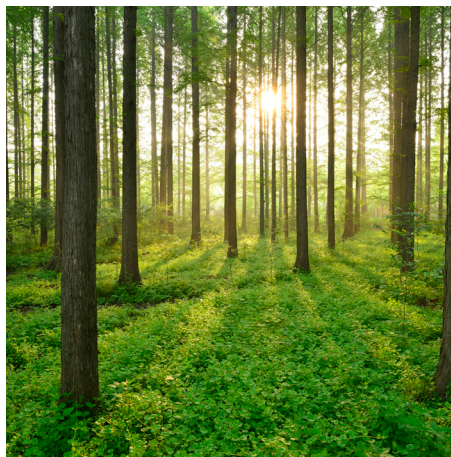
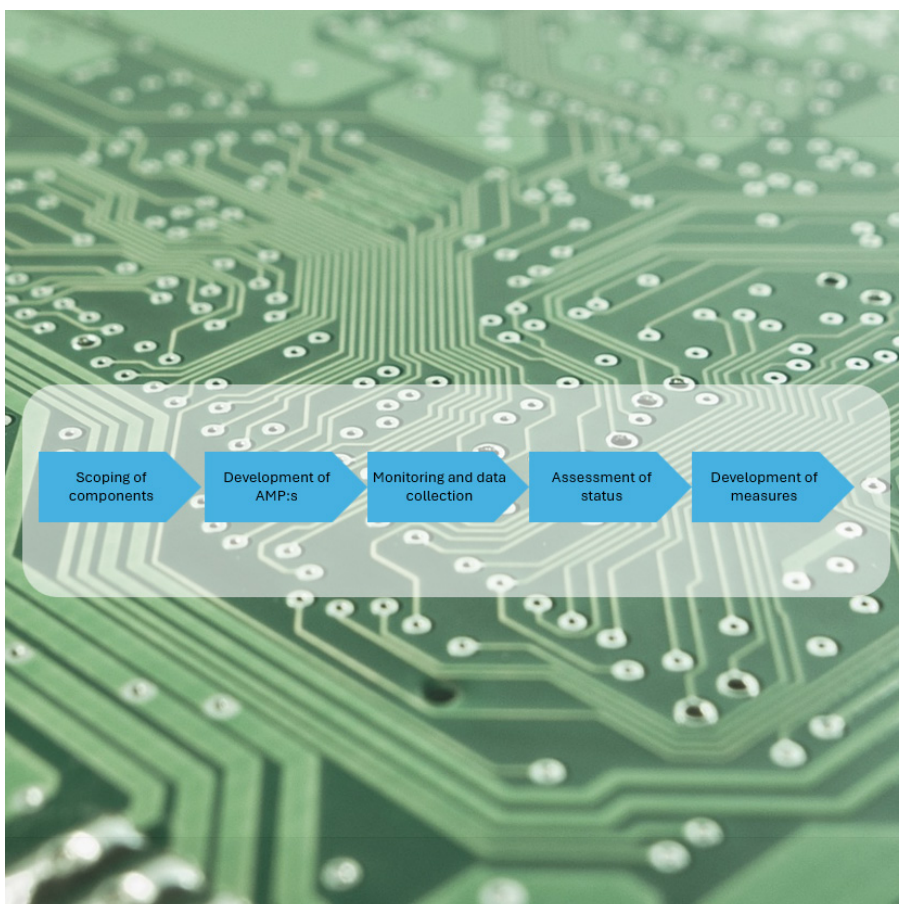


PROCESS FOR MANAGING AGEING OF I&C EQUIPMENT

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NUCLEAR SAFETY RELATED I&C
ENSRIC



Process for Managing Ageing of I&C Equipment

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Foreword

This report forms the results of a project performed within the Energiforsk Nuclear Safety Related I&C (ENSRIC) Program. The ENSRIC Program aims to increase the knowledge of aspects affecting safety, maintenance and development of I&C systems and their components in the Nordic nuclear power plants. Part of this is to investigate possibilities to facilitate and simplify the work that is performed in the nuclear business.

The Instrumentation & Control (I&C) systems can be regarded as the nerves and brain of a nuclear power plant. Thus, effective processes for management of I&C ageing and obsolescence are crucial for maintaining safe and reliable operation of nuclear power plants over time.

This study aims to lay the foundations for a best-practice process for managing ageing and obsolescence of I&C systems in the Nordic nuclear power plants. It has been performed through interviews and studies of existing processes, as well as literature studies. The proposed process includes guidelines for monitoring, assessing and mitigating ageing effects, to ensure continuous safe operation.

The study was carried out by Gabriel Aspegren and Emelie Gaveberg, Solvina. The study was performed within the Energiforsk ENSRIC Program, which is financed by Vattenfall, Uniper, Fortum, TVO, Skellefteå Kraft and Karlstads Energi.

These are the results and conclusions of a project, which is part of a research Program run by Energiforsk. The author/authors are responsible for the content.

Summary

A majority of the Nordic nuclear power plants were built in the 1970:s and 1980:s and are operating beyond its first intended lifespan and are subject to further lifetime extensions. To maintain a safe and reliable operation it is crucial to prevent failures in structures, systems and components that are part of the reactor safety. Instrumentation & control (I&C) components are part of several safety related systems. Ageing and obsolescence of components are inevitable and therefore management of ageing and obsolescence is crucial for maintaining safe operation over time.

This project was initiated to review the available literature and guidelines regarding ageing and obsolescence management of I&C components and based on the findings and interviews with the Nordic nuclear power plants propose a generic best-practice process for ageing and obsolescence management of I&C systems. The process should be commonly applicable by Nordic nuclear power plants.

The literature review identified multiple guidelines and reports on the topic, offering guidance in strategic matters, e.g. organisation and design of Ageing Management Programs (AMP), and in technical matters, e.g. analytical methods and identification of degradation mechanisms. The interviews showed on similar challenges between the nuclear power plants regarding ageing management of I&C, e.g. significantly shorter lifespan for new I&C components, and the introduction of programmable components.

Based on the IAEA SSG-48 guideline and interviews with the licensees a high-level process with main process steps was developed. The process is initiated upon the introduction of new components and is conducted regularly for existing ones. Its output is a decision proposal indicating whether action is required, and if so, specifying the appropriate measures. The process specifies what to do, with examples of actions at each process step, but does not detail how it should be performed. To be efficient it shall be implemented with existing operating and maintenance procedures, and continuously include system owners, specialists and management in the process.

