minutes. This will prevent the formation of deposits within the pump and the pump intake area.

Vertical, Can-§ type Ring—section Pump (WKTB 6, WKTB 7, WKTB 8, WKTB 9)
The pump is supplied for indoor storage for up to 12 months if stored in a dry room with a constant atmospheric humidity. Outdoor storage is permissible in a box and with heat-sealed waterproof PE sheeting together with a desiccant. If the storage period exceeds 5 years the sealing function of seal elements may be impaired by, for example embrittlement. This could result in escaping of hot and pressurised medium pumped during operation. After a storage period of more than 5 years, the pump must be dismantled before it is installed, and seal elements (e.g. O-rings) must be replaced.

Instructions of Sulzer

SMH 602-570 Axially-Split Single Stage Pump
The pump unit should be stored in a dry room, possibly with constant temperature as well as a clean, shock-free storage space to avoid the forming of condensate and consequently corrosion, bearing damage and contamination and without maintenance actions depending on the type of dispatch preservation applied. The types of preservation available are the standard packaging, the seaworthy packaging and the special packaging. Pumps which are not installed and commissioned immediately after delivery can be stored for the period determined by the dispatch preservation. The time period of the dispatch preservation is respectively 6 months, 1 year and 2 years.

The manual provides besides the passive safeguarding mentioned above the following active safeguarding (preventive maintenance) for the long-term stored pumps.

Visual inspection: The exterior of the stored pump unit should be conducted every 30 days and inspected for surface damage, dirt or animals in the pump area. If required initialise appropriate measures.

Maintain rust prevention coatings: If any rust is observed, measures should be taken to remove rust and protect against it.

Turn pump rotor manually: To avoid corrosion damage at bearings, drain the preservation oil every 3 month and refill if on the top of the bearing housing. The pump rotor should manually be turned simultaneously, so that the preservation oil will be distributed over the running surfaces of the bearings. Turn pump rotor at least 5 revolutions in the proper direction of rotation.

Filled pump parts: At the parts which are filled with rust preventative (pump casing / bearing housing) the condensate should be drained every 6 months; rust preventative should be added, if required.

According to manufacturers indications, the rust preventative has to be drained and refilled every 12 month. If the rust preventative is not renewed within this period the risk is to be
taken by the storage keeper. In order to have a guarantee for the proper execution of the maintenance instructions, we recommend to establish maintenance sheets.

If in the case of large pumps interiors are only sprayed preservation has to be repeated not later then after 6 months.

**Instructions of Siemens**

Low voltage IEC motors 1LA5/6/7/9, 1LP7/9, 1PP6/7/9, 1MA6/7, 1MF6/7, 1MJ6 and 1LE1 Siemens informs that prolonged storage periods reduce the useful life of the bearing grease. The grease may lose some of its oil content or may be contaminated by ingress of condensation for example. The ingress of condensation leads to changes in the consistency of the grease which must be replaced be for the commissioning of the low voltage motor. It is advised by Siemens to check the condition of the grease if the low voltage motor is stored for more than 12 months.

Another active safeguarding is the frequent turning of the shafts with an interval of once a year. The shaft turning prevents marks due to the shaft resting in the same position for a long time.

If the time from delivery to start-up of the machine is longer than 4 years the rolling-contact bearings should be renewed.
Appendix C – Safeguard Determination Procedure

**START**

- Make the production of the Recommended Spare Parts List (RSPL) with the METRIC method of Sherbrooke.

**Part 1 Preparation**

- Learning the applicable storage condition when not in use.
- Write them down in the yellow box below.

**Part 2 Determination**

- Performing the following procedure for each listed spare part.

**Type of equipment?**

- Single item
- Assemblies

**Passive or Active Safeguarding inquired?**

- Single item equipment: Passive safeguarding required.
- Assemblies: Passive and Active safeguarding required.

**What are the applicable inducing factors?**

- Are there perishable items installed on or in the assembly? - Oil - Grease - Rubber or Elastomers
- Possibly Passive and Active safeguarding required.

