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Reliability Centered Maintenance miniseminar

Edited by
Kari Laakso & Kaisa Simola

VTT Automation, Espoo, Finland

14.10.1999

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Abstract

In the Earlier NKS-project RAK-1 (1994-1997), the sub-project RAK-1.4, "Maintenance Strategies and Ageing" focused on development of metholodogies and tools for improving maintenance strategies. In the NKS/SOS-2 project (1998-2001), the maintenance related Nordic co-operation is continued. For exchange of information and as background and for discussions related to maintenance decisions in the NKS/SOS-2 project, a mini-seminar on maintenance strategies with an emphasis on reliability centred maintenance (RCM) approaches was arranged 14.10.1999. The report summarises the topics of the presentations and discussions at the seminar. The transparencies presented at the mini-seminar are enclosed in this report.

Keywords

Reliability centred maintenance, maintenance strategies, maintenance indicators

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NKS/SOS-2

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CONTENTS

1 Introduction

In the Earlier NKS-project RAK-1 (1994-1997), the sub-project RAK-1.4, "Maintenance Strategies and Ageing" focused on development of metholodogies and tools for improving maintenance strategies. In the NKS/SOS-2 project (1998-2001), the maintenance related Nordic co-operation is continued. For exchange of information and as background and for discussions related to maintenance decisions in the NKS/SOS-2 project, a mini-seminar on maintenance strategies with an emphasis on reliability centred maintenance (RCM) approaches was arranged.

A maintenance strategy gives guidelines on how actions and resources should be prioritised and allocated on different systems and components in order to achieve the safety, availability and cost related objectives. This signifies optimal allocation of preventive maintenance, testing, condition monitoring, repairs or modification. Based on analyses of maintenance history and operating experience data, it is possible to verify that the maintenance goals are met. The level and trend of performance should be measured against quantitative acceptance criteria that are based on maintenance objectives. Indicators, such as unavailability of technical equipment, are compared to some reference value in order to determine if they are significantly deviating. The analyses form a basis for maintenance related decisions, which may include modifications in the maintenance programme or the introduction of development projects. Such development project can be for instance the introduction of a reliability centred maintenance (RCM) analysis of the maintenance action program of the most important technical systems. Justification of optimal action changes in the maintenance programmes is based on signals from the maintenance indicators and decision logics helping the selection of correct actions. A simplified model for maintenance management is illustrated in Figure 1 [Laakso et al. 1999].

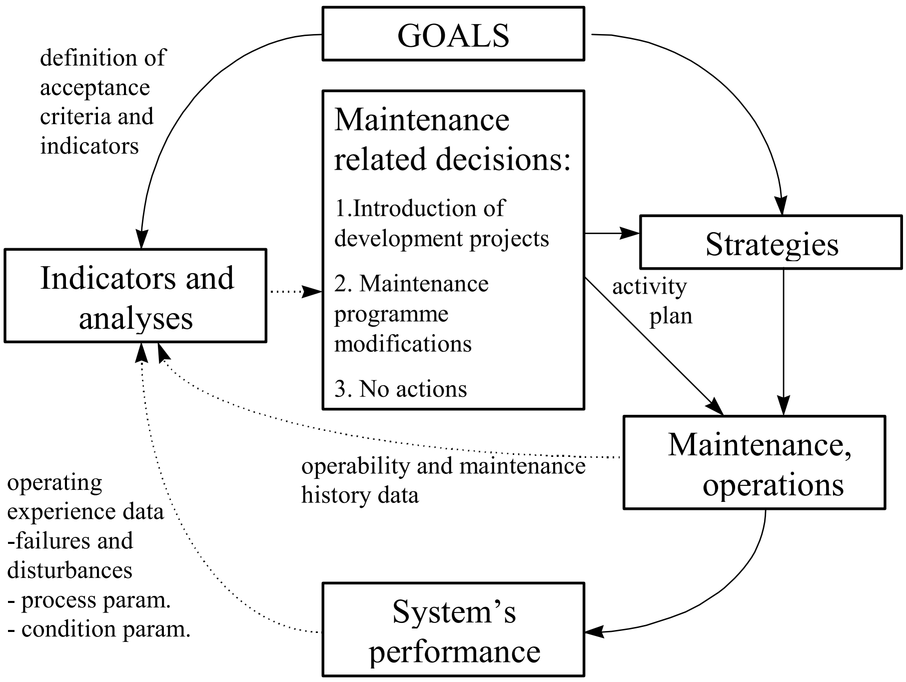

Figure 1. A model of maintenance management.

2 Summary of presentations

The topics of the presentations and discussions are summarised below. The transparencies presented at the mini-seminar are enclosed in this report.

A Swedish RCM study on feed water system (Enclosure 1)

Pekka Skogberg presented the RCM study performed by BKAB, OKG and FKAB on the feed water system. The study aimed at developing and adapting further, in co-operation of three utilities, the systematic maintenance analysis method developed in the NKS/RAK-1.4 project. In the NKS/RAK-1.4 subproject, the hydraulic scram systems of BKAB units had been selected as the object of the case study because the system had exhibited rather high frequency of component failures.

The feed water pumps were selected as the new study object because of their relatively high maintenance costs. The case studies were aimed at identifying potential for improvements in the maintenance programme of the feed water pumps and included also benchmarking between the utilities' cases. The feed water pump units to be compared were from Oskarshamn 2, Barsebäck 1 and 2 and Forsmark 3 because they have "similar" system designs. BKAB, OKG and FKAB had however different operational strategies of their 3 feed water pumps. BKAB seemed also to have too much inspections, preventive maintenance and testing compared to OKG AB.

A suitable and effective maintenance is needed to achieve the long-term goals of reactor safety, availability and production cost. The complex NPP plant requires ranking of maintenance actions and resources for "important" equipment. The maintenance strategy gives guidelines on how actions and resources should be ranked and distributed on different systems and components in order to achieve the defined goals.

Ranking within maintenance can be based on the results from RCM analyses. The RCM methodology is initially based on importance selection and ranking of objects for more detailed RCM analysis. Importance ranking of maintenance objects for a detailed RCM analysis was based on the conflicting criteria on reactor safety, availability, radiation doses and corrective maintenance cost. The reactor safety classification of objects was based on allowed outage time requirements according to the technical specifications. No availability studies on plant level were available for this Swedish RCM study, but the scoring of different failures' significance was based on evaluation of their effects on plant production capacity. In this new RCM study, the weighting of the selection criteria against each other was done according to the decision analysis principles demonstrated in the NKS/RAK-1.4 project. It was discussed, whether the weighting of selection criteria is too obscure for the plant personnel uses and practical understanding. Thus the "Top Ten" maintenance significant item lists for the detailed RCM analyses in this new RCM study were generated based on the following criteria only:

1. High failure frequency for objects which are critical for reactor safety,
2. High failure frequency for objects which are critical for plant production availability, radiation protection or maintenance cost,
3. High preventive maintenance costs or low failure frequency for components which are not critical – do we have excessive preventive maintenance (actions)?