Proposed future work is to arrange workshop activities with the Nordic NPPs to allow for discussion on how the process could be implemented and integrated into existing plant management and development processes and routines, and to facilitate exchange of experiences.

Keywords

Ageing, obsolescence, obsolete, ageing mechanisms, I&C, instrumentation and control systems, nuclear power plants, long term operation, LTO, extended lifetime

Åldring, åldrande, föråldrad, åldringsmekanism, I&C, instrumenterings- och kontrollsystem, kärnkraftverk, långtidsdrift, LTO, utökad livslängd

Sammanfattning

En majoritet av de nordiska kärnkraftverken byggdes mellan 1970 och 1980 och har passerat livslängden de var designade för och förväntas genomgå ytterligare livstidsförlängningar. För att upprätthålla en säker och tillförlitlig drift är det avgörande att kunna förhindra att strukturer, system och komponenter som är del av reaktorsäkerheten felar. Instrumenterings- och styrsystem (I&C) är en del av flertalet system med betydelse för säkerheten. Åldrande och föråldring av komponenter är oundvikligt, vilket gör att ålders- och föråldringshantering är avgörande för att upprätthålla säker drift över tid.

Det här projektet initierades för att kartlägga tillgänglig litteratur och riktlinjer rörande hantering av åldrande och föråldring av I&C-komponenter och, baserat på litteraturstudien och intervjuer med de nordiska kärnkraftverken, föreslå en generell best-practice-process för hantering av åldrande och föråldring av I&C-system. Processen ska vara möjlig att tillämpa oavsett tillståndshavare.

Litteraturstudien identifierade ett flertal riktlinjer och rapporter inom området, med vägledning både i strategiska frågor, t.ex. organisering och utformning av ett åldrandehanteringsprogram (AMP), samt i tekniska frågor, t.ex. analysmetoder och identifiering av degraderingsmekanismer.

Intervjuerna visade att kärnkraftverken står inför liknande utmaningar gällande hantering av åldrande av I&C-system, där problem med att nya I&C-komponenter upplevs ha betydligt kortare livslängd än äldre komponenter nämndes av alla.

Utifrån IAEA:s riktlinje SSG-48 och intervjuer med tillståndshavare utvecklades en övergripande process med fem huvudsakliga processteg. Processen initieras vid införande av nya komponenter och genomförs sedan regelbundet för befintliga. Processen resulterar i ett beslutsunderlag som anger om åtgärder krävs och i så fall vilka åtgärder som är lämpliga. Processen beskriver vad som ska göras, med exempel på åtgärder i varje steg, men specificerar inte hur det ska genomföras i detalj. För att vara effektiv bör processen integreras med befintliga drift- och underhållsrutiner samt kontinuerligt involvera systemägare, specialister och ledning. Föreslaget fortsatta arbete är att arrangera workshopaktiviteter med de nordiska kärnkraftverken för att möjliggöra diskussion om hur den föreslagna processen kan implementeras och integreras i nuvarande processer och rutiner för förvaltning och utveckling av anläggningen, samt för att möjliggöra erfarenhetsutbyte inom ämnet mellan tillståndshavarna.

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1 Introduction

1.1 BACKGROUND

Most of the Nordic nuclear power plants were built during the 1970:s and they are coming close to the end of their original lifetime. The original Instrumentation & Control (I&C) systems and technology of the power plants are still in use in many places of the plants. All power plants are monitoring the state of the technology in use, but methods and ways of performing this follow-up are differing. Reliable I&C systems are crucial for a safe operation. To have an effective ageing management program (AMP) in place is therefore of great importance, to be able to keep track of the I&C systems' status and expected remaining lifetime. This requires an AMP organization and adequate processes in place.

This project was initiated to produce a best-practice process that can be commonly applied to manage ageing and obsolescence of I&C systems in the Nordic nuclear power plants.

1.2 SCOPE, METHODOLOGY AND DEFINITIONS

The scope of this study was to gather experiences of ageing and obsolescence management methods of safety classified and safety related I&C systems in power plants and suggest a best practice process for the Nordic Nuclear power plants (NPP:s). Non-safety classified I&C systems are not considered in this report. However, the process presented in this report may be adjusted to include all I&C systems.

Information was gathered from guidelines and reports from IAEA, IEEE and EPRI, and from interviews with licensees of the Nordic NPP:s.

In this report, *ageing* refers to the deterioration of the physical characteristics of a system or component over time or with use, due to degradation mechanisms. This process is also known as *physical ageing*.

Obsolescence is defined as the process by which a system or component becomes outdated due to advancements in technology or changes in requirements and standards. This is also referred to as *non-physical ageing* or *functional ageing*.

In this report, the term *ageing management* as a concept includes obsolescence. When there is a distinction between ageing and obsolescence, this will be clear.

1.3 LIST OF ABBREVIATIONS

Term	Explanation
AMP	Ageing Management Program
AMR	Ageing Management Review
IEEE	Institute of Electrical and Electronics Engineers
EPRI	Electric Power Research Institute
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IGALL	International Generic Ageing Lessons Learned
NPP	Nuclear Power Plant
PM	Preventive Maintenance
POMS	Proactive Obsolescence Management System
RTM	Run-to-Maintenance
SSC	Structures, systems and components

2 Analysis

2.1 SUMMARY OF EXISTING GUIDANCE AND PREVIOUS RESEARCH

The International Atomic Energy Agency (IAEA) has established recommendations for aging management, and the regulatory authorities in Sweden and Finland mandate the implementation of systematic procedures to prevent and address the aging of structures, systems, and components (SSC:s) [1] [2]. The purpose of ageing management of SSC:s in nuclear power plants is to uphold the required safety functions throughout the lifetime of the power plant [3]. The ageing of I&C equipment has the potential to affect the reliability of I&C systems and in turn may affect a safe operation of the power plant. The procurement of replacements and spare parts may present a challenge in the event of equipment obsolescence [4].

The IAEA Safety Standard SSG-48 [3] presents an extensive guide for the design, implementation and improvement of ageing management with the objectives to provide recommendations for meeting Requirement 30 *Qualification of items important to safety* and 31 *Ageing management* of the Safety Standard SSR-2/1 [5] and Requirement 14 *Aging management* and 16 *Programme for long term operation* of the Safety Standard SSR-2/2 [6].