**Possible Inducing Factors**

- Temperature (high and low)
- Solar radiation (Ultraviolet radiation, visible light, infrared light, etc.)
- Precipitation (rain, snow, etc.)
- Gaseous pollutants (Carbon monoxide, Carbon dioxide, Sulphur dioxide, Hydrogen sulphide, Hydrogen Cyanide, Ammonia gas, Nitrogen oxides, Ozone, Methane, Nitrous oxide, Sulphuric acid, Nitric acid, etc.)
- Dry aerosols (dust, smoke, salt, ashes, volcanic emissions)
- Wet aerosols (water vapour [steam, mist])
- Solid particles (dirt, etc.)
- Forces (use loads, gravity, vibrations)
- Fluids (water, acids, bases, carboxylic compounds, nitrogenous wastes)
- Electromagnetic radiation
- Microorganisms (bacteria, algae, fungi, lichens)
- Macroorganisms (insects, animals, plants)

**What are the applicable inducing factors?**

- Determine the period of safeguarding.
- Initial production of the Recommended Spare Parts List (RSPL) with the METRIC method of Sherbrooke.

**Perform the following procedure for each listed spare part.**

**Determine the period of safeguarding.**

- What are the characteristic changes? - change of Material characteristics - change of Shape characteristics - change of Location characteristics

**Which safeguarding action(s) should be applied to prevent the characteristic changes?**

- For perishable items:

  - Passive safeguarding (example)
    - Storage area A
      - Closed building
      - Ventilation system with filters and air-conditioning – ensuring an atmosphere free of dust and harmful vapours
      - Heating to ensure a constant temperature between 20 - 25 graden C
      - Relative humidity of max. 40%
    - Storage area B
      - Closed building
      - Ventilated
      - Heating to ensure a constant temperature between 5 - 50 graden C
      - Relative humidity of max 60%
    - Storage area C
      - Closed building that protects against direct weather influences like rain, snow, etc.
    - Storage area D
      - Outdoors
      - Protection against precipitation

**Inventory the available storage condition areas at your disposal. Write them down in the yellow box below.**

**Safeguarding Perishable Items**

- Oil - maximum storage life 5 years
- Grease - maximum storage life 5 years
- Rubber
  - Type: Nitrile (Buna N) Styrene Butadiene (Buna S) Polybutadiene Polyisoprene Hypalon Ethylene Propylene Neoprene Polyurethane (polyether) Epichlorohydrin Fluorocarbon (Viton) Perfluoroelastomer Silicone Fluorosilicone Polyacrylate Polysulfide
- ASTM designation
  - NBR SBR BR NR, IR CSM E P DM , E PM CR E U CO, E CO FKM FFKM QFVMQ ACM , ANM T
- Maximum storage life [years]
  - 3 – 5
  - 3 – 5
  - 3 – 5
  - 3 – 5
  - 5 – 10
  - 5 – 10
  - 5 – 10
  - 5 – 10
  - Up to 20
  - Up to 20
  - Up to 20
  - Up to 20
  - Up to 20
  - Up to 20

**Determine the total costs of the selected passive and active safeguarding for each year of the total safeguarding period.**

**Part 3 Calculation**

- Calculate the Net Present Value on the basis of the purchase price and the total safeguarding costs for the total safeguarding period.

**Part 4 Implementation**

- Use the METRIC method to recalculate the RSPL but now with the NPV’s of all components.
- Is the Net Present Value of all the components on the RSPL calculated?
- Are for all spare parts on the new RSPL the safeguarding costs determined?
- For the components on the new RSPL and apply the SDP.
- The new component on the RSPL and apply the SDP.
- Select the next component on the RSPL and apply the SDP.
- Select the first component on the new RSPL and apply the SDP.