After that, maintenance critical items could be selected by using quantitative maintenance indicators produced by using the computerised Bi-Cycle data analysis support based on work order data base in the maintenance information system. Important indicators for follow-up of the effectiveness of maintenance were:

1. Number of failures + trend,
2. Cost of corrective maintenance per year + trend,
3. Cost of preventive maintenance per year + trend.

The most important question for maintenance critical items is: "Are correct preventive actions performed to identify failures early and to prevent failures?" An updated LTA (logic tree analysis) diagram for selection of different types of maintenance actions taking into account failure characteristics, evaluation of effectiveness and the scheduling into the maintenance outage or plant operation had been prepared. The need of specific LTAs for selection of maintenance actions for different equipment types (rotating machines, passive, valves etc) contra use of generic LTAs only was discussed.

Also qualitative FMECA analyses of the experienced failure modes of maintenance critical items, PMEA compilations and cost analyses of the related preventive action programs were needed to identify the potential opportunities for changes in the maintenance programs. For identification of optimal intervals for the actions in deviating cases, the experiences and knowledge of maintenance personnel were intended to be used. The optimal interval shall take into account the failure characteristics, the failure criticality and the MTTF (mean time to failure).

The case study has resulted e.g. at Barsebäck to a proposal for a maintenance programme, which is estimated to reduce the maintenance costs of the feed water pumps by ca. 50 %. The proposed actions are e.g.:

1. Introduction of more condition monitoring, i.e. more need steered actions,
2. Reduction of expensive overhauls,
3. Reduction of overhauls, reducing human induced failures,
4. Reduction of testing, reducing wear of equipment,
5. Change of maintenance strategy on standby pumps, reducing maintenance needs.

A transformer study (Enclosure 2)

Jette Paulsen summarised the status of a recently started transformer study. The aims are to get a better knowledge on how to protect the transformer and avoid operation modes, which seem to lead to failures, and to evaluate the operability of the transformers for selection of optimal maintenance strategies. The aim is also to get a sufficient knowledge of transformers to design a structure for a database. Information is collected on transformer damages, failure modes, weak points and influence factors to produce fault/fog gases.

Jette also informed about condition monitoring equipment available for measuring the amount of transformer gases and water content in the oil. Gas analysis of hot points or shortcuts is done. Continuous measurement of the content in ppm of the total amount of gases is done today. Transformer explosions can occur as a consequence due to formation of H_2 and CO_2.

More stresses on transformers can today be expected when competitive electricity suppliers are now delivering more power.

Loviisa NPP maintenance strategies and indicators (Enclosure 3)

Alpo Savikoski gave an introductory presentation of LoNPP maintenance strategies and maintenance indicators. The maintenance strategies of equipment will be controlled by the newly developed maintenance strategy classification of equipment places.

LoNPP uses LOTI information system for follow-up as well a) the history at component places (locations) as b) the history of the individual items by item numbers. E.g. LoNPP 1 has 35000 component locations marked. The maintenance indicators (e.g. availability, maintenance rates, number of repairs and number of preventive actions) at component place level are presented for the treatment of the LoNPP maintenance sections and foremen. “Top Contributors to Component Level Unavailability Hours” within the different maintenance strategy classes are also presented in the annual maintenance history reports of the plant. Similarly compiled indicator information for the plant management and system responsible engineers is presented in the maintenance summary reports of the operating periods (from refuelling outage to refuelling outage).

The annual bonus payments to personnel are also based on performance indicators. Some examples of the indicators and their weights are:

- OM costs, 30 %
- Work accidents, worker accidents, 10 %
- Plant unavailability, 20 %
- Delayed preventive maintenance (PM) work
- Delayed corrective maintenance (CM) work
- Tidiness index.

The LoNPP plant life management (KISU) process includes 20 subprocesses. The main KISU process owner is the maintenance manager. The KISU process has 20 system responsible engineers, which come from the maintenance, operation and technical branches.

The Loviisa NPP organisation wants, according to its KISU plant life management and planning system, to know the condition of the NPP in real time.

LoNPP will perform an RCM study on a case, which has not yet been selected. Fortum Power & Heat may in future have less financial resources for maintenance, but a maintenance reduction cannot be done on the cost of safety. Electricity price and potential loss of production are important criteria. One question for the RCM study is: “How to reduce the maintenance costs?” It was simultaneously discussed whether the LoNPP should start with maintenance strategy class 1 components to see if enough PM is done.

TVO maintenance analysis and classification (Enclosure 4)

The representative (Esa Unga) from Olkiluoto NPP was not able to attend the meeting, but Kari Laakso gave an initial presentation of the slides obtained from Olkiluoto.

The number of process components in the Olkiluoto NPP is about 25000 per unit. In addition some thousand electrical components, electrical supplies etc. must be taken into account in the maintenance information system.

In the Olkiluoto maintenance analysis, the maintenance of components is intended to be prioritised according to the following classification:

- Maintenance priority 1: components that have to be always functionally operable,
- Maintenance Priority 2: components for which limited unavailability is allowed,
- Maintenance Priority 3: components for which economically reasonable preventive maintenance is justified,
- Maintenance priority 4: components without planned preventive maintenance.

The main question focusing on availability and safety performance for the classes 1 and 2 is: “Are we making the correct maintenance measures?” The main question focusing on the maintenance costs for the class 4 and even class 3 is “Are we making unnecessary maintenance measures?” Expensive repair costs may mark up a lower maintenance priority. The questions are at general level based on a similar logic as in RCM: “Does the failure affect plant safety/and/or operational availability?” “Does the failure affect immediately?” “Is the preventive maintenance economically reasonable?”

3 Discussion on future NKS/SOS-2.2 work on maintenance decisions

After the presentations, issues of common interest were discussed. Pekka Skogberg introduced following five topics for consideration:

1. *Principles on selection of "maintenance critical objects":*

- How to use maintenance information systems, Technical Specifications etc.?
- How to use PSA models (e.g. risk increase factors)?

2. *How to decrease the cost without simultaneously compromising the safety?*

- The LoNPP new maintenance classification is based on valuing of different selection objectives. One main problem is how to decrease the maintenance costs simultaneously as the safety authority requires high safety.

3. *How to rank the objects for resource demanding maintenance analysis?*

- Plant availability: Is it more cost-effective to reduce the scram frequency than the core damage frequency, when the present core damage probabilities are used in calculations?

4. *What are the principles for the selection of optimal actions?*

- Should tailored LTAs be reviewed for different types of equipment such as e.g. rotating machinery, closing valves and metallic structures? How should LTAs be connected to the maintenance information systems to initiate the need to change the maintenance strategy at equipment level?