IAEA has also developed the International Generic Ageing Lessons Learned (IGALL) program. The publication *Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL)* [7] serves as an introduction to the IGALL-programme. It provides technical guidance and best practices for managing the ageing of structures, systems, and components (SSC:s) in nuclear power plants, supporting the application of IAEA safety standards. It includes ageing management review (AMR) tables, proven ageing management programs (AMP:s) and other related activities. It serves as a roadmap for ageing management, offering an internationally recognized framework for effective AMP:s.

The IGALL-programme also offers a database of AMR:s and AMP:s for different groups of equipment and components. The IGALL report serves as a guide to the AMR:s and AMP:s. IAEA arranges conferences and technical meetings on the topic of ageing for NPP:s to participate in.

2.1.1 Definition of ageing and obsolescence

IAEA defines in [3] physical ageing, the process in which the physical characteristics gradually degrades with time or use, as *ageing*. In [4], ageing is defined as degradation occurring at a rate that threatens the equipment's ability to perform its required function.

Non-physical ageing, the process of equipment becoming out of date due to the availability and evolution of knowledge and technology as well as changes in requirements and standards, is defined as obsolescence [3].

2.1.2 Monitoring of ageing and obsolescence

The monitoring of ageing differs depending on the type of component as well as its importance to safety. For some components monitoring of performance is important while visual inspections may be sufficient for others. There may be components that is not worth monitoring due to complexity or cost and a single failure do not lead to any safety-related risk.

Defining a generic set of acceptance criteria for I&C equipment is not feasible, as different degradation mechanisms result in varying ageing effects. A deviation in performance of e.g. 10 percent over time may be acceptable for some components and its functions, but not for others. Instead, it may be feasible to determine a set of measurable parameters for different component groups or specific components with defined cut-off points where the component is considered no longer able to perform its intended function reliably. Further, where practicable, regularly monitoring and trending of these components allow appropriate and timely mitigating measures to be taken. The identification of parameters is more challenging for programmable components than for analogue, as visual inspections is unlikely to be suitable since ageing often leads to the die of components. Programmable components may also utilise software, which required integrity may be difficult to demonstrate [4].

What parameters to choose is dependent on the component and its function. It is crucial to understand the present degradation mechanisms and its effect on ageing, as well as the dominant failure mechanisms. Performance may sometimes be a good indicator for ageing, but it is also advisable to inspect the physical condition to register any signs of degradation (e.g. cracks, changes in colour, corrosion). Changes in parameters (e.g. response time, voltage, resistance) may also be indicators of degradation of equipment [4] [8].

Apart from degradation of components, it is important to keep track of obsolescence of components. Therefore, details of the equipment are important, e.g. manufacturer, model, hardware, software and firmware serial numbers. It is also necessary for the NPP to maintain a dialogue with the supplier to get information about when components are about to become obsolete and possible exchanges. There are multiple proactive obsolescence management tools to utilise which gathers information about components that are soon to be obsolete, exchange components and experiences from other NPP:s [4].

2.1.3 Cause of failures

In [4], it is advised to trend failures and investigate them to see if it is ageing related. Further, it states that failed equipment sometime is returned to the manufacturer for repair and it is advised to at the same time ask for a cause of failure report. It is mentioned that some countries have a common practice to utilize external specialist facilities to perform forensic examinations of failed equipment to determine the reason for failure.

2.1.4 Maintenance and mitigating measures

In the WANO guideline *Equipment Reliability* [8] two approaches to maintenance are introduced, Preventive Maintenance (PM) and Run-to-Maintenance (RTM). Preventive maintenance is applied to SSC:s that plays a crucial role in the reactor safety. For components where risks and the consequences of failures are acceptable, the RTM-approach may be applied. If risks and consequences of failures are not acceptable, PM shall be applied.

Taking mitigating measures is a preventive action to slow down the degradation of components. One approach is to minimize the environmental stressors. This may be adding thermal insulation, improve ventilation of electrical enclosures e.g. cabinets, or adding of radiation shielding if possible. Another approach is to adjust operational practices. It may be to reduce the number and rate of shutdowns and startups or reduce the period of operation [9]. The EPRI study [10] on printed circuit boards in EDF (Électricité de France) plants identifies limiting the handling of circuit boards as the most effective measure to reduce failures. The study references findings indicating that the most severely damaged boards were those subjected to the most handling. Additionally, another study found that over 20% of electronic component failures were due to electrostatic discharges, often resulting from improper handling. Implementing protective measures against electrical discharges is a cheap and relatively easy mitigating measure in this case [10].

There are ways to take actions to mitigate obsolescence risks. When procuring components from the supplier, the purchaser may include minimum service time or time for support of components and software from the supplier in the contract, as well as supply of spare parts. This enables planning for obsolescence.

2.1.5 Exchange of I&C components

If a component is to be exchanged there are different approaches to consider. In a report from World Nuclear Association [11], five different replacements methods are listed:

1. Spare parts replacement – the broken component is replaced by identical spare parts from the inventory. This is cost effective and do not affect documentation but presents no improvement of failure rates in existing system.
2. Form, fit and function module replacement (retrofit) – a slightly upgraded replacement component is used. It allows for a fast replacement.
3. I&C rack replacement – a full rack is replaced with the same or similar interface within the cabinet and using existing I&C products and platforms.
4. New I&C cabinet implementation – a full cabinet is replaced within the same footprint but introduces more complex interfaces.
5. New I&C systems implementation – the system which the components are part of are replaced as a larger modernization project. This allows for interface optimization but is a complex task and affects overall plant.

These methods are in varying extent a modernization of the system and all methods, except for method 1, requires requalification and affects plant documentation. The IAEA report [4] defines eight methods to deal with obsolescence of components. They are listed below in order of increasing complexity of change, cost and required resources:

1. Last time buy – the possibility to restock to cover future needs until an alternative, long term solution is in place.
2. Aftermarket buy – refers to stock sourced from a company that retains original, unused inventory.
3. Second user stock – potentially viable sources of second-hand stock equipment, e.g. from on-site modifications and removed units.

If these non-modernization methods are not sufficient, the following modernization replacements may be appropriate:

4. Alternative form, fit and function – the use of alternative components that match the fit, form and function.
5. Remanufacture/reengineering – remanufacturing of the original components without any changes, either by the original manufacturer or by another supplier.
6. Reverse engineering – reproduction of the original functionality without all original design documentation. May necessitate change of the original design, by introducing new devices.
7. Subsystem replacement – partly replacement of system.
8. System replacement – fully replacement of system.