**END**
## Appendix D – SDP fill-in sheet

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of equipment?</td>
<td>Single item equipment / Assembly</td>
</tr>
<tr>
<td>2</td>
<td>Determine the period of safeguarding.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>What are the applicable inducing factors?</td>
<td></td>
</tr>
</tbody>
</table>
| 4    | What are the characteristics changes?  
- change of Material characteristics  
- change of Shape characteristics  
- change of Location characteristics |  |
| 5    | Are there perishable items installed on or in the assembly?  
- Oil  
- Grease  
- Rubber or Elastomers |  |
| 6    | Which safeguarding action(s) should be applied to prevent the characteristic changes and for the perishable items? |  |
| 7    | How many active safeguarding actions are needed during the safeguarding period?  
(n/a for single item spare parts) |  |
| 8    | Determine the total costs of the selected passive and active safeguarding for each year of the total safeguarding period. |  |
| 9    | Calculate the Net Present Value on the basis of the purchase price and the total safeguarding costs for the total safeguarding period. |  |
### Appendix E – Test Case 1

<table>
<thead>
<tr>
<th>Equipment description</th>
<th>Date</th>
<th>Reference number</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Düchting pump ROWA MCC 400-500</td>
<td>5 November 2012</td>
<td>30HT3/40 AP001 Quick empty pump absorber and tank</td>
<td>R. Weezenaar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of equipment?</td>
<td>Single item equipment / Assembly</td>
</tr>
<tr>
<td>2</td>
<td>Determine the period of safeguarding.</td>
<td>10 years (life time power plant is 40 years, it is expected to change the pump after 10 years – replacement)</td>
</tr>
<tr>
<td>3</td>
<td>What are the applicable inducing factors?</td>
<td>Solar radiation (visible light), Dry aerosols (dust), Gaseous pollutants (ozone), Forces (gravity, assembly forces o-rings), Wet aerosols (condense)</td>
</tr>
<tr>
<td>4</td>
<td>What are the characteristics changes?</td>
<td>Material – O-ring, Corrosion</td>
</tr>
<tr>
<td></td>
<td>- change of Material characteristics</td>
<td>Shape – O-ring, Axle, Bearings, Mechanical seal spring</td>
</tr>
<tr>
<td></td>
<td>- change of Shape characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- change of Location characteristics</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Are there perishable items installed on or in the assembly?</td>
<td>Oil (new pump is delivered by the factory without oil)</td>
</tr>
<tr>
<td></td>
<td>- Oil</td>
<td>Rubber / elastomers – O-rings (quantity 12) (material – expected Viton FKM)</td>
</tr>
<tr>
<td>6</td>
<td>Which safeguarding action(s) should be applied to prevent the characteristic changes and for the perishable items?</td>
<td>- Store pump in a facility with a constant temp (prevent condensation inside pump) and constant humidity (silica gel bags)</td>
</tr>
<tr>
<td></td>
<td>- Replace O-rings every 20 years (Viton) (not required during safeguard period)</td>
<td>- Turn axle (and bearings) every 2 weeks 1½ turn</td>
</tr>
<tr>
<td></td>
<td>- Loosen spring of mechanical seal (mechanical seal does not contain elastomers)</td>
<td>- All non-Rust free bare parts must be protected against corrosion with a preservative. - - Seal or cover pump with a cover against dust and dirt.</td>
</tr>
<tr>
<td>7</td>
<td>How many active safeguarding actions are needed during the safeguarding period? (n/a for single item spare parts)</td>
<td>O-rings 0 times (quantity 12) (storage life 20 years)</td>
</tr>
<tr>
<td></td>
<td>Axle 26 times/year x 10 years = 260 times</td>
<td>Loosen spring only once, fasten spring once</td>
</tr>
<tr>
<td></td>
<td>General Inspection yearly 10 times</td>
<td>Replacement of cover/sealing 2 times</td>
</tr>
<tr>
<td>8</td>
<td>Determine the total costs of the selected passive and active safeguarding for each year of the total safeguarding period.</td>
<td>O-rings -&gt; approximately €7,50 x 12 (qty) x 0 (actions) = €0</td>
</tr>
<tr>
<td></td>
<td>Axle -&gt; ¼ hours x €70,- x 260 = €4,550,-</td>
<td>General Inspection -&gt; 1 hour x €70,- x 10 = €700,-</td>
</tr>
<tr>
<td></td>
<td>Replacement cover -&gt; 2 times x €100 = €200</td>
<td>Loosen spring and fasten spring 2 x 2 hrs x €70,- = €280,-</td>
</tr>
<tr>
<td></td>
<td>Total = €5,730,-</td>
<td>Yearly average cost = €573,-</td>
</tr>
<tr>
<td>9</td>
<td>Calculate the Net Present Value on the basis of the purchase price and the total safeguarding costs for the total safeguarding period.</td>
<td>Inflation = 1.7%</td>
</tr>
<tr>
<td></td>
<td>Interest = 3%</td>
<td>NVP = € 82899,02</td>
</tr>
<tr>
<td></td>
<td>(purchase price = € 78000,-)</td>
<td></td>
</tr>
</tbody>
</table>
Maintaining your spare parts in store serviceable
Overview drawing of the Düchting pump ROWA MCC 400-500
Cross section drawing of the Düchting pump ROWA MCC 400-500
Appendix F – Test Case 2