5. *What are the principles for selecting optimal intervals for preventive maintenance including consideration of condition monitoring?*

- This subject can be discussed in the group, but no main item for developments.
- The RCM maintenance analysis produces grounded proposals of changes but the experience of maintainers shall then be used to select the revised interval or another strategy (e.g. condition monitoring can replace preventive replacements or decompositions of components).
- How to connect the condition monitoring data to maintenance information systems and produce condition monitoring indicators?

After the discussions, it was decided that a discussion and working group will be invited and established within NKS/SOS-2 project in order to promote the exchange of information between Swedish and Finnish utilities in the area of maintenance decisions. The following items were decided to be covered in the discussion and working group meetings:

1) Presentations and discussions on maintenance strategy, maintenance indicators and RCM analysis related items,
2) Preparation of survey report based on benchmarking of maintenance strategy classifications from the different utilities.

4 Invitation and work plan (2000-2001)

The following invitation and work plan for NKS/SOS-2.2. Maintenance Decisions- Discussion & Working group was prepared and sent to the Nordic nuclear power utilities.

1. Introduction

The aim of the task "Maintenance decisions" in the NKS/SOS-2.2 project "Management of plant maintenance and renewal" is to enhance the use of plant information systems, and the available expertise, for improvement of maintenance strategies. A suitable and effective maintenance is needed to achieve the long-term goals of reactor safety, economic returns, plant availability and production costs. One main problem is, how to manage or decrease the maintenance costs at the same time as the safety authority requires high safety. The safe and remunerative production of a complex NPP plant requires ranking of planned maintenance actions and resources for both "important" and "less important" equipment. The maintenance strategy gives guidelines on, how actions should be ranked and resources distributed on different systems and components to achieve the defined goals.

Justification of changes in maintenance programmes may arise from e.g. learning from operating experience or development of novel condition monitoring techniques. RCM analyses utilising maintenance data bases and efficient data analysis tools, completed with structured decision models, have recently been introduced and demonstrated at the Barsebäck plant in the NKS project RAK-1.4. The case studies exhibited that the decision making of maintenance changes and plant modifications is not always straightforward because of different conflicting or non-measurable objectives. The RCM studies helped to pinpoint and justify correct maintenance and testing actions and optimal intervals to decrease failures, repairs, wear and maintenance costs.

2. Tasks

The tasks within a NKS/SOS-2.2 discussion and working group on "Maintenance decisions" were discussed and ranked in a Nordic SOS-2.2 mini-seminar at October 14, 1999:

The first task is to survey and discuss principles and examples of maintenance strategy classifications of equipment and systems. How to select the "maintenance significant items" and rank objects for resource demanding maintenance analyses? What are the important decision objectives and criteria? Should the different selection objectives be valued or is the valuation too obscure for the plants? The presentations and discussions result in a survey report based on benchmarking of examples and ideas on maintenance strategy classifications from the different Nordic utilities and researchers.

The additional task is presentation and discussion of maintenance strategies and indicators and RCM analyses. The very important question for the maintenance critical items is: Are correct preventive actions performed to identify failures early and to prevent failures? Are spares and services available for the critical items? Is too much preventive maintenance or testing done on some equipment? The methods and logical principles for selection of optimal actions and intervals should thus be discussed because they vary significantly between different utilities. The maintenance planning and RCM studies for CCF avoidance can also be discussed. In addition RCM analyses done, principles for maintenance effectiveness reporting, indicators used and their targets, can be presented.

The aim of the NKS/SOS-2.2 report is to find and present the best practises for learning.

3. Resources and invitation

The joint NKS/SOS-2.2 discussion and working group consists of Nordic utilities and researchers. The group will start in the 12 April 2000 meeting and come together during 4-6 days in total during 2000-2001. Survey report is prepared by VTT Automation, with support and review from other participants.

The NKS reporting is financed by NKS and the costs of the participants are covered by their organisations. Maintenance developers and planners from BKAB (Barsebäck), Fortum Power & Heat (Loviisa) and TVO (Olkiluoto) have already entered for the group. Maintenance or production developers and planners from OKG, FKAB and Vattenfall/Ringhals are kindly invited to join the group to follow-up the discussions and diversify the learning and contributions of the joint work.

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Enclosure 1. A Swedish RCM study on feed water system

(Pekka Skogberg, BKAB)

RCM - ett koncept för underhållsoptimering

Pekka Skogberg,
utvecklingsingenjör inom underhållsoptimering (F&U)
Barsebäck Kraft AB

RCM - ett koncept för underhållsoptimering

Innehåll

- Underhållsprocess
- Systematisk underhållsanalys
- Resultat från en pilotstudie

Ett effektivt underhåll krävs för att uppnå långsiktiga mål

- Mål för bl a reaktorsäkerhet, drifttillgänglighet och produktionskostnad.
- Komplex anläggning kräver **prioritering** av underhållsåtgärder och resurser för ”**viktig”** utrustning.

→ Prioriteringar inom underhåll kan baseras på resultat från RCM- analyser

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Underhållsstrategi

Definition;

” Underhållsstrategi ger riktlinjer om hur åtgärder och resurser skall **prioriteras och fördelas** på olika system och komponenter för att **uppnå ställda mål** ”.

→ Prioriteringar inom underhåll kan baseras på resultat från RCM- analyser (Reliability Centered Maintenance)

Vad är RCM (Reliability Centred Maintenance)?

- En systematisk och logisk metod som strävar till att:
  - utvärdera effektiviteten av FU-programmet
  - framta ett optimalt FU-program.
- Metodiken baseras på att initialt välja ut/ prioritera kritiska objekt för underhållsanalys

Vanliga frågor om underhåll

- Är det nuvarande förebyggande underhållsprogrammet **effektivt** (behov av förstärkning, överflöd)?
- Utförs **rätta förebyggande åtgärder** för att identifiera felen tidigt samt för att förhindra feluppkomst?
- Utförs åtgärderna såsom förebyggande underhåll och de periodiska proven vid **rätta tidpunkter** (intervall)?