The appropriate method depends on the specific component failure and its impact on surrounding systems. Each case requires individual assessment to determine the most suitable approach, and a combination of methods may be the best option.

2.1.6 Ageing management program

An effective ageing management program should be incorporated into existing surveillance and maintenance programs. Ageing assessment should be integrated into existing work practices e.g. by using recurring maintenance windows to perform testing to assess ageing of equipment and components. Already existing activities e.g. vibration monitoring, equipment hot-spot mapping, could be adjusted to support ageing assessment as well [9].

It is critical to develop engineering evaluations of the gathered data and experiences from the day-to-day surveillance and maintenance work to be able to draw adequate conclusions about ageing mechanisms and effects. The goal for recurring inspections should be to be able to conclude if the equipment or component could remain in service until the next scheduled inspection [9].

In [3], it is recommended to establish an authorized organizational entity with responsibility for ageing management, that works closely with maintenance,

operation, engineering and management. Interdisciplinary ageing management teams with staff from different units of the plant are also suggested. The organization proposed in [3] is seen in Figure 1.

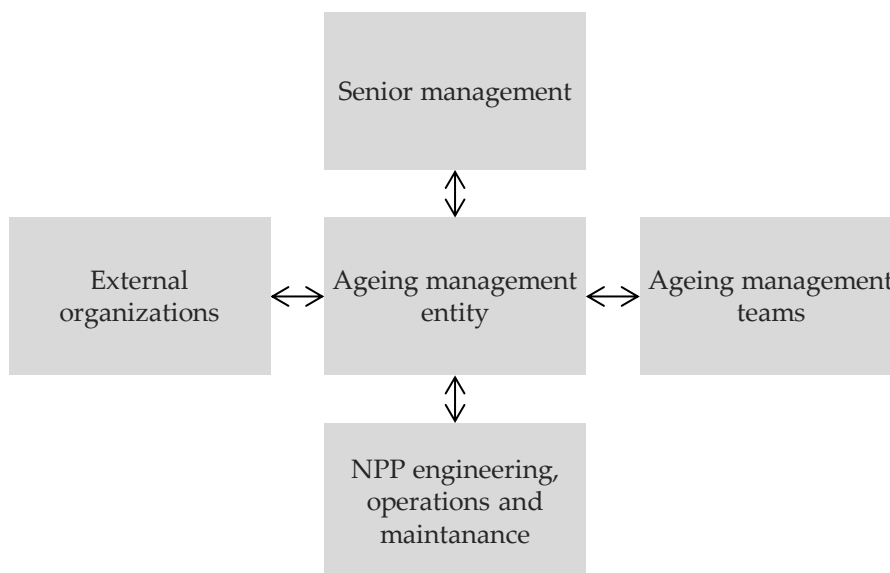


Figure 1 Example of ageing management organization proposed in SSG-48.

2.2 EXPERIENCES FROM NPP:S

Interviews were performed with the NPP owners in the ENSRIC group, including Forsmark, Oskarshamn, Ringhals, Fortum and TVO. Questions were sent out as a preparation before the interviews and then discussed during the interview. The interviews were 60 to 90 minutes with NPP staff, selected by the ENSRIC-group representatives for each NPP, and two persons from Solvina.

Common for all NPP:s was that their ageing management program for I&C was based on the IAEA Safety Guide SSG-48 to different extent. Both Swedish and Finnish authorities demand that the NPP:s have an ageing management program, and the Finnish authority specifies what to include and some approaches and processes to apply. The IAEA IGALL database is utilized by all NPP:s to different extent.

All NPPs distinguish functional and physical ageing and emphasises that functional ageing of I&C in most cases is the most challenging. Especially for new I&C components where the functional lifetime is significantly shorter than for the original components.

All interviewees mentioned that the NPP:s perform some sort of categorization of equipment, either by system, type of component or other. One plant is using a “catalogue of defectives”, which is a script from a supplier, to identify ageing mechanisms and divide components into commodity groups for all components during scoping. The components are then categorized further based on ageing mechanisms. The catalogue is a compilation of all ageing mechanisms, ageing effects and ageing driving factors that have been identified in the plant in the areas of metals, polymers, and reinforced concrete.

Obsolescence is managed via a proactive obsolescence management system that gets updates from suppliers about components that is going to be obsolete and possible exchanges. To ease the process of keeping track of obsolescence, a good relation to suppliers is of importance.

2.2.1 Good examples

Below are some good examples that are in practice at some NPP:s.

Workshop

To have an inhouse workshop where it is possible to dismantle components to inspect its constituents and what materials they consist of to be able to predict ageing mechanisms and possible ageing mitigating measures.

Accelerated ageing

To send components or even whole cabinets to an external research institute to perform accelerated ageing to be able to see how components and equipment degrade and to determine an expected lifetime.

Supplier and product family rationalisation

To implement a strategy to keep the number of product families as low as reasonably practicable to be able to maintain a high level of competence about the products and secure a stock of spare parts.

Supplier relationships

To have a close relationship with supplier of I&C components to always have an updated information about expected lifetime of equipment, spare parts availability, known failures and weaknesses of equipment and recommended replacement strategies in case of obsolescence. Suppliers also often have so called Proactive Obsolescence Management Systems (POMS) to help customers when it comes to obsolescence issues.

2.2.2 Current challenges

Below are some challenges listed that was mentioned during the interviews.

How to identify if a failure is due to ageing or not

When a component fails, it can be hard to determine if it was due to ageing or something else such as manufacturing defect, incorrect installation or operational error. Component failures are not always caused by the component itself but may result from the failure of another part within the system. It may be interesting to determine the reason of failure to be able to take mitigating measures. Conducting root-cause analyses can help identify the underlying cause of failure, potentially preventing repeated failures of replacement components and improving overall system reliability. However, for some components it may be more practical and reasonable to just replace it with a spare component, depending on the safety class of the system.

The shortening of functional lifetime for I&C components

The NPP:s still have original I&C components that have been in use for the entire lifetime of the plant. Nowadays the lifetime of I&C components, both physical and functional, is much shorter which demands a higher frequency of exchanges. Some interviewees noted that sometimes during the time from decision on component replacement to the installation of the new component, it has already become obsolete.

Grouping of I&C components

Grouping I&C components during the scoping process can be challenging, as different grouping approaches may yield varying synergies in inspections, maintenance, and supervision. Effective grouping is a critical step in establishing a comprehensive ageing management program, yet it can be performed with many different approaches.

