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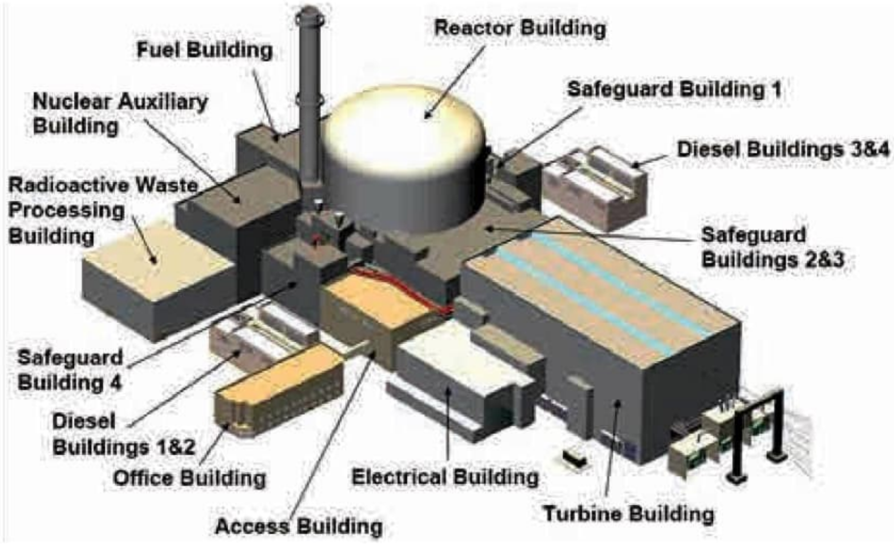

From Ageing Management to Long-Term Operations - Overview of Future NPP Needs

Authors: Elina Paukku

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Summary

The ageing management of systems, structures, and components in Finnish nuclear facilities is in a new stage due to fact that most of the facilities are near the end of their design service lifetime. The service lifetime of the oldest plants is wanted to carry on. This report is a review of that literature, how the ageing management, or the process of it, is described in the literature, when transferred into long-term operations stage. At the same, some key knowledge gaps or lacks in practices were found out. During the design and construction periods of the oldest plants, existing concrete codes did not cover explicitly the deterioration of concrete structures or their ageing management.

The ageing management of structures, materials, or technical systems means those different actions, which are needed for preparing oneself for changes in the functionality of structures, systems, and components, and the control of those during their service lifetime. The process typically contains the monitoring of structures and systems, and the programming of repair actions so that the safety and functionality can be maintained, and after that those can be either repaired, or renovated, or decommissioned in a controlled way. When discussing about ageing management, that is also a discussion regarding details in design of a new build, the quality of work execution on site, inspections and investigations of structures in-service, and correctly timed maintenance and repair actions. The long-term operations (LTO) of nuclear facilities means that extended time which can be given for structures, systems, and components after their original service lifetime has fulfilled. This provides lots of different type of inspection, research, verification, maintenance, and repair actions to ensure and guarantee the safe and undisturbed use of systems, structures, and components. LTO is strongly connected to ageing management.

A questionary was developed and send to the personnel responsible of maintenance of Finnish nuclear facilities. One of the key development issues in ageing management and LTO is the huge amount of different data and the management or control of it. There is no uniform data collection system. The questionary brought out wishes regarding the needs to increase the deeper knowledge and understanding in concrete deterioration mechanisms and acceptance criteria of those, which could be possible to develop further. One key challenge regarding the repair actions is the effect of deterioration degree on the repairability or the selection of the repair method. Evaluation of this is also related to acceptance criteria. Both the concrete industry, and the nuclear industry in Finland are well networked and cooperative both domestic and internationally, so there are plenty of possibilities in development work.

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Espoo 16.4.2024 **Written by** Elina Paukku Senior Scientist	**Reviewed by** Miguel Ferreira Team Leader

VTT's contact address
Kemistintie 3, 02150 Espoo

Distribution (customer and VTT)

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Approval

VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

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Preface

This publication is part of the first phase of National Nuclear Safety and Nuclear Waste research program SAFER 2028 / FN-CAMP (Finnish Nuclear Concrete Ageing Management Project). A questionnaire and an interview of NPP personnel involved in ageing management, were part of this work package. Based on those, some development proposals are presented in the end of this report.

The project steering group is SG3 Nuclear Waste and project funding comes from VYR to whom the author(s) will express the compliments.

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Author(s)

List of abbreviations

AM	Ageing management
ASR	Alkali-silica reactions
ISI	In-service inspections
LTO	Long-term operations
NF	Nuclear facilities
NPP	Nuclear power plant
PRA	Probabilistic risk assessment
PSR	Periodic safety review
SSC	Systems, structures, and components
STUK	Radiation and Nuclear Safety Authority

Contents

1. Introduction

Ageing management of structures, systems, and components in Finnish NPPs is in a new stage. Most of the plants in service are at the end of their design service life – only the OL3 and Onkalo SSCs are new, in the beginning of their design service life. Due to good state of older plants, the service life of those is highly wanted to carry on. This will require some actions to guarantee the safety and good functionality of structures, systems, and components in them, when moving towards LTO.

1.1 Background

One key objective of this SAFER 2028 / FN-CAMP (Finnish Nuclear Concrete Ageing Management Project) project, in National Nuclear Safety and Nuclear Waste research program, is to help to identify and estimate the ageing management in relation to damage in concrete structures, which could affect the functionality of those. The other key objective is to define the approvable deterioration degree in line with safety requirements, mostly regarding the ASR damage in structures connected with this project (i.e., containment building and pool liners). The project contains four different work packages (WP1-WP4) according to its research plan [1]. This report contains the WP1 literature survey and questionary/interview results of NPP owners, in relation to ageing management practices and needs in Finnish NPPs.

Among this SAFER 2028 / FN-CAMP project a participation in OECD/NEA project "LTO beyond 60 years" has realized. This project is led by Dutch Nuclear Research and Consultancy Group NRG. The project outcome will be a comprehensive report of LTO and methods in that [2]. The current schedule for publishing this report will be in May 2025.