Förbättra FU-programmet
- med ett erfarenhetsbaserat RCM- koncept

Fel- och underhållserfarenheter

Val av ASI's ; påverkan på säkerhet, tillgänglighet, uh-kostnader strålningsdos eller annat kriteria

vikta, klassificera, rangordna och prioritera

Val av effektiv underhållsåtgärd/-intervall

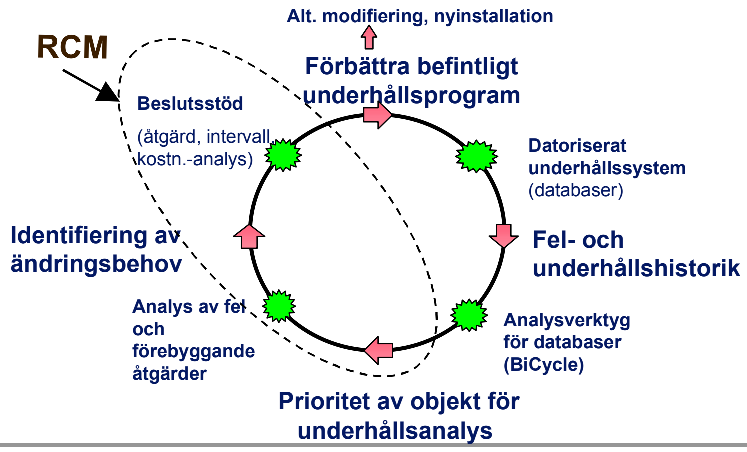
Förebyggande åtgärder
- periodiska prov
- återkommande provning (tryckkärl)
- förebyggande underhåll, utbyten
- tillståndskontroll

Avhjälpande åtgärder
- avhjälpande underhåll

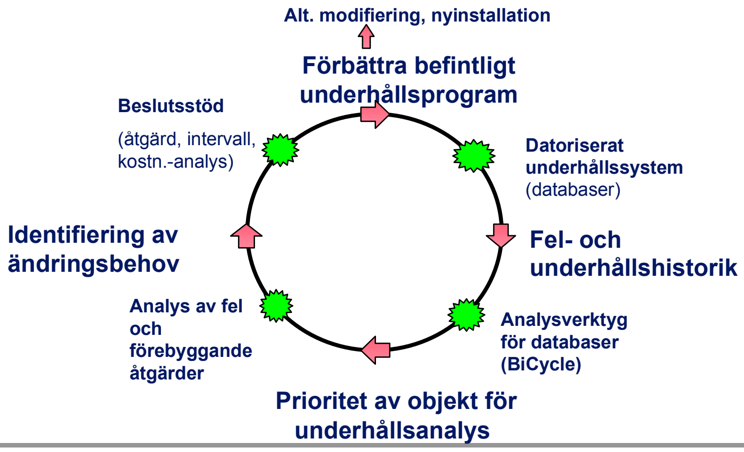
alt. nykonstruktion, modifiering

Underhållsprogram

Underhållsprocess



Underhållsprocess



Prioritet av objekt för underhållsanalys

1	**Fel- och underhållshistorik**	Definition av underhållsindikatorer
2	**Kriticitetsutvärdering**	Objekten betydelse utvärderas/ specificeras utifrån olika kriterier
3	**Val av kritiska objekt**	Prioritering/rangordning av kritiska objekt med hjälp av underhållsindikatorer (datorstöd)

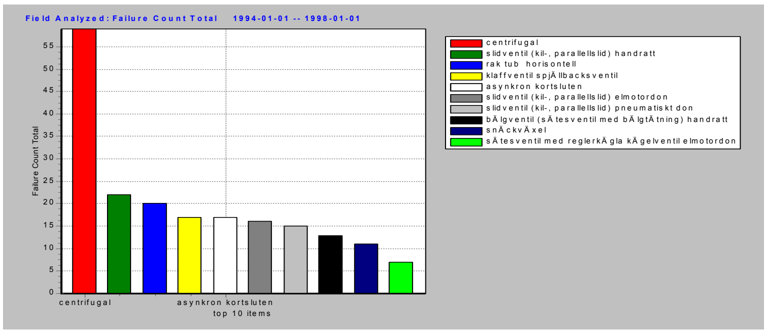
Underhållsindikatorer

Viktiga indikatorer för uppföljning av underhållets effektivitet:

- Antal fel per år + Trend
- Kostnad för AU per år + Trend
- Kostnad för FU per år + Trend

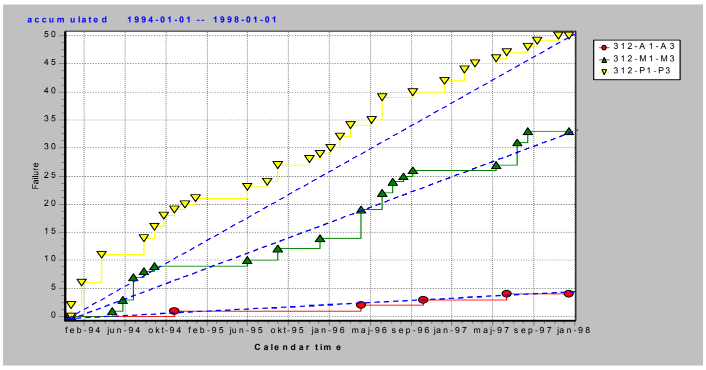
Uppföljning av antal fel

Identifiera objektgrupper med högt felutfall
- kompletteras med trendanalys



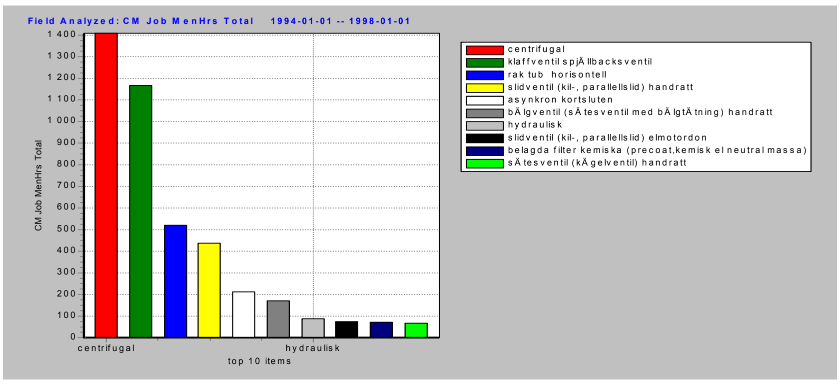
Uppföljning av feltrend

Identifiera objektgrupper med ökande feltrend



Uppföljning av AU-kostnad

Identifiera objektgrupper med hög underhållskostnad
- kombineras med trendanalys



Kriticitetsutvärdering

Objekten klassindelas och värderas utifrån följande kriterier:
(0 = ej kritisk, 1= låg kriticitet, 2 = hög kriticitet)

• Reaktorsäkerhet	kriticitetsvärden 0,1 och 2
• Drifttillgänglighet	” - ”
• Arbetsmiljö (stråldos)	” - ”
• Underhållskostnad (AU)	” - ”

Reaktorsäkerhet- klassindelning

Värde	Konsekvens
0:	Ej STF.
1:	Felet skall åtgärdas och vara driftklart inom en tid som tillåts **överstiga 48h.**
2:	Felet skall åtgärdas och vara driftklart **inom 48h.**

Reparationskriterer och driftklarhet definieras enligt STF.