Qualification of new or new versions of I&C equipment

New components or updates of components may require a qualification process. This is time consuming and may be difficult for components not especially designed for the NPP industry. To have a common qualification procedure between the Nordic NPP:s, so a qualified component in one NPP then also is qualified in the other Nordic NPP:s, would be beneficial. However, qualification to some extent would still be mandatory for each site and application.

Effects on plant structure when going from analogue to programmable I&C components

Analogue I&C components are considered relatively simple to implement functions with due to its basic structure and functionality. Often, analogue I&C components are structured to the objects in the facility that they control. This changes when transitioning to programmable I&C technology. From being an object-bound technology, programmable systems take over in terms of how the structure of the plant is managed, as multiple control functions for many different objects are integrated into the same technical solution. This is a challenge which affects strategies and plans for replacements when transitioning from old technology to new.

2.2.3 Possible improvements

Below are some possible improvements listed that was mentioned during the interviews.

Common qualification of new components

Qualification of new components is a time-consuming and sometimes tricky process. To be able to qualify a component for all Nordic NPP:s would significantly ease the process of renewal of components and would save both time and money. Site and application specific qualifications would still be the case to some extent.

Cooperation between NPPs regarding ageing management I&C

Some interviewees noted that an increased cooperation between the licensees to be able to share experiences, findings and methods would be beneficial.

Findings in why some components have failed, how to tackle challenging ageing mechanisms, or promising component exchanges would be important to discuss. Also, external experiences from e.g. IAEA, research institutes and authorities would be on the agenda. There are existing collaborative networks for the Nordic NPP:s which could be developed for this kind of ageing management issues.

2.3 RESULT

There is no golden rule on how to conduct ageing management of I&C components. How components age varies with its materials and functionality in combination with the environment and operation. For ageing management to be effective, each component group needs its own ageing management program. What makes I&C more challenging than other SSC:s is the programmable components. These are often more complex to supervise and analyse, and the expected lifespan is substantially shorter than what has been common for the NPP industry.

All NPPs interviewed have used IAEA SSG-48 as a base for the ageing management program and the IGALL-database as input when determining degradation mechanisms and ageing effects.

A key factor to succeed with ageing management of I&C components is groping of components to ease the identification of degradation mechanisms and ageing effects. For example, grouping components by degradation mechanisms eases the process of developing mitigating measures. It is preferable to have an obsolescence management system in place that includes supplier-provided information on component obsolescence and recommended replacements.

Maintaining a good relationship with suppliers and manufacturers is a cornerstone of ageing management planning, especially for obsolescence. There are a lot of literature and guidelines on the topic published by IAEA, IEEE, WANO and EPRI amongst other, to utilise.

3 Generic process for ageing-related renewal decision

Based on the literature and the interviews the following process was developed. It is a generic process for ageing management of I&C equipment that is continuous throughout the component lifecycle. It is a step-by-step process, with defined activities and outputs for all process steps but also offer freedom for adjustments. It is designed to be a guideline and support for ageing management. The proposed process can be seen in Figure 2.

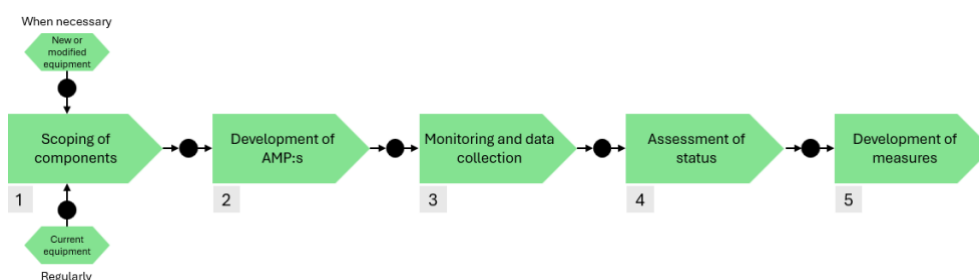


Figure 2 Process for ageing management of I&C components

The process has mainly taken input from the IAEA Safety Report SSG-48 and WANO Equipment Reliability report, but also from interviews with the Nordic NPPs and other reports and guidelines, cited in the study.

For the ageing management to be effective and the status of components to be up to date, it is important to integrate this process into existing processes and everyday activities. It shall be seen as a continuous process which enables always up to date status information, rather than an isolated process repeated at a predefined interval.

The process applies to both new I&C equipment and components, as well as existing equipment. The workload is typically greater during the implementation phase and when introducing new components, compared to the continuous execution of the process. It is initiated either as needed — such as when new components are to be installed — or conducted continuously for existing equipment.

When procuring components, it is important to set requirements on the manufacturer or supplier for the provision of information about materials, expected lifetime, maintenance, software support, and other information that will be used as input in the AMP.

The abbreviation AMP refers to the broader ageing management program of I&C components, and group-AMP refer to a specific ageing management program for a specific group.

In Table 1, each process step is described with purpose, output, activities and input. A detailed description of the process is presented in this section below.