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of equipment?</td>
<td>Single Item Equipment / Assembly</td>
</tr>
<tr>
<td>2</td>
<td>Determine the period of safeguarding.</td>
<td>5 years</td>
</tr>
<tr>
<td>3</td>
<td>What are the applicable inducing factors?</td>
<td>Humidity, vibration, Gaseous pollutants, Temperature, Dust</td>
</tr>
<tr>
<td>4</td>
<td>What are the characteristics changes?</td>
<td>Corrosion in bearing and windings -&gt; degradation isolation -&gt; partial discharges Material – O-rings, V-rings, Simm rings, Gaskets, connectors (oxidation) Shape – Brinelling bearings, axle, damage due to collissions</td>
</tr>
<tr>
<td>5</td>
<td>Are there perishable items installed on or in the assembly?</td>
<td>Grease in the bearings Rubber – O-rings, V-rings and Simm rings, Gaskets</td>
</tr>
<tr>
<td>6</td>
<td>Which safeguarding action(s) should be applied to prevent the characteristic changes and for the perishable items?</td>
<td>Corrosion – constant temperature and Humidity – storage area B (no direct sunlight) Axle (and bearings) – 1¼ rotation once per 2 months O-rings, V-rings, Simm rings – NBR – replace after 5 years Gaskets – replace after 5 years Bear metals – (axle) – textile</td>
</tr>
<tr>
<td>7</td>
<td>How many active safeguarding actions are needed during the safeguarding period? (n/a for single item spare parts)</td>
<td>Axle rotation 6x each year (total 30 times in 5 years) O-rings, V-rings, Simm rings and Gaskets once</td>
</tr>
<tr>
<td>8</td>
<td>Determine the total costs of the selected passive and active safeguarding for each year of the total safeguarding period.</td>
<td>Axle rotation ¼ hr * € 70,- * 6 = € 105,- Seals &amp; gaskets set = € 15,-</td>
</tr>
<tr>
<td>9</td>
<td>Calculate the Net Present Value on the basis of the purchase price and the total safeguarding costs for the total safeguarding period.</td>
<td>Inflation = 1,7% Interest = 3% $NPV = \€ 1619,53 (purchase price = \€ 1100,-)$</td>
</tr>
</tbody>
</table>
## Appendix G – test case 3