1.2 Goal

WP1 (Overview of future NPP needs when transitioning from Ageing Management to Long-Term Operations) is supposed to be an overview for those actions and practices, how ageing management – or that management process - are going to be run or transferred to LTO stage. Also, the main knowledge or practices gaps will be detected. This overview concerns mainly the concrete structures, but the idea is easily to apply to any other materials, systems, or components. The goal is to help NPP owners to achieve safe goals in long-term operation.

2. Brief basics of ageing management

The oldest NPPs in Finland are at the age of 44-47 years. During the design and construction period of those, existing concrete codes did not address explicitly the deterioration of concrete structures, nor their ageing management. At that time, the idea of systematic maintenance or repair was not considered. In Finland e.g., the systematic development of condition investigations and assessments begun in the end of 80's, and the first instructions for a basic condition investigation was given about in a middle of 90's. Instead of that, repair instructions of concrete structures were systematically developed in bridge construction from the beginning of 70's, while first comprehensive repair instructions in house building were published in the end of 90's. The requirements for design of service lifetime of concrete structures have been obligatory in Finland since 2005, and the Finnish Concrete Codes were updated according to European standards. This marked the beginning of the idea of ageing management of concrete structures developed in Finland, quite long after the first NPP's have been in service. Luckily, the NPPs in Finland have been able and capable to perform along this idea since the beginning, which has promoted the good ageing management practices of concrete structures. One recognized (generic) approach for ageing management is presented in the figure 1.

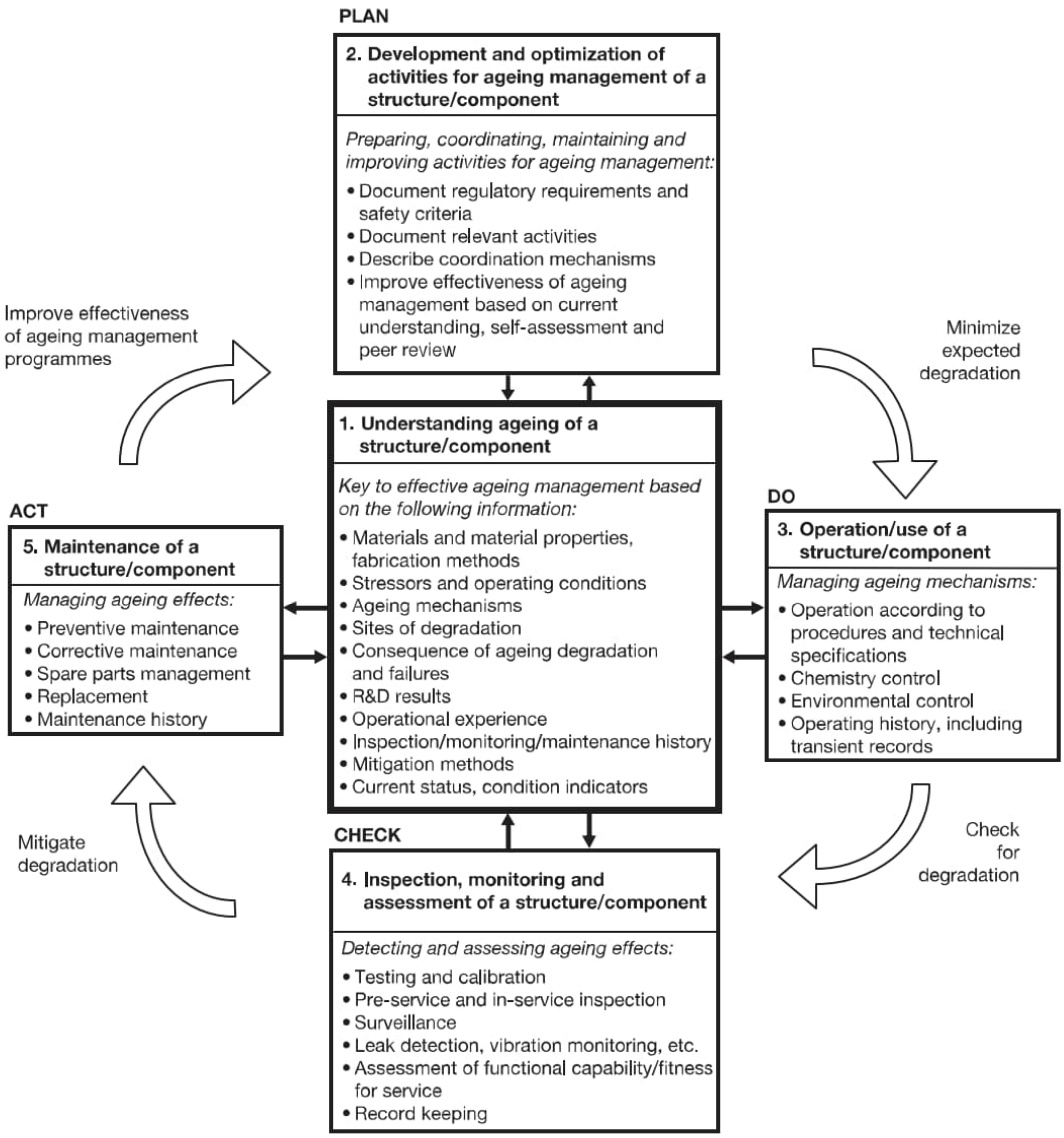


FIG. 1. Systematic approach to managing ageing of a structure or component.

Figure 1. One approach for ageing management according to reference [3].

2.1 Ageing Management (AM) of concrete structures

The ageing management of structures, systems and components means different technical actions, which are needed to provide for changes of deteriorating effects and control of them in different parts of SSC. The ageing management process typically contains the monitoring and programming the maintenance actions of SSCs in a way, that the safety and technical functionality of SSCs' can be maintained. After that, those can be repaired, replaced, or decommissioned in controlled way.