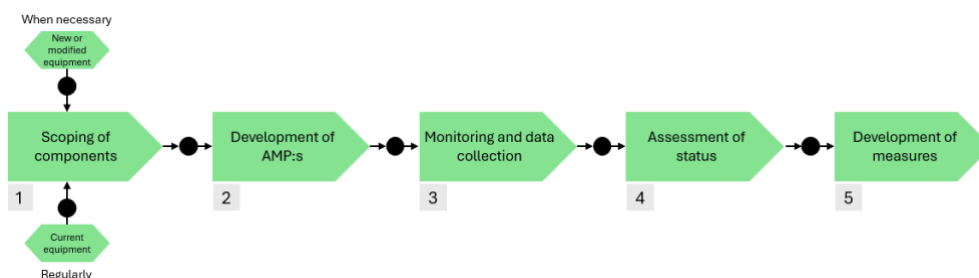


Table 1 Description of the process steps of the ageing management process

	1. Scoping of components	2. Development of AMP:s	3. Monitoring and data collection	4. Assessment of status	5. Development of measures
<i>Purpose</i>	To define the scope of the components to be part of the AMP and to group the components to relevant group-AMP:s. AMP covers both ageing and obsolescence.	To define necessary monitoring and mitigating activities based on ageing mechanisms and obsolescence risks.	To track and confirm data on key attributes for ageing and obsolescence.	To assess components condition and obsolescence risk.	To develop measures to address ageing and obsolescence, and present decision proposal for management.
<i>Output</i>	A comprehensive list of all relevant components included in the ageing management program, grouped based on which group-AMP shall be established.	One AMP per group of components – group-AMP:s, for physical ageing and obsolescence.	Confirmed data on the performance and condition of components, including monitoring reports and data logs.	Assessment reports highlighting ageing and obsolescence risks.	Action plans and implementation schedules for mitigation measures to address identified ageing and obsolescence issues.
<i>Activities</i>	- Define criteria for which components to be part of the AMP/group-AMP:s. - Identify all relevant components including spare parts based on criteria, SAR, plant documentation and if necessary, plant walkdowns. - Group the components for suitable group-AMP:s.	- Identify ageing mechanisms and expected lifecycle for equipment. - Establish key attributes and criteria for the equipment. - Define and implement activities for monitoring and mitigation.	- Collect data on performance and condition. - Collect data on availability. - Maintain data logs and generate reports. - Collect supplier information about possible obsolescence matters.	- Assess collected data and risk. - Compare current status against expected performance and key attributes. - Prepare assessment report highlighting any deviations and risks and anchor the result with relevant parts of the organisation. - Report results from assessment to plant/system owner.	- Identify necessary mitigation measures based on evaluation. - Develop action plans for implementing mitigation measures. - Summarise and present decision proposal for management.
<i>Input</i>	Plant design documentation, system descriptions, safety analysis reports, historical performance data, equipment data from supplier.	Material properties, environmental conditions, operational history, industry guidelines, research studies.	Sensor data, inspection reports, maintenance records, operational logs, supplier info about equipment.	Collected monitoring data, performance benchmarks, degradation models, expert assessments.	Evaluation reports, risk assessments, industry best practices, supplier recommendations.

3.1 SCOPING OF COMPONENTS

The purpose of the first process step is to define the scope of the components to be part of the AMP and to group the I&C components to relevant group-AMP:s. In this report the focus is safety classified- and safety related I&C systems, but it is possible to broaden the scoping to include all I&C systems if needed.

The first action is to define criteria for which functions to include in the AMP. All safety related functions should be included but there may be additional functions that is of importance for e.g. reliable operation that also should be within the scope.

The next action is to identify all I&C components that are part of the functions within the scope. This is done based on information in the SAR and other plant documentation, and by plant walkdowns. Components to include are:

- a) components needed to fulfil fundamental safety functions,
- b) components whose failure may prevent other SSC:s that are important to safety from fulfilling their functions,
- c) components credited in deterministic and probabilistic safety analyses as performing functions that is intended to cope with certain events.

All components should be noted in the plant register, or any other suitable register, as part of the ageing management program. Inventory of stock of spare parts shall also be performed at this stage.

When all components are identified and noted to be a part of the AMP they should be grouped. This step allows for a more effective and structured supervision of the components as it may be easier to direct mitigating measures to components with similar degradation mechanism, to facilitate bulk procurement of spare parts or lowering cost due to reduced need to inspect every individual component. The grouping may be performed with different approaches and there is no golden rule. Some examples of approaches are:

- Ageing mechanisms – grouping based on primary degradation processes affecting the component, e.g. thermal ageing, radiation-induced degradation, corrosion.
- Functional role in the system – grouping based on the function of the component, e.g. safety-related, control regulation, monitoring and diagnostic.
- Environmental conditions – grouping based on exposure to environmental stresses, e.g. high temperature, high radiation, operational stresses.
- Lifespan and replacement strategy – grouping based on expected operational lifetime and replacement schedules, e.g. short-, mid- and long-lifespan.
- Technology type – grouping based on technological factors, e.g. analogue vs. programmable, software vs hardware based, vendor and manufacturer dependencies.

- Maintenance and inspection requirements – grouping based on maintenance schedules and inspections needs, e.g. components requiring frequent testing, periodic maintenance, on-condition maintenance.

The output from the scoping process step is a list of all components to be included in the AMP, divided into groups that will get its own group-AMP. The components to include is tagged in the plant register.

3.2 DEVELOPMENT OF AMP:S

The purpose of the second process step is to define necessary monitoring activities and mitigating measures.

The first step is to, for each of the component on the list from the scoping, identify the degradation mechanisms and ageing effects, and the expected lifespan. Input to this step is supplier information about the components, the IGALL database and experiences from operation and maintenance. Here, dismantling of components to determine its constituents and materials, as well as accelerated ageing may be helpful if there is lack of supplier information.

When the ageing mechanisms are identified, key attributes and acceptance criteria for the components is to be determined. The key attributes are used to monitor the performance and to determine the state of the component. The acceptance criteria is the acceptable level of performance or degradation of the component before any acute action is necessary. It is important to recognise that performance may not always be a good indicator of ageing, but instead e.g. heat exchange, cracking, corrosion. Key parameters on obsolescence, e.g. availability of spare parts and expected lifespan shall also be identified.

The third step is to define and implement activities for monitoring the key attributes, and mitigation measures to prevent unnecessary stresses of the components. Operational and maintenance experiences is key as well as external experiences, e.g. from the IGALL database and industry guidelines. This may result in new instructions and procedures for the operational and maintenance teams of the NPPs.

Two approaches can serve as guidelines for maintenance; preventive maintenance (PM) and run-to-maintenance (RTM). PM is for components that cannot failure and consists of good monitoring and maintenance as soon as the acceptance criteria is exceeded. If monitoring is too complex or not possible, the component is subject for regularly replacement. The acceptance levels are lower, i.e. lower tolerance level for failures, than for other components. RTM is for components that is not directly crucial for safety, e.g. has redundancy or where failure do not directly lead to any safety related issues. It is monitored but maintenance is only performed after acceptance criteria is exceeded and after components of higher prioritization is maintained. Acceptance levels are higher than for PM components.

The output will be ageing management programs for each group from the scoping, group-AMP:s.

3.3 MONITORING AND DATA COLLECTION

The purpose of the third process step is to gather data of the component's key attributes.

During this step data is collected on the key attributes defined in the previous process step to monitor the performance and state of the components. Data collection methods differ depending on component and what key attributes is being monitored. For some components there may be some sort of self-diagnostic function and more advanced data collection, while some components are limited to e.g. visual inspections. Obsolescence key parameters are monitored based on spare part availability and supplier information concerning expected availability of spare parts and support timeframe.

The data is registered and stored and used to perform trending and statistical analyses of the component's status, to be able to perform renewed lifespan assessments and plan maintenance and potentially mitigating measures.