<table>
<thead>
<tr>
<th>Equipment description</th>
<th>O-ring EPDM 80 SH ID 658,88 x 5,33</th>
<th>Date</th>
<th>5 November 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference number</td>
<td>E.ON SAP material number 46274057</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of equipment?</td>
<td>Single item equipment / Assembly</td>
</tr>
<tr>
<td>2</td>
<td>Determine the period of safeguarding.</td>
<td>Maximum expected safeguarding period 10 years</td>
</tr>
<tr>
<td>3</td>
<td>What are the applicable inducing factors?</td>
<td>Temperature – High temperatures, Solar radiation – Ultraviolet radiation, visible light, Gaseous pollutants - Ozone</td>
</tr>
<tr>
<td>4</td>
<td>What are the characteristics changes?</td>
<td>Material – temperature, solar radiation, gaseous pollutants</td>
</tr>
<tr>
<td>5</td>
<td>Are there perishable items installed on or in the assembly?</td>
<td>Item is a perishable rubber item – Ethylene Propylene EPDM maximum storage life = 5 – 10 years</td>
</tr>
<tr>
<td>6</td>
<td>Which safeguarding action(s) should be applied to prevent the characteristic changes and for the perishable items?</td>
<td>- Place O-ring in an opaque packaging to shield it from UV-light, visible light and Ozone. No printers or other operational electrical devices in the neighborhood. - Discard the O-ring after 5 years (counting from receiving date) (No storage life limit printed on the packaging)</td>
</tr>
<tr>
<td>7</td>
<td>How many active safeguarding actions are needed during the safeguarding period? (n/a for single item spare parts)</td>
<td>Once in 10 years</td>
</tr>
<tr>
<td>8</td>
<td>Determine the total costs of the selected passive and active safeguarding for each year of the total safeguarding period.</td>
<td>Year 10 = € 237,42</td>
</tr>
<tr>
<td>9</td>
<td>Calculate the Net Present Value on the basis of the purchase price and the total safeguarding costs for the total safeguarding period.</td>
<td>Inflation = 1.7%  Interest = 3%  NPV = € 446,52 (purchase price = € 237,42)</td>
</tr>
</tbody>
</table>
## Appendix H – Test case 4

<table>
<thead>
<tr>
<th>Equipment description</th>
<th>Date</th>
<th>Reference number</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-ring NBR 70 SH ID 430,66 x 5,33</td>
<td>5 November 2012</td>
<td>E.ON SAP material number 46274059</td>
<td>R. Weezenaar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of equipment?</td>
<td>Single item equipment / Assembly</td>
</tr>
<tr>
<td>2</td>
<td>Determine the period of safeguarding.</td>
<td>Maximum expected safeguarding period 10 years</td>
</tr>
</tbody>
</table>
| 3    | What are the applicable inducing factors? | Temperature – High temperatures  
Solar radiation – Ultraviolet radiation, visible light  
Gaseous pollutants - Ozone |
| 4    | What are the characteristics changes?  
- change of Material characteristics  
- change of Shape characteristics  
- change of Location characteristics | Material – temperature, solar radiation, gaseous pollutants |
| 5    | Are there perishable items installed on or in the assembly?  
- Oil  
- Grease  
- Rubber or Elastomers | Item is a perishable rubber item – Nitrile (Buna N) NBR maximum storage life = 3 – 5 years |
| 6    | Which safeguarding action(s) should be applied to prevent the characteristic changes and for the perishable items? | Place O-ring in an opaque packaging to shield if from UV-light, visible light and Ozone. No printers or other operational electrical devices in the neighborhood. 
Discard the O-ring after 5 years (counting from receiving date) (No storage life limit printed on the packaging) |
| 7    | How many active safeguarding actions are needed during the safeguarding period? (n/a for single item spare parts) | Twice in 10 years |
| 8    | Determine the total costs of the selected passive and active safeguarding for each year of the total safeguarding period. | Year 5 = € 6,22  
Year 10 = € 6,22 |
| 9    | Calculate the Net Present Value on the basis of the purchase price and the total safeguarding costs for the total safeguarding period. | Inflation = 1,7%  
Interest = 3%  
NPV = € 11,70  
(purchase price = € 6,22) |
O-ring NBR 70 packaging – No manufacture date or Max. storage life date displayed.