The processing of AM begins already in the design and construction stages of the concrete structures, and it continues during the design service life by maintaining and controlling the structures and systems. The regular monitoring and surveys of SSCs, repair or renovation – in correct timeline and with correct methods in relation to deterioration degree – are part of the ageing management.

When talking about the *life cycle or lifetime* of structures and buildings, means this typically that timeline, which begins from the design of land use and structure, or the purchase of raw materials – and it is ending to demolishing of the structure and the sorting of decommissioning waste. *Service lifetime of structures* typically means the time after commissioning the structure or building, when all the requirements of functionality are still fulfilled, and when the structure or the part of it is maintained and taken care in planned, systematic way, according to the valid instructions. A term *'design working life'* means the service lifetime defined by designer or the owner. The *technical lifetime* of technical systems, or materials and components, means that same. The service lifetime of structures, or the technical lifetime of systems and components, is thus little bit shorter period than the whole period of ageing management timeline – which typically begins already in the design and construction stages, i.e., in a beginning of the life cycle of structure, systems and components.

Several publications [3] - [12] have been written in different countries and organizations related to ageing management of concrete structures – and particularly of NPP structures - and the process descriptions of them. General trend seems to be very small differences between them – if the differences exist at all.

When talking about the ageing management of structures, the discussion is related to details in design of a newbuild, as well as the quality of construction site execution, or inspections and investigations in-service, or maintenance and repair actions carried out on correct time and in correct level.

2.2 Regulations and instructions in Finland regarding the ageing management for concrete structures.

Ageing management of concrete or concrete structure is not explicitly mentioned in design standards or construction instructions. Standards and other instructions contain many requirements affecting directly on load bearing capacity or durability of structures, and thus affecting on the ageing management, longevity, and long-term operations of structures. Generic ageing management is however considered in international guidelines for NPPs and nuclear facilities, e.g., IAEA safety guides, WENRA reference levels [13], KTA 1403 [14], etc.

Radiation and nuclear safety authority (STUK) regulation on the safety of a nuclear power plant includes requirements for ageing management and condition monitoring and maintenance to ensure the safety of the facility. Fulfillment of the above-mentioned sections are reviewed periodically (PSR) or when operation license is renewed. Finnish regulation does not include specific LTO requirements, but description of the facilities' ageing and ageing management concerning the operating license period applied or remaining for the facility shall be submitted to STUK for periodic safety assessment. LTO demands are assessed in PSR, during continuous oversight activities and through corresponding research. Safety requirements and applicability of new technology or research shall be periodically assessed.

Finnish general instruction for ageing management of concrete structures is the Regulatory Guides on nuclear safety and security YVL A.8 'Ageing management of a nuclear facility [15]. This is a comprehensive description of the requirements in ageing management processes and control actions of authorities when execution of this guide is followed. That guide obliges the NF owners to compile a plan of ageing management. Also, the basic ageing mechanisms of structures and components are described in the appendix A of this guide. E.g., the publication of Finnish Concrete Association, BY68, is dealing with durability design of concrete structures ('Selection of concrete mix type and design of service lifetime – Guide for designers, 2024'). This guidebook is not discussing about ageing management itself, but the longevity and service lifetime is managed only from the durability properties point of view. The Swedish Energiforsk publication [16] deals with the acceptance criteria presented in different instructions, and according to deterioration mechanisms.

2.2.1 Design and construction periods of concrete structures

Standards related to design of concrete constructions (i.e., standard series SFS-EN 1990-, 1991- and 1992) have presented requirements for load bearing capacity and durability properties, cover concrete, and e.g., allowed crack widths of concrete structures. The standards regarding concrete material (SFS-EN 206 and its national annex SFS 7022) are presenting requirements for concrete mix composition and the components of it, in relation to different durability or functionality properties of concrete. Standards related to construction work and site execution of concrete structures (SFS-EN 13670 and its national annex SFS 5975) are presenting the requirements e.g., for concrete handling on site like compaction and curing. All the above-mentioned requirements or actions have straight effect on the ageing management of concrete or concrete structures, via the given valid durability instructions. The Regulatory Guides on nuclear safety and security YVL E.6 'Buildings and structures of a nuclear facility' [17] present the standard for safety requirements for design, construction, commissioning, and later inspections, which contains the idea of high-quality result in safety significant structure, also from the ageing management and LTO point of view – even though YVL E.6 does not unequivocally mention words "ageing management" or "LTO", the guide includes requirements for in-service inspection programs, maintenance and monitoring of structures and also references YVL A.8 (ageing management of nuclear facilities).

The design and construction stage of structures contain a lot of details, where designers or contractors can affect straight to ageing management of those structures. This type of details is e.g., design and construction of drainage, general forming of structures (so that water is not accumulating anywhere), or design and construction of all inaccessible structures, especially the surfaces of them. Detailed instructions maybe are not given comprehensively (or the requirements are moderate), but they have significant effect on durability and ageing management if the execution on site is most correct (and requirements maybe are on one-degree higher level). YVL guides require that safety significant structures such as fuel pools and reactor containment, can be inspected (accessible), monitored and repaired if necessary.

2.2.2 In-Service inspections and investigations of concrete structures

Standards related to concrete material and concrete construction are not presenting any requirements for in-service inspections or investigations. The only guidance for these is given in RT-register (instructions for surveys in different type of real estate), in the publications of Finnish Transport Agency (inspection instructions and handbooks for bridges and other infrastructures), and in the publication of Finnish Concrete Association BY42 (instructions for condition investigation of concrete façade structures). Even though these instructions and guides are mainly directed to different type of houses, bridges, and other infrastructures, those can be applied also for inspections, surveys, and investigations of concrete structures in nuclear facilities.