Drifttillgänglighet- klassindelning

Värde	Konsekvens
0:	Felet medför **ingen** påverkan på anläggningens produktionskapacitet.
1:	Felet medför **reducerad** (automatiskt eller påtvingad) produktionskapacitet men leder ej till stopp av anläggningen.
2:	Felet medför **stopp** (automatiskt eller påtvingad) av anläggningens produktion.

Arbetsmiljö (stråldos) - klassindelning

Värde	Konsekvens
0:	Felet medför ingen eller låg dosbelastning för personal i samband med underhållsarbeten: **< 0,025 mSv/h** (jmf strålningszon BLÅ) Genomsnittlig dosbelastning: ca 0,005 mSv/h.
1:	Felet medför dosbelastning för personal i samband med underhållsarbeten: **0,025 mSv/h - 1mSv/h** (jmf strålningszon GUL) Genomsnittlig dosbelastning: ca 0,1 mSv/h.
2:	Felet medför dosbelastning för personal i samband med underhållsarbeten: **>1mSv/h** (jmf strålningszon RÖD) Genomsnittlig dosbelastning: ca 0,5 mSv/h.

Underhållskostnad- klassindelning

Värde Konsekvens

0: Felet medför avhjälpande underhållskostnad **upptill** 10 kkr.

1: Felet medför avhjälpande underhållskostnad mellan 10 kkr -100 kkr.

2: Felet medför avhjälpande underhållskostnad som **överstiger** 100 kkr.

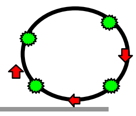
Prioriterade objekt för underhållsanalys

”Tio i Topp”- listor genereras (med datorstöd) för t ex:

1 **Högt felutfall** för objekt som är kritiska utifrån **reaktorsäkerhet**

2 **Högt felutfall** för objekt som är kritiska utifrån **drifttillgänglighet, miljö eller underhållskostnad**

3 **Höga förebyggande underhållskostnader** och/eller **lågt felutfall** för **ej** kritiska objekt
- Finns överflödiga FU-insatser ?



Metodik för underhållsanalys

Analys av fel- och underhåll:

- FMECA (förekommande feltyper, kriticitet mm)
- PMEA (befintliga förebyggande underhållsåtgärder)
- Erfarenheter från drift- och underhållspersonal

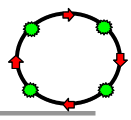
Identifiera förändringsbehov

FMECA →

- **Kan åtgärder förbättras för kunna identifiera fel tidigt samt förhindra feluppkomst ?**
- **Kan tidpunkt/ intervall ändras?**

← **PMEA**

Identifiera förbättringsbehov



Utveckling av beslutsstöd

- välja optimal underhållsåtgärd (LTA)
- välja optimalt underhållsintervall

→ uppskatta framtida underhållskostnader för alternativa underhållsprogram !

Välja optimal underhållsåtgärd
(Metod:Logisk felträdsanalys - LTA)

Exempel på sekvens av ja/nej frågor:

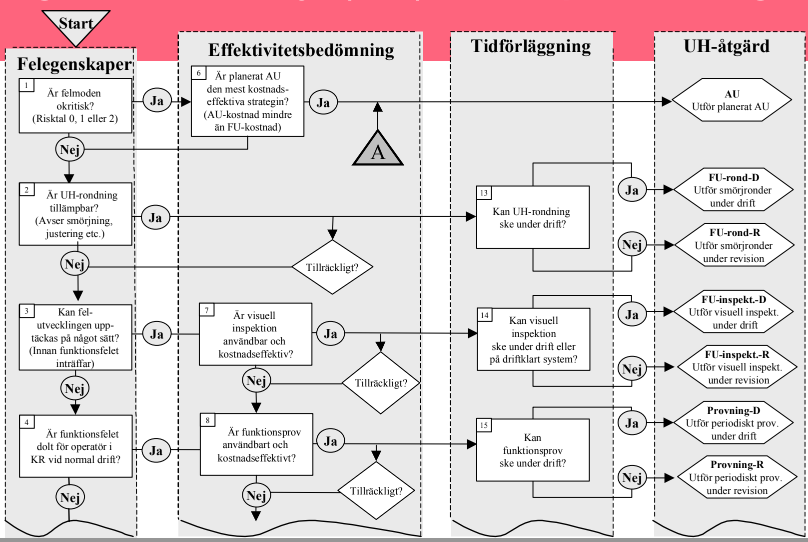
- Finns **behov** av en förebyggande åtgärd, d v s är objektet **kritiskt?**
- Är kostnaden för FU- åtgärden **mindre** än AU-kostnaden?
- Kan felutveckling **upptäckas** på något sätt ?
- Är felet **dolt** för operatör i kontrollrummet ?
- Är åtgärden **kostnadseffektiv?**
- **Ökar felfrekvensen** med åldern **?**
- Kan åtgärden **utföras** under **drift** ?

→ ger förslag till optimala underhållsåtgärder !

Exempel på optimala uh- åtgärder (via LTA-analys)

- FU (ronder, inspektion, periodisk översyn, periodiskt utbyte)
- Tillståndskontroll (periodisk, kontinuerlig)
- Provning, återkommande provning
- Planerat avhjälpande underhåll (” kör till fel”)
- Anläggningsändring (modifiering/ modernisering)

Logiskt felträdsanalys (LTA)- val av optimal UH-åtgärd



Välja optimalt underhållsintervall

Metodik finns för att bestämma intervall för:

- Periodisk FU- åtgärd (eller periodiskt byte)
- Tillståndskontroll
- Periodisk test/ inspektion

→ Utnyttja erfarenheter från UH- personalen !

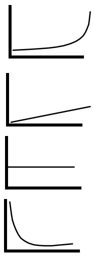
Bestämning av (periodiskt) FU- intervall

Följande beaktas:

- felets karaktäristik
- hur kritiskt felet är (jmf med kriticitetsvärdet)
- hur ofta felet inträffar (MTTF)

Bestämning av felkaraktäristik (FK) (degraderingsprocess)

FK- typ



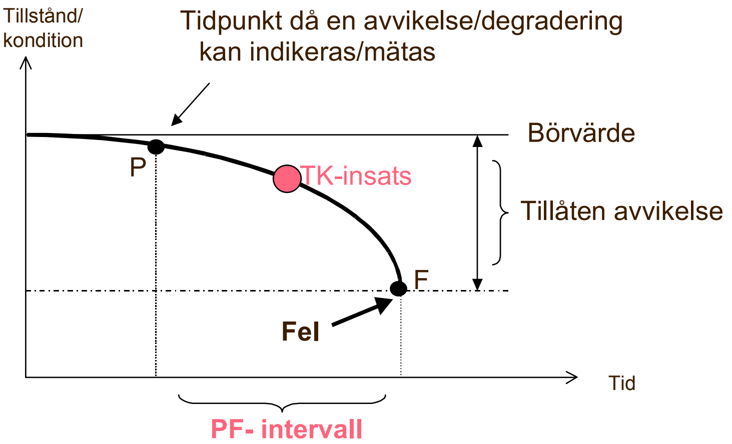
FK- typ		
1	Tidsberoende fel, drastisk ökning	erfordrar periodisk FU- insats !
2	Tidsberoende fel, successiv ökning	
3	Konstant felintensitet	
4	Tidsberoende fel, successiv minskning	