The output is updated data for the components in the AMP.

3.4 ASSESSMENT OF STATUS

The purpose of the fourth process step is to determine the status of the components and possible risks.

At this step, data from the previous step is used to assess the status of the components. The key attributes are compared to the expected values to highlight any deviations. Risk assessment is performed for possible deviations and unexpected degradation or loss of performance. Data on the key parameters for obsolescence are reviewed and analysed, e.g. changes in the timeframe for support or production of spare parts. Analyses are reviewed e.g. by system specialists or other staff with knowledge of the component. The analyses are used as input to an assessment report of the status that is going to be delivered to the system or plant owner, as a basis for development of mitigation measures or replacement.

The history of each component is preserved, and the latest analyses is appended to the component's documentation index. The assessment reports take current state presents current state and makes an assessment based on current state and historic data.

The output is the assessment reports.

3.5 DEVELOPMENT OF MEASURES

The purpose of the fifth process step is to address measures to manage ageing and obsolescence.

At this process step necessary mitigation measures are identified, based on the assessment report. Depending on the severity of the degradation and the prioritization of components, proposals on actions is developed. There may be several alternative actions, e.g. improved environmental conditions or increased surveillance of key attributes.

Assessment reports for all components are considered and the proposed actions is a balance of all components and their respective risks. The results from the deliberation are action plans and implementation schedules for actions and mitigation measures. For measures of greater extend, e.g. that needs funding other than ordinary operating and maintenance financing, that need qualification of components, or redesign of system, the output is a decision proposal to management and system owner. The proposal may include cause of action, the risks if no action, possible alternative actions as well as impact on other systems and plant safety.

Preferably a decision proposal template is developed that addresses all necessary information for a decision to ease the process and avoid important actions being overlooked due to lack of information.

The output is action plans and implementation, or decision proposals for actions.

3.6 REVIEW OF AGEING MANAGEMENT PROGRAM

The ageing management should be subject to continuous evaluation to enable adaptations and improvements. The staff function responsible for ageing management should evaluate if the ageing management process is appropriate and that the result is safe and reliable operation of the NPP, without issues due to ageing and obsolescence. The review should address the following questions:

1. Is the scoping capturing all safety related I&C components? Are there components in the AMP that in fact not should be covered? Is the grouping of component appropriate? Are all spare parts included?
2. Are all degradation mechanisms and ageing effects covered? Have the environmental conditions or other conditions changed that may affect the degradation?
3. Is the obsolescence management system continuously maintained and updated? Are there continuously dialogues with suppliers about obsolescence? Is software still supported?
4. Have the mitigating measures been implemented appropriately and are they effective?
5. Are the key parameters capturing the ageing? Are there any more suitable key parameters? Is the monitoring and trending useful?
6. Are the acceptance criteria reasonable or is there a need for adjustments?
7. Are operating and maintenance experiences collected and used as input to the development of group-AMP:s and mitigating measures?
8. Are there enough allocated resources to perform the ageing and obsolescence management?

4 Conclusions and recommendations

4.1 CONCLUSIONS

One of the objectives of this study was to identify applicable guidelines and literature on the topic of ageing and obsolescence management of I&C components. There are a lot of literature and guidelines available, produced by IAEA, IEEE and EPRI amongst others. The IAEA guideline SSG-48 serves as the main standard for ageing management programs at the Nordic NPP:s. The literature presented in Appendix A: Recommended reading offers both guidance in strategic matters, e.g. how to design AMP, organization and follow-ups, as well as in technical matters, e.g. monitoring and analysing techniques, examples of degradation mechanisms and data on ageing for different materials. The available literature in combination with forums for NPP:s to exchange experiences provides good conditions for an effective AMP.

It is important to integrate the proposed ageing management process into existing processes and component life cycles to enable a continuous process. By doing so, the status information of the plant is always up to date and ensures optimal conditions for safe and reliable operation.

Based on the literature and interviews with the Nordic NPP:s, some aspects of ageing and obsolescence management are worth extra consideration. Grouping of I&C components facilitates the identification of degradation mechanisms and development of mitigating measures. The grouping may be performed with different approaches, depending on what synergies are preferred.

Another aspect of importance is to establish a good dialogue with the suppliers. This facilitates the obsolescence management since obsolescence often is due to factors that the supplier may affect, e.g. timeframe for support, designed expected lifespan and production of spare parts. It is also of interest to have a dialogue about technical details of components during procurement to be able to get as much information as possible as input to the development of group-AMP:s.

There are some challenges specific to ageing management of I&C components. New I&C components have significantly shorter expected lifespan, both physical and functional than older components. Programmable components often include software which needs continued support to be secure and functional. The transition from analogue to programmable I&C technology also presents structural and strategic challenges, as programmable systems shift control from object-bound components to integrated solutions managing multiple functions. This complexity impacts planning and replacement strategies during modernization efforts.

4.2 RECOMMENDATIONS

It is recommended that the proposed process for ageing management of I&C is integrated in the existing plant management and development processes and routines to ensure optimal conditions for effective ageing management and

continuous improvements. It is important that it is not an isolated, parallel process, but integrated in the everyday work.

The dialogue with the supplier has been raised by all interviewees as important in the management of ageing and especially obsolescence. A dialogue in other matters is certainly already in place at the NPP:s but it is important to introduce the topic of ageing and obsolescence in these conversations. Both the continuous dialogue but also during procurement.

Grouping of I&C components as part of the development of AMP:s facilitates more efficient management of ageing and obsolescence due to synergies within groups. It allows for more standardised monitoring and mitigating measures.

Supplier and product family rationalisation strategies may help to keep the number of supplier and commodity groups down. This will help to maintain a high level of competence within the plant and ease the ageing and obsolescence management when introducing new components.

When procuring new I&C components it is important to take ageing and obsolescence aspects into account. Reassure to get information about the components constituents and materials, expected lifespan, possible degradation effects and contract timeframes for spare part availability and software support. This facilitates the development of AMP and management of obsolescence.

It may be beneficial to extend the possibilities to determine expected lifespan for components where this is unknown, e.g. by performing accelerated ageing or dismantle equipment whose constituents are unknown. This can be performed inhouse or by procuring the service e.g. by research institutes or external laboratories.

It has been raised by interviewees that extended cooperation on this topic would be beneficial. It is recommended to participate in conferences and other forums where these topics are discussed and utilise existing cooperations. Introduce new cooperations when necessary and utilise the available literature and guidelines.