Guide YVL E.6 includes requirements for in-service inspection programs, maintenance, and monitoring of structures. It also refers to YVL A.8 (ageing management of nuclear facilities). Licensees shall develop nuclear facility specific ISI programs and corresponding detailed instructions for preventing adverse ageing and for early detection of the need for repair and modification. The guide YVL E.6 [17], chapter 9 (Inspections of civil structures) is presenting some requirements for inspections during construction and commissioning periods, as well as for performing of in-service inspections. This guide demands the nuclear facilities to have inspection plans for scheduled inspections. E.g., for those testing organisations, who are performing non-destructive (NDT/NDE) testing, or laboratory testing for condition investigations, there are some requirements in the Regulatory Guides on nuclear safety and security YVL E.12 'Testing organisations for mechanical components and structures of a nuclear facility' [18]. By these instructions, it is possible to ensure the compliance of different testing methods. On civil engineering industry, the requirements for personal competences/certificates are given in Finland, for many different work tasks – e.g., separately for persons performing surveys (= non-destructive inspection of structures) and investigations (= destructive inspections and study of structures). There are specific requirements for persons performing condition investigations of concrete structures. This competence/certificate requirement is not based in law (unlike the designers' competences/certificate requirements are), but this competence/certificate is so-called need-based competence/certificate. Perhaps for this reason, the requirements are not presented in the Regulatory Guides on nuclear safety and security. Corresponding STUK requirements for persons in charge of design and construction are based on Finnish building code. Licensees can justify competence using e.g., FISE qualifications. In general, licensee shall have enough qualified personnel and instructions for e.g., NDT/NDE testing of concrete structures.

Due to inspection plan requirement (presented in the Regulatory Guides on nuclear safety and security), the concrete structures in Finnish nuclear facilities in-service have been inspected already since long ago. The general instructions for condition investigations (BY42) are presenting, that first destructive investigation of concrete structures should be perform at the age of 15 years, then continuing at least every 10 years, depending on the structures and exposures. This is well understood in NPPs, and the structures in older plants are inspected and investigated regularly. Only few concrete properties, or the contents of harmful matters in concrete have accurate numerical limit values or acceptance criteria. E.g., concrete crack mapping during and after containment leak-tightness and pressure tests, and corresponding global behaviour of containment is monitored and measured. Acceptable behaviour can be assessed in relation to design values. In general, cracks in concrete structures are measured, and significance assessed during in-service inspections. Related instructions are directing the repair actions (mainly injections) when allowed crack widths are exceeded, or damage reduces the structural performance. Thus, the analysis of the investigation and inspection results, as well as the given action recommendations, are depending on the professional competence investigator (or inspector). This may also have some significant influence on the programming and performing of ageing management.

2.2.3 Maintenance and repair actions

Standards related to repair and protection of concrete structures (series SFS-EN 1504, parts 1-10), and other repair instructions (e.g., BY 41 – 'Betonirakenteiden korjausohjeet' / 'Repair instructions of concrete structures' and all SILKO instructions of Finnish Traffic Agency, Siltojen korjausohjeet (SILKO) - Väylävirasto (vayla.fi)) are not mentioning the ageing management specifically from the repair actions point of view. All these instructions are dealing only different repair methods and the applicability of them in different type of deterioration degrees. Neither the Regulatory Guides on nuclear safety and security are giving any specific instructions for maintenance and repair methods. The Regulatory Guides on nuclear safety and security YVL A.8 [15] is giving general instructions for condition monitoring and maintenance (chapter 7), as well as for modifications (chapter 8). The Regulatory Guides on nuclear safety and security YVL E.6 [17] contain even shorter instructions for use, condition monitoring, maintenance, and in-service inspection plans (chapter 11.9) or for modifications (chapter 11.10).

The correct timing, adequate extent, or technical validity of different maintenance or repair actions can affect significantly on the ageing management of concrete structures. Over-repair, or under-repair of concrete structures is affecting not only the maintenance or repair costs, but also on the remaining service lifetime of the structure. Many of the condition stage estimations of different deterioration mechanisms, or the damage degrees of them, are only qualitative – and in some cases only experimental 'I feel' estimations. For this reason, the professional competence of persons involved in maintenance actions or repair design is affecting on that, how the selection of repair methods and materials is done. This has effect on the result, from the ageing management point of view.

Unlike the requirements for concrete evaluation, there are lots of both quantitative and qualitative quality requirements for performance of maintenance and repair actions, which makes the quality control and assurance quite 'easy' with modification works. Also, the performance of repair work methods is affecting on the durability of the result, and through that also on the ageing management. Typically, badly incorrect work performance is not approved, and then the execution must be repaired according to the approvable level of quality requirements.

3. From ageing management to LTO

In today's world, a significant number of nuclear power plants have reached an age where they require either controlled decommissioning or the renewal of their operational licenses, accompanied by specific actions.

3.1 What means LTO?

The term "Long-Term Operation" (LTO) refers to an extended period granted to structures, systems, and components of nuclear facilities after their original design working lifetime has elapsed. This extension allows for the continued service lifetime of these elements without decommissioning or demolition. It requires many types of inspections, surveys, and investigations as well as confirmation, maintenance, and repair actions so that the safe and disturbance-free use of these SSCs' can be guaranteed. Nuclear facilities can also be decommissioned, when the original design lifetime has fulfilled, in which case the LTO contains a well-planned, slow, and controlled shutdown – in the end of the lifecycle of those structures/facilities. In the last resort, everything is focused on safety and reliable technical functionality, as all the actions in nuclear facilities even during their normal, original service lifetime. In some literal references (e.g., IAEA NP-T 3.5 [4]), the service lifetime has been divided in 'elapsed service life' and 'remaining service life'. The LTO-stage typically begins at some point of this remaining service life, continuing up to the dismantling and demolition of the structures, as presented in the figure 2.

The LTO is still strongly connected to ageing management because the ageing and deterioration, maintenance needs, or occasional repair needs of SSC's are not disappearing anywhere, even though the original design service lifetime of structures has fulfilled. The frequency of periodic inspections should be assessed when service life of a nuclear facility is extended beyond original design life. Only the temporal cycles regarding maintenance and repair actions possibly will change, which is affecting on the actions itself and the monitoring and control of their execution. When decommissioning, the purpose of controlled shutdown is to ensure serious damage or accidents not to happen.

The Finnish older NPPs are looking for continued operation licences, in which case the LTO is focusing to safe, continuous operation (not decommissioning yet).