Bestämning av (periodiskt) FU- intervall

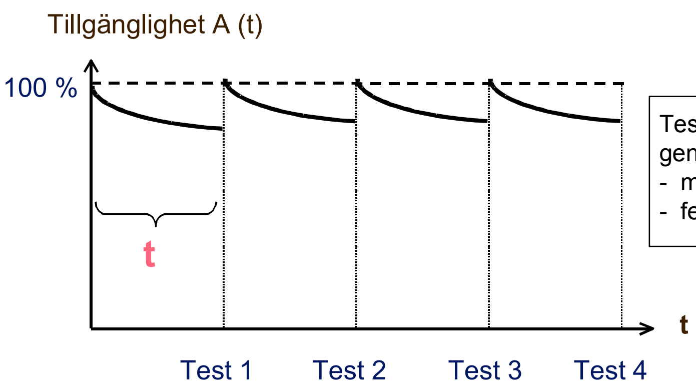
Felkaraktäristik	Kriticitet	Intervall
Tidsberoende fel, drastisk ökning	låg	**50 % av MTTF**
Tidsberoende fel, drastisk ökning	hög	**25 % av MTTF**
Tidsberoende fel, successiv ökning	låg	**25 % av MTTF**
Tidsberoende fel, successiv ökning	hög	**10 % av MTTF**

Vid långsam ökning bör FU ersättas med tillståndskontroll!

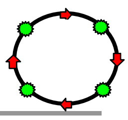
Tillståndskontroll (TK)
- bestämning av PF- intervall



Periodiskt testintervall (t)



Testintervallet kan beräknas genom att bestämma:
- medelotillgängligheten och
- felintensiteten (λ)



Resultat från ”Risk based test intervall….)”

Benämning	Testintervall (h)	
	Original	Optimerat
Pumpar (323, Härdnödkylsystem)	728	2685
Pumpar (327, Hjälpmatarvattensystem)	2184	886
Gasturbiner	336	834
Dieselmotorer	336	473

Några resultat RCM- pilotstudie (centrifugalpumpar i matarvattensystemet)

Befintliga underhållskostnader kan **reduceras med 50%** :

- **öka** utnyttjandet av tillståndskontroll, d v s mer **behovsstyrt UH**
- **färre** antal ”dyra” översyner
- **färre** antal översyner minskar ”UH- introducerade fel”
- **färre** antalet prov- minskar ”slitage” på utrustningen**.**
- ändring av underhållsstrategi för standby-pump- **minskat UH-behov**

Matris för presentation av samordningsmöjligheter i förebyggande åtgärdsprogram

System	Objekt	Komp.	Beskrivning av FU-åtgärd	Uh-typ	Prov- eller FU- intervall										
					1V	2V	4V	12V	1Å	2Å	3Å	4Å	5Å	6Å	
312	P1-P2	39	Tillståndskontroll (vibrationsmätning)	FUK			X								
		39	Tillståndskontroll/pumpkondition	FUK				X							Tillkommit
		39	Visuell inspektion /läckagekontroll	FUK			X								Tillkommit
		39	Oljeanalys	FUR					X						
		39	Prov av pumpstart i samband med gasturbinstart och sekvensinkoppling	PP					X						
		39	Översyn/inspektion efter 6Å eller vid behov!	FUR							X →			?	Ändring av intervall
	P3	39	Prov av pumpstart/ funktionskontroll (2 timmar drift)	PP			X →	?							Ändring av intervall
		39	Oljeanalys	FUR					X						
		39	Tillståndskontroll/pumpkondition	FUK				X							Tillkommit
		39	Tillståndskontroll (vibrationsmätning före och efter pumpstart)	FUK			X →	?							Ändring av intervall

Effektiv styrning av underhållsverksamhet

1 Definiera mål och strategi för underhållsverksamheten.

2 Indela anläggningens utrustning i olika klasser utifrån dess kriticitet (utnyttjas för att prioritera system och komponenter).

3 Utnyttja indikatorer för systematisk uppföljning av underhållets effektivitet.

4 Vid avvikelser- utför fördjupad analys (FMECA-PMEA-LTA-kostnadsanalys).

5 Utnyttja datoriserade underhållssystem och analysverktyg.

Fortsatt utveckling av underhållsoptimering

- Principer för val av ”underhållskritiska” objekt :
  - Utnyttja process- och underhållsinformationssystem, STF etc
  - Utnyttja PSA-modeller (jmf. med *riskökningsfaktorn*)
- Principer för val av optimal FU-åtgärd:
  - Vidareutveckling av LTA samt dess integrering i datoriserat underhållssystem
  - Uppbyggnad av gemensam FMECA-databas (TUD)
  - Kostnadsanalys
- Principer för val av optimalt intervall för FU, prov, tillståndskontroll:
  - Utnyttja fel- och underhållsdata, indikatorer, konditionsövervakning.
  - Utnyttja PSA-modeller (optimering medelst *riskminskningsfaktor*)
  - Kostnadsanalys

Enclosure 2. A transformer study

(Jette L. Paulsen, Risø National Laboratory)

Transformers

Goal:

Get some more knowledge about transformers

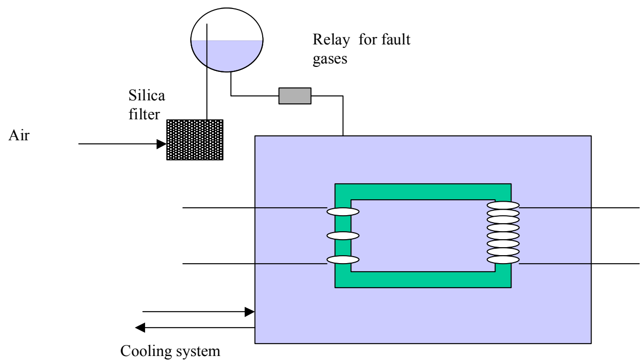
Why do they fail ?

What can be done to prevent failures ?

Jette Lundtang Paulsen, RISØ

Transformer

Filled with dielectric oil and paper



Jette Lundtang Paulsen, RISØ

Failures

Explosions due to formation of H_2 and CO

The gases develope at hot points

The hot points are due to bad connections

The transformers are handmade and ‘born’
with bad connections (??)