For the implementation of this process, it is recommended to perform a workshop-like activity with multiple NPP:s together or with each NPP individually. Attendants with varying roles, e.g. system owners, experts in maintenance and strategy managers, are important for a proper integration into existing plant processes. A session with multiple NPP:s would allow for a discussion about the integration on a conceptual level and be an opportunity for exchange of experiences on how to perform efficient ageing management, while separate sessions would allow more in detail discussions on how to perform an adequate integration of the process into the existing plant management and development processes and routines .

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Appendix A: Recommended reading

Below is a list of recommended reading material that provide further details on topics covered in the report, as well as other relevant information that may be useful for ageing management of I&C equipment.

- a. **Handbook on Ageing Management for Nuclear power Plants** (IAEA 2017)
 - A technical report which serves as a general reference report on nuclear power plant ageing, covering topics such as material degradation mechanisms and ageing management techniques. It covers ageing management processes and techniques that can be used to mitigate ageing effects. Some topics covered are:
 - Proactive Ageing Management
 - Degradation and its Mitigation in SSCs
 - Regulatory Frameworks on Ageing Management.
- b. **Management of Ageing and Obsolescence of Instrumentation and Control Systems and Equipment in Nuclear Power Plants and Related Facilities Through Modernization** (IAEA 2022)
 - This IAEA publication offers a comprehensive guide to managing the aging and obsolescence of instrumentation and control systems within nuclear power plants, advocating for modernization as a key strategy. It explores various aspects, including identifying degradation mechanisms, obsolescence management processes, and different modernization approaches like replacement, reverse engineering, and digital upgrades. Some topics covered are:
 - Strategies for I&C System Modernization
 - Methods and Techniques to Identify Ageing
 - Case Studies from NPPs.
- c. **Ageing Management and Development of a Programme for Long Term Operation of Nuclear power Plants** (IAEA 2018)
 - An IAEA Specific Safety Guide serving as a guide on how to design, implement and improving an ageing management program and how the organisation may look like. The guide focuses mainly on managing the physical ageing of SSCs. It also provides recommendations on safety aspects of managing technological obsolescence and recommendations on the programme for safe long-term operation of nuclear power plants with emphasis on ageing management related activities. Some topics covered are:
 - Organizational Arrangements
 - Ageing Management Review
 - Management of Technological Obsolescence

- d. **Management of Ageing of I&C Equipment in Nuclear Power Plants (IAEA 2000)**
 - This IAEA TECDOC is solely concerned with the ageing management of I&C systems. It draws together experiences from various nuclear utilities across the world, examining ageing of specific components and ageing management techniques. It presents a suggested ageing management strategy, and several practical steps are suggested. Some topics covered are:
 - Past and Present Efforts in I&C Ageing and Ageing Management
 - Ageing Effects and its Consequences for Sensors, Electronics, Relays and Cables
 - Maintenance, Testing and Surveillance Strategies
- e. **Equipment Reliability (WANO 2018)**
 - This guideline provides guidance on how to maintain equipment reliability by presenting a process and process steps. Each process step consists of a short description followed by a bullet list with hands-on action. The guide is extensive and offers a good starting point when designing a process for management of equipment. Some topics covered are:
 - Scoping and Identification of Critical Components
 - Performance Monitoring
 - Continuing Equipment Reliability Improvement
- f. **Guidance for Aging Management of instrumentation and Control (I&C) Circuit Cards and Components Based on Électricité de France (EDF) Experience (EPRI 2010)**
 - This report deals with good practices recommended by EDF R&D concerning the maintenance of printed circuit boards used in nuclear power plants. The report also discusses ideas to mitigate stressors that may affect the remaining lifetime of printed circuit boards. Data and experiences come from observations of a few thousand failed and abnormal circuit cards and components from EDF fleets of 50 nuclear power plants. The reports offer lots of in-detail pictures of components and damages. Some topics covered are:
 - Inspection Approaches for Printed Circuit Boards
 - Criticality of Components and Preventive Maintenance
 - Mitigation of External Factors
- g. **IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Electrical Equipment Used in Nuclear power Generating Stations and Other Nuclear Facilities (IEEE 2014)**
 - This guide provides guidance on assessing and monitoring ageing effects in electrical equipment used in nuclear power plants and other nuclear facilities. It offers a structured framework for conducting ageing assessments and developing and implementing ageing management programs to ensure the continued reliability and safety of these systems. The guide also appends literature, e.g.

“Aging effect tables”, “Conditioning monitoring techniques” and “Examples of practical applications of aging methodologies”.

Some topics covered are:

- Principles of Ageing Assessment
- Monitoring and Mitigating Aging Degradation
- Data

h. Collected Field Data on Electronic Part Failures and Guidelines for the Monitoring of Aging of Instrumentation and Control (I&C) Electronic Components (EPRI 2012)

- This report provides information about ageing mechanisms for electronic boards and components, as well as defining tools and methods to measure aging indicators on electronic parts. The objectives of the report are to increase knowledge about ageing mechanisms of electronic components in non-harsh environments, and to define generic methods for monitoring ageing electronic boards and components by identifying tools and methods that measure aging indicators on a representative sample of electronic parts. The report presents multiple hands-on examples, pictures of aged components and methods for calculating ageing. Some topics covered are:
 - Aging Mechanisms and Indicators, Tools to Assess Aging Level of Components
 - Environmental Conditions Found in a Nuclear Power Plant
 - Guide for Monitoring of Aging

i. I&C Modernization: Current Status and Difficulties (WNA 2020)

- This report presents different reasons for modernization of I&C systems and components as well as different approaches for replacements. It states pros and cons with the different methods. Further it presents I&C modernization challenges. It also offers a generic approach for I&C modernization. Some topics covered are:
 - Guidelines, Codes and Standards for I&C Modernization
 - Scope of Modernization
 - Causes of Modernization Difficulties

PROCESS FOR MANAGING AGEING OF I&C EQUIPMENT

The Instrumentation & Control (I&C) systems can be regarded as the nerves and brain of a nuclear power plant. Thus, effective processes for management of I&C ageing and obsolescence are crucial for maintaining safe and reliable operation of nuclear power plants over time.

In this project a generic process for ageing and obsolescence management of I&C equipment was developed, based on existing guidelines and interviews with the Nordic NPPs. The suggested process can be used when developing AMPs of I&C or to improve existing processes.

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