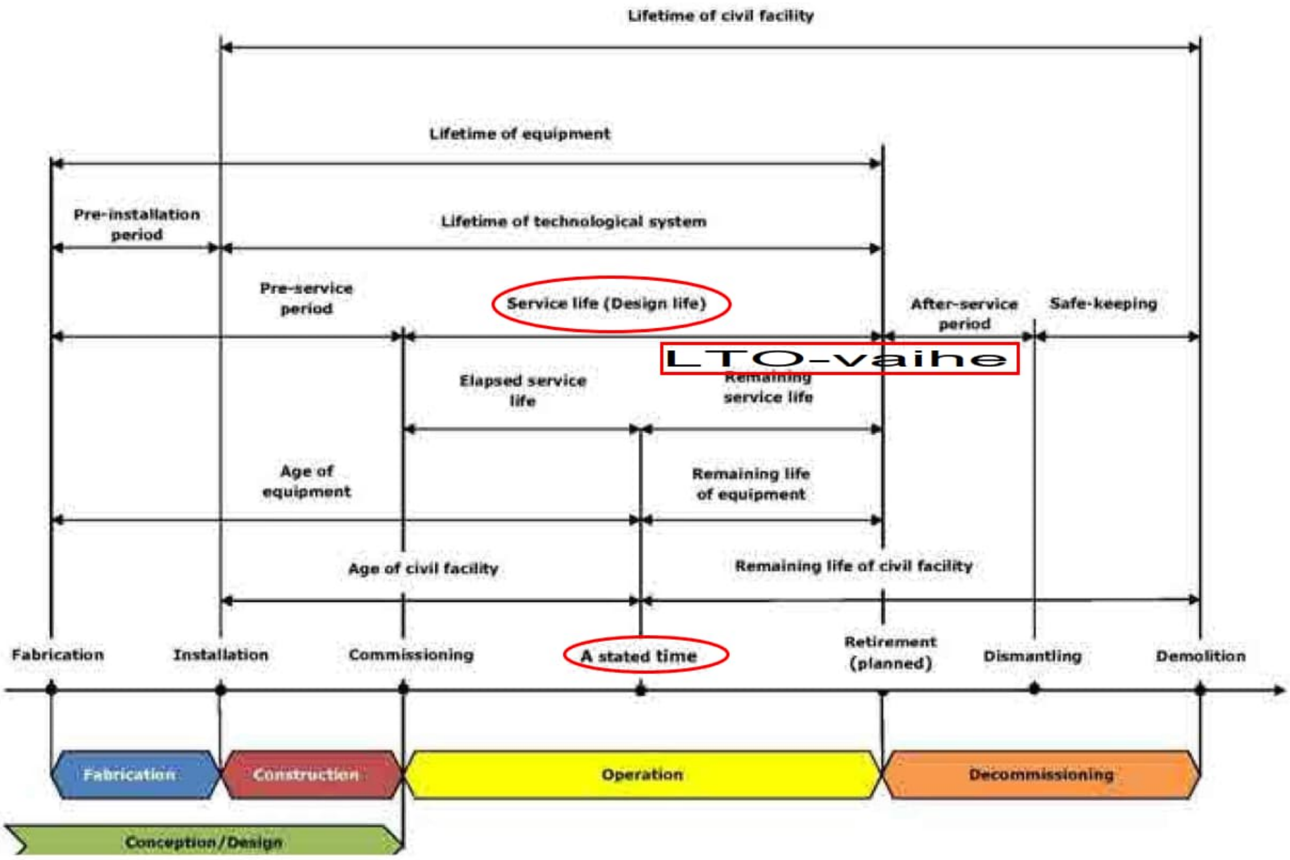


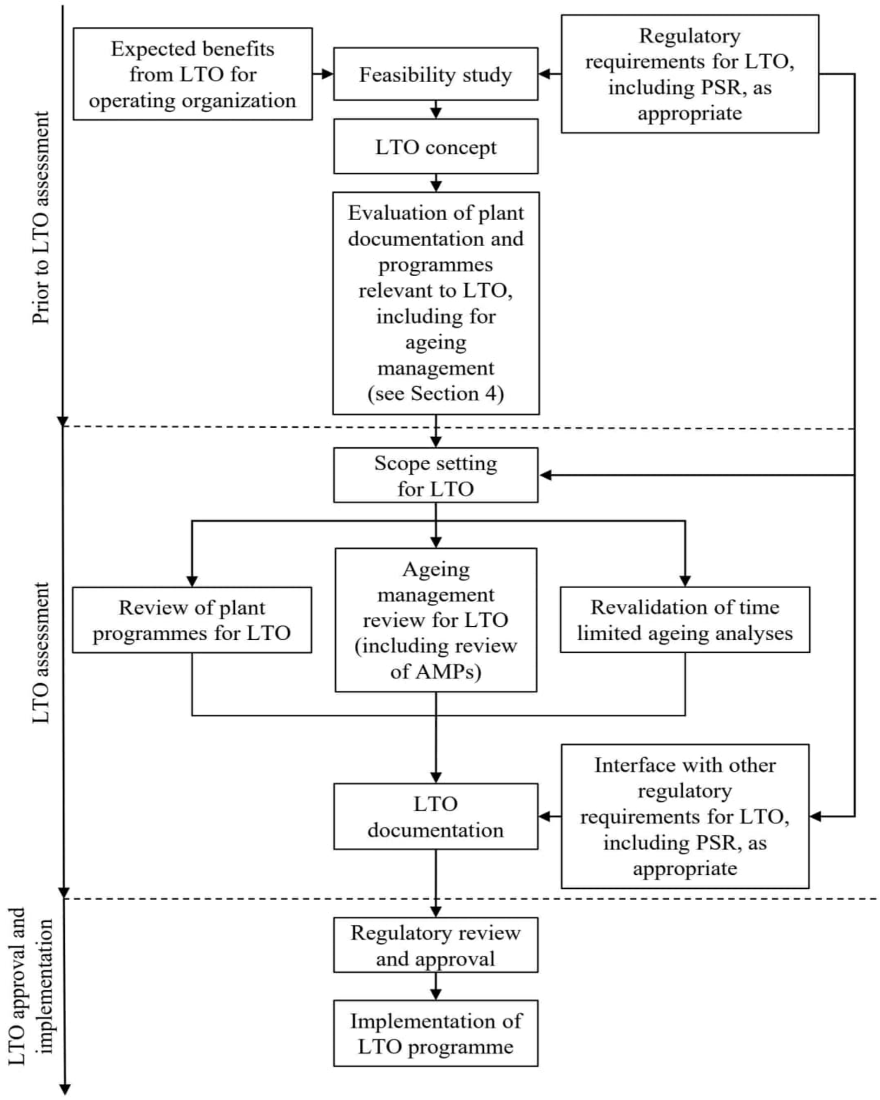
FIG. 2. Visual representation of the terms associated with the lifetime of structures, systems and components [4].