Influence factors

- Overload
- Lightning
- Variations in load ?
- Water content
- Loss of cooling
- More ?

What to be done

- Collect sufficient knowledge about transformers to be able to design a structure for a data base.
- Collect data by a questionnaire survey
- Analysis of the collected data

What do we expect to get

- Dominating influence factors
- Are the influence factors independent ?
- ?

Is it possible to prevent failures ?

Jette Lundtang Paulsen, RISØ

Condition monitoring

Equipment available today

Online measurement of the content in ppm of the total amount of gases.

Online measurement of the content of water in the oil

Jette Lundtang Paulsen, RISØ

Enclosure 3. Loviisa NPP maintenance strategies and indicators

(Alpo Savikoski, Fortum Power and Heat)

OPTIMIZATION OF THE PRODUCTION OF LOVIISA NPP REQUIRES

- Minimum disturbances during operation period
- Minimum duration of the reloading outages
- Reloading outages during the season of low energy consumption (May-Sep)

↓

- Efficient long term backfitting program
- Efficient and high quality work performance during outages
- Efficient method to choose the works to be carried out during outages

↓

CONDITION BASED MAINTENANCE

EARLY AND DETAILED OUTAGE AND BACKFITTING PLANNING

OUTAGE STRATEGIES

* Inspection outage (every eighth year, ~ 32 days)

* Extended inspection outage (every eighth year, ~ 40 days)

* Short reloading outage (every second year, ~ 15 days)

* Normal reloading outage (every fourth year, ~ 22 days)

Fortum

IMATRAN VOIMA OY
Loviisa Power Plant

CLASSIFICATION OF COMPONENTS

- Enhancement of reports
- Enhancement of preventive maintenance
- Enhancement of condition monitoring and tests
- Enhancement of life management
- Knowledge of status for devices, safety, production, faults, service and price

Fortum

IMATRAN VOIMA OY
Loviisa Power Plant

CLASSIFICATION OF COMPONENTS

Component	Safety (TTKE)	Price	Loss of production	Points	Class of component	Service staff	Fault detection	Points for maintenance	Maintenance class	Follow-up of life management
10AT02T004	0	0	0	0,00	3	1	4	0,71	3	
10BA	1	1	2	1,96	1	1	4	2,08	1	1
10BA02	0	1	2	1,32	1	1	3	1,46	1	1
10BA03	0	1	0	0,20	3	1	3	0,68	3	
10BA05	0	1	0	0,20	3	1	3	0,68	3	
10BA06	0	1	0	0,20	3	1	3	0,68	3	
10BA07	0	1	0	0,20	3	1	3	0,68	3	
10BA08	0	1	2	1,32	1	1	2	1,34	2	1
10BA09	0	1	0	0,20	3	1	3	0,68	3	
10BA10	0	1	0	0,20	3	1	3	0,68	3	
10BA11	0	1	1	0,60	2	1	3	0,96	2	
10BA12	0	1	1	0,60	2	1	3	0,96	2	
10BA13	0	1	0	0,20	3	1	3	0,68	3	
10BA15	0	1	0	0,20	3	1	3	0,68	3	
10BB	1	1	2	1,96	1	1	4	2,08	1	1
10BB02	0	1	2	1,32	1	1	3	1,46	1	1

Fortum

IMATRAN VOIMA OY
Loviisa Power Plant

PERFORMANCE INDICATORS IN MAINTENANCE

- concrete
- well-defined
- easy to repeat (reliable trend)

Fortum

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Loviisa Power Plant

PERFORMANCE INDICATORS IN MAINTENANCE

- internal indicators (owner)
- external indicators (society)

Fortum

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Loviisa Power Plant

PERFORMANCE INDICATORS IN MAINTENANCE

1. ECONOMICAL INDICATORS
2. TECNICAL INDICATORS
3. SAFETY INDICATORS
4. OTHER INDICATORS

Fortum

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Loviisa Power Plant

ECONOMICAL INDICATORS

- budge/production costs
- production costs/unit
- quantity of overtime work
- quantity of subcontract work

Fortum

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Loviisa Power Plant

TECHNICAL INDICATORS

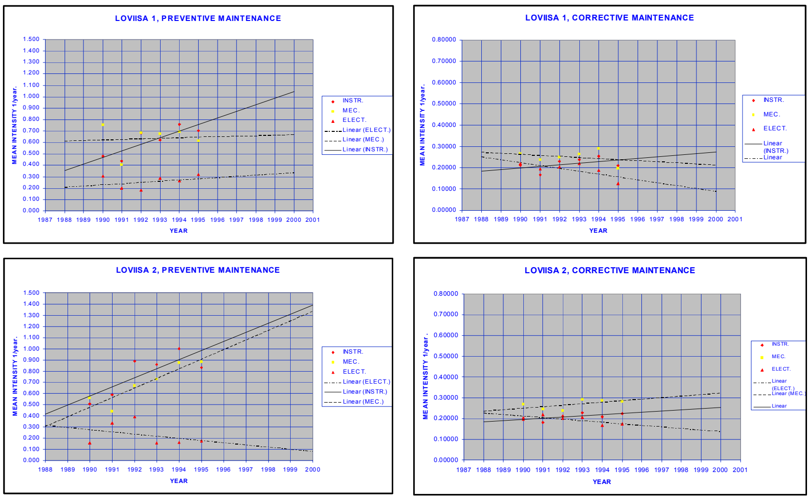
- load factor
- duration of annual outages
- number of modification, corrective and preventive maintenance works (number/year, delayed, not completed)
- planned/realized working hours
- availability and maintenance frequency of components (reporting based on unit, section and foreman)
- quantity of spare parts
- classification of components

Fortum

IMATRAN VOIMA OY

Loviisa 1 & Loviisa 2 Power Plant, maintenance works trend

(includes all the works when component has been unavailable)



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Loviisa Power Plant

SAFETY INDICATORS

- number of accidents
- incidents againts the procedures
- process leakages (hydrogen, ammonia, steam,…..)
- radiation doses (exposures)
- number of reports
  - disturbance reports
  - root cause analysis

Fortum

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Loviisa Power Plant

OTHER INDICATORS

- condition index (condition/health of employees)
- average age of employees
- tidiness index
- number of initiatives