Figure 2. Some terminology related to systems, structures, and components life cycle, according to references [12] and [4]. LTO stage highlighted with red lines, in relation to whole lifetime of SSC.

Ageing management and LTO-stage programming has been discussed most diverse e.g., in references [19, 20, 21]. In these documents, this topic has been presented from the point of view of design, construction period, and service lifetime, by also describing the process itself, and how the goals, criteria, preventing of damage or performance of repair actions should be set. Particularly in the references [20] and [21], the processes in different fields have been described elaborated, while the reference [19] is focusing on descriptions of methods and deterioration mechanisms.

The present type of service life design has been carried out only for the newest nuclear facilities, and the programming of ageing management in older facilities has been possible only by surveying the existing design and material data, as well as all the documentation of construction period of those facilities. Nevertheless, comprehensive data on all aspects is available, facilitating the implementation of aging management programs and LTO processes.

The research point of view focuses on the programming of the Long-Term Operation (LTO) stage within the context of aging management in nuclear facilities. It emphasizes the importance of data collection, goal setting, systematic planning, and documentation of various maintenance actions, inspections, and quality control measures. Key elements include task descriptions, preventative actions, effects of aging, monitoring and development directions, mitigating actions, acceptance criteria, repair actions, feedback from experiments, research, and development (R&D) initiatives, and descriptions of quality control measures. Figure 3 likely illustrates the leading principles guiding LTO programming in this context. The overall aim is to ensure the safe and effective operation of nuclear facilities over an extended period.



Note: AMP — ageing management programme; LTO — long term operation; PSR — periodic safety review.

FIG. 8. Major steps in a programme for long term operation.

Figure 3. Basics of LTO programme, according to reference [20].

3.2 Limitations or obstacles in proceeding towards LTO

The challenges regarding ageing management and LTO-stage are presented in several publications, with different extent, e.g., in references [19, 20, 21, 22]. If there is some lack in the input data (in the design documents, material data, or in the documentation data of installations and construction execution), that is affecting straight on the programming of ageing management and LTO. The resulting documentation of inspections in-service or monitoring data contains typically lots of different type of data. The exploitation of these is depending on the recording methods and systems in use. Inadequate understanding of deterioration mechanisms or ageing phenomena, or e.g., lack in communication, leadership or in safety culture will affect in ageing management and LTO-stage programming. This is particularly discussed in the reference [22].

The ACES publication, reference [19] presents extensively the concrete deterioration mechanisms and the knowledge gaps regarding the measuring and verification of deteriorating, or damage estimation criteria. Most part of those knowledge gaps are related to corrosion of reinforcement and metallic structural materials, or ASR, or irradiation damage of concrete and effects of high operational temperatures. This publication is elaborating the deterioration mechanisms, probably best at the moment. A good checklist regarding deteriorating mechanisms is also presented in the appendix of reference [15].

In addition to the existing discussion, it's important to note that the ageing of fuel pool structures remains an area of incomplete understanding, especially considering that the Long-Term Operation (LTO) phase can extend service lives up to 100 years for these structures. Moreover, changes in concrete containment tendon stresses and relaxation (loss of tendon stress) could present challenges during future LTO phases, underscoring the need for ongoing research and monitoring.

Furthermore, comprehending the effects and quantitative significance of concrete structure ageing/deterioration is crucial for ensuring the protection of Nuclear Power Plants (NPPs) against both internal and external hazards. This understanding is typically assessed using Probabilistic Risk Assessment (PRA) and fragility analysis to ensure structural integrity, emphasizing the importance of ongoing research in this area from a nuclear safety perspective during LTO.

Additionally, ageing mechanisms affecting containment and pool liners should be highlighted as part of reinforced concrete structures, further emphasizing the need for comprehensive research to address ageing-related challenges in nuclear facilities.

4. Experiences and actions in Finnish NPPs

Employees working on Finnish NPPs are highly qualified, and they know and understand well the concrete deterioration, as well as the significance of regular investigation and controlled repair actions, in relation to ageing management and safe functionality of structures. This was the starting point to draw up a questionary to the plant personnel. This questionary was sent to personnel responsible of maintenance/ageing management, and to the radiation safety authorities as well.

Later, after sending the questionary, meetings were arranged and the personnel on both NPP's had possibility to discuss and talk more about issues, which e.g., cause some concern (regarding mainly topics of ageing management and LTO).

4.1 Questionary to Finnish NPP owners

The questionary sheet was MS/Word-based, so the answering was easy also in electrical form. The questionary sheet was divided in three sections: i) The first section was dealing with existing, collected monitoring and investigation data (= initial data); ii) The second section was dealing with programming and planning of different actions and measures related to ageing management; and iii) the third section is dealing with control and execution of maintenance and repair actions related to ageing management of structures. Some of the questions were in a form, where answering was possible only with one word, yes or no, while some of the questions needed little bit longer justifications. The length of the answers was not limited in the questionary sheet, and the answering was anonymous. The questionary sheet is presented in the *appendix 1*.