Enclosure 4. TVO maintenance analysis and classification

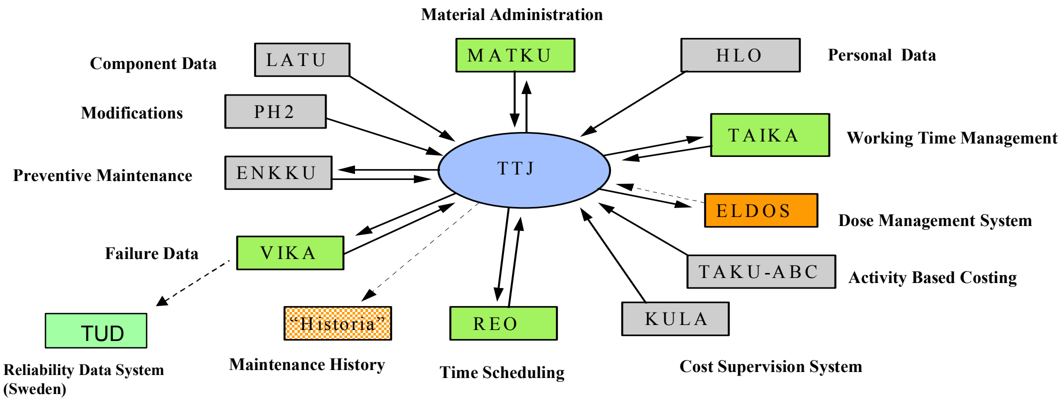
(Esa Unga, TVO)

TVO Maintenance Analysis

Olkiluoto NPP

Esa Unga
Teollisuuden Voima Oy
Olkiluoto, Finland

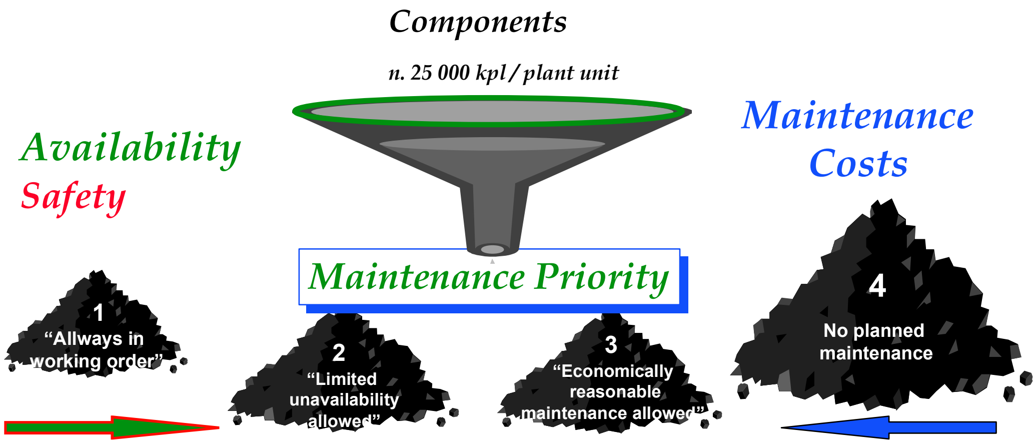
Olkiluoto NPP - Maintenance Data Systems



Olkiluoto NPP - Number of Components

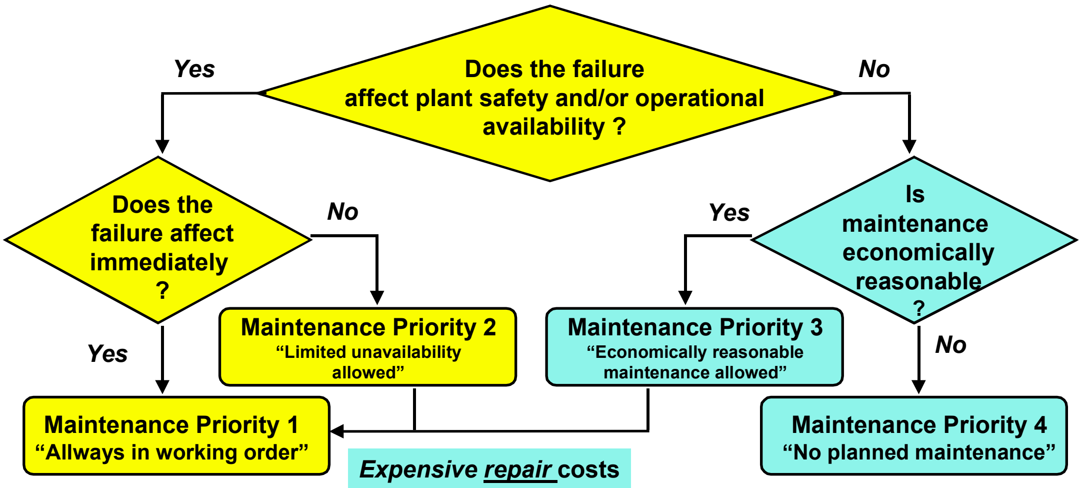
	Olkiluoto 1	Olkiluoto 2
Process components	25577	23814
Electrical cubicles	3643	3567
Electrical supplies etc.	2869	2823
Valves	12739	11921
Pumps	359	353
Compressors	55	51
Fans	331	362
Measuring point	5510	5239
Heat exhangers	490	501
Filters	643	630

Maintenance Priority of Components



Are we making right maintenance measures ? **Are we making unnesessary maintenance measures ?**

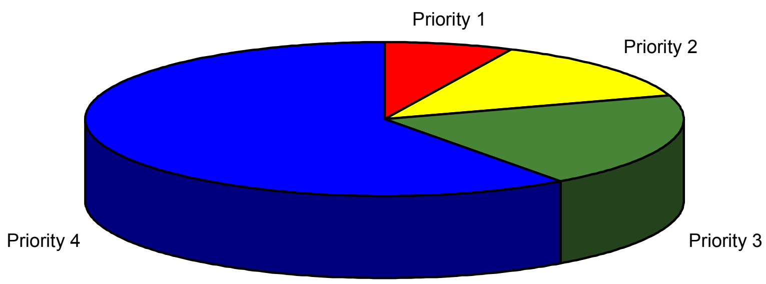
Olkiluoto NPP - Maintenance Analysis
Maintenance Priority of Components



Olkiluoto 1 and 2 -
Maintenance Priority Distribution of Components

(estimated)

More attention on priority 1 and 2 components !



Less unnecessary maintenance !

Bibliographic Data Sheet **NKS-18**

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Author(s)	Kari Laakso & Kaisa Simola (eds.)
Affiliation(s)	VTT Automation
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No. of tables	
No. of Illustrations	1
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Abstract	In the Earlier NKS-project RAK-1 (1994-1997), the sub-project RAK-1.4, "Maintenance Strategies and Ageing" focused on development of methodologies and tools for improving maintenance strategies. In the NKS/SOS-2 project (1998-2001), the maintenance related Nordic co-operation is continued. For exchange of information and as background and for discussions related to maintenance decisions in the NKS/SOS-2 project, a mini-seminar on maintenance strategies with an emphasis on reliability centred maintenance (RCM) approaches was arranged 14.10.1999. The report summarises the topics of the presentations and discussions at the seminar. The transparencies presented at the mini-seminar are enclosed in this report.
Key words	reliability centred maintenance, maintenance strategies, maintenance indicators

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