4.2 Results of the questionary

The documentation of design and construction periods are well archived in Finnish NPPs. The design basics, structural drawings and modifications in them, measurements, and test results from construction period, are archived, but only small amount of them is in electrical form (in practice only newest designs and documents). All the initial data can be found, but not necessarily fast or easily. In general, the number of all type of designs and documentation is significantly bigger in newest facilities, compared to older ones.

A lot of different type of inspection, investigation, and measurement data exist already from older facilities. Most part of that is in electrical form, but the number of data is huge, which makes the searches (of some specific information) quite slow and difficult. A uniform way of records is missing, and even the data collected of same structures but in different time periods, is now located in different files.

All the in-service inspection, monitoring, and maintenance plans have been drawn up in time, and those are updated when necessary. Inspections, monitoring, and investigations are performed regularly in all nuclear plants.

Several different condition investigations in different structures have already carried out for planning the ageing management. There are also lots of structural parts, where destructive investigations are very difficult or even impossible to carry out – these are e.g., many underground or sub-merged structures exposed to seawater or groundwater. In the former, the diving inspections, investigations, and repairs would be justified, but so far those haven't been used in that extent as desirable. In underground structures, difficult to access, the investigations have been carried out in structures nearby, where concrete composition is known to be the same. The state of structural condition has then been evaluated roughly on bases of that.

So far nothing has been found in structures, which wasn't known already beforehand, based on the initial data and documentation. No 'surprises' originated in construction period, have been found – which often is quite common in older ordinary residential, or commercial, or industrial structures and buildings.

Deterioration damage observed in inspections and investigations were as expected, according to the age of structures – no damage was observed 'at wrong age'. In addition to this, some uncommon deterioration mechanisms were observed in structures, where those were not initially expected. For reasons unknown, the utilities and STUK did not open up on specific of the ageing mechanism when questioned.

Research laboratories are doing tests and giving results from those – but they are not analysing what those results mean for the SSC performance. Structural designers usually cannot analyse those test results. There are only few condition investigators or inspectors in Finland, who can analyse the significance and effect of test results on the remaining service lifetime or repair capabilities of structures. Further, regarding the investigation methods, in some recent cases it has been possible to give up the traditional core drill sampling, and instead use NDT-methods. However, there is a known risk: If the NDT expert (tester) or the apparatus used will be changed, that have influence on the interpretation of the results.

The need for deeper knowledge on deterioration mechanisms is constantly growing. Further, the acceptance criteria in relation to some deterioration mechanisms should be more accurate and specified. Also, the effects of some deterioration degrees on repair actions, or on selection of repair methods, should be defined. This is found to be one of the most important challenges in the stage, where planning of repair actions is about to begin.

The present valid instructions and guidance for condition investigations have been found to be adequate, and there is no need for 'NPP specific' investigation guidance. Also, the present valid instructions and guidance for repair actions has been found to be adequate: In any case, the repair works execution must be adjusted according to structures and their environment, which always means very accurate planning of work methods and actions to be used.

The execution of repair actions has shown of some challenges: In many cases, the availability of repair contractors and their professional competence has been good, but at the same time some lack of qualified repair work foremen or concrete foremen has appeared.

5. Conclusions and discussion

In general, the staff responsible of the maintenance on Finnish NPPs is highly motivated and committed to their work: The significance and the effects of deteriorating in concrete material and concrete structures is well understood, and those (structures and systems) are wanted to be maintained well and truly. No special big troubles have been found regarding the maintenance of the structures, but some minor always exist.

Great amount of different type of data, and the control of it is one of the key targets for development: Now there is not any possibility to collect the data into the platform, where all available data could be found quickly, only by few pushes of buttons. Even though the data exist, they are not stored/collected into same location. This requires lots of effort to find the correct data. On the other hand, this is quite understandable, due to huge amount of different type of technical systems, structures, and buildings – as also exist different type of measurable data. To create that type of database, which would contain all required data, in easily findable and connectable form, is a great challenge.

Only the data output from different inspections and investigations is very large, and the amount of those is increasing year by year, from every structure or part of it. Compilation of these into common database would be very important – but again very laborious. The results of those (inspections and investigations) contain also great amount of purely different type of statistical data, for which reason the creation of appropriate format is not very simple, due to great number of different factors affecting on the data.

The questionnaire included a query regarding the assessment of the professional competence of experts involved in Nuclear Power Plants (NPPs), such as condition investigators, repair designers, and structural designers, as well as potential changes in their skill levels. The rationale behind this inquiry stemmed from ongoing concerns, particularly within the structural design field, regarding a noticeable decline in competency among newly graduated engineers, even in fundamental professional matters. This trend has unfortunately been observed in educational institutions as well. However, the absence of any mention of this issue in the questionnaire suggests that assignments related to NPPs are likely being handled by the most experienced staff of engineering companies, particularly those with a background in civil engineering.

Conversely, the questionnaire revealed shortcomings in the reporting of various types of testing and research results. The analysis and interpretation of findings do not consistently meet the expectations of clients. Reports often fail to clarify the significance of results or their implications, indicating either a lack of in-depth knowledge and understanding or deficiencies in reporting methods. While it may be challenging to influence the academic curriculum of universities and colleges, companies and research organizations involved in NPP-related topics should recognize the need for additional education or enhancements to their operational processes to address these deficiencies effectively.

In reference to the preceding section, the technical expertise of engineers has become increasingly specialized, with individuals delving deeper into narrower areas of expertise. For example, designers of concrete structures may lack familiarity with the design principles of steel structures, and vice versa. Similarly, structural designers may not possess in-depth knowledge of the material properties of concrete or metallic materials. This specialization can lead to challenges if the holistic perspective is not adequately maintained, or if the cause-and-effect relationships are not properly interpreted. Addressing these challenges may be facilitated through targeted supplementary professional education.

Furthermore, the questionnaire highlighted a desire to enhance deeper knowledge and understanding of concrete deterioration mechanisms. Research in this field is ongoing worldwide, with a focus on increasingly nuanced details of various phenomena. However, a significant portion of this research is published in refereed articles that are not universally accessible. There is a growing demand for open access publications, which are freely available to all. Additionally, most articles are published in English, hindering the dissemination of knowledge. Given that individuals find it easier and faster to study in their native language, efforts should be made to increase the dissemination of research results in Finnish (or in Swedish) as well. This could be achieved through increased dedicated educational events or by writing and publishing more content in domestic languages, whether in domestic publications or guidance textbooks. Anyway, the NPP owners in Finland are active in international cooperation regarding the ageing management and LTO of SSCs' in NPPs.

The questionnaire also brought out some lack of acceptance criteria. It is not possible e.g., to give numerical acceptance criteria for all of deterioration mechanisms of concrete. Evaluation of the proceeding of degradation is quite often based only on qualitative values, because the number of samplings is way too small for quantitative evaluation – or the computational methods are just too expensive. Regarding the condition investigations and surveys, and the instructions related to those in Finland, for those concrete deterioration mechanism, where numerical acceptance criteria are possible, that already has given. However, there could be a change to develop several qualitative criteria for some parts – now e.g., the degree of damage related to ASR (according to Finnish guidance) is evaluated on tri-stepped scale V0-V2. Similar evaluation method could be needed e.g., to evaluate the degree of freeze-thaw damage, or some damage regarding the dissolution/leaching of concrete binders e.g., in chemical or sulphate exposures.

According to the questionnaire, one key challenge regarding repair actions of concrete is the effect of different damage degrees on repairability or selection of repair methods of concrete. Evaluation of this is related also to previous text section and this can be developed and specified further. Now perhaps only the experience and knowledge of repair designer is defining the method selection, which causes a risk for 'over-repair' and 'under-repair'. In long term, both options (over and under repair) may cause more expensive costs to the owner as was intended.

One concern brought out in the questionary was the occasional poor availability of professionally competent concrete foremen and repair works foremen on construction and repair sites lately. This observation is correct: This lack of foremen has been noticed also in the 'ordinary' construction industry, among several construction companies during the past years of very busy construction boom.

The major concerns or knowledge gaps brought out in the questionnaire seems to be issues or a whole complex of issues, for which, in general, there exists measures to resolve them, but those measures are not fast to execute (e.g., a uniform platform for different databases 'discussing' together). Also, some of those measures creates a need for cooperation with concrete industry (e.g., publications or textbooks with domestic languages). There are plenty of potential for different type of development work, if putting forward in the correct context.

6. Summary

The ageing management of Finnish nuclear facilities – of their systems, structures, and components – is in a new stage, when most of the plants in service now, are close to their design service lifetime. Anyway, even the older plants are still very well-functioning, which offers a possibility to continue their service lifetime for long term operations. The key objective of SAFER 2028 FN-CAMP (Finnish Nuclear Concrete Ageing Management Project) project is to help identify and evaluate the ageing of concrete structures in relation to the damage in them. The whole project contains four work packages according to its research plan. This report is dealing with the work package 1 (WP1), which contains a brief survey related to the present state of ageing management and needs in that, in the Finnish nuclear facilities. The aim of WP1

(Overview of future NPP needs when transitioning from Ageing Management to Long-Term Operations) is to be a review for those actions and practices, how the ageing management (of structures) – or the management process – will be transferred to long term operations. At the same time, the key knowledge gaps shall be clarified.

The oldest NPPs in service here in Finland are about at age of 44-47 years. During their design and construction periods, no discussion about concrete deteriorating or ageing management existed, not at least in way how we today know and understand it. Since new instructions, developed during the 80's and 90's, the ideas regarding the ageing management could proceed – when the first NPPs' had been service already for several years.

Ageing management involves a series of actions undertaken to anticipate and address the gradual deterioration in the performance and functionality of systems, structures, and components over their intended service life. These actions are designed to ensure that systems, structures, and components continue to meet safety and performance requirements throughout their operational lifespan. Key elements of the ageing management process include ongoing monitoring, assessments, and planning of repair activities for structures and technical systems. This proactive approach enables the timely identification and mitigation of potential issues, ultimately allowing for the preservation of safety and functionality. Additionally, ageing management encompasses considerations related to new construction design, the quality of work execution during construction, routine inspections, and investigations of in-service structures, as well as the implementation of appropriate maintenance and repair measures at optimal intervals.

Long-Term Operation (LTO) of nuclear facilities refers to the prolonged utilization of systems, structures, and components beyond their originally intended design service life. During this extended operational phase, these elements remain in service without decommissioning, necessitating various activities to ensure their continued safe and uninterrupted function. These activities include comprehensive inspections, surveys, research, validation, maintenance, and repair efforts aimed at safeguarding the reliable and secure operation of these components. It's important to note that the LTO stage remains closely intertwined with ageing management practices. Factors such as insufficient understanding of deterioration and ageing processes, as well as deficiencies in communication, leadership, and safety culture, can impact the planning and execution of both ageing management and LTO strategies.

A questionary was drawn up and it was sent to the staff responsible of maintenance (in civil structures) in Finnish nuclear power plants. Later, a meeting was arranged with both NPP representatives.

One of the key development issues in ageing management and LTO is the huge amount of different type data and the control of it. There is no uniform compilation form for it. The questionary brought out some needs for increasing the deeper knowledge and understanding of concrete deteriorating. This could come true e.g., by increasing the educational events, or writing/publishing more with domestic languages. The questionary also brought out the lack in acceptance criteria of some deterioration mechanism. Several qualitative criteria could be possible to develop more accurately. One key challenge regarding the repair actions is the effect of different deterioration degrees on repairability or on the selection of repair methods. Evaluation of this is related also to acceptance criteria, and it can be developed and focused more. Both the concrete industry and nuclear industry in Finland are well networked and cooperative in domestic and international levels, so there is plenty of possibilities for different type of development work. An international document development project regarding LTO is ongoing ("LTO beyond 60 years") and will be finished by the end of May 2025, from where the outcome will be an extensive report regarding LTO methods, as well as the identified knowledge gaps.

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Appendices

1. Questionary form, 5 